SURVEY OF CHEMICAL AND CHEMICAL ENGINEERING RESEARCH AND DEVELOPMENT IN CANADA

for the Scientific Secretariat

by the Chemical Institute of Canada

Report of Committee 3

Metallurgy

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COMMITTEE 03 - METALLURGY

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COMMITTEE 03 - Metallurgy

1. Field Covered and its Boundaries

Metallurgy has been defined as "The art and science of extracting metals from their ores and adapting them to use". For the purpose of this survey the field of metallurgy has been interpreted by Committee 03 to include:

1. The beneficiation of ores by physical or chemical means, including mineral chemistry and flotation.
2. Chemical metallurgy, including: hydrometallurgy, pyrometallurgy, electrowinning and refining, the physical chemistry of process metallurgy.
3. Physical metallurgy, including: alloy preparation, properties and structures; powder metallurgy.

With the above major divisions of the field we have included:

high purity metals,

intermetallic compounds,

composite materials of metals and non metals.

Committee 03 concluded that the field of metallurgy should be considered to extend to the preparation of the metal for fabrication, but should not include fabrication.

Throughout this report the term "research" is intended to mean "research and development" except where the expression "basic research" is used.

2. Background

The winning of metals from their ores and their fabrication into useful or decorative articles antedates by many centuries the development of chemistry as a science. The first metal to be discovered and used was almost certainly gold, followed by silver and copper. It has been estimated that copper was mined as early as 6000 B. C.

Improvements in the art of extracting metals from their ores were painfully slow. The practices recorded by Agricola in his "De Re Metallica" published in 1556 had not changed much in the preceding several centures, and except for mechanical improvements, did not change much in the following three centuries. By the early part of the nineteenth century, however, the development of all science was accelerating and these developments were being applied to "extracting of metals from their ores and adapting them to use". Metallurgy, through the development of chemistry and physics, was becoming less of an art and more of a science.

It is not surprising, therefore, that in the early years of Canada's history metallurgy followed the practices developed elsewhere, and that these were not greatly different from those described by Agricola. Canadian research in metallurgy probably began in the fourth quarter of the nineteenth century.

In the final decade of the nineteenth century the School of Practical Science at the University of Toronto and the School of Mining at Queen's University, Kingston, installed metallurgical equipment for the testing of ores, and it would appear that metallurgy had become a part of the curriculum in these universities.

In many cases research was carried out by the pioneers with full scale equipment. The success or failure of many early metallurgical plants depended on bold innovation and courageous experiment on a commercial scale.

3. Research in the Various Branches of Metallurgy

(a) Mineral Dressing

The technology of flotation, the most versatile and widely used concentration process, was developed without a complete understanding of the complex underlying chemistry of the process. Today flotation is still more of an art than a science. The established methods of empirical testing have been of great value but further progress will demand more knowledge of fundamentals. The present lack of this basic knowledge is a powerful argument for more extensive research in the future.

Recent studies at the universities have included:

McGill University - Liquid phase adsorption studies using scintillation counting techniques,

Queen's University - Research on the fundamentals of the flotation of semiconductors,

Universities of Alberta and British Columbia - The study of the adsorption of xanthate and related compounds using infrared spectroscopy, the use of ultraviolet spectroscopy to study xanthate solutions, and interaction between surfactants.

At the Mines Branch, Department of Energy, Mines and Resources, Ottawa, numerous fundamental programs have been under way, some of which involve the flotation of oxide minerals. The Mines Branch has carried out studies on the flotation of uranium ores including the concentration of Elliot Lake ores by the column flotation method.

In industry much test work is still based on empirical methods which continue to produce process improvements. Perhaps the most rapid developments have been in instrumental control. The ultimate in mill control will come wit computer directed operations.

In the iron ore industry research work has included studies on cationic flotation to upgrade magnetic concentrates and on the concentration of hematite-magnetite ore with varying amounts of magnetite.

In the development of new flotation equipment the column flotation cell has attracted some attention. The trend to larger single units of equipment is evident in mineral processing as it is in other fields.

Notwithstanding the progress in research, the development of a true understanding of the science of flotation still lags behind technology. Thus there is a clear cut need for increased research in flotation and other methods of mineral dressing and for improved liaison between mill operators and basic researchers.

(b) Chemical Metallurgy

The term "chemical metallurgy" is used rather than the generally synonymous terms "process metallurgy" and "extractive metallurgy" and in this report is interpreted to include pyrometallurgy (roasting, smelting and fire refining), hydrometallurgy (leaching and precipitation) and electrometallurgy (electrowinning or electrorefining of metals using aqueous or fused salt electrolytes). The physical chemistry of process metallurgy is a part of chemical metallurgy.

Canadian research in metallurgy has been strongly oriented toward chemical metallurgy because of the problems in the exploitation of mineral resources.

Canadian universities have played a significant role in chemical metallurgy, both by providing graduates of a high standard of training and by conducting research. Historically, only four Canadian universities have departments of metallurgy with a reputation of substantial emphasis on chemical metallurgy. These are University of Toronto, University of British Columbia, McMaster University, and Laval University, but other universities are now active in this area. Each has had some areas of specialization, one example of which has been the emphasis at the University of British Columbia on pressure leaching and hydrometallurgy.

Research in chemical metallurgy is a major general concern of the Mines Branch in Ottawa. Its laboratories are engaged on projects dealing with recovery of values from typically Canadian ores or raw materials. Provincial research councils are also involved, such as British Columbia Research Council (bacterial leaching), Alberta Research Council (HCl leaching and H_2 reduction of iron ores and scrap), and Ontario Research Foundation (direct reduction of iron ores).

