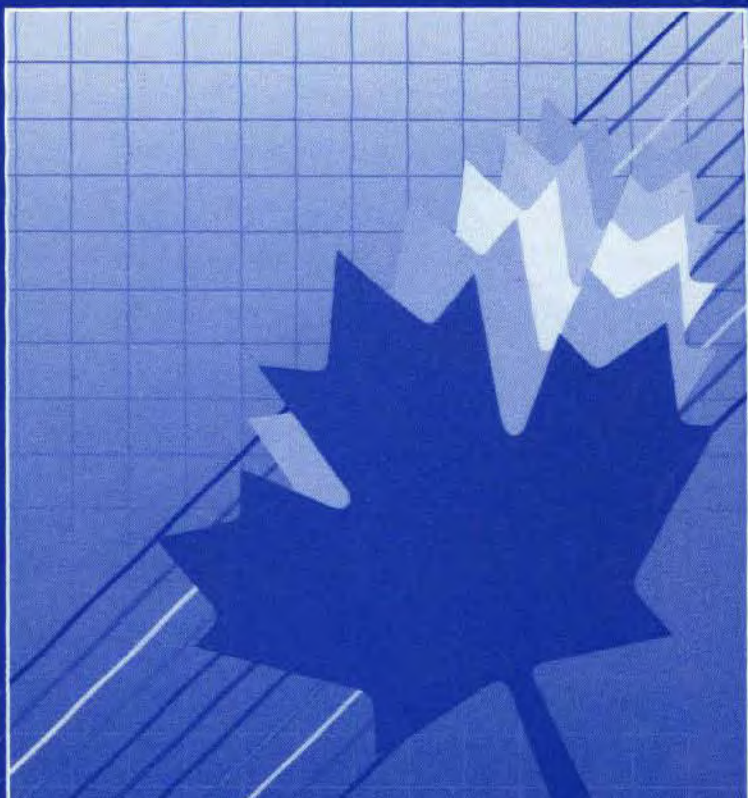
Science and Technology

ADVANCED MATERIALS TECHNOLOGIES: UNDERPINNINGS OF INDUSTRIAL COMPETITIVENESS

A Working Paper



stry of State
nce and Technology
ada

Ministère d'État
Sciences et Technologie
Canada

Canada

ADVANCED MATERIALS TECHNOLOGIES: UNDERPINNINGS OF INDUSTRIAL COMPETITIVENESS

A Working Paper

Prepared and Issued by the
Stategic Technologies Branch
Minstry of State for Science and Technology
on behalf of the
Interdepartmental Working Group on
Advanced Industrial Materials

Ottawa
October 1986

SUMMARY: PURPOSE AND ISSUES

This working paper is intended to form the basis for a nationwide process of consultation on Canadian strategy in advanced materials technologies. It is designed to raise issues, and to elicit comments and suggestions. It is aimed at decision-makers and planners in the private, academic and public sectors, but will be of interest to anyone connected with the development or use of new materials.

Advanced materials technologies are a family of emerging materials and, perhaps more importantly, new processing and testing techniques that will find application in a wide range of industries. These are enabling technologies. They underlie the competitiveness of various industrial sectors. Because of their critical importance to the economic future of Canada, advanced materials, like microelectronics and biotechnology, are strategic technologies for Canada.

To be internationally competitive, Canada must have a national commitment to excellence in materials science and technology - a commitment that can be shared by business, the research community and governments, and manifested in aggressive efforts to develop and apply world-class technology.

In considering a Canadian response to this challenge, the following issues are apparent:

- Leading firms, and the governments of several industrialized countries, have espoused a new view of advanced materials, and other enabling technologies, as <u>strategic assets</u>. This view has been slow to take hold in Canada, but it appears that Canadian initiative must come quickly or we may suffer an irreversible deterioration in our ability to compete.

- Canada's $38-billion minerals and metals industries are threatened by declining world demand and substitution by new materials. In some commodities such as steel, aluminum and nickel, the most optimistic forecasts point to modest world-wide market growth and a steady or declining market share for Canadian producers. In other commodities such as zinc and copper, Canadian revenues are almost certain to decline. Under these circumstances, survival for Canadian firms will require: (1) the recognition in public

policies and corporate strategies that markets are changing to favour materials suppliers that can flexibly meet the more exacting demands of tomorrow's users and (2) concerted programs of technology development to secure market niches. These realities have been recognized in Japan, the U.S.A. and Europe, but there is little evidence that they have been recognized here in Canada.

- While there have been some success stories in Canada, we lag well behind other industrialized nations in the development and application of advanced materials technologies. The lack of a national focus and sense of purpose derives largely from a limited demand for technology from the private sector.

- Although Canada cannot expect to be a world leader across the board in materials technologies, we can excel in niche areas that build on our strengths. What are these niches? How can we ensure that we have the industrial base and the technological infrastructure to pursue them? How do we best build on our strengths - including the strengths inherent in our long experience in materials production and processing? What will be the role of cooperative research and development?

The need for a strategy that could be developed cooperatively by the public, private and academic sectors is apparent.

In the process of consultation, you might consider your response to the following questions, in the light of the issues raised in this paper:

- How do you, or how does your company, institution or organization, view the structural changes taking place in the materials field?

- What major threats or opportunities do you see in the emergence of advanced materials technologies?

- How should Canada as a nation respond?
- What will be <u>your</u> strategic response?
- What constraints threaten to limit your ability to carry out that response? How can those constraints be overcome?

CONTENTS

SUMMARY: PURPOSE AND ISSUES i

THE NEED FOR STRATEGY 1

Advanced Materials: A Family of Strategic Technologies 2

The Evolving Materials Industries 3

Changing Demand 4

Strategic Issues 7

Canada's Position 9

DEVELOPING A STRATEGY 10

Areas of Technological Opportunity 10

Markets, and Access to Them 11

International Issues 11

Structural Issues 12

The Canadian Technology Development Effort 13

Information Needs and Availability 15

Performance Standards 15

Regulations 15

Skilled Personnel 16

DETERMINING OUR FUTURE 17

APPENDICES

A Definitions

B Issues Related to Selected Fields and Sectors

C Strategic Advanced Industrial Materials Programs in some Industrialized Countries

D Canada: Federal Government Programs, Advanced Industrial Materials

E Participating Departments and Agencies in the Interdepartmental Working Group on Advanced Industrial Materials

THE NEED FOR STRATEGY

The history of technology - indeed, the history of civilization - is to a large extent the history of the mastery of materials. Stone tools characterized the Stone Age. A remarkable alloy ushered in the Bronze Age. Ancient Greeks and Romans developed the use of iron, giving birth to the Iron Age. Improved iron and steel techniques underpinned the Industrial Revolution. In the 20th century, iron and steel have continued to dominate, but have faced new competition from aluminum, plastics, synthetic fibres and synthetic rubber. Advanced materials have helped make the Space Age possible.

