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Conseil des sciences du Canada

Report 38

Seeds of Renewal:
Biotechnology and Canada's Resource Industries

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September 1985

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September 1985

The Honourable Thomas Siddon
Minister of State for Science and Technology
House of Commons
Ottawa, Ontario

Dear Dr Siddon:
In accordance with Section 13 of the Science Council of Canada Act, I take pleasure in forwarding to you the Council's Report No. 38, *Seeds of Renewal: Biotechnology and Canada's Resource Industries.*

Yours sincerely,

Stuart L. Smith
Chairman
Science Council of Canada

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Preface

New technologies will help to modernize and diversify traditional industries and develop new ones. Biotechnology in particular promises to benefit the resource industries that are the backbone of the Canadian economy. Advances in this technology in the last few years have been rapid, and many experts predict that its impact will be at least as profound as that of the information revolution.

The Science Council's interest in biotechnology dates back to the early 1980s. In 1982, following preliminary work in the field,* the Science Council of Canada launched a major study of biotechnology in Canada's resource-based industries. The Council's aim was threefold: to increase awareness of the potential impact of biotechnology on Canada's economic strength and on its environmental and social wellbeing; to develop policies to ensure the optimum economic and social benefits from the adoption of advanced biological techniques by the resource-based industries; and to promote a dynamic, well-integrated biotechnology community.

This report is based on case studies of plant agriculture and the pulp and paper industry. The case study approach enabled the Council to highlight the potential of and the constraints facing the adoption of biotechnology in the resource-based industries in general and to generate policy recommendations geared to the needs of two industries in particular. At the same time, it enabled the Council to identify the broader policy requirements needed to help the resource sector fully exploit biotechnology.

During the study, the Council held workshops on the application of biotechnology to plant agriculture, the pulp and paper industry, and the forest sciences, and on culture collections. The Council also commissioned several manuscript reports on topics ranging from the adoption of biotechnology by seed companies to the state-of-the-art of biotechnology in the pulp and paper industry. Project staff consulted government officials, academics, industrialists, and others across the country to get their opinions on the future of biotechnology. Speeches and articles in journals and magazines kept the public aware of the study's progress. The Council listened to representatives of all the interests involved and encouraged discussion among the members of the biotechnology community.

By the close of the study, the Council was convinced that biotechnology could improve the quality of life for all Canadians. This report

*In 1980 the Science Council and the Institute for Research on Public Policy co-sponsored a workshop entitled "Biotechnology in Canada: Promises and Concerns." Discussion with key actors in biotechnology encouraged the Council to pursue some of the issues raised in greater depth. A related study of Science and the Legal Process produced the report *Regulating the Regulators: Science, Values and Decisions* (1982), which examined some actual and potential effects of biology on contemporary society. A discussion paper, *Regulation of Recombinant DNA Research* (1983), based on a trinational study, also examined some of the issues raised by biotechnology.

identifies promising areas for Canada and describes some of the environmental benefits of the new technology. It shows how Canada can seize the opportunities in biotechnology by removing existing institutional, legislative, and attitudinal barriers.

Frank Maine
Chairman
Biotechnology Study Committee

Chapter 1

Biotechnology: The Challenge and the Promise

Biotechnology may generate the last major technological revolution of the 20th century. The promise is already turning to profit; the pace is rapid; the potential is vast and exciting.

The Science Council believes that Canadians must grasp the opportunities offered by biotechnology if Canada is to improve its competitive position on world markets. This report explores the potential of biotechnology applied in the resource-based industries and argues that Canada should focus efforts in biotechnology on its existing strengths in the resource sector. Examples from agriculture and the pulp and paper industry show that the application of advanced biological techniques could invigorate these industries whereas failure to adopt them will weaken Canada's economic position.

In view of the momentum of biotechnology R&D throughout the world, a strong government R&D sector is vital to ensure the optimum application of the benefits of biotechnology to society. The need for government support is accepted even in the United States where there is a strong corporate presence. The central importance of basic research to biotechnology and the reluctance of big business to invest in basic research leaves the responsibility for increased investment mainly in the public sector.

This report identifies opportunities that the Canadian resource industries could realize if the public sector and private business work together to ensure the speedy and aggressive adoption of advanced biological techniques. It makes specific recommendations to promote a dynamic, well-integrated biotechnology community, identifies obstacles to the adoption of biotechnology, and proposes measures to overcome these obstacles. The report also shows how Canada can focus its limited resources for R&D to realize the full potential of biotechnology.

The Reality

Biotechnology is rapidly converting science fiction into science fact. Earlier detection of diseases such as lung cancer is being made possible. Diabetics are now able to treat themselves, not with animal insulin, but with human insulin produced by modified bacteria in fermentation vats. Farmers protect newborn calves from infection using vaccines produced by biotechnology, and they harvest hardy and nutritious varieties of corn, tomatoes, and barley developed by genetic modification. Foresters use biological pest controls. Fish farmers use biotechniques to improve yields from commercial stocks. Microbial extraction of minerals is helping metal producers cut energy and capital costs and reduce pollution. Moreover, the negative effects of established technologies—oil spills, toxic wastes, and foul-smelling emissions from paper mills—can be treated using biological controls. Advances are occurring more quickly than expected. Although world sales of biotechnological products in 1984 are estimated at only $50 million,[1] they are projected to reach $180 billion within 10 years.

As shown in Figure 1, biotechnology is grounded in the life sciences and engineering. Its industrial applications in the next five to 10 years are expected in a wide range of areas, including pharmaceuticals, agriculture, specialty chemicals, food additives, forest products, bioelectronics, and aquaculture. The new technology will engender completely new products, more productive, cheaper sources of existing products, and safer industrial processes to replace some of those in current use. Potential applications include anticancer drugs, growth hormones, improved means of treating high blood pressure, vaccines to control foot-and-mouth disease, genetically superior tree species, and nutritionally enhanced corn. In addition, a wide range of environmental applications are anticipated for pollution control, toxic waste management, mineral leaching, and the like, all of which will directly affect the natural resource industries.[2]

Worldwide, the application of biotechnology to the natural resource industries is of great commercial interest. In Canada alone, the annual value of goods produced using biotechnology could exceed $20 billion within 10 years. More than half this total could come from agriculture and food.[3]

The effects on the economy would be profound as shown by the example of biological nitrogen fixation. Farmers around the world supplement available plant nitrogen with about 60 million tonnes of nitrogen fertilizer a year. By the year 2000, the amount used could reach an annual total of 160 million tonnes. The manufacture of nitrogenous fertilizers uses large amounts of energy and the cost of these fertilizers has risen sharply in recent years. Canadian farmers spend $500 million on nitrogenous fertilizers every year.[4] Although biological nitrogen fixation could reduce farm production costs, it threatens the chemical industry with the loss of a huge market. As a result, research to develop a new range of nitrogen-fixing plants is being carried out by many multinational chemical companies. These firms realize that biotechnology will change the profit structure of the resource sector[5] and are getting involved in research to protect their own interests.

Figure 1: Biotechnology and its Disciplines

Field	Discipline	Biotechnology
Biology	Genetics	Plant/Animal Cell Cloning Techniques[a]
	Plant Biology	
Chemistry	Animal Cell Biology	Cell Fusion Techniques[a]
	Microbiology	
Physics	Biochemistry	Recombinant DNA Technology
	Immunology	
	Enzymology	
Mathematics	Engineering	Bioprocess Engineering[b]

Notes: [a] Incorporating traditional cell culture as used by plant breeders to develop new varieties.
[b] Incorporating traditional fermentation technology as used to produce wine and cheese.

A Definition:
Biotechnology is not an industry but an interdisciplinary scientific activity that can potentially benefit several industries. Almost all reports on biotechnology wrestle with a definition of the subject. The Organisation for Economic Co-operation and Development (OECD) notes the confusion and prejudice involved in the task and concludes that biotechnology is defined as "the application of scientific and engineering principles to the processing of material by biological agents to provide goods and services."* However, the OECD definition is too vague.

Biotechnology in contemporary usage refers to a range of new techniques coming from the life sciences (especially microbiology, biochemistry, and genetics) and biochemical and chemical engineering, and applied to various industries. All have used a variety of techniques for centuries. Many of the techniques associated with the modern concept of biotechnology, such as cell culture and fermentation, are old. What is new is the development of new techniques centred on recombinant DNA technology, cell fusion, plant and animal cell cloning techniques, and bioprocess engineering. These allow greater control over biological processes, a faster pace of change, and the possibility of many completely new products and services unobtainable using traditional techniques.

*A.T. Bull, G. Holt, and M.D. Lilly, *Biotechnology: International Trends and Perspectives* (Paris: Organisation for Economic Co-operation and Development, 1982), 21.