Industrial research in chemical metallurgy has been carried on by most of the major producers of both ferrous and non-ferrous metals. Each company has specialized in the problem areas peculiar to its particular situation, and the successful development of Canadian mineral resources has in many cases depended on the success of these research programs.

In the opinion of this committee, research in chemical metallurgy deserves a larger role than it now plays in Canada, particularly in university programs. Canada's national role as a supplier of substantial part of the world's metals, particularly of nickel, copper, lead, zinc, silver, and uranium, deserves more support in the form of research for new processes, engineering advances in existing processes, and related basic research. Failure to maintain and advance Canadian chemical metallurgy research can only lead to increased export of ores and concentrates, and increased licensing costs for foreign inventions and proprietory processes used by Canadian industry.

(c) Physical Metallurgy

Physical metallurgy became established in Canadian universities in the first quarter of this century and grew rapidly, spreading to industrial and other laboratories. Physical metallurgy research in Canadian universities is presently benefiting from the recognition of the importance of materials science and research in the economy of the country. With the award of Negotiated Development Grants in Materials Science at U.B.C. and McMaster and Toronto Universities, the Canadian government is taking cognizance of this important trend. Although the support is aimed at research in the complete range of materials, physical metallurgists are playing a major part, since their science and methodology is a major base for studies in materials other than metals. At present about a dozen universities have active programs in physical metallurgy and/or materials science and most of these are offering degree programs to the Ph.D. level. At least half are undertaking major expansion programs in facilities and scope of activities.

Research activity in government laboratories has tended to remain relatively stable during the last few years, perhaps reflecting a recognition that the amount of government in-house research has been out of line with the scale of activity in industry and the universities. Reactor materials remain the largest area of government concern and some expansion in this area has been undertaken (e.g., the Whiteshell Laboratories of Atomic Energy of Canada Limited).

The scale of industrial research in metallurgy has expanded significantly with the organization and construction of a number of new laboratories in recent years. Alloy and new materials development, which occupies the major place in research in the industrial metallurgical laboratories of the advanced countries, is not yet pursued in Canada with any great enthusiasm. Since in Canada, economic necessity requires major emphasis on research in mineral dressing and chemical metallurgy, the scale of research on physical metallurgy in our universities is perhaps adequate. The universities are now able to undertake the basic research and to provide trained personnel for industrial research in this area. There exists in this area as in many others a real need for improved liaison and understanding between industry, government and universities.

It should be remembered that research in materials science is related to the utilization of our raw materials, the development of new products and the establishment of much needed secondary industries.

4. Education and Research in Metallurgy at Canadian Universities

Approximately 11 Canadian universities have research programs in metallurgy suitable for post graduate studies (see Table I). In 1966 these schools employed about 65 faculty members and enrolled about 180 graduate students. Six of these universities have comparatively large schools, accounting for more than 80% of the graduate students and 75% of the faculty members. Five of these, the exception being McMaster University, also account for an equivalent fraction of undergraduate students in metallurgy. Fewer than 100 students graduate at the Bachelor's level in metallurgy each year in Canadian universities.

Research in metallurgy at Canadian universities is largely supported by the National Research Council (NRC) in its program of Grants in Aid of Research and Major Equipment Grants. In 1967 this support of metallurgical research resulted in the granting of $730,000 for the 1967/68 fiscal year. In addition, in 1967 three universities - British Columbia, McMaster and Toronto - received special Major Installation Grants for Materials Science. These grants total about $1,200,000 and are spread over three years. Grants are also received by the universities for research in metallurgy from the Defence Research Board (DRB).

Both NRC and DRB grants are used to support postgraduate students and their research programs. In addition, a substantial number of NRC awards are made to students, and a number of scholarships are available that are donated by industries and by philanthropic institutions.

University faculty members in metallurgy often engage in research contracts for industry. Some of these are supported by individual organizations, and some are with industrial associations, such as the International Lead Zinc Research Association and the International Copper Research Association. In general, the research contracts permit universities to become involved in specific current problems of industrial significance, and to have a healthy relationship with industry. A connection with industry is essential for faculty members if they are to keep their teaching and research programs up to date.

The supply of trained personnel for staffing Canadian universities, government and industrial laboratories has been sustained by a strong immigration policy and many contributors to our progress in metallurgical research have received their training in other countries or as graduates in chemistry or chemical engineering.

Committee 03 is particularly concerned about the supply of graduates specializing in chemical metallurgy and mineral dressing. Today only about a quarter of the college seniors in metallurgical courses are preparing for careers in chemical metallurgy.

TABLE I

GRADUATE STUDENTS AND FACULTY IN METALLURGY AT CANADIAN UNIVERSITIES 1966/67*

	Faculty	Grad. Students
McMaster University	8	30±
University of Toronto	11	27
University of British Columbia	11 Metallurgy 3 Mineral Eng.	43
Queen's University	6	17
McGill University	6	14
University of Alberta	3	5
Laval University	6	20
Nova Scotia Technical College	2	7
Ecole Polytechnique (Montreal)	4	5
Waterloo University (Chem.Eng. + Mech.Eng.)	3	9
University of Windsor	2	6
Totals	65	183

* National Research Council, Publication #9340 "Graduate Students at Canadian Universities in Science and Engineering", 1966/67, January, 1967.

± Estimated. The above publication lists all McMaster graduate students in either Physics or Chemistry.

5. Research on Various Metals

(a) Iron and Steel

The iron and steel industry has kept abreast of world technology in its field and has been quick to apply the discoveries of others but, prior to World War II, did little research on its own behalf. In a study made for the National Productivity Council in 1962-63, Convey, Faurschou and Walsh noted that expenditure reported by four fully integrated steel companies and one specialty steel company for research in 1961 was 0.29% of sales which, by today's standards, is low. However, substantial progress had been made in fuel injection into blast furnace tuyeres, in improvements to blast furnace burden including self-fluxing sinter, in the development of a direct reduction process and in the application of the basic oxygen steelmaking process. In 1960 and 1961, the non-ferrous metal producers and metallurgical development companies spent approximately half as much in total dollars on research on iron and steel as the total reported by the primary iron and steel industry (61% in 1960 and 45% in 1961).