Without the best materials, leadership in any major field of technology is impossible. The capacity to develop and use advanced materials technologies is an important determinant of industrial competititiveness.

The world of industrial materials is undergoing a dramatic transition. Traditional materials such as wood, copper, zinc and steel are being supplanted by substitutes in a variety of applications. In many applications, specifications are becoming more exacting.

Materials scientists have responded with new materials and processes to meet these needs. Sometimes this involves the use of unfamiliar raw materials, but more often it is a matter of novel processing techniques or combinations of materials that produce the desired properties. Increasingly, the impetus for technological change is coming from engineers and designers at the user end, as science continues to improve industry's ability to customize materials for specific uses. Integration and networking are the watchwords, as links among product designers, manufacturers, materials experts and others concerned with product performance grow stronger.

These technological and structural changes bring with them excitement and opportunity, but for a country such as Canada that has always depended on the materials industry as a major source of wealth, these changes can appear threatening, especially when traditional market forces are being superseded by concerted national efforts in other countries. Whether we turn market-based threats into opportunities, and those opportunities into wealth, depends on how successful we are as a nation at applying our strengths to the challenge of competing with other countries in the <u>development</u> and <u>application</u> of advanced materials technologies. Leading firms, and the governments of several industrialized countries, have explicitly recognized advanced materials, and other enabling technologies, as strategic assets. It appears that Canadian initiative must come quickly or we may suffer an irreversible deterioration in our ability to compete.

The worldwide recognition of the economic potential of advanced materials technologies has been evident in a range of programs and business activity. While Canada is not a leader in these technologies, enthusiasm is being expressed in this country. In a 1984 information needs survey conducted by the Canadian Manufacturers Association, industry managers ranked material developments and innovations first among 15 technological subjects of interest. There is a growing sense of the need to establish priorities and take action.

National and regional seminars and workshops held recently have brought together leading specialists and decision-makers to consider the issues facing Canada in the AIM field. While stimulating interest, networking, and business activity, these gatherings have also brought to light the main issues that must be considered by industries and governments in formulating plans.

Advanced Materials: A Family of Strategic Technologies

Advanced industrial materials is a very broad field. The term is more a concept than a definable category. Such materials are typically at an early stage of the innovation cycle. They are generally not in widespread use relative to potential. Their engineering properties and failure mechanisms are generally not fully understood, but they have properties that can not be met by most materials now in use. Until volume production reduces costs, their early applications will be to components and structures where first cost is secondary to maximizing performance. The field includes advanced metals and alloys, ceramics, plastics, composites, coatings, and processes to make and apply them. More detail is given in Appendix A.

Advanced materials are the starting point for a range of high-performance industrial products that will be of increasing economic importance in the future: products such as semiconductors, gas turbines, aerospace and automotive components and sensors. Advanced materials enable us to create or improve such products. Moreover, advanced materials represent not a discrete industrial sector, but a generic family of processes and products that underlie the performance of all industrial sectors. This generic characteristic is evident in the synergistic relationship that materials exhibit with other enabling technologies: for example, with microelectronics in the form of semiconductors, and with biotechnology in biosensors. These factors make advanced materials of strategic importance to Canada.

The Evolving Materials Industries

The materials industries have traditionally constituted one of the foundations of the Canadian economy. The $38-billion minerals and metals industries, from mining through smelting, refining and semi-fabricating, account for 8% of GNP and more than 20% of merchandise export earnings.

Recent world trends have, however, forced Canadians to question whether our materials industries can continue to be a stable and growing source of wealth. The accompanying figures show that while many traditional materials will continue to be important contributors to Canada's GNP, the trend lines provide little reason to be optimistic about growth. In some commodities such as nickel and copper, Canada faces a shrinking share of the world market. While many factors are at work, substitution by advanced materials is taking on increasing importance.

It is important to recognize that while the mineral industry is subject to cyclical swings, the changes of concern are not cyclical, but structural. They arise not from fluctuations in prices and economic activity, but from long-term adjustments in world industrial structure, materials substitution and technological change.

The recent economic performance of Japan, the United States, West Germany and other industrialized nations, the strategic plans that have been announced in these countries, and the large sums of money directed into advanced materials R&D all illustrate a conviction that the real economic growth opportunities for industrialized countries lie in industries that add value to raw materials by utilizing the most advanced technology. This is especially true for countries like Canada which face uncertain futures in the markets for basic commodities that make such a key contribution to our economy.