The World Scene

Many countries have developed intensive R&D programs in biotechnology. Interest in the new technology has generated a profusion of government reports, studies by international agencies, and reviews in scientific and financial journals. The United States is the world leader in the commercial development of biotechnology,[6] with its large number of new biotechnology companies and the sizable involvement of its large established firms. However, Japan, West Germany, Switzerland, the United Kingdom, and France are all important rivals. In specific product areas, one of these countries may already have taken the lead.

The United States is the only country in which venture capital plays an important part in the development of biotechnology in high-risk small firms. In Japan and Europe, established firms that have expanded into biotechnology dominate the research. Large food and beverage corporations in Japan (such as Kikkoman, Kyowa Hakko, and Toyo Jozo) have a long and successful tradition of conducting fermentation research to make soy sauce, sake, and other products. These companies are now applying their traditional skills to produce pharmaceuticals using modern biotechnology.[7]

In Europe the key players are the multinationals such as Hoechst (West Germany), Elf Aquitaine (France), Imperial Chemical Industries (United Kingdom), and Hoffmann-La Roche (Switzerland). Their range of interests extends from pharmaceuticals to specialty chemicals, food additives, genetically improved crops, and single-cell protein. Because of their enormous market (and profits), pharmaceuticals have become the major investment target, whereas investment in agricultural biotechnology is largely neglected.[8] In particular, because they are subject to less rigorous testing requirements, veterinary products and human health diagnostics* can generally be put on the market much more quickly than drugs for human use. Many firms are adjusting their investments accordingly to gain faster if lower returns from investment in animal and human health diagnostics. In this way, they can improve their cash flow until the new drugs reach the market.[9]

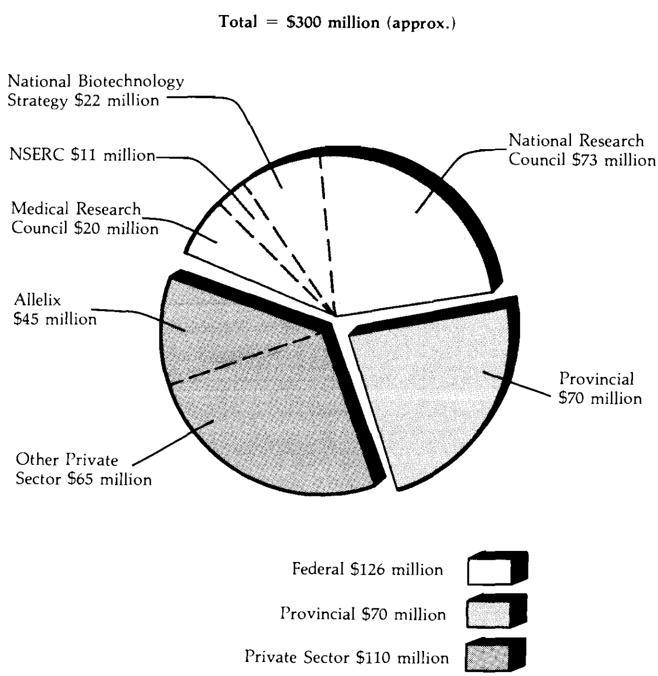
The Canadian Scene

Estimates of new funds spent on or committed to Canadian biotechnology from all sectors in 1983/84 range from $300 million to $350 million (Figure 2). During this period the federal government committed $95.5 million to the National Biotechnology Strategy and to capital facilities managed by the National Research Council. In addition (but not as

*Chemicals used to detect diseases.

part of the strategy), the Medical Research Council spent $20 million to support biotechnology-related research, and the Natural Sciences and Engineering Research Council disbursed grants totalling $11 million on research projects related to biotechnology. Provincial governments spent or committed approximately $70 million. The private sector, including venture capital, spent about $110 million, including $45 million from the Canada Development Corporation earmarked for Allelix (a Toronto-based biotechnology company funded jointly by the Canada Development Corporation, Labatt, and the Ontario government). Over the same period, Canadian corporations and venture capitalists invested about $50 million in biotechnology in the United States.

Figure 2: Estimates of New Funds Spent or Committed to Biotechnology in Canada, 1983/84



Source: Field data.

Of the total amount of money committed to biotechnology in Canada in 1983/84, approximately 40 per cent ($126 million) came from federal sources. This represented about 3 per cent of the federal government's total expenditure on science and technology. (In comparison, of the total federal expenditure on science and technology, 4.5 per cent was spent on defence, 7.5 per cent on health, and 12.1 per cent on energy.)[10]

It is difficult to distinguish a pattern of industrial investment in Canadian biotechnology. However, a recent survey by the Science Council of Canada reveals some interesting data. Of 258 industrial R&D performers in engineering, pharmaceuticals, and the agri-food sector, only 33 companies (13 per cent) are performing biotechnological research. Of the remainder, only 18 intend to do any biotechnology R&D in the next five years.

In line with international trends, some small firms have sprung up in the area of human health care products and human and animal diagnostic kits. Other new companies, such as Agrogen in Vancouver, Allelix in Toronto, and Laboratoires Rhizotec in Quebec, are directly involved with natural resources, especially plants. A few large established firms, mainly in the food and beverage sector, are investigating biotechnological techniques to strengthen their existing product lines as well as to diversify.[11] The only commercial developments using biotechnology in the minerals sector are by a new firm in British Columbia, PM Mineral Leaching Technologies, which is developing a bioleaching extraction process for precious metals; by Denison Mines, which is using a microbial process for uranium recovery; and by DeVoe-Holbein/John Brown BV, which is using synthetic analogues of proteins to capture radioactive metals and toxic metals from industrial effluents. Seagrams and Noranda have invested in biotechnology companies in the United States and Inco in a Swiss-United States firm.

Government Involvement in Biotechnology

The 1981 report of the Task Force on Biotechnology to the Ministry of State for Science and Technology[12] identified weaknesses in the research base, federal programs, regulations, and industry. It made specific recommendations to resolve these issues, which included a 10-year national biotechnology development plan with federal expenditures of $33 million in the first year and $50 million each year thereafter.

In belated response to this report, the federal government announced a two-year National Biotechnology Strategy in May 1983,[13] with a total budgetary commitment of $22 million. In line with the task force's recommendations, the National Strategy identified areas of strategic importance to Canada such as nitrogen fixation and plant strain development, cellulose utilization, mineral leaching and metal recovery, and human and animal health-care products. To promote these interests, the strategy designated $6.1 million to bolster existing programs within federal departments and agencies; to promote interaction among federal departments, universities, and industry; and to create research networks for each of the strategic areas outlined (Tables 1 and 2). To encourage the commercial exploitation of research findings, the strategy assigned $15.4 million to a new biotechnology program to be managed by the National Research Council's Program for Industry/Laboratory Projects (PILP). A National Biotechnology Advisory Committee with 25 members from all sectors (including eight from industry) was established to advise the Minister of State for Science and Technology directly on the development of biotechnology. An Interdepartmental Committee on Biotechnology was formed to coordinate all federal government activities in support of the National Biotechnology Strategy.

However, of the total budgetary commitment of $22 million, only $16.6 million was spent under the two-year program (Figure 3). Problems arose in the implementation of the additional funding under the National Research Council's PILP program, the eligibility of industrial participants was not adequately defined, and the new aspects of the program could not be marketed in time to attract enough participants to absorb all the funds.

To complement the National Biotechnology Strategy, the National Research Council was authorized to strengthen its commitment to biotechnology by three separate projects[14] (Figure 4). These were:

- the establishment of a $61 million Biotechnology Research Institute in Montreal;
- the $6 million strengthening of the Prairie Regional Laboratory in Saskatoon and its reorientation as the Plant Biotechnology Institute;
- the $6.5 million strengthening of the National Research Council's Division of Biological Sciences in Ottawa.

Table 1: Funds ($000s) Expended and Projected by Federal Departments and Agencies Under the National Biotechnology Strategy (1983/84 and 1984/85)

	Object of Allocation			
Department	**Strengthen Capacity**	**Promote Interaction**	**Create Research Networks**	**Total**
Agriculture	2323.5	717.0	75.0	3115.5
Energy, Mines and Resources	—	333.0	50.0	383.0
Environment	776.0	—	—	776.0
Fisheries and Oceans	188.9	4.0	—	192.9
Health and Welfare	407.4	185.1	25.0	617.5
National Research Council	400.0	592.0	50.0	1042.0
	4095.8	1831.1	200.0	6126.9

Table 2: Biotechnology Research Networks

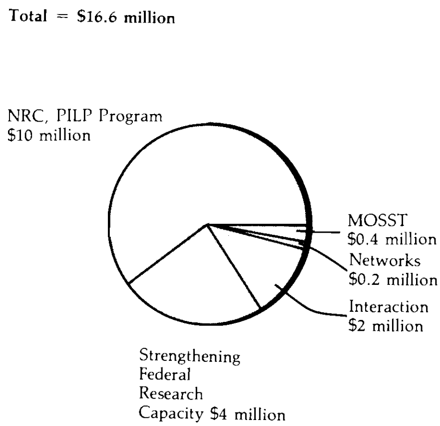
Theme	Sponsoring Organization
Nitrogen fixation Plant-strain development	Agriculture Canada
Novel aspects of cellulose utilization Waste treatment and utilization	National Research Council
Mineral leaching and metal recovery	Energy, Mines and Resources
Human and animal health care products	Agriculture Canada and Health and Welfare Canada

By the time the Biotechnology Research Institute in Montreal opens in 1986, the National Research Council will employ over 550 persons in biotechnology. This will give it one of the largest staff complements in biotechnology of any organization in the world. To oversee the development of its program in biotechnology, the National Research Council has appointed an Associate Committee on Biotechnology. Five of its members are also members of the National Biotechnology Advisory Committee. In addition, each of the National Research Council's biotechnology laboratories has its own advisory committee to guide program development.