One of the dramatic developments in the industry has been in the production, concentration and agglomeration of iron ore which has become an important industry in eastern Canada. In general, we understand that this industry has used technology and equipment developed outside Canada. In 1965 total shipments of iron ore products were nearly 40 million tons. Exports of iron ore products grew from a value of $43,000 in 1939 to $99 million in 1955 and $360 million in 1965 (Canada Year Book 1967).

Non-Blast Furnace Iron Reduction

At the present time there are two commercial operations producing iron by non-blast-furnace methods and several other processes have been developed or are under development.

Quebec Iron and Titanium Corporation Ltd. produces iron as a co-product of the electric furnace smelting of ilmenite concentrate at Tracy, Quebec.

Cominco, at Kimberley, B. C., produces pig iron by the reduction of iron sinter obtained from pyrrhotite and converts pig to steel ingots in a basic oxygen furnace for fabrication in Vancouver along with scrap derived ingots.

Direct Reduction Processes

Direct reduction processes have been developed to a substantial scale by the Steel Company of Canada Limited and by Imperial Oil Limited. Other organizations have investigated or are investigating various other methods of pre-reduction, partial reduction, direct reduction, jet smelting, etc. The direct production of iron powder from superconcentrates is reported to be nearing commercial production.

Peace River Mining and Smelting Ltd. have been operating a pilot plant producing five tons per day of iron powder from low grade iron ore and other raw materials. The process, developed under their sponsorship by the Alberta Research Council, involves hydrochloric acid leaching, crystallization of ferrous chloride tetrahydrate and hydrogen reduction of the chloride to produce iron sponge and hydrochloric acid which is recycled. The iron sponge is ground to make a high purity iron powder.

Research

In recent years two of the major integrated steel companies have established new research centres. The total current expenditures of the industry on research increased from 0.29% of sales in 1961 to 0.47% of sales in 1965, indicating significantly increased emphasis on research. Plans for the future appear to include research on all parts of the steel making process from raw materials preparation through reduction and fabrication, coating, corrosion and utilization studies. Some fully integrated steel companies have product research programs.

(b) Copper, Nickel and Associated Metals

Copper

The copper smelting industry first began in Canada over a hundred years ago. The early smelters contributed to the technology of the industry but it was not until the present smelters were established that formal research began. Research laboratories are maintained by The Hudson Bay Mining and Smelting Company at Flin Flon, Manitoba and by Noranda Mines Limited at Pointe Claire, Quebec. An important part of the copper industry is associated with nickel recovery, and the major nickel producers, The International Nickel Company of Canada Limited (Inco), Falconbridge Nickel Mines Limited and Sherritt Gordon Mines Limited maintain research organizations which serve the copper and nickel industries.

Canadian companies have supported the International Copper Research Association whose programs have included work on stainless copper and on protective coatings for copper and brass.

Some developments in copper metallurgy in recent years have been:

oxygen smelting of copper concentrate,

smelting of concentrate in a converter, including the use of oxygen enriched air,

a continuous converting process,

the bacterial leaching of copper from ores.

There have been significant developments in instrumentation and process control including use of electronic pyrometers for measuring the temperature of the converter bath.

Nickel

Inco has research laboratories at Copper Cliff, Ontario; Port Colborne, Ontario; Thompson, Manitoba; and the recently opened J. Roy Gordon Research Laboratory at Sheridan Park, Ontario. In addition it has laboratories at

Clydach and Acton in the United Kingdom. These laboratories are primarily devoted to research in chemical metallurgy; only minor attention is directed to product research. The major portion of the product research done by Inco is carried out in its United States laboratories.

Falconbridge Nickel Mines Limited has a research organization at its operations near Sudbury and the Richvale Laboratory at Thornhill, Ontario, which are engaged in process research and related problems. The Richvale Laboratory carries on a program of product research. At Kristiansand, Norway, a research laboratory adjacent to the Falconbridge refinery carries on research related to nickel refining activities. At the present time a major development program is being carried out in the Dominican Republic on the smelting of lateritic nickel ores. In addition, Falconbridge owns and operates Lakefield Research of Canada Limited which does contract research in mineral dressing for other clients as well as for Falconbridge and associated companies.

Sherritt Gordon Mines Limited has a research organization at Fort Saskatchewan, Alberta. Attention is devoted to pressure hydrometallurgy of nickel, cobalt, copper and, more recently, lead, zinc and iron. Since a number of metals are recovered from solution as powders, Sherritt does considerable research in powder metallurgy, powder properties, composite materials, and the direct conversion of powders to other shapes.

Metals Associated with Copper and Nickel

In addition to iron, the following elements are found in copper-nickel ores and research on their recovery has been an important part of the research effort of the copper and nickel companies: sulphur, cobalt, selenium, tellurium silver, gold, and the platinum metals.

Inco has recently reported the production of high purity osmium, increasing to 15 the number of elements recovered from Sudbury district area.

(c) <u>Lead, Zinc and Associated Metals</u>

<u>Lead</u>

Lead smelting began in Canada near the end of the nineteenth century, and in 1902 the pioneer electrolytic lead refinery was established at Trail, British Columbia. Cominco's Technical Research Centre and Metallurgical Development groups at Trail have been the main centre for research in Canada on lead metallurgy.

A new approach to lead metallurgy in recent years has been the aqueous oxidation and amine leaching of lead sulphide concentrate developed by Sherritt Gordon.