Changing Demand

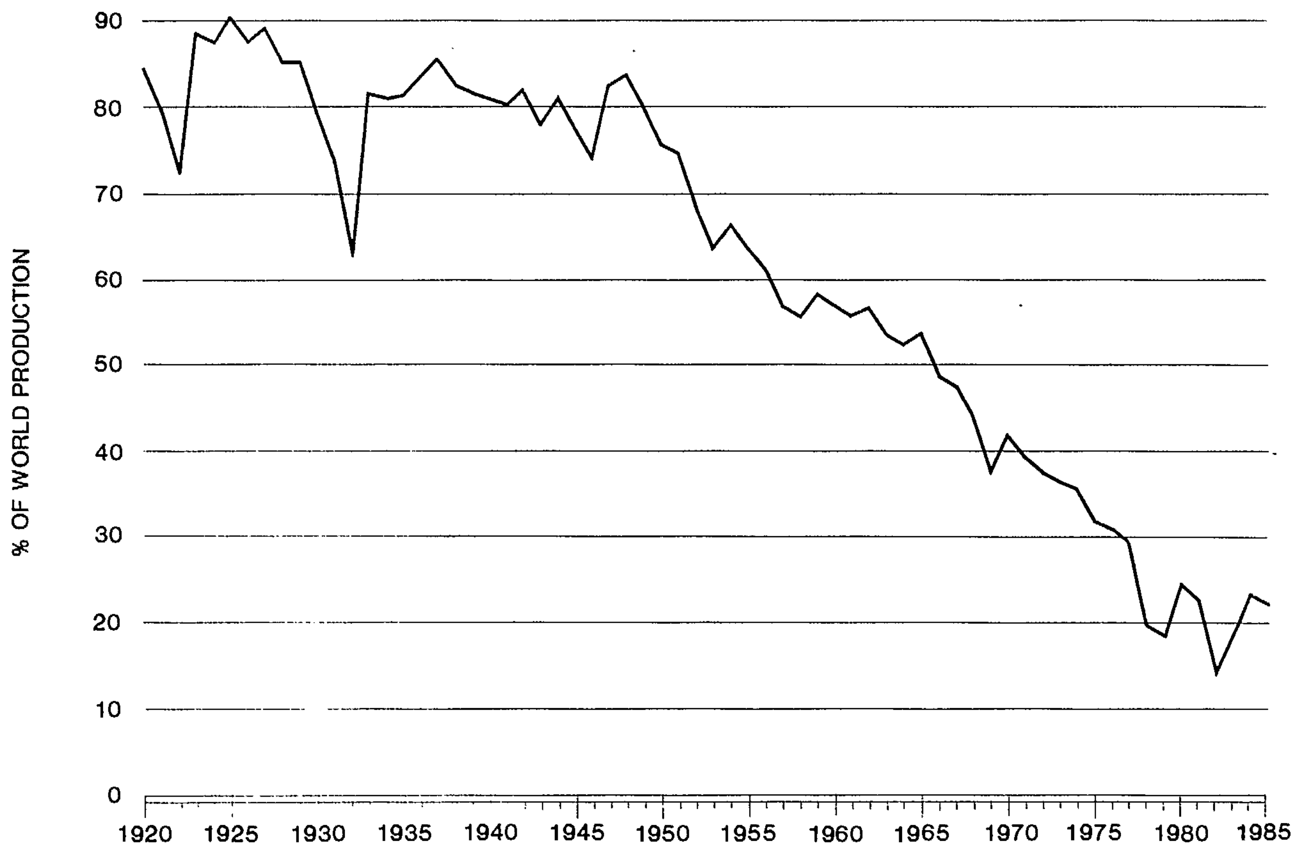
Substitution originates largely from a market pull. The automobile is one example. As the accompanying table shows, the usage of materials in the average U.S. automobile is changing dramatically. While the trend was forced largely by the spectre of high fuel costs, substitution will continue as engineers continue to discover the performance, efficiency and durability advantages of new materials.

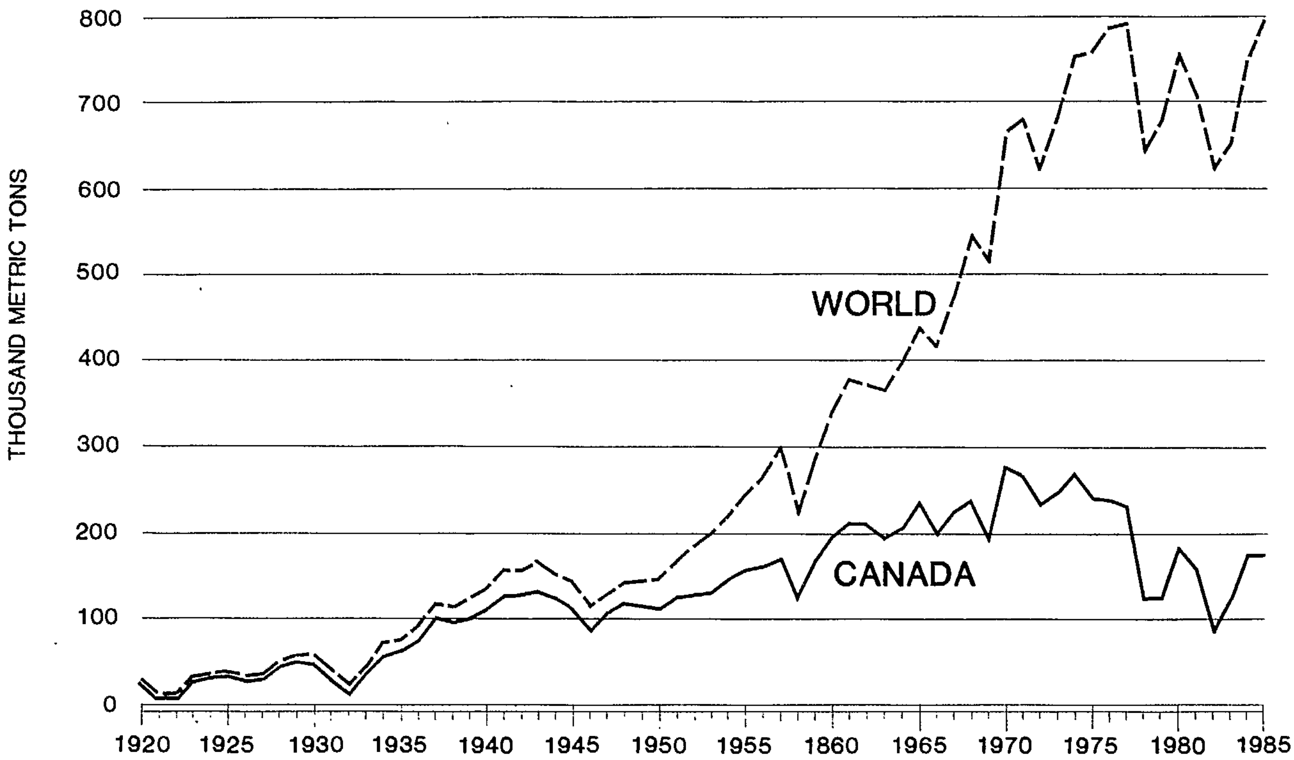
Similar examples can be drawn from the aircraft, space, military and electronics fields. In aircraft, for example, aluminum is being challenged by composites and advanced aluminum-lithium alloys. In electronics, new materials such as gallium arsenide and polymers are demonstrating the properties needed for the high-speed, micro-scale components of the future. Intensive R&D is underway to find substitutes for the lead-acid battery. Optical fibres are replacing copper in telecommunications.

The fact is that traditional materials simply can not meet the exacting performance standards of many of the products being designed or contemplated today. Better control of properties through improved processing technology, such as powder metallurgy, is sometimes the answer. In some instances, combinations of materials in alloys or composites generate the desired properties. In other cases an entirely new type of material must be used to meet the requirements of the application. Often, as in the case of electronic devices, product yields and specifications are heavily dependent on the materials.