An emphasis on agriculture is implicit in the National Research Council's creation of the Plant Biotechnology Institute in Saskatoon. The Institute has the specific task of doing research in plant-related industrial, forest, and agricultural biotechnology throughout Canada. By contrast, the Biotechnology Research Institute was established in 1983 without any particular objectives. A preliminary strategic plan became available only in the fall of 1984.[15] The Montreal institute is to conduct basic and applied research oriented toward industrial development. Joint research with industrial partners is expected, as well as cooperative research with both the Plant Biotechnology Institute and the Biological Sciences Division of the National Research Council. The precise nature of the research has not been defined but is to be determined by the economic opportunities for biological applications. As identified by the National Research Council, these include an emphasis on the resource sector, especially the agriculture/food, forestry and paper, and petrochemical industries.

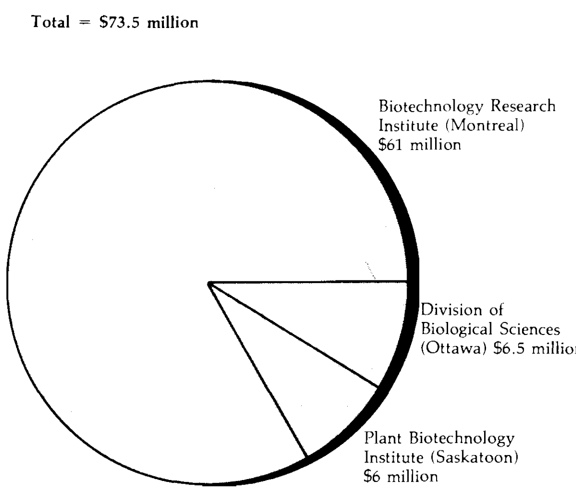
The National Biotechnology Strategy and the funding for biotechnology awarded to the National Research Council amount to a massive boost for government science but offer little direct support either to the universities or to the industrial community. They are typical of many federal initiatives in that they provide only a technological "push." In this, they do little to promote cooperation among governments, industry, and universities or to resolve one of Canada's fundamental problems in

Figure 3: Expenditure on Canada's National Biotechnology Strategy, 1983-85



Source: Field data.

Figure 4: New Commitment to Biotechnology Under the National Research Council, 1983



Source: National Research Council of Canada, *Estimates* (Ottawa, 1984).

advanced technology, that of responding to market "pull" by commercializing research findings.

To be fair, the government did introduce measures to promote intersectoral cooperation and commercial development. It has allocated additional funding for biotechnology projects under the National Research Council's PILP program to industry and called for matching funding from industry of at least 20 per cent of the total project costs. Twenty-five per cent of the overall cost of any project has to fund university-based research and industry has to identify a university sponsor.

University funding for research related to biotechnology was strengthened more directly with the commitment by the Natural Sciences and Engineering Research Council (NSERC) in 1983/84 of close to $11 million. This organization shares a pivotal role with agencies such as the Medical Research Council in maintaining the strength of basic research. NSERC is of particular importance to the natural resource industries. Since 1979/80, program expenditures for targeted research have grown by over 230 per cent.[16] Most of this growth has taken place in the Strategic Grants Program. In 1984/85, 68 strategic grants valued at $3.6 million (11 per cent of the total strategic grants funds) were awarded to projects in biotechnology.[17] Although close to one-third of this funding was for medical-related projects, the agriculture/food sector and animal science absorbed over 23 per cent.[18] Overall, NSERC supports a wide range of biotechnology research with application to the resource industries, including research on the biotechnological aspects of nitrogen fixation, biomass utilization, waste treatment, and mineral recovery. However the overall level of support remains too low.[19]

The delay in Canada's full-fledged entry into biotechnology has had a high price-tag. Internationally, Canada's attempt to carve out a niche in strategic research areas suffers from an inability to compete for the services of experienced scientists and research managers. Domestically, the federal government's slow reaction to the needs of this area has caused disenchantment in the biotechnology research community. Inaction has led to frustration. Some particularly well-qualified scientists have left the country for better jobs elsewhere.

The absence of clearly stated objectives to back many of the initiatives in place has diluted the effect of the government's commitment. The emphasis on the resource-based industries in the strategic areas identified and the networks selected has duplicated some provincial efforts. Individual provinces, in some cases in concert with metropolitan development or technology organizations, have already backed their own specific interests: agriculture in Alberta, Ontario, and Saskatchewan; agriculture and forestry in Quebec; and fisheries, minerals, and forestry in British Columbia. The National Biotechnology Strategy failed to consider these initiatives and to develop a coherent plan for the country.

Most provinces have some biotechnological work in place, from B.C. Research's growing of exotic mushrooms on cellulosic waste to Memorial University of Newfoundland's research on using marine enzymes in making cheese. Provincial initiatives in promoting biotechnology in the resource-based industries are essential to the development of biotechnology. Not only do provincial governments have constitutional control over their own natural resources but they also have authority over education.

Quebec and Saskatchewan have large federal biotechnology laboratories; they also have well-developed provincial strategies that include a focus on the resource sector and are good illustrations of the scope of provincial involvement.

Recognizing that the absence of a sound industrial infrastructure would hamper the development of biotechnology in the province, Quebec is using its long-standing solution, the crown corporation (société d'état) to create a bio-industry. Most recently, Quebec's agriculture-food corporation, Société québécoise d'initiatives agro-alimentaires (SOQUIA) established a subsidiary, Société québécoise des bio-technologies agro-alimentaires (BIO-AGRAL). This organization will help small and medium-sized businesses exploit biotechnology in the food industry. In addition, a recent report on the Quebec forestry industry has identified biotechnology as an important factor in development[20] and a further report is expected to propose specific strategies to capitalize on this potential. These initiatives are part of a five-year biotechnology development plan with total funding of $35 million to $40 million. A five-year agreement to promote cooperation in training programs and information exchange has been signed by the Quebec and French governments. A Quebec white paper on biotechnology[21] has identified the need to strengthen industry-university linkages and recommends the identification and financing of centres of excellence within Quebec research institutions in support of training in biotechnology.

Saskatchewan has designed a strategy to further the commercial application of biotechnology, particularly in agriculture, in collaboration with the federal government. The province is already working on a Canada-Saskatchewan technology strategy with the federal Department of Regional Industrial Expansion, and a Consultative Committee on Biotechnology has been set up to coordinate the activities of the various key actors in the biotechnology community. The major federal participants are Agriculture Canada and the National Research Council; private-sector commitment is being encouraged by the Saskatchewan Council of Biotechnology, a body designed to link private industry in the province with the appropriate public research groups. To complement these initiatives, the University of Saskatchewan is exploring the possibility of establishing a new interdepartmental program with specialization in biotechnology.

The sub-agreement on biotechnology as part of a broader Canada-Saskatchewan technology strategy is a valuable mechanism to minimize the duplication and fragmentation of already scarce resources. More bilateral approaches of this nature will be needed. The policies and programs set up by provincial governments have often been the result, at least in part, of continued uncertainty over the long-term goals of federal government policies for biotechnology.

Opportunities in the Natural Resource Sector

Biotechnology will help change the terms of world trade. Recognizing this, individual countries are working to create their own market niches by setting priorities for their R&D funds. Canada must do so too.

Until now, its abundant resources have given Canada a comparative advantage on world markets. However, that advantage is not large. The long harsh winter, permafrost, soil infertility, and a wide range of other characteristics severely limit land use, so that only 13 per cent of Canada's total area can support any agricultural production. Many timber species mature five times more slowly in Canada than in the southern United States. Major resource areas are often distant from markets and transportation costs are high.