<u>Zinc</u>

Most of the major producers (Cominco Ltd., Hudson Bay Mining and Smelting Company, Noranda) of electrolytic zinc also maintain research programs aimed at improving operating costs, recoveries and product quality, developing better methods of treating waste materials, and recovering by-products. Brunswick Mining and Smelting Corporation has installed the first Imperial Smelting furnace in Canada at its new Belledune smelter for combined lead-zinc production, and is engaged in working out plant and process problems.

For some years Cominco has been investigating process mechanisms in the electrowinning of zinc, and significant improvements appear possible, despite the fact that it is over 50 years since the process was first put into commercial operation.

In recent years Sherritt Gordon has applied the principles of its pressure leaching processes to the treatment of zinc sulphide, producing zinc sulphate solutions and elemental sulphur. Cominco has cooperated with Sherritt Gordon in the pilot scale development of this process.

Recovery of the metals associated with lead and zinc, chiefly antimony, bismuth, cadmium, indium, and tin has been the subject of numerous research programs and these metals continue to receive research attention.

Product Research

In 1964 Cominco established its Product Research Centre at Sheridan Park, Ontario, devoted to the development of new and improved applications of lead and zinc. A staff of about 40 people is engaged in investigating metal alloying, fabrication, coatings, and the evaluation of physical and chemical properties of metals and alloys.

Other laboratories have been active in lead and zinc product research, notably:

the UBC Department of Metallurgy in the powder metallurgy of lead and zinc,

Sherritt Gordon Mines Limited in dispersion strengthened materials.

(d) Gold

Gold has been an important metal in the Canadian economy for many years. Chemistry, however, did not enter into gold recovery until after the discovery of the cyanide process in Scotland in 1887. This process, first used in Canada in the early 1900's is the chief method of recoverying gold from gold ores.

In recent years, research in gold extraction has been directed largely toward improved control and automation of the process. There is an active organization of Canadian gold metallurgists composed of metallurgical staff from the various gold mines, who are working to facilitate exchange of information on gold ore processing technology and to improve contact between research and operational groups of the gold mining industry. The Mines Branch staff has worked closely with this group and has provided laboratory assistance.

In 1959, a cooperative research program was jointly sponsored by the Canadian Metal Mining Association and the Department of Mines and Technical Surveys aimed at increasing the industrial uses of gold. Considerable information was gathered and published for the benefit of potential users.

(e) Silver and Cobalt

Silver is recovered in the electrolytic refining of lead, copper and nickel, but little silver is produced by direct treatment of silver ores. The complex arsenical cobalt ores of northern Ontario, containing nickel, iron and sulphur as well as silver, posed a particular problem in the early years of this century. A process worked out by Messrs. Kirkpatrick, McKay and Drury of Queen's University at that time forms the basis of the process still used in the treatment of these ores.

Cobalt is recovered in the electrolytic refining of nickel and by the Sherritt Gordon process for pressure leaching cobaltic materials and subsequent hydrogen reduction.

(f) Uranium

The history of uranium in Canada began in the summer of 1930 when Gilbert Labine found a vein of pitchblende ore on the shore of Great Bear Lake. By 1933, Eldorado Gold Mines Limited had developed a mine, a process for recovering radium from the ore had been worked out with the assistance of the Mines Branch laboratories, and a refinery built at Port Hope was operating to produce radium, with uranium salts as a by-product. In 1940 declining radium markets and war conditions caused the closure of the operation but in 1942 the Manhattan Project with its urgent need for uranium made reactivation necessary. In 1944 it was thought desirable to bring the company under complete government control, and Eldorado Mining and Refining (1944) Ltd. was set up as a crown corporation.

When the war ended it became apparent that the demand for uranium would increase still further, so the Mines Branch was asked to set up a major investigation into hydrometallurgical methods of uranium recovery. Similar groups were working in the United States and the United Kingdom.

This research resulted in the construction at Port Radium, NWT, of the first modern plant for the acid leaching of primary uranium ores in North America. This plant began operation in 1952 and featured the automatic control of acid strength, the use of sodium chlorate to control oxidizing strength and the precipitation of the uranium by reduction with aluminum powder.

Ore discoveries at the Elliot Lake, Bancroft and Beaverlodge areas necessitated the development of processes to suit these particular ores.

The Eldorado refinery produces uranium trioxide, ceramic type UO_2 both natural and enriched, and is prepared to produce uranium tetrafluoride and uranium metals and alloys as well as other compounds of uranium in various physical forms.

The primary responsibility for research in uranium recovery was transferred from the Mines Branch to the Eldorado Mining and Refining Ltd. when it set up its own Research and Development Division. In addition, a number of other companies and research groups have been active in this field, notably: the University of British Columbia, Queen's University, the University of Alberta, the University of Saskatchewan, the Rio Tinto Research Group, and Denison Mines Limited.

Some of the areas that have received extensive study and which may be of future value are these:

a. Pre-concentration of uranium ores, using all the conventional techniques.

b. Solvent extraction from acid leach slurry.

c. Production of sulphuric acid from pyrite or sulphur without a conventional plant, directly in the ore pulp, or in a slurry or by other means.

d. Recovery of uranium from ores by chloride volatilization.

At the present time, UO_2 appears to be the preferred material for use in nuclear reactors, but enriched UO_2 could be produced in Canada from Canadian UF_6 enriched in the United States.

Thorium oxide and yttrium oxide products are produced by Rio Algom Mines Limited and by Denison Mines Limited.

It can be expected that there will be increased pressure for the recovery of uranium at competitive costs from lower grade ores.