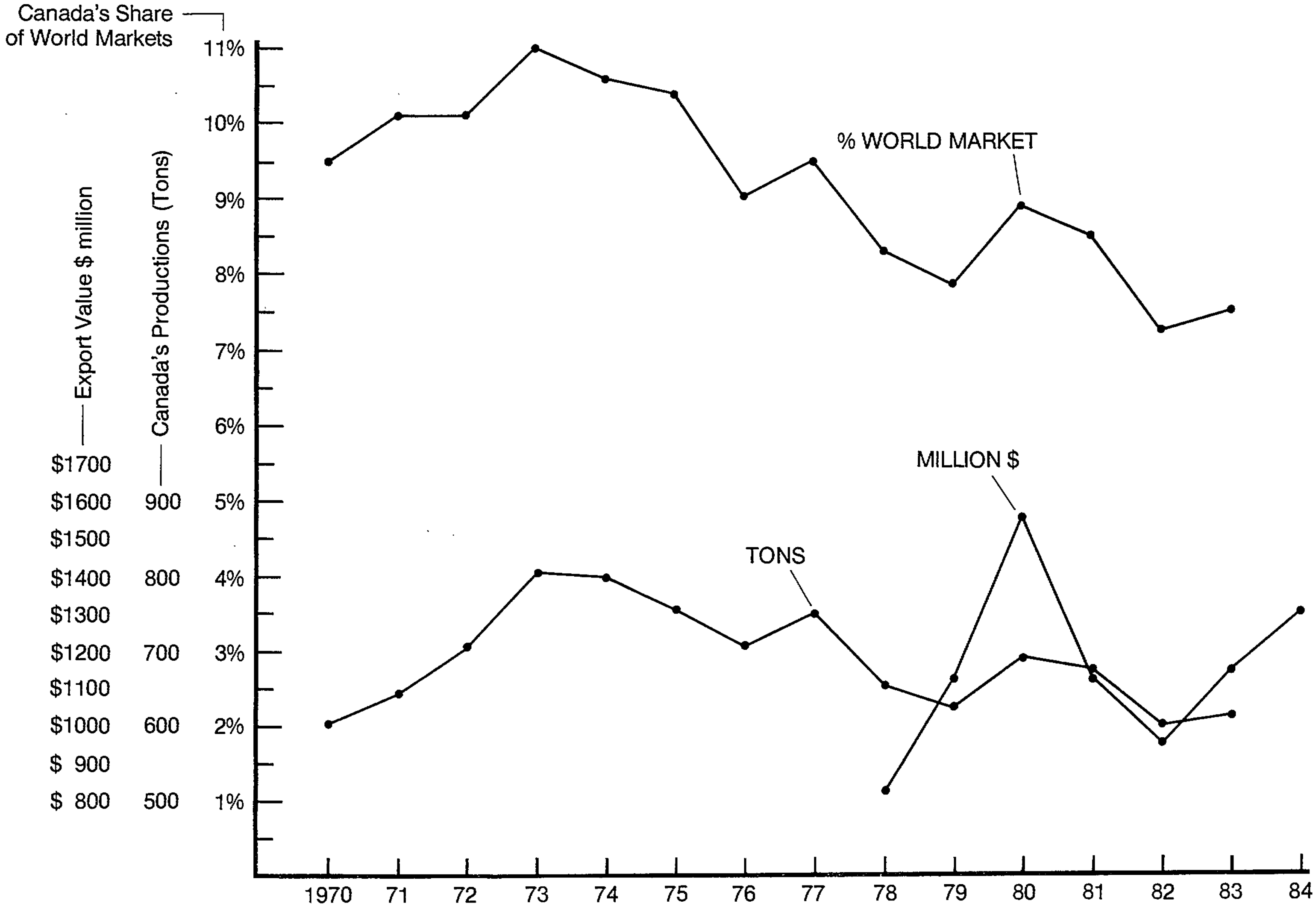
This focus on demand highlights the importance of excellence in materials to the manufacturing sector. While advanced materials may represent outputs and therefore diversification and growth opportunities for the materials industries, they are inputs for manufacturing. Producing high-value-added products competitively may require that a company be on the leading edge of new materials developments. While the total market for some new materials per se may not be large, these materials can be critical inputs for products that do represent large markets - for example, products in the aerospace, electronics, machinery, telecommunications and transportation sectors.

NICKEL
CANADIAN SHARE OF WORLD PRODUCTION





COPPER
CANADIAN PRODUCTION AND SHARE OF WORLD MARKET



ESTIMATED MATERIALS CONTENT PER U.S. PASSENGER CAR (KILOGRAMS)

	1977	1985	1987	1992
CARBON STEEL	905	672	590	478
HIGH STRENGTH AND STAINLESS STEEL	69	111	136	145
TOTAL STEEL	974	783	726	623
IRON	245	212	159	113
PLASTICS/COMPOSITES	76	96	91	113
RUBBER	68	62	50	50
ALUMINUM	44	63	62	61
GLASS	39	39	36	34
COPPER	14	12	10	10
LEAD	11	11	**	**
ZINC DIE CASTING	17	8	7*	7*
OTHER	175	160	55	55
TOTAL	1663	1446	1196	1066

Source: 1984 Ward's Automotive Yearbook.

* Including coatings
** Included in Other

Strategic Issues

These changes may represent threats, but they can also open up opportunities. Canada must move with these trends to avoid missing out on the economic benefits. The starting point must be in areas of strength - many of which result from our long experience in materials production and processing - and our special advantages such as the availability of abundant, low-cost energy.

As Appendix C illustrates, governments of several leading industrialized countries have mounted strategic development programs in advanced materials, often as part of a broader national policy for the development of critical technologies. The programs shown are focussed initiatives with clear goals, and in some cases are over and above regular program spending by government departments and agencies. The programs are predominantly market-oriented; however, they also have an element of science and technology "push", which arguably is necessary to ensure leadership in the underlying know-how required to efficiently secure, and sometimes create, commercial opportunities. The very existence of these programs demands a response from Canada if we wish to stay competitive. The question is: Are we in a strong position to make that response?

These focussed national programs exemplify a major change in the way in which leading industrial firms and whole nations view enabling technologies such as knowledge technologies, biotechnology and advanced materials. Increasingly, such technologies are being viewed as strategic assets. This view is reflected in the incorporation of technology development programs into strategic plans, not only in the sense of improving technology to do existing business better, but more importantly in the sense of ensuring that the nation or corporation has at its disposal those enabling technologies that are necessary to adapt to changing markets, to capitalize on new opportunities for wealth generation, and to maintain a competitive edge in a range of business ventures.