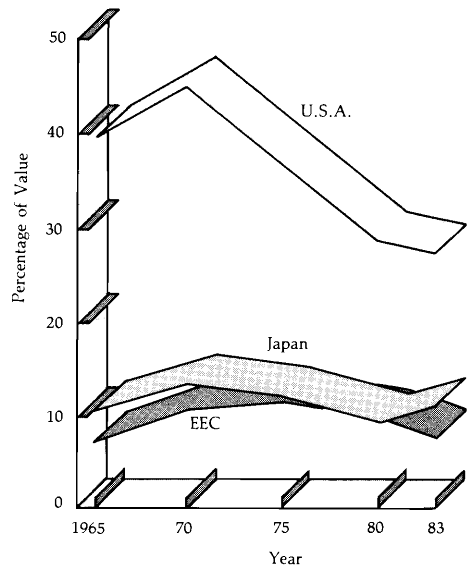
What comparative advantage Canada has is dwindling.[22] In certain areas, mismanagement and depletion of resources — overfishing, soil erosion, and excessive felling — have undermined the resource industries and there is no strong processing sector to fall back on. Canada's reserves of some raw materials are shrinking and its capability to compete on world markets is shrinking even faster. Competition from the United States (crops), Chile (minerals), and Sweden (pulp and paper) is encroaching on Canada's traditional share of world trade in natural resources and weakening its hold on long-standing key markets (Figure 5). Unless this trend is reversed, the economic outlook for Canada is dismal.

Biotechnology may shrink some existing international markets for raw materials by boosting the self-sufficiency of Canada's traditional trading partners. Any sharp increase in grain production in the Soviet Union or China, for example, could dramatically alter the demand for Canadian wheat. Meanwhile, many of Canada's trade competitors are rapidly developing biotechnology to fit the needs of their own resource industries. The United Kingdom and the United States are applying it to agriculture, and New Zealand and the Scandinavian countries to forestry and the pulp and paper industry. By aggressively adopting biotechnology, Canada could stave off decline in its natural resource industries and reinforce its position in world trade. Moreover, it could use its natural resource base to create a range of new, spin-off, knowledge-intensive industries.

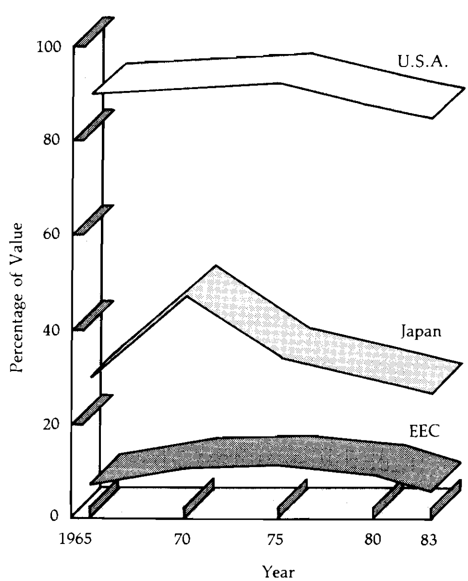
Canada should be well positioned to command a share of the burgeoning world market in biotechnological products, such as new hybrid

Figure 5: Canada's Share of Selected Markets in Key Resource Materials, 1965-83

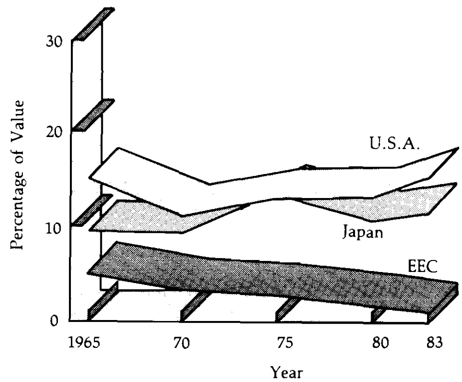
5a: Canada's Share of Metal Imports to the United States, Japan, and the European Economic Community, 1965-83



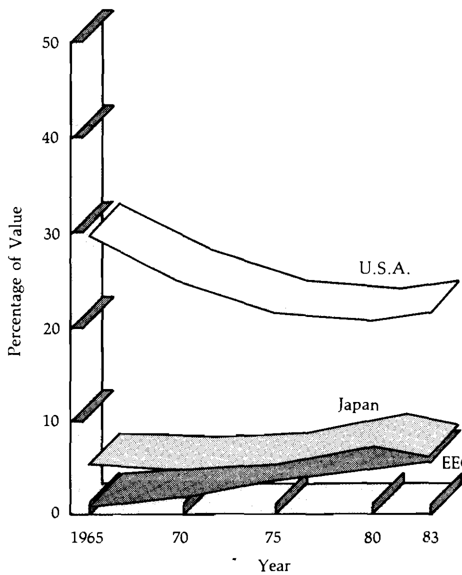
5b: Canada's Share of Pulp and Paper Imports to the United States, Japan, and the European Economic Community, 1965-83



5c: Canada's Share of Agricultural Imports to the United States, Japan, and the European Economic Community, 1965-83



5d: Canada's Share of Fisheries Imports to the United States, Japan, and the European Economic Community, 1965-83



Source: External Affairs, International Trade Databank seeds, stress-tolerant crops, improved pulp and paper products, faster-growing trees, and new biological methods of mineral extraction. Its traditional expertise in the natural resource industries has inherent advantages, and some financial commitment to the new technology is already in place. Canada, however, has neither a strong industrial sector nor much industrial involvement in R&D.[23] Moreover, increased investment in biotechnology R&D is taking place against a background of years of declining support to government facilities and a severely underfunded university community.

No clear national goals or objectives for biotechnology have yet emerged. Although new buildings have been commissioned, funds for the working scientist are scarce. The result is a major commitment of funds to no clear end.

Agriculture and Pulp and Paper

Biotechnology is expected to transform all the natural resource industries.[24] This report uses the examples of agriculture (particularly plants) and pulp and paper to examine the opportunities and impediments facing Canada in applying the new techniques. These examples share certain characteristics related to their dependence on the natural environment, but each has evolved along its own path and differs in its form, its structure, and the nature of its R&D system.

Biotechnology is the basis for a new revolution in agriculture. The new technology will reduce the time-lag formerly necessary for producing new plant varieties and improve plants in ways that were impossible with traditional methods. Crosses of unrelated genera and species and alterations in the genetic make-up of plants are two key techniques designed to produce high-yielding hybrids and to breed varieties with enhanced biological nitrogen fixation properties, resistance to disease or drought, or increased tolerance for salt or frost.[25] Commercializing these improved crop varieties will increase returns on agricultural R&D investment and reduce the risks inherent in farming.

In the pulp and paper industry, biotechnology could allow more efficient use of trees; develop more energy-efficient, cleaner processes; produce new products from wastes and residues; and offer alternatives to conventional effluent treatment that would deal with foul-smelling emissions from mills and reduce pitch and slime in machines. The production of better-quality, stronger paper by fungal treatment of mechanical pulp could result in substantial cost savings to the industry. Waste from pulp and paper mills could be transformed from a costly disposal problem to a valuable source of animal feed, a medium for growing food (such as mushrooms) for human consumption, or a source of food additives, pesticides, and drugs.[26]

Although some new products and processes based on biotechnology are already in use (Table 3), the resource industries must place greater emphasis on research. With greater emphasis on R&D, dramatic research breakthroughs could occur within the next 15 years. Many of these may arrive within the next five years.[27] By 1995 biotechnology will supply the bulk of food additives; genetic stock enhancement through embryo transplants will affect 30 per cent of cattle; 20 per cent of all Canadian crops will have been developed through biotechnological processes; and 15 per cent of stock feed will be produced using biotechnology.[28]

Table 3: Some Products and Processes Based on Biotechnology in the Natural Resource Sectors

Sector	Products	Processes
Agriculture	single-cell protein pesticides e.g., *B. thuringiensis* bovine interferon growth hormones monoclonal antibodies vaccines e.g., rabies scours foot-and-mouth	anther culture embryo transplants gene splicing
Forest Products	biomass products e.g., single-cell protein ethanol mushrooms mycelial paper vanillin	effluent treatment silviculture wood seasoning
Mining		bio-leaching e.g., copper leaching
Petroleum	bio-polymers e.g., polyhydroxybutyrate (PHB)	tertiary oil recovery
Fisheries	vaccines monoclonal antibodies hormones e.g., salmon sex hormones	aquaculture

Increasing Fundamental Research

Biotechnology could revolutionize almost every aspect of Canada's natural resource industries. Despite efforts to correct the situation, the allocation of funds to biotechnology R&D in agriculture and the forest products sector is still inadequate. Other resource areas such as fisheries, minerals, and water also offer opportunities for the application of biotechnology, but they are not being suitably addressed. The overall research situation remains depressingly familiar—a weak industrial base, a fragmented provincial and federal R&D effort, and underfunded university research.[29]

Properly exploited, biotechnology, like microelectronics, could help make Canada's resource sector competitive. As with all advanced technologies, its commercial success depends on strong fundamental research: the essential need for basic knowledge cannot be overstated. This is widely accepted in the industrial community.[30] Even though increased funding for the life sciences and biotechnology will not alone guarantee financial returns, no advanced technology research can go forward without fundamental science. Given the increased pressures on its natural resources, Canada must ensure it has the basic knowledge it needs to develop the resource technology that will ensure its success as a trading nation. Fundamental research is traditionally undertaken in the universities. Yet in the recent federal policies supporting biotechnology in Canada, government laboratories have received a disproportionately large share of new funding.