(g) Aluminum

While the original development work on the Hall-Heroult process for aluminum production was done outside Canada, research was begun in Canada by Alcan at an early date. In the first years of aluminum production the scale of research remained small but there was rapid growth beginning about 1938, and in 1941 a research laboratory devoted to physical metallurgy was established at Kingston, Ontario. Some five years later a research laboratory for chemical metallurgy was established at Arvida. Research for the Alcan group is carried out by a separate company, Aluminium Laboratories Limited, which, in addition to two laboratories in Canada, operates a laboratory in the United Kingdom and maintains close liaison with the many international associates of Alcan.

The chemical metallurgy laboratory with a total staff of about 360 carries on research in alumina technology, fluorine chemistry, ceramics, carbon technology, fused salt chemistry and electrothermics, as well as in analytical chemistry and unit operations.

A research and development program of major scope on the monochloride direct reduction process for the production of aluminum was discontinued in 1967.

The physical metallurgy laboratory with a total staff of 165 carries on research in surface chemistry, corrosion, electroplating and paints, as well as in metal solidification, deformation, heat treatment, alloy systems, metal physics, joining of metals, etc.

The Mines Branch laboratories and a number of university departments of metallurgy have worked and are working on the physical metallurgy of aluminum and its alloys.

It is expected that there will be a continued long term growth in research on the extraction of aluminum. The growth of product research and physical metallurgy of aluminum could accelerate if independent fabricators become of sufficient stature to undertake separate research programs.

Magnesium

During World War II, Dr. L. M. Pidgeon, working at the National Research Council developed a process for the reduction of magnesium from dolomite with ferrosilicon. A pilot plant was built in 1941 and a full scale plant in 1942 by Dominion Magnesium Limited in Renfrew County, Ontario. Although the electrolytic process remained predominant, the Pidgeon process was used for magnesium production at several plants in the United States during World War II.

This process has been adapted to the reduction of various metals from their oxides, and Dominion Magnesium Limited produces metallic calcium, thorium, barium, strontium and zirconium in addition to magnesium.

(h) Titanium and Other Metals

Titanium

While some research has been done in Canada on the production of titanium metal, the only successful treatment of a Canadian raw material is the operation of Quebec Iron and Titanium Corporation Limited at Tracy, Quebec. Here, a high iron ilmenite from Allard Lake, Quebec, is smelted in electric furnaces to produce pig iron and a slag high in titanium suitable for use in pigment manufacture and other processes. The original research on this process was carried on outside Canada, but the application of this process on a commercial scale required a development program of a high order. The solution of the problems was assisted by investigations at the Mines Branch.

Other Metals

Numerous other metals have been the subject of research programs because of the availability of Canadian ores or the desire for production in Canada. Some of these programs were extensive in scope while others were minor. A list of some of these metals is as follows: antimony, cesium, columbium (niobium), chromium, lithium, mercury, tin.

Some of these research programs were carried out in industrial laboratories and many were assisted in varying degree by government or other laboratories, notably the Mines Branch.

High Purity Metals

A research program on refining processes of metals led Cominco into the production and sale of very high purity grades of various metals. Some 14 metals are offered in extreme high purity to meet exacting specifications.

Other products include semiconductor grades of indium antimonide, indium arsenide and bismuth telluride. Most of these products find their final application in solid state electronics. A continuing program of research and development is being maintained.

Noranda Mines Limited has been active in the high purity metal field with particular emphasis on its major products - copper, zinc, selenium, tellurium and molybdenum.

6. Measuring Canadian Research in Metallurgy

(a) Dollars

In considering the extent of the Canadian research effort in metallurgy, Committee Ø3 found that statistics from different sources did not entirely agree. It presumed these discrepancies to be due to differences in definition and in methods of classification.

One of the valuable sources of statistics was DBS 13-527 "Industrial Research and Development Expenditures in Canada 1965". In this report there were three categories which Committee Ø3 considered to be metallurgical research: Mines, primary metals (ferrous), and primary metals (non-ferrous).

"Mines" is considered to be metallurgical research because out of a total of 237 scientists and engineers employed, 95 or 42% were metallurgical engineers, 85 or 36% were chemists or chemical engineers, while only 20 or 8.5% were mining engineers or earth scientists.

"Metal Fabricating" was considered to be a manufacturing operation and was not included, since of the 118 scientists and engineers employed only 3 or 2.5% were metallurgical engineers and 26 or 22% were chemists or chemical engineers, while mechanical, electrical and civil engineers totalled 72 or 61%.

Apparently a number of mining and other companies doing research in metallurgy did not respond to the CIC survey questionnaire concerning research in chemistry and chemical engineering, since the total expenditures reported by industry for current operating research in metallurgy for 1966 was \$18,449,100 (Table III) whereas DBS 13-527 showed \$23,678,000 for total intramural expenditures in 1965 (Table II). Committee 03 concluded therefore that to arrive at the total current operating effort in research in metallurgy it should combine what appeared to be the best results from both DBS 13-527 and the CIC survey questionnaire as shown in Table IV.

Committee 03 concluded that in considering the scale of the research effort in metallurgy, the <u>current operating</u> expenditure was the most important factor and that <u>capital</u> expenditures should not be included. So while capital expenditures are included in the Survey Questionnaire results and in DBS 13-527 they are not quoted by Committee 03.

The following comments apply to the tables which follow:

1. The periods covered by the statistics do not all coincide exactly, but it is considered that errors from this source are minor.

2. The expenditures by the metals industry reported in Tables II and IV include federal government grants of \$846,000.

3. The term "intramural" refers to research carried out in the companies' own laboratories, while "extra mural" refers to research paid for by the companies but carried out by others.