The programs often feature the formation of strategic alliances involving companies, universities and governments, to pool expertise and to share risks and information. These may take the form of government-to-government agreements, joint ventures, government coordinated networks, and research consortia involving leading companies. The emergence of such alliances presents a very real threat to firms and governments that must compete on their own against them. Indeed, the competitive importance of access to technical information in these fast-moving fields is leading to growing protectionism in which access may be available, if at all, only to those partners in the alliance.

The view of enabling technologies as critical assets does not appear to have taken hold in Canada. Yet given the structural ramifications for economic sectors such as our materials industries, it is clear that we must espouse and elaborate such a view. Staying competitive, and ensuring that we are in a position to create new wealth through the application of technology, will require an international orientation. Traditional views on access, diffusion and infrastructure must be re-thought. How do we ensure that we have the industrial base and infrastructure to identify and pursue niche opportunities? What strategies are appropriate for companies and for governments? How can we most effectively form domestic and international alliances to access and pool technology? What opportunities are present for integrated or cooperative activities in the materials field?

The advanced industrial materials opportunity embodies all the issues relating to a growing desire to add value to our resources. Will we, for example, continue to export commodity resins while we import engineering plastics and high-value finished products? Will we continue to export cadmium mercury telluride (a material in which Canada has world-class expertise), and re-import it in the form of infra-red devices? Will we mine and ship raw materials, or take those raw materials, process them using the latest technology, and create high-value, finished products that compete with the best other countries have to offer?

Canada's Position

Canada has some very innovative companies, some world-class scientific expertise and some leading-edge products in the advanced materials field. There are some real success stories - in electronic materials, for example.

Overall, however, we are not a leader. Indeed, three regional workshops involving the private, public and academic sectors, and the Science Council of Canada, concluded that "there is now very little research in, or use of, advanced materials by Canadian industry". The lack of a national focus and sense of purpose derives largely from a limited demand for technology from the private sector. There is, for example, very little automotive industry R&D in Canada - a major driving force in other countries.

In general it is fair to say that Canada has not yet begun to be a significant player in the world of advanced materials technologies. A special effort will be required to establish a position.

DEVELOPING A STRATEGY

The need for a nationwide commitment to excellence in advanced materials science and technology, and to the achievement of a competitive position in world markets, is apparent. A strategy should be developed cooperatively by the public, private and academic sectors, and must fully recognize that:

- the view of technology by leading corporations and governments is changing;
- the structural changes taking place in the materials field threaten to reduce Canada's competitiveness in a range of industries unless an aggressive, focussed response is developed;
- the development and application of advanced materials offer major opportunities for the generation of new wealth; and
- the Canadian R&D and commercialization efforts seriously lag behind those of our main trading partners.

Such a strategy would constitute a national response to worldwide developments. The commitment could take the form of a set of clear objectives toward which the public, private and academic sectors could subscribe, and a related set of actions by key players.

Areas of Technological Opportunity

The technological opportunities in advanced materials are many. Key growth areas emerge in most discussions - fields such as semi-conductor materials, structural ceramics, aerospace composites and high-temperature plastics. Identification of specific technological opportunities remains the job of the business and R&D communities. The question arises, however, of whether and how the government can assist the process - through measures such as the dissemination of information, increased R&D support to specific areas, and technology assessment. Issues related to selected fields and sectors are presented in Appendix B.

Markets, and Access to Them

Markets are the key to business success, whether these markets are for materials or for the products based on them. Market changes may pose threats to existing industries. At the same time, opportunities for new technology are constantly developing.

World markets for advanced industrial materials are projected to grow very rapidly as the accompanying table shows. In such a broad field opportunities are available to a great many producers. The challenge for Canadian firms is to reach those markets with a product that features state-of-the-art technology at a competitive price. The successful Japanese firms have integrated strategies for advanced materials that recognize both the needs of the end user, and the potential of advances in science and technology to provide a competitive edge and to open up new opportunities.

The development costs of high-technology products often mean that the Canadian market alone may not generate sufficient sales to provide reasonable returns. Inevitably, firms with growth in mind must turn to the U.S. and foreign markets. They have pointed out on many occasions that assistance with market information and market access is of crucial importance to them; this is especially true of smaller companies which lack the internal resources to economically tap these markets. As the worldwide AIM effort accelerates, it will become increasingly difficult for Canadian firms to compete.

International Issues

The strategic programs of other nations threaten to squeeze out Canadian firms and technology development organizations. They challenge our traditional markets. How can we best meet this challenge?

On the other hand, these programs offer opportunities to participate, provided we have something to offer. Worldwide acceleration of R&D generates technology that could be available to Canada, through joint ventures, for example. But will we have access? What are the implications of the increasing technology protectionism that is a feature of government-sponsored R&D programs such as those in the U.S.A.?

Typical World Market Projections for Advanced Industrial Materials

	to 1990		to 1995		to 2000	
	Pessimistic	Optimistic	Pessimistic	Optimistic	Pessimistic	Optimistic
Steel	0.4% growth	4% growth			1.2%/y loss	
*RS - Aluminum - Titanium				2000 tons/y 6% growth		
Ceramics	$2.4 B	$4.2 B	$5.0 B	$12.0 B	$15.0 B	$17.0 B
Engineering Thermoplastics		9%/y growth				
Composites						
Aerospace		22%/y growth				
Sport		11%/y growth				
Automobile	low growth					

Sources: Various published and unpublished reports.

* Rapidly solidified

Materials technology development is increasingly being dominated by international alliances of companies that pool expertise. Few Canadian companies have the credentials to participate in such alliances, and those that do are in some cases preoccupied with survival. The usual minimum requirement for participation is unique capability in relation to technologies or markets. As Canada is a small market, Canadian firms must be prepared to contribute technology.

Structural Issues

a) Dispersion and Fragmentation

Canada is a large country with a small, widely dispersed population. This creates special problems in communication and coordination, and in building on our strengths.

The materials community is also widely dispersed throughout various industrial sectors. The resultant lack of a coherent voice for the materials community has often been noted during attempts to identify issues and develop public policy responses. The apparent lack of coordination also weakens Canada's position in dealing at the international level. Strengthening of trade and professional associations, networking, and other mechanisms could help overcome this weakness.

b) Industrial Structure

Although the manufacturing sector has maintained a significant share of GNP in recent years, Canada is still characterized as a resource-based economy. In future, growth must come from the addition of value to the products of resource industries - industries that have extensive expertise that can assist that process. In the resource industries themselves, opportunities for diversification and vertical integration into advanced materials exist. There is a growing world trend toward user/supplier networks. Outside the resource sector, new materials can rejuvenate some industries, and give rise to others. Government could play a role in examining any constraints that inhibit the necessary adjustments.