The National Biotechnology Advisory Committee has considered the potential for university-based centres of excellence and made appropriate recommendations to the Minister of State for Science and Technology, but no action has followed. Some universities such as Waterloo, McGill, and Dalhousie have taken the initiative and created their own research focus in biotechnology. However, the financial constraints on Canadian universities make it difficult for them to assemble world-class research teams. In addition, the equipment and materials needed for research in biotechnology are expensive. At present, few of Canada's universities can afford to outfit state-of-the-art laboratories.

Biotechnology is an interdisciplinary mix of the biological sciences and engineering. Canadian universities need research teams in biotechnology that bridge disciplinary boundaries and that bring together the necessary numbers (critical mass) of highly qualified personnel to perform effectively. In addition, sizable research teams would provide Canadian university scientists with the management experience that could allow them to transfer their research expertise into an industrial setting. Therefore,

1. The Natural Sciences and Engineering Research Council should receive extraordinary funding of $15 million each year for 10 years for the

creation of from five to 10 interdisciplinary teams, each with a research focus on some topic of fundamental importance to the advancement of biotechnology.

Each team should include a minimum of five scientists from at least two different universities. Selection of the teams should be by open competition and the Natural Sciences and Engineering Research Council should establish a committee of experts, including representatives from foreign universities and Canadian industry, for this purpose.

Stimulating Industrial R&D

A strong commitment to basic research is a vital preliminary step toward a healthy biotechnology community. However, increased research alone will have little impact on the economy unless industry makes a concomitant effort to apply the results of this research. This raises the general problem of university-industry links and of the extent to which market needs should influence university research. This problem is currently under detailed examination by the Science Council as part of a separate study.*

The commercial success of biotechnology in Canada also depends on an increased level of industrial R&D. As noted earlier, some large Canadian firms, mainly in the food and beverage sector, already conduct R&D in biotechnology. Other sectors in which biotechnology research is important, such as the chemical and pulp and paper industries, are characterized by relatively high levels of foreign ownership and correspondingly low levels of R&D activity in Canada. Among large firms, R&D is primarily market-driven and government policies are of limited importance.

Canada might, however, promote greater biotechnology research in small and medium-sized firms, because their research activities are more readily influenced by government policies. The potential to generate a lively biotechnology community, whether by establishing new biotechnology firms or by encouraging existing firms to adopt biotechnology is illustrated by the United States.[31] Its success in establishing a sizable pool of small and medium-sized firms involved in biotechnology is one of the elements contributing to its current world leadership in biotechnology. However, few small or medium-sized firms in Canada have the resources to do biotechnology research without government support. A recent survey of Canadian high-technology firms identified government grants as being particularly important to those industries involved in the newest technologies (biotechnology and advanced materials).[32]

The high-risk, high-cost, long-term nature of biotechnology research makes cost-sharing programs between industry and government inade-

*University Science and Technology and the Canadian Economy.

quate. In the United States, this has been recognized by the National Science Foundation. It operates a program known as the Small Business Innovation Research Program (SBIR), which specifically aims at stimulating technological innovation in small, high-technology firms. The program is designed to increase the commercial application of government-funded research and to boost the economic and social benefits from such research. The program is not cost-sharing like Canadian programs. Rather, it involves 100 per cent funding for research over a fixed period. It has helped to double employment in the firms that receive support and has encouraged firms to establish research links with the university community.[33] To stimulate the adoption of biotechnology by existing firms (such as seed companies) and to encourage the start-up of new firms using the research developed in universities and in government laboratories,

2. The National Research Council should establish a $10 million contract research program to support biotechnology research by small and medium-sized firms.

Chapter 2

Plant Agriculture: Preparing Biotechnology for Takeoff

Little biotechnological research is under way in Canadian agriculture. Yet historically, this industry is one of Canada's greatest success stories. Canada ranks third among the world's largest agricultural trading nations. Success, however, has generated complacency: there is a regular trading surplus and, for domestic consumers, an abundance of good food at reasonable prices. The fact that this success has been achieved in spite of the limitations on Canada's resource base is forgotten.

Biotechnology offers a wonderful opportunity to remove what to date have been considered inherent geographical barriers to production and to tackle environmental issues. Genetic manipulation could allow scientists to breed crops able to resist disease, herbicides, or pollutants or to tolerate environmental stress, including salinity, low temperatures, floods, or drought. Food crops with higher yields and improved protein content and without toxins could also be developed as well as self-fertilizing varieties of corn or wheat that will not need nitrogen fertilizers. In addition, completely new kinds of crops may be introduced.

With this wealth of opportunity opened up by biotechnology, it is amazing that so little research is being done. The fact that Canada has so much space available to grow food has blinded Canadians to alternative forms of production that would minimize waste and stimulate agriculture in areas that were formerly unsuitable for growing crops.

The government has committed some funds, facilities, and personnel to research in biotechnology. This is a start, but that commitment must be intensified, focused, and geared to specific goals if Canada is to get a return on this investment. At the same time, the regulatory environment must be made more conducive to the development of this important new technology.

What Canada needs is more firms involved in agricultural research. The establishment of Allelix using joint government-private funding is a novel approach to meeting this need. In due course, another establishment in this mould may be necessary. For now, however, the greatest need is for more spin-off firms from government laboratories and universities and more involvement in biotechnology research by existing firms. The implementation of recommendation 2 would be one step toward achieving this objective. This chapter includes further recommendations designed to promote an environment conducive to more industrial research in agricultural biotechnology.

Government Research in Biotechnology

Publications by the Canadian Agricultural Research Council (CARC), the Ministry of State for Science and Technology (MOSST), and the Science Council[1] have reviewed the level of biotechnological R&D in Canada. In agriculture,[2] the greatest research effort is in crop improvement using embryo culture and sexual and somatic hybridization, and there is some interest in gene transfer between different plant species. Specific goals for this research include a frost-tolerant alfalfa, salt-tolerant flax, tobacco, and sugar beet, and genetically improved oilseeds, cereals, and horticultural crops. The quantity of research on each topic, however, is minimal. Only three researchers are focusing on salt tolerance in plants (in Calgary, Kingston, and Saskatoon) and only one group is working on frost tolerance (the Alberta Research Council).

Biotechnological techniques are also being applied to the detection and control of disease in plants and the control of pests and to the genetic engineering of disease-resistant crops. Symbiotic relationships between plants and microorganisms are being explored to find a microorganism that will act as a nitrogen fixer for wheat. In the vital area of biological nitrogen fixation, out of a total of 200 researchers, more than half are in temporary or training positions.[3]

There are more than 100 research groups working on plant biotechnology.[4] However, that effort is scattered and, in view of the potential that biotechnology offers Canadian agriculture, several gaping holes remain. Relatively little effort is directed at cereal improvement, for example, although cereals are a mainstay of the agricultural economy and wheat generates 30 per cent of Canada's total export income. Field crops represent almost half of farmers' total cash income, yet studies on forage legumes such as alfalfa and clover, or on forage grasses or other field crops, are few.[5]

Research in other sectors of the agricultural industry is equally patchy. Canada lags so far behind other countries in applying biotechnology to animal biology that it has to spend over $25 million every year on imported veterinary biologics.[6] The greatest research emphasis is on the use of monoclonal antibodies* in the detection of disease and on the production of vaccines for the control of serious infectious diseases. Yet there is no testing facility for these vaccines in Canada. Only in the development of embryo transfer to increase animal reproduction has Canada made its mark, although the total research effort is weak.[7] Agriculture Canada sponsors no significant research on the application of biotechnology to food processing, although the new Food Research Centre in St-Hyacinthe may meet this need. The CARC report concluded that Canada is misdirect-

* Laboratory-produced clones of the body's natural defences against specific diseases.

ing its funds for biotechnology by concentrating on alcohol production from biomass and the production of single-cell protein for animal feed, areas from which Canada is unlikely to reap any significant economic return.

Corporate Research in Biotechnology

The paucity of industrial R&D in Canada is a recognized phenomenon and has been fully documented in other Science Council reports.[8] In agriculture, this situation is reinforced by the fact that agricultural research has traditionally been backed by a large amount of public funding and the results of that research have been distributed free. Moreover, the market for most new or improved plant species in Canada is small and fragmented and has offered little scope for large corporate profits. The largest market is for wheat, but, as with many other crops, seed firms must make a profit on the first sale; after that, farmers can multiply the seed themselves.