TABLE II

1965 Current Operating Expenditures by the Metals Industry for R & D in Metallurgy

Based on DBS Report 13-527
(Tables 22, 25, 26)

$000	Intra Mural R & D	Extra Mural R & D In Canada	Extra Mural R & D Outside Canada	Total Current R & D
Mines	8,404	1,002	582	9,988
Primary Metals Ferrous	5,603	229	140	5,972
Primary Metals Non-Ferrous	9,671	507	6,599	16,777
	23,678	1,738	7,321	32,737

TABLE III

Total Current Operating Expenditures on R & D in Metallurgy in 1966
Based on CIC Survey Questionnaire
(Tables 11, 26, 39)

$000

	Basic $	Basic %	Applied $	Applied %	Development $	Development %	Total $
By Industry	445.8	2.4	15,054.3 ~~12,923.3~~	70	5,079.9	27.5	18,580.0 ~~18,449.1~~
By the Federal Government	798.3	24.3	1,351.5	41.1	1,138.1	34.6	3,288.
By Universities	740.8	69.3	275.1	25.8	52.0	4.9	1,068.
Total	1,984.9	8.7	14,6[illegible] ~~14,549.9~~	63.8	6,270.0	27.5	[illegible] ~~22,805.1~~

<u>NOTE</u> 1: In this table expenditures by Provincial Government research bodies are included with "Industry".

In the case of the Ontario Research Foundation this amounted in 1966 to approximately: ($000)

Basic	Applied	Development	Total
79	123	54	256

<u>NOTE</u> 2: The expenditure of $18,449,100 reported by Industry for research in metallurgy in 1966 in response to the survey questionnaires compares with D.B.S. 13-527 for 1965 as follows:

By Field of Science (Metallurgy) Table 12 - $22,556,000

By Industry (Mines and Primary Metals) Table 3 - $23,678,000

Committee 3 considers this to be due largely to the definition of the field of metallurgy and the fact that this definition for the purpose of the survey was broadened by Committee 3 to include mineral dressing. The Committee has preferred to use the industry classification and the total figure of $23,678,000 for 1965.

TABLE IV

Estimated Total Current Operating
Expenditures on R & D in Metallurgy

$000	Intra Mural	Extra Mural In Canada	Extra Mural Outside Canada	Total
By the Metals Industry DBS 13-527 1965	23,678	1,738	7,321	32,737
By the Federal Government (Survey Questionnaire) 1966	3,288	-	-	3,288
By Provincial Research Councils and Institutes DBS 13-527 1965	966	-	-	996
By Universities (Survey Questionnaire) 1966 Table 37, Section 18	1,068	-	-	1,068
Total	29,030	1,738	7,321	

Total Expenditures for Research in Canada	29,030
Total Expenditures for Research outside Canada	7,321
Grand Total Expenditures by Canadian sources for R & D in Metallurgy	$36,351

NOTE 1: Committee 03 considered that some or all of the $1,738,000 extra mural expenditure in Canada reported by the metals industry was included in the amounts reported by government, research councils, institutes and universities and that it could not be added to the intramural total of $29,030,000. Actual total expenditures may therefore be somewhat greater than $36,351,000.

TABLE V

Percentage Distribution of R & D in Metallurgy by performer in Canada

	Performer	
	$000	%
By the Metals Industry	23,678	81.6
By the Federal Government	3,288	11.3
By Provincial Councils	996	3.4
By Universities	1,068	3.7
	29,030	100.

Committee Ø3 was interested to note, as shown in Table II, that the metals industry makes substantial payment for research done outside Canada. Of the total current research expenditure in 1965 by the metals industry of $32,737,000, 22% or $7,321,000 was spent outside Canada. Of this amount spent outside Canada, $6,599,000 or 90% was spent by the primary metals (non-ferrous) section. This section spent 39% of its current research expenditures outside Canada.

Committee Ø3 has not made an exhaustive study of this situation but suggests the following points:

a. Falconbridge Nickel Mines, in addition to its research in Canada, carries on research at Kristiansand, Norway, related to nickel refining activities there, and is also carrying on a major development program in the Dominican Republic on the smelting of lateritic nickel ores.

b. Inco has research laboratories at Clydach and Acton in the United Kingdom in addition to its Canadian research facilities, and also carries out most of its product research in its laboratories in the United States.

c. Aluminium Laboratories Limited, in addition to its laboratories in Canada, has a research laboratory in the United Kingdom; and some research is carried out at the plants of Alcan operating subsidiaries in many countries.

Performers of All R & D in Canada

Based on DBS figures for current intra-mural expenditures for all R & D (operating and minor equipment costs) the performers of R & D in Canada were about as follows:

TABLE VI

Performers of All R & D in Canada

	Millions Dollars	Percent of Total
Industry (1965) DBS 13-527	235	49.2
Federal Government (1965-66) DBS Daily Bulletin Suppl. #4	173.1	36.2
Universities (1965-66) (NRC Forecasting Committee)	54.8	11.5
Provincial Research Councils 1965 DBS 13-527	6.6	1.4
Non Profit Organizations DBS 13-526 (Est)	8.0	1.7
Total	477.5	100.0

It has been suggested that Canada should be closer to the pattern in the United States and the United Kingdom where industry performs about two-thirds of the total research and development and government less than 20% in the U.S. and 25% in the U.K.

It is interesting to note from Table V that the metals industry in Canada performs over 81% of the research and development, the federal government about 11%, and the universities less than 4%. It must be remembered, however, that accounting procedures in industry, government and universities are not identical and these percentages can be considered only approximations. University research probably includes less overhead than other sectors.