The degree of foreign ownership is often cited as a key factor in the development of new technology in Canada. Subsidiaries often rely on foreign parents for

R&D, and technology developed by subsidiaries may be commercialized by parents outside Canada. Activities of subsidiaries tend to be truncated. Even firms with world product mandates can depend on headquarters for technology and may have limited interaction with the Canadian R&D infrastructure.

Parent companies can, however, be relatively inexpensive sources of new technology for application here. While assessments vary as to the overall effect on Canadian technological development, the foreign ownership variable can influence the kinds of strategies needed in Canada. Its importance in the materials field is not clear.

The Canadian Technology Development Effort

Canadian organizations are involved in research and development in most areas of advanced materials. Some of the larger materials companies have broad-ranging programs, and a host of smaller companies are involved in the development of innovative components and products in selected areas. The full extent of this industrial R&D effort has not been quantified, but there is little doubt that it is not commensurate with the challenges facing Canada, and with our position as a leading trading nation. Evidence to this effect is given in Appendices C and D.

A number of Canadian universities have individuals with strength in advanced materials, supported by the Natural Sciences and Engineering Research Council. The effort is, however, fragmented and dispersed, and the research groups small. Inadequate linkages with industry have also been identified as a weakness. Mechanisms could be developed to encourage a more pro-active role for companies in the development and execution of fundamental research programs.

In the ceramics field, both of these problems have been addressed through the formation of the Canadian University-Industry Council on Advanced Ceramics, initially involving five leading universities and more than 20 firms.

Universities are attempting to strengthen industrial links in other fields as well. The objective is to reap economic benefits from the good science available in Canadian universities, and in the process further strengthen that scientific effort. Linking universities with each other and with government and industry through multidisciplinary, cooperative R&D programs can help to create a "decentralized critical mass" of researchers. Coordination and communication are the keys. Seminars, conferences, workshops and the like can help create the links.

Technology centres and provincial research organizations (PRO's) can also be important players because of their close ties to industry. Some PRO's in Canada have recently taken steps to strengthen their materials programs.

The federal government, through scientific departments and agencies, promotes progress in materials in a number of ways. Government-funded research is carried out or sponsored in a number of fields as outlined in the table in Appendix C. Research and development on materials is also supported through assistance programs such as Natural Sciences and Engineering Research Council (NSERC) grants, the Industrial Research Assistance Program (IRAP), the Industrial and Regional Development Program (IRDP), and R&D investment tax credits.

These programs, which operate independently, might more efficiently stimulate innovation in AIM if operated in the context of a coordinated strategic plan for the government as a whole. Current tax incentives provide no special encouragement to strategic technologies. In the United States, procurement programs, particularly in the space and military fields, are used very effectively to encourage the development and application of new materials technology, and could be used in these and other fields in Canada. Since Canada is not a military-based economy, we might need to broaden our procurement scope to include all fields that benefit the economy. Mechanisms for transferring technology from government laboratories in response to market needs must continue to improve.

Given the areas of scientific strength in Canada, the future could hold a great deal of promise for Canada to lead in some fields. While we lag other countries, much of the world-wide research is still at an early stage. The challenge is to focus the efforts of the R&D community and create the conditions necessary for rapid commercialization of ideas. Advanced materials is a field in which cooperative research may be essential.

One must wonder, too, whether we as a nation adequately market our scientific and industrial capabilities. As a small economy we cannot afford to undersell these capabilities. Is there more that can be done in this respect in the materials field?

Information Needs and Availability

Of all the issues raised by companies in the various seminars and workshops, the need for information on science, technology and markets is perhaps the most persistent and the most widely recognized. Government has traditionally been a provider of such information, particularly in relation to research and development. Various surveys have revealed, however, that government is rarely if ever a firm's principal source of such information. In the materials field, there may be mechanisms that could more efficiently or effectively provide information; alternatively, the government could take steps to ensure that it is more readily available from private sources. It would first be important to ensure systems are in place to keep information suppliers aware of the needs of information users.

A special need exists for efficient access to reliable data on materials characteristics. Several countries (Japan, some European Countries) have, or are establishing, national data banks to efficiently disseminate such information and avoid duplication in testing. Countries such as Canada that do not have such data banks will be at a disadvantage. In addition, participation in international data banks will be difficult for those without national programs. A dedicated information centre with data banks, established perhaps as a cooperative venture, may be needed in Canada.

Performance Standards

The lack of uniform performance standards can be a serious impediment to commercialization. On the other hand, control over standards can mean control of market access. This important issue has been recognized by Japan and other countries. While Canada participates actively in international standards-setting organizations, these organizations act slowly and a special effort may be needed in advanced materials.

In leading countries, industrial standards are being developed for advanced materials. As market access can depend on the ability to meet such standards, nations such as Canada which do not have a vigorous national program of standards development can find themselves at a disadvantage.

Regulations

Government regulations can either encourage or discourage technological innovation. Pipeline regulations, for example, can carry specifications requiring continual technical improvements, or can favour innovative domestic suppliers. Other regulations can discourage new materials development or application by requiring lengthy approval processes or public disclosures.

It is not clear whether, on balance, federal government regulations are a negative or positive force in advanced industrial materials development. In safety regulations, the performance advantages of advanced materials may be offset by risk-aversion and cost considerations. In this and other areas, however, government departments and agencies can encourage or sponsor leading-edge R&D in support of a regulatory mandate. Product liability is another area in which conflicting objectives may inhibit innovation.

Skilled Personnel

Capturing opportunities in new materials technologies will require skilled personnel. While no inventory has been taken of the number of Canadian scientists, engineers and technologists working on advanced materials or likely to graduate in the coming years, experience in other fields raises concern about our ability to produce the skills we will need and to keep those people in Canada. Undergraduate engineering courses offer little emphasis on non-metallic advanced materials.

Given the excellent university and community college system in Canada, the availability of skilled personnel should not be a constraint. Measures to ensure that it is not may have to be identified.

A related issue is the effect of changes in materials processing technologies on the labour market. The trend toward near-net-shape forming, for example, can reduce the number of processing steps and the need for tooling. Information on these effects is limited.

DETERMINING OUR FUTURE

Momentum has been building in the Canadian advanced materials effort and there is good reason to be optimistic about Canada's chances of being a serious competitor in this field. But will conditions be right? What constraints do the business and R&D communities face in attempting to exploit the opportunities?

Our major trading partners have made aggressive moves, in some cases to the extent of having national programs with clearly identified priorities. The need for national leadership and coordination has been a recurring theme in the various meetings and studies of the past two years. Such leadership can come in the form of a national strategy that addresses regional needs and builds on regional strengths. The views and suggestions of the private, public and academic sectors will help to identify the necessary objectives and elements of such a strategy.