Canadian seed companies do little research and their involvement in biotechnology is minimal.[9] Among the 21 seed companies doing research, only 96 person-years are involved; two-thirds of this involvement is in research on corn. Only two seed companies (both large multinationals) are using biotechnological techniques for crop improvement. The reasons given by seed firms for this low level of research activity range from lack of funds and the high cost of biotechnology, to ignorance of the new techniques and dependence on American parent firms for research data.

Although the small Canadian seed companies are not keeping pace with technological change, the giant multinational pharmaceutical and chemical firms are working to identify the potential impact of biotechnology on agriculture and on their own profit margins and are moving in to take a share of the seed industry.[10] In Canada, Ciba-Geigy, Sandoz, and Pfizer have bought seed firms. So far, this development has not increased Canadian R&D activity.

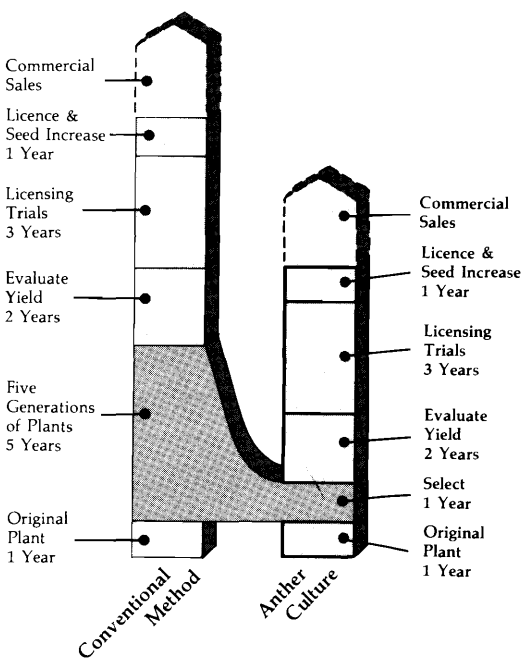
Some small Canadian horticultural firms are successfully exploiting biotechnology in Montreal, Quebec, Toronto, and Vancouver. These firms use micropropagation techniques to reproduce ornamental shrubs, plants, and fruit trees, and they serve an international market. Plant Products in Toronto is an excellent example. It produces thousands of tropical and subtropical ornamental plants from its base in southern Ontario and supplies African violets and other house plants to markets in California and other parts of the United States. Expansion plans include the production of asparagus and other economically significant crops. This firm has overcome its own lack of R&D facilities by monitoring research activities in the university community and by establishing good links with the research staff in the department of horticulture at the University of Guelph.

Why Invest in Biotechnology?

The potential profits that biotechnology could bring to plant breeding have been calculated for rapeseed in a study undertaken for the Council.[11] Rapeseed (or canola) is one of Canada's most important export crops and a major source of edible oil. Scientists have been breeding new varieties of canola since the 1950s, working to increase the yield and improve the quality of the crop. Using traditional breeding techniques, it takes up to 12 years to develop a new variety to the point at which it can be marketed. This includes five years for cross-breeding and selection. The biotechniques of anther culture and tissue cell culture could reduce this breeding and selection period to as little as a year (Figure 6).

In 1983, $2.5 million was spent on canola breeding in Canada. The return on this investment has been estimated at about 51 per cent. However, if biotechnological methods were used to shorten the breeding time

Figure 6: Relative Lengths of Breeding Programs for Rapeseed



Source: A. Ulrich, H. Furtan, and K. Downey, *Biotechnology and Rapeseed Breeding: Some Economic Considerations*, manuscript report (Ottawa: Science Council of Canada, 1984).

for canola, the investment could be increased to $14.3 million (600 per cent greater) and still yield a return of 51 per cent.

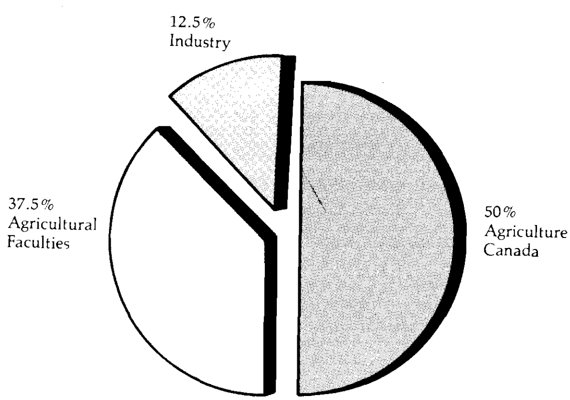
Canada has failed to realize what research can do for the agriculture industry.[12] Estimated returns on investment in traditional agricultural research are very high — between 40 and 100 per cent.[13] Returns on biotechnological research may be even higher. However, because these returns are dispersed among a large population, including farmers, farm suppliers, processors, retailers, and consumers, the overall benefits are not clearly perceived.

Stepping Up Support for Agriculture Canada

The initiative for increasing support for biotechnological research in Canadian agriculture must come from Agriculture Canada. It is the only national agency with a significant research commitment in plant tissue culture, somatic cell genetics, molecular biology, nitrogen fixation, and conventional plant breeding.

Most agricultural R&D (45 to 55 per cent) is funded by the federal government through Agriculture Canada at its centre in Ottawa and at 28 regional research stations across the country. Of the other funds, from 35 to 40 per cent is channelled from federal and provincial sources to the agricultural faculties in universities, and the remaining 10 to 15 per cent comes from industry (Figure 7).[14] However, the share of Agriculture Canada's budget committed to research is decreasing. Research person-

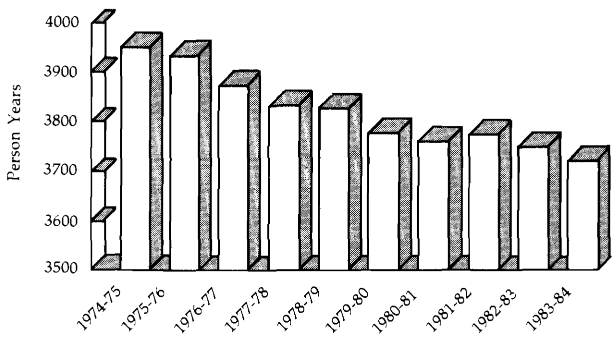
Figure 7: Distribution of Agricultural R&D Investment



Source: D.G. Hamilton, *Evaluation of Research and Development in Agriculture and Food in Canada* (Ottawa, Canadian Agricultural Research Council, 1980).

nel and support staff have been cut by 5 per cent over the past decade (Figure 8). Faced with this situation, Agriculture Canada in 1983 undertook a major reallocation of resources and succeeded in allocating $9.3 million in grants, contributions, and operating budget to biotechnology. In addition to this, Agriculture Canada received $3.1 million in biotechnology funding (for 1983-85) through the National Biotechnology Strategy. As a further move to strengthen its biotechnology focus, Agriculture Canada recently proposed plans to merge its Chemistry and Biology Research Institute with the Ottawa Research Station to create a biotechnology research institute.

Figure 8: Agriculture Canada: Research Branch, Person-Years



Source: Agriculture Canada, *Estimates* (Ottawa, various years).

Agriculture Canada's efforts to reallocate already scarce resources toward the new field of biotechnology deserve credit. The department has obtained a small amount of additional money to continue its work. It has not, however, produced a public discussion paper outlining the department's goals and strategy. Most major departments involved in biotechnology, such as the National Research Council, the Department of the Environment, and the Department of Regional Industrial Expansion, have produced public discussion papers outlining their strategy in biotechnology. These provide a guide for allocating scarce national resources and for developing a comprehensive national strategy.

3. Agriculture Canada should publish its strategic interests and long-term research plans in biotechnology and increase by reallocation its research funding for biotechnology to 20 per cent of its total research budget.

Support for Plant and Animal Health Research

Biotechnology offers a wide range of opportunities for disease and pest control in plants, including the control of growth and reproduction of insects and increased plant tolerance of disease and infestation. Yet there is little biotechnology research on plant health in Canada and almost all of it is on diagnosis.[15] Canada sorely lacks a national facility for plant health protection.

Canada also lacks adequate facilities to test veterinary products. Annual livestock losses from disease in Canada total about $1.2 billion and imported vaccines cost Canadian farmers more than $20 million. The efficacy of these vaccines, however, has been seriously questioned.[16] More research is needed to develop alternative methods of controlling disease.

A short-lived government initiative in 1983 to establish two national facilities for testing phyto-protection and veterinary products under the aegis of Agriculture Canada would have supported research into plant and animal health. Unfortunately, this move was deferred as a cost-cutting measure. Institution of these facilities is essential for the health of agriculture as well as for the development of biotechnology.

4. The federal cabinet should establish phyto-protection and veterinary products testing facilities.

The original total establishment cost of $14 million (1983 dollars) should be adhered to. The mandate of the veterinary testing facility should include provision for close collaboration with animal vaccine research institutes and manufacturing firms in Canada.