Desirable Level of R & D for the Metal Industry

TABLE VII

R & D Expenditures of the Metal Industry as Related to Sales based on DBS 13-527

	$000 (Table 32) Sales	1965 Operating Research Expense	Research Expense % of Sales
Mines	888,064	9,988	1.12
Primary Metals (Ferrous)	1,259,109	5,972	0.47
Primary Metals (Non-Ferrous)	1,161,595	16,777	1.44
	3,308,760	32,737	0.99

R & D performed by the Metals Industry: $000

In Canada	25,416	= 0.77% of sales
Outside Canada	7,321	= 0.22% of sales
Total	32,737	0.99% of sales

National expenditures on R & D are usually expressed as a percentage of Gross National Product. On a national basis Canada spends about 1% of GNP on current R & D, compared to about 2% for the United Kingdom and about 3% for the United States. There is a general opinion that Canada should be spending more on R & D and some have suggested a figure of 3% of GNP as a target. Because of the large service content of GNP, 3% of GNP is approximately equivalent to 6% of sales of products.

The National Science Foundation reports that in 1965 the primary metal industry in the United States spent 0.8% of net sales on R & D. This is slightly less than the Canadian metals industry. U. S. manufacturing industries which performed R & D spent, as a whole, 4.3% of net sales on R & D. All Canadian companies reporting R & D (DBS 13-527) show an average expenditure on current R & D of 1.14% of net sales.

There is no simple and easy method by which it is possible to determine the proper amount of its resources which a company, an industry or a country should devote to research and development. It is possible to obtain technology by purchasing or licensing patents or processes. Canadian subsidiaries of foreign companies may obtain technology from their parent companies, sometimes free or at a nominal cost. Industries which produce a large volume of a relatively low priced product or whose processes are less complicated or less sophisticated than others probably require less research.

After considering the comments by informed observers in the industry, together with its own knowledge of the state of metallurgical technology, Committee Ø3 is convinced that there should be increased effort devoted to metallurgical research in Canada.

This conviction is strengthened by the fact that the 1967 Canada Year Book reports that in 1965 the dollar value of metals in ores and concentrates exported from Canada exceeded the value of metals exported as metals, alloys and simple fabrications.

Committee Ø3 suggests that the effort devoted to metallurgical R & D in Canada should be increased by at least 50%.

(b) <u>Manpower</u>

Committee Ø3 has found that precise information on manpower in metallurgical research is not readily available in spite of the various questionnaires which have attempted to gather the necessary information. It considers DBS Report Catalogue 13-527, Industrial R & D Expenditures in Canada 1965, its most useful source of information. This report indicates two interesting points:

1. That of 281 metallurgical engineers employed in industrial research in 1965 only 204 or 73% were employed by the metals industry.
2. Of the 568 scientists and engineers employed in research by the metals industry in 1965, the 204 metallurgical engineers amount to only 36%.

There does not appear to be a direct relationship between scientific discipline and area of research. Statistics based on scientific discipline should therefore be used with caution.

Canadian universities are graduating metallurgical engineers at the Bachelor level at the rate of about 100 per year, (CIM Bulletin April 1967): while some increase is projected it seems unlikely that this figure will be greatly exceeded in the next few years.

The percentage of graduates who take employment in research is not large, and, even if immigration of qualified personnel continues, it seems unlikely to Committee Ø3 that the number of metallurgical engineers available for research will much exceed normal attrition.

The increase in research by the metals industry of about 50% suggested by Committee Ø3 would require 102 metallurgical engineers in addition to scientists and engineers of other disciplines. To achieve this, a significant increase in the number of metallurgical engineers graduated by Canadian universities will be necessary.

TABLE VIII

Best Estimates of Total Manpower engaged in Metallurgical Research in Canada

Source	Employer	Professional Staff: Bachelors	Professional Staff: Masters	Professional Staff: Doctors	Professional Staff: Univ. staff	Professional Staff: Total	Non Professional Staff: Tech.	Non Professional Staff: Other	Non Professional Staff: Total	GRAND TOTAL
DBS 13-527 1965 (Table 25)	Industry	402	90	76	-	568	555	383	938	1506
Survey Questionnaire 1966 (Tables 16 + 44)	Government	51.5	11	31	-	93.6	126	-	126	219.6
	Univer'ties	106.2	-	12.2	20.3	138.7	28.6	-	28.6	167.3
	TOTAL	559.7	101	119.2	20.3	800.3	709:6	383	1092.6	1892.9

TABLE IX

NUMBER OF PERSONS ENGAGED IN R & D
BY INDUSTRY AND TRAINING-1965

DBS Cat. No. 13-527 Table 25 (excerpts)

	Scientists and Engineers				Supporting Personnel			
	BSc	MSc	PhD	Total	Techns	Other	Total	Total
Mines	174	40	23	237	202	121	323	560
Primary Metals (Ferrous)	85	14	14	113	70	62	132	245
Primary Metals (Non-Ferrous)	143	36	39	218	283	200	483	701
Totals	402	90	76	568	555	383	938	1,506

TABLE X

SCIENTISTS AND ENGINEERS ENGAGED IN R & D
(INDUSTRIAL) BY SCIENTIFIC DISCIPLINE AND DEGREE

DBS Cat. No. 13-527 Table 26 (excerpts)

	Bachelors	Masters	Doctors	Total
Metallurgical Engineers	198	44	39	281

TABLE XI

SCIENTISTS AND ENGINEERS ENGAGED IN R & D
(INDUSTRIAL) BY INDUSTRY AND SCIENTIFIC DISCIPLINE
OF EMPLOYMENT

DBS Cat. No. 13-527 Table 27 (excerpts)

	Chem Eng	Civil Eng	Elect Eng	Mech Eng	Metal Eng	Mining Eng	Other Eng	Total Eng	Chem	Earth Scien	Math	Physics	Admin	Other	Total Scien	Total Scien and Engs
Mines	35	-	3	7	95	14	1	155	50	6	6	1	19	-	82	237
Primary Metals (Ferrous)	14	10	11	3	55	-	-	93	10	2	-	-	8	-	20	113
Primary Metals (Non Ferrous)	58	-	7	20	54	4	-	143	40	7	1	11	12	4	75	218
Total	107	10	21	30	204	18	1	391	100	15	7	12	39	4	177	568

7. SUMMARY AND RECOMMENDATIONS

The importance of the mineral industry to the Canadian economy is attested by the statement in the 1967 Canada Year Book that 1965 mineral exports (including coal and petroleum) accounted for one third of Canada's merchandise exports. The exports of the metals industry, excluding coal and petroleum but including metals in ores and concentrates and in simple shapes such as bars, rods, plate, rails, etc., in 1965 accounted for nearly 20% of the dollar value of Canadian merchandise exports.