APPENDIX A

DEFINITIONS

Advanced Industrial Materials:

Advanced industrial materials display special and unique properties. They are at an early stage of the innovation cycle, and are often associated with characteristics such as: not being in widespread use relative to potential; processing methods which are still being developed; engineering properties and failure mechanisms which are not fully known or understood; and relatively high cost in initial applications.

Examples:

METALS:

Clean Steel: Steel very low and closely controlled in defects and inclusions and thus having superior mechanical properties such as weldability, formability, surface quality and low temperature toughness. These properties are important to frontier energy projects and certain consumer products.

Superalloys: Alloys made with carefully controlled amounts of additives and accurately processed, based on cobalt, nickel or iron with additions of transition, refractory metal or other elements. These alloys have high temperature and corrosion resistance and are used for turbine blades and other heat-resistant components.

PLASTICS/POLYMERS:

Advanced Polymers: Polymers displaying special strength or high-temperature characteristics because of binding of adjacent polymer chains or because of other chemical structure or composition arrangements.

Co-polymers:	The result of the combining of two or more chemical building blocks (monomers) within the polymer chains. The ratio of monomers is varied to obtain desired properties.
Polymer Alloys:	A mixture of two or more polymers, not chemically combined, but offering properties different from those of any of its components.

COMPOSITES:

Advanced Composites:	Materials made of strong thin fibres, chips, flakes or whiskers embedded in a solid matrix. The fibres could be glass, carbon, boron, polymer, aluminum or ceramic and the matrix plastic, metal or ceramic. Aerospace and sporting equipment are now the main users of composites but automotive and building material uses are developing.

FINE CERAMICS:

Functional Ceramics:	Ceramics made of high-purity, high quality powders to display various desired electric, magnetic, optical, biological and nuclear properties. Electronic equipment accounts for the largest use at the present time.
Structural Ceramics:	Ceramics made of high-purity, high-quality powders, closely controlled for defects and having special mechanical properties or corrosion and high-temperature resistance. Tools and heat engine components are the main uses.

ELECTRONIC MATERIALS:

Materials of high purity and great uniformity, displaying degrees of electrical conductivity affected by sample purity, crystal perfection and external conditions such as temperature, pressure and frequency of the applied electric field. Semi-conductors (silicon, gallium arsenide, etc.), dielectric, magnetic, optoelectronic materials, and optical fibres are examples.

Advanced Materials Processing Technologies:

Advanced materials processing technologies, when applied to conventional or unconventional starting materials, make substantial improvements possible in the properties of final materials. Advanced materials can be a result of the use of new starting materials, the application of advanced processing technologies, or a combination of both.

Examples:

Rapid Solidification Technology: A group of techniques used to cool metals from the molten to the solid state at extremely high rates. The result is alloys having highly refined crystal structures or with no crystal structure at all, and having exceptional electrical, magnetic or mechanical properties. Much development in consolidation processes is needed to enlarge the scope for applications.

Powder Metallurgy: Technique for forming metallic parts from high-purity metal or alloy powders, using different molding, pressing, sintering and heating methods. It is a near-net-shape process.

Surface Treatment: Processes for treating the surface of metallic parts with laser, electron or ion beams to locally improve wear or corrosion resistance without affecting the interior. These processes have applications in automotive parts, aircraft components, consumer products, etc., where corrosion or wear resistance is paramount.

Non-Destructive Testing: Methods used to verify the quality of materials, to detect defects or to make in-process measurements of a number of parameters without altering or changing properties, shape and appearance or affecting quality of products tested.

Other specialized processes need not be described in detail such as strip casting, continuous casting, die casting, squeeze casting, since these have applications in semi-finished metal production and do not substantially modify material properties. However, improvements in primary metal processing are needed for Canadian industry to be competitive in world markets.

APPENDIX B

ISSUES RELATED TO SELECTED FIELDS AND SECTORS

- Ceramics and other high-temperature materials. (including structural superalloys, inorganic composites, and cermets). Canadian research in these fields is very limited. In other countries it is driven by large defense and space programs, or by concern over supplies of energy and raw materials. Large investments in R&D in these fields by Canada may not appear warranted on the basis of domestic market needs, but it must be remembered that such materials can displace current Canadian products from existing markets. Opportunities to apply such materials in, for example, the resource industries could lead to Canadian and world-wide applications of Canadian concepts in manufacturing and other sectors. Some Canadian companies, many of them aided by government, have established good reputations for quality and reliability in niche markets. These successes could provide the foundation of an expanded, strengthened industry.

- Polymer alloys and blends, with or without reinforcements. The science and technology of such materials is still in its infancy, and the field is full of opportunity. Canada, however, has a large trade deficit in finished plastics and a limited technological base. Among other things, a greater emphasis on plastics is needed in engineering curricula.

- Semi-conductor materials. Canada has world-class expertise (developed with government assistance) in materials such as gallium arsenide and cadmium mercury telluride, but little of the raw, electronic-grade material we produce is used here. The present seller's market for these materials weakens the producer's resolve to do R&D, but other nations are doing the R&D that will capture the value added by making electronic components from these materials. There is an urgent need for research to improve the quality of Canadian gallium arsenide wafers. There may also be niche opportunities in indium phosphide. Domestic sources of defect-free wafers could represent an advantage for our device producers. To what extent are we willing to see the tools of technological change in an array of our industries depend upon progress in, and access to, foreign sources? What fraction of the electronic-materials-based industry can we expect to have (and support) in Canada?

° <u>Automotive engines and parts</u>. It is often in the automotive sector that new materials concepts first reach the large-scale production stage. While automobile manufacturers do almost no R&D in Canada, some parts manufacturers have active programs involving new materials such as ceramics and battery materials. As inroads by, for example, ceramic engine components are expected to be achieved incrementally, there should be scope for components suppliers to innovate. But a number of questions arise in the Canadian context. Given the heavy influence of Detroit over designs and specifications, how important is R&D to the Canadian parts industry? What opportunities exist for innovators based in Canada? How will Canadian materials suppliers respond to the changing mix of materials used in motor vehicles?

° <u>The steel industry</u>. This is an industry in transition. Faced with stiff foreign competition in standard products, the industry has been seeking to identify future profitable product lines, and attempting to cope with structural changes that will orient the North American industry towards more specialized and sophisticated products. This will involve the acquisition and installation of new technology. But what portion of the market can Canadian mills expect to capture? Do we have adequate technical expertise in advanced processing methods? What could be the implications of depending on other nations for new technology? What diversification opportunities are present that could change the steel industry into an integrated materials industry?

° The aerospace industry. While the Canadian aerospace industry is the world's fifth largest, and has been very successful in some fields, R&D on advanced aerospace materials such as composites is very limited. Over the past ten years Canada has invested perhaps about $6 million in R&D on aerospace composites - less than the annual composites budget of single U.S. military laboratories. The airframe companies in Canada tend to employ engineering staff on materials development work rather than maintaining permanent materials research departments. Only one company produces prepregs in Canada, with most requirements being imported.

  Nonetheless, some important advance have been made. De Havilland's DHC-8, for example, contains a higher proportion of high strength composite materials than any other known commercial aircraft. Canadian-produced resins could find their way into Canadian-produced prepregs. An additional challenge lies in the transfer of aerospace and space technologies to consumer products manufacture, where the effects are often profound. How important is it to expand aerospace composites R&D in Canada? What measures would be required to achieve that expansion?

° Computer-integrated materials processing. Synergism between two families of strategic technologies - information and materials - is evident in the application of computers to the integrated design, processing and evaluation of materials. The scope for advances here is immense. It is also critically important to competitiveness in industries ranging from steel to semiconductors. Progress in this field involves, among other things, multi-disciplinary and perhaps multi-firm research programs, the best available materials property data, and excellent communications channels.

° Non-destructive evaluation (NDE). One of the keys to the success of new materials such as ceramics will be the ability to non-destructively examine and test products. The worldwide effort in this field is very large, and Canada has shown some strength.

The challenge of applying techniques in industry could be addressed by programs for introducing prototypes into industry. Building on Canadian successes could also result in marketable technology.

° <u>Rapid solidification technology</u>. Rapid cooling methods can impart useful properties to a variety of metals and alloys. While applications of rapidly solidified metals, also known as amorphous metals or metallic glasses, may currently be limited, variations of the technology have tremendous potential for tailoring the properties of materials. The Canadian effort in this field is very limited. Only one company and one university have substantial programs, although modest efforts are being made here and there. Given the importance of the minerals and metals industries to Canada, this would appear to be a prime field for attention.

APPENDIX C

STRATEGIC ADVANCED INDUSTRIAL MATERIALS PROGRAMS IN SOME INDUSTRIALIZED COUNTRIES

A number of industrialized countries have given priority to advanced industrial materials programs, in some cases over and above existing R&D programs, thereby recognizing the importance of materials for future economic growth in an increasingly competitive world market. The United States is listed first not only because it is the world leader in many technologies but also because of the leverage exercised by the large military and space programs.

United States:

Military and space program spending for 1986 is estimated to include approximately $2 billion for advanced industrial materials research and development. In addition, close to 20% of SDI expenditure is estimated to be dedicated to material research. The National Science Foundation provides approximately $400 million a year for materials research. A National Critical Materials Council reporting to the White House has been charged with formulating a National Critical Materials Plan.

Japan:

The Ministry of International Trade and Industry (MITI) has identified revolutionary basic technologies targeted to R&D areas essential to the establishment of new industries. The Basic Technologies for Future Industries Program includes $33 million for advanced industrial materials R&D programs for 1985. This is only the visible part of an iceberg. There is a very strong commitment by the large industrial conglomerates.

West Germany:

In 1985 approximately $55 million, in addition to other existing R&D programs, was dedicated specifically to advanced industrial materials R&D. Alloys, powder metallurgy, composites and fine ceramics were identified as significant fields of research.

European Economic Community (EEC):

In addition to existing national programs, targetted programs and EUREKA, an advanced industrial materials program of $38 million over 4 years is proposed. The priorities are rapid solidification technology, ceramics, powder metallurgy, and composites.

APPENDIX D

FEDERAL GOVERNMENT PROGRAMS

Advanced Industrial Materials

Ministries/Agencies and Divisions	Clean Steel	Powder Metal-lurgy	Super Alloys	RST	Composites	Polymers	Advanced Ceramics	Laser Processing	Surface Treatment Coating	Non Destructive Evaluation	Process Control	CAD/CAM	Semi Con-ductors
Research Programs													
National Research Council													
Industrial Materials Research Institute		*			**	**	*	*	**	**	*	*	
National Aeronautical Establishment		**	*		**				**	**			
Division of Space							**						**
Division of Physics													**
Division of Chemistry						**							
Division of Mechanical Engineering												**	
Atlantic Research Lab							*						
Energy, Mines & Resources													
Canada Centre for Mineral and Energy Technology	*			**			**	**	*	**	**		*
Communications													
Communications Research Centre					*			*		*			**

o Rapid Solidification Technology
* Minor programs ** Major programs

APPENDIX D

FEDERAL GOVERNMENT PROGRAMS

Advanced Industrial Materials

Ministries/Agencies and Divisions	Clean Steel	Powder Metal-lurgy	Super Alloys	RST	Composites	Polymers	Advanced Ceramics	Laser Processing	Surface Treatment Coating	Non Destructive Evaluation	Process Control	CAD/CAM	Semi Con-ductors
Research Programs													
National Defence													
Defence Research Establishments													
Pacific					**					**			
Ottawa													
Val Cartier		*		*	**								
Atlantic				*			*		**		*		
Support Programs.													
National Research Council													
Industrial Research Assistance Program					**	**				*	*	*	**
Natural Sciences and Engineering Research Council **	*	*	**		*	**	*	*	*	*	*		**

o Rapid Solidification Technology
* Minor programs ** Major programs

APPENDIX E

PARTICIPATING DEPARTMENTS AND AGENCIES IN THE INTERDEPARTMENTAL WORKING GROUP ON ADVANCED INDUSTRIAL MATERIALS

Ministry of State for Science and Technology
- Strategic Technologies Branch

Department of Regional Industrial Expansion
- Office of Industrial Innovation
- Resource Processing Industries Branch

Energy, Mines and Resources Canada
- Mineral Policy Sector
- Research and Technology Sector
- CANMET

National Research Council of Canada
- Industrial Materials Research Institute
- National Aeronautical Establishment
- Industry Development Office

Department of Communications
- Communications Research Centre

External Affairs Canada
- Science, Technology and Communications Division

Agriculture Canada
- Canadian Forestry Service

Department of National Defence
- Research and Development Branch

Transport Canada
- Research and Development Branch

Natural Sciences and Engineering Research Council of Canada

Science Council of Canada

Economic Council of Canada