Linking Corporate Efforts with Government and University Research

The growth of biotechnology requires better links among research personnel in the corporate sector, in science faculties, and in the professional schools. Such links would be enhanced by easy access to up-to-date research information and by giving all three groups equal access to agricultural research funds.

If companies are to increase R&D and the commercial exploitation of research findings, they must keep aware of the range of research information available from public institutions. Annual updating of the Canadian Agricultural Research Council's inventory and review of research in agricultural biotechnology, *Biotechnology: Research and Development for Canada's Agriculture and Food System*, would help to disseminate the results of research to industry.

5. In order that the Canadian Agricultural Research Council can continue updating its review and directory of biotechnology research, Agriculture Canada should provide it with sufficient resources.

Comparable to microelectronics and the information revolution in its dependence on know-how, biotechnology requires the cooperation of all the different research institutions involved if it is to grow and succeed. Progress in agricultural biotechnology requires that the agricultural constituency be extended to include researchers in science and engineering departments outside agricultural faculties. This means that funding for research in agricultural biotechnology must be open to all research personnel with expertise in agriculture regardless of institutional or faculty affiliation.

Canadian universities can muster an impressive array of talent and have considerable expertise in agricultural biotechnology in science departments and professional schools. University science departments probably do as much agricultural research as agricultural faculties, and corporate biotechnological research in agriculture is increasing. Competition for limited research funds is severe, and scientists in nonprofessional faculties have difficulty in obtaining research funds for agricultural biotechnology because the funds tend to be tied to faculties of agricultural or veterinary sciences. In Ontario, for example, almost all provincial support for agricultural research goes to the University of Guelph, one of the leaders in agricultural research in Canada. However, the science departments of other universities, such as the University of Toronto and Queen's University, are also doing important work in agricultural biotechnology. They too should have access to agricultural research funds.

6. Agriculture Canada and provincial governments that fund biotechnology research in agriculture should award funds regardless of the institutional or disciplinary affiliation of the applicants.

Using Legislation to Promote Biotechnology

Plant Breeders' Rights

In Canada, the beneficiaries of new plant varieties are those who sell them and those who grow them, not those who breed them. Plant breeders' rights legislation is intended to ensure that plant breeders can obtain a reasonable return on a new variety.

In most western countries, plant breeders' rights are protected under the International Convention for the Protection of New Varieties of Plants. Every major western agricultural nation except Canada has ratified the convention. Enabling legislation was submitted to Parliament in 1980.

Although it had the support of both major parties and it allowed restrictions on plant breeders' rights where required in the public's interest, this legislation never progressed beyond first reading.

Supporters of plant breeders' rights argue that such rights would:

- encourage plant breeding research in both the public and private sectors;
- increase the availability of improved varieties from other countries for use in Canada;
- facilitate the collection of royalties from Canadian varieties that are sold abroad.

Plant breeders' rights would change the status of plant varieties from public goods to commercial property. Their impact could change the distribution of agricultural research between the private and public sectors, with public research tending more toward basic research with less emphasis on variety development. Consequently, the argument for plant breeders' rights extends well beyond the specific needs of biotechnology. However, plant breeders' rights do have a central role in the development of biotechnology and in its transformation of agriculture into a research-intensive industry.

Several reports question the need for plant breeders' rights.[17] There has been some opposition to plant breeders' rights legislation, particularly from farm groups. However, a comprehensive survey of the impact of plant breeders' rights in other western countries found a broad level of satisfaction, in many cases evidence of heightened R&D activity, and an increase in the number of varieties released. Farmers themselves expressed little dissatisfaction.[18]

In Canada there is an acute shortage of agricultural R&D in the private sector. The absence of plant breeders' rights is cited as a major constraint on increased R&D by almost all seed companies.[19] The conditions for compulsory licensing included in the proposed legislation in 1980 and the maintenance of a strong public-sector R&D component should protect farmers from any threat of profiteering by seed firms.

As a move to increase private-sector R&D in plant breeding and to promote biotechnology R&D in particular,

7. Agriculture Canada should reintroduce a plant breeders' rights bill to Parliament.

Licensing of New Crop Varieties

The economic recession of the 1980s has hit agriculture hard and there has been a record number of farm bankruptcies. These problems could be alleviated by a qualitative change in agricultural exports that would keep Canadian farmers competitive on world markets. Much of the research in biotechnology is helping to bring about this change, but the current legislative framework is too rigid to respond readily to shifts in market demand.

One area in which legislative change is essential is the licensing of crop varieties. Research in biotechnology is helping to develop new kinds of crops and new varieties of traditional crops. However, existing legislation may block the commercialization of the results of this research if the new crops do not meet existing licensing requirements. If research in biotechnology is to boost productivity and increase growth in the natural resource industries, these unnecessary barriers to developing new crop varieties must be dismantled.

8. Agriculture Canada should review the existing varietal licensing system as it affects the development and introduction of all new varieties, including those developed through biotechnology, with a view to encouraging the rapid introduction of new crop varieties.

Wheat Licensing Regulations

The licensing of new varieties of wheat is a notable example of the way in which existing regulations hamper attempts to respond to market demand with crops enhanced by biotechnology.

Canada has an enviable reputation as an exporter of high-quality wheat. However, cultivating high-quality varieties of wheat costs Canada at least 5 per cent in yield.[20] Moreover, the market for high-quality (high-protein) wheat is growing very slowly, while that for lower-quality wheats (those with lower protein content) is experiencing a rapid increase. To allow Canadian farmers to compete for this new, expanding market, licensing requirements must be changed to allow the cultivation of new kinds of wheat, including those developed using biotechnological techniques.

Existing regulations have blocked the introduction of new varieties, such as red spring wheat, which yields 10 to 15 per cent more grain than traditional varieties at the cost of a 1 per cent decline in protein content.[21] These varieties are particularly valuable in areas not suited to growing high-quality wheats.[22] Because of their lower protein content (as little as 1 per cent less), they cannot be licensed into the top class of wheats, yet the visual similarity of their kernels to those of high-quality wheats means that they cannot be licensed into the lower grades. They could only be made available if a wider range of classes were created.

A change in the licensing requirements would allow cultivation of new high-yielding, high-quality wheats that currently cannot be licensed into the top class or into a lower class. It would also permit the production of lower-quality wheats, especially in areas of the Prairies that are not particularly suited to growing the higher-quality varieties. Recently, after a long delay, a new high-yielding wheat with a lower protein content (44-320) has been licensed. This is an important move in the right direction. To bring production into line with shifting market requirements and to eliminate artificial barriers to new varieties,

9. Agriculture Canada should increase the range of wheat varieties licensed to be grown in Canada.

Technology Transfer and Extension Services

Canadian taxpayers support a nationwide system of provincial, regional, and local structures for the transfer of new technologies to farmers. This system must be made more effective and efficient if Canada is to benefit from the opportunities expected with the development of biotechnology.

In recent years, agricultural extension services have been allowed to run down.[23] Provincial farm advisers are increasingly restricted to giving out information on the availability and benefits of specific provincial agricultural programs instead of providing general advice.

The range of groups and organizations providing information to farmers has proliferated and their role has become more complex. In particular, agri-business is getting involved in technology transfer to certain categories of commercial farmers and this involvement is likely to increase. In some provinces these new corporate links have strengthened specific sectors (such as hog farming in Quebec).[24] However, the reliance on corporate information, whether supplied through contracts, sales representatives, or printed material, and the lack of a strong, complementary public system worries farmers and others who look to the public service as a neutral source of information.[25]

The public system employs general advisers who have extensive practical training and experience in agriculture and who have developed an enviable rapport with key sectors of the farm community. However, these general advisers have insufficient conceptual and theoretical training in communication and extension activities, and there is little coordination and integration among the various extension organizations. These problems may hinder the transfer of biotechnological products and techniques to farmers.

Estimates of the annual cost of technology transfer through federal and provincial agencies and the universities go as high as $125 million. This amounts to almost $400 for every Canadian farmer, a sizable investment. A comparable amount may be spent by the private sector. In view of this investment and of the need to assure the rapid adoption of high technology by Canadian farmers, a full review and evaluation of the existing technology transfer system is needed. Federal and provincial departments of agriculture have recently initiated such a study of technology transfer in the public sector. In anticipation of the potential impact of biotechnology on agriculture and of an increased involvement in technology transfer by private industry,

10. The provincial departments of agriculture and Agriculture Canada, in their current review of technology transfer, should propose mechanisms for increased cooperation and coordination with the private sector.

Regulation and Risk

A healthy regulatory environment for the commercial development of biotechnology is essential, not only to allay public fears of the new technology, but also to encourage corporate participation. Good regulations can promote development; the absence of clear guidelines may retard it.

Public debate on the impact of biotechnology on society in Canada is negligible compared to the widespread concern expressed in the United States. The need for regulations to govern the move of biotechnology out of the laboratories into the commercial arena is being reviewed by several federal departments, in particular Environment Canada and the Ministry of State for Science and Technology. The Canadian Environmental Law Research Foundation and the Law Reform Commission of Canada are also actively involved.[26] The Science Council has already taken several initiatives to influence policy and to promote informed discussion, including a workshop entitled "Biotechnologies in Canada: Promises and Concerns" and several publications.[27] Consequently, the present study did not assess the risks associated with the development of biotechnology, but did examine the mechanisms in place to deal with risk when it arises.

Whereas with most new technologies in the past, regulations were considered only after harmful effects have emerged, biotechnology has prompted attempts to enact legislation in advance of its commercial exploitation. The areas in which problems might arise in the industrial exploitation of biotechnology correspond to existing legislation for biohazards in laboratory research. The three main areas are:

- the health and safety of workers directly involved in the development of the new technology;
- possible health and safety hazards to users of products derived from biotechnology;
- environmental risks.

Uncertainty over ecological repercussions from the introduction of new organisms into the environment is compounded by a confused regulatory system. Federal, provincial, and, in some cases, municipal laws and agencies overlap, and mechanisms for cooperation abound. Even so, there are many gaps in the system concerning the potential health and ecological effects of biotechnology.[28] Vigilance is required against possible adverse effects from biotechnology and existing legislative gaps must be filled both for the benefit of the industries employing biotechnology and for the public at large.

Registration of Pest-Control Agents
One important area for regulation is the use of genetically engineered microorganisms as pest-control agents. Some of these agents will be developed in the next few years, but the number of new products is likely to be small and most of them will probably be developed by multinational corporations. Requests for Canadian registration will probably be preceded by registration in the United States. In anticipation of a small number of Canadian registrants, Canada could review standards for registration in the United States and use them as a basis for its own requirements.

11. Agriculture Canada, in collaboration with Health and Welfare Canada and Environment Canada, should establish guidelines for the registration of pest-control agents that are not found naturally in the environment, including pest-control agents that are genetically engineered microorganisms.

Field Testing of Seeds
Although the Canada Seeds Act stipulates that genetically engineered seeds must be certified for general farm use, seeds can be field tested without notification or review. No agency reviews genetically modified seeds prior to field testing, even though the seeds can be propagated into the environment. Nor does Agriculture Canada review newly developed seeds on the basis of their potential ecological effects. Review of genetically engineered seeds is an essential part of the regulatory environment for biotechnology.

12. Agriculture Canada, in collaboration with Health and Welfare Canada and Environment Canada, should develop policy guidelines on field testing of genetically engineered seeds intended for commercial applications.

Conclusion

Biotechnology offers an arsenal of techniques to remedy many of the problems facing agriculture. Using biotechnology, agricultural scientists can develop plants and animals likely to make the most of inexpensive or even free factors of production, including those in the natural environment. Additional opportunities exist for precise intervention to modify the behaviour of plants. If successful, biotechnology would reduce farm production costs and minimize the risk of crop losses from such problems as salinity, drought, and frost.

In terms of jobs, national income, balance of payments, tax revenue, and private investment, Canada has an enormous stake in agricultural development.[29] Approximately 50 per cent of Canadian farm income comes from exports. Overall, production greatly exceeds domestic market needs. The maintenance of existing markets is therefore vital. In the long term, Canadian agriculture can develop only through the expansion of export trade. Important opportunities exist. If realized, they could revitalize the farm industry. Although biotechnology offers no "quick fix," backed by effective policies, it could offer the support required to maintain Canada's competitive position.

Chapter 3

Pulp and Paper: Biotechnology at the Starting Gate

The Canadian pulp and paper industry cannot be directly compared to agriculture. Its structure, management, and problems are unique and therefore require solutions different from those that apply to agriculture. Nevertheless, biotechnology can make an important contribution to the industry's productivity. In particular, biotechnology can help the industry cope with the shrinking of its traditional resource base and the rising costs of production inside Canada, and with the shifting demands, strong competition, and growing self-sufficiency of other countries.

To maintain a narrow range of low value-added products would confirm Canada's position as a marginal supplier on world markets and leave it vulnerable to sudden cyclical shifts in demand such as those experienced in the early 1980s. Canada's trade competitors in pulp and paper have responded to market trends by using R&D to lower production costs and to develop their own market niche in higher value-added goods. The United States, for example, is the leader in tissue, Western Europe in top-quality printing papers.[1] If the Canadian pulp and paper industry is to cope with the anticipated expansion in world demand and increase its profits, existing products must be upgraded, processes improved, and a greater product mix developed. Biotechnology offers a powerful set of tools to help achieve these goals.

Problems Facing the Pulp and Paper Industry

The Shrinking Resource Base

Until now, the dominant fact in the economics of the Canadian forest industry has been the large surplus of available wood over current demand. However, for decades experts have cautioned that the natural wood supply rate has limits and that the apparent vastness of the resource hides its increasing vulnerability to international competition. Canadian forests have been cut down without adequate replacement. Moreover, Canada is at a disadvantage because trees grow much more slowly here than in warmer countries and because insects infest many areas. Canadian forests may even become redundant as the use of broad-leaved trees, many of which do not thrive in Canada, becomes more widespread. Technological progress has delayed the realization of the gloomiest forecasts by permitting the use of smaller logs and different species and access to more remote areas. Nevertheless, the natural limits to forest exploitation cannot be expanded indefinitely. The problems facing the industry are multiplying and competing demands for forest use, such as for recreation and watershed management, are rising. Resource scarcity has become an urgent issue. In some local areas the problem is already acute.[2]

Rising Production Costs

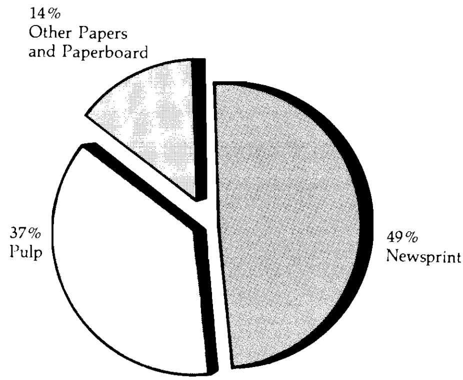
The relatively low price of its wood has given the Canadian forest industry a competitive advantage in the past. However, these prices cannot be kept down in the face of a shrinking resource base and increasing labour and investment costs. Other factors also add to the price of wood. The remaining accessible timber is often of poor quality, and trees from more remote forests are usually small, thin, and expensive to log and transport. Because trees grow more slowly in Canada than in the United States, the size of the forest necessary for sustained yield is greater and the cost of building and maintaining access roads is higher. The harsh, long winter also reduces productivity and boosts production costs.

The capital investment costs of establishing a new pulp mill have increased fivefold since the early 1970s,[3] further reducing the possibility of using remote timber resources. At the same time, however, high investment costs have delayed the development of the timber industry in tropical countries and given Canada a period of grace to adapt to new market conditions.[4] Nevertheless, the fact remains that Canada no longer has a surplus of cheap, readily available wood.

Changing Consumer Demands

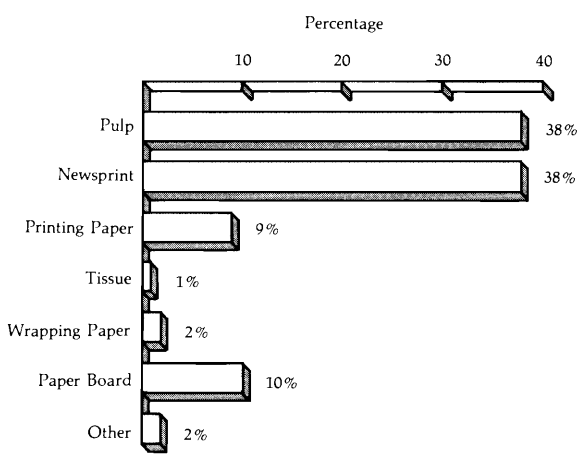
In addition to increasing costs of production, the Canadian pulp and paper industry faces changes in consumer demand and increasing competition from foreign suppliers. In 1983 newsprint represented 49 per cent of the industry's total exports, woodpulp a further 37 per cent (Figure 9).[5] Other kinds of paper and board (tissue, wrapping paper, printing and writing papers, and paperboard) are produced mainly for the domestic market (Figure 10). More and more, however, end products of higher value are forming part of the international forest products market. Better quality is demanded of these products and, in the industrialized world, the demand for high-quality papers is increasing relative to that for products such as newsprint.[6] Although the Canadian industry may have anticipated these changes, it has not responded effectively. Pulp producers have not adapted to the shift from softwood pulp to hardwood pulp. Even though specialty papers are one of the fastest growing segments of Canadian production, newsprint producers have not adapted sufficiently rapidly to the increasing demand for higher quality papers such as those used in advertising inserts.

Figure 9: Composition