Committee 03 considers that to retain and improve this position of importance in world markets and to ensure the optimum utilization of Canadian mineral resources, a vigorous and aggressive program of metallurgical research in Canada is extremely important.

In 1967 most of the large metallurgical enterprises in Canada were fully aware of the necessity for and the value of research and had research departments of what they considered adequate size, staffed by competent men. The Government of Canada, chiefly through the Mines Branch, provides laboratories staffed with capable men who are working on Canada's metallurgical problems and are prepared to assist industry where required. Most of the provincial research councils and foundations have metallurgical capabilities. Several Canadian universities have departments of metallurgy (or metallurgical engineering) which carry on notable research programs in addition to their teaching responsibilities.

While in the early years, ore dressing and chemical metallurgy received most attention, at present physical metallurgy receives a substantial proportion of the total effort. In addition to process research, several companies now devote considerable attention to product research.

In a number of cases, companies in certain industries have joined together to form associations to undertake research on common problems, or existing industry associations have undertaken to sponsor research. This type of approach is particularly suited to small companies and to non-competitive areas.

RECOMMENDATIONS

On the basis of the information provided by the CIC survey and other surveys, the comments received from informed people and its own consideration of the problems of metallurgical research in Canada, Committee 03 makes the following recommendations:

1. Canadian Effort in Metallurgical Research

While much has been accomplished by all sectors of the metallurgical research community in Canada, much remains to be done if the optimum utilization of Canadian resources is to be achieved.

It is recommended that the total effort in metallurgical research in Canada should be increased by about 50% to not less than 1.5% of the sales value of the products of the metals industry.

2. Research by Industry

Since industry now performs over 80% of the metallurgical research done in Canada Committee Ø3 recommends that all appropriate measures be taken to encourage the growth of industrial research.

The present government programs set up to stimulate industrial research and to assist industry through sharing the cost of research have been helpful. Committee Ø3 considers that participation by industry in these programs can be increased by liberalization of the rules and regulations and recommends that this be done.

Committee 03 considers that government can encourage and strengthen industrial laboratories by channeling major research projects to industrial laboratories with suitable capabilities and recommends that this be done.

3. Research by Government Laboratories

It is recommended that research in government laboratories be increased only as the metals industry grows and that every effort be made to improve contacts and communications between government and industrial laboratories. The creation of a formal advisory committee by the industry is recommended to provide a forum for discussion and improve understanding.

4. Research by Universities

Committee 03 recommends that university research be directed more specifically toward Canadian problems and the utilization of Canadian resources. This can be assisted by a closer relationship between university staff and industrial research personnel. Appointment by universities of industrial advisory committees and acceptance by university staff of consulting assignments for industry is recommended. The exchange of staff between industry and universities would promote understanding.

5. Government Support of University Research

Committee 03 is aware that a study is now in progress on federal government support for research in universities and that present procedures may be substantially changed. It is strongly recommended that major project grants to university departments be used to supplement and perhaps partially replace the present procedure of grants to individuals.

6. Research Manpower

In view of the general opinion that metallurgical research is being handicapped by a shortage of people with proper training, and in view of recommendation #1 that the target for the future calls for an increase of the order of 50% in research effort, it is recommended that every effort be made to increase the number and the capability of graduates in metallurgy from Canadian technical colleges and universities.

To achieve this end the following steps are suggested:

a. A substantial increase in funds granted to universities for metallurgical research.

b. A sincere effort on the part of both industry and universities to improve the liaison and understanding between them.

c. An increased effort on the part of universities, professional organizations (e.g., Canadian Institute of Mining and Metallurgy), industry and high schools to interest more high school graduates in further study in the metallurgical field.

d. An increased effort by universities to attract more graduate students in metallurgy.

e. An increase in the attention given by industry and universities to training in the management of research. In this connection the Canadian Research Management Association might be of assistance.

7. Types of Research

Committee 03 endorses the principle that Canadian effort should be directed more toward applied research and development than toward basic research.

Committee 03 likewise endorses the emphasis on "materials research" in Canadian universities and the establishment of "materials research institutes" with a close relationship to university departments of physical metallurgy.

Committee 03 recommends increased emphasis on research in mineral dressing and chemical metallurgy in universities, and in government and industrial laboratories.

8. Research Associations

It is recommended that the formation of associations of companies to carry on research in fields of common interest be encouraged by the Government of Canada through financial support and perhaps by initiative in formation.

9. Future Surveys and Statistics

The committee has found that the statistical information available to it for this survey has been in many respects incomplete and unsatisfactory. This stems to a large degree from a failure on the part of many people to recognize metallurgy (or metallurgical engineering) as a distinct branch of science and engineering. In many respects the DBS reports are excellent and if improved would be a completely satisfactory source of statistical information.

The committee recommends:

a. That the DBS be requested to improve its collection and presentation of statistics on scientific research with particular reference to the branches of chemical and physical metallurgy. Research in government laboratories and in universities deserves particular attention.

b. That consideration be given by the Science Secretariat and the Canadian Institute of Mining and Metallurgy to a further survey of research in metallurgy in 1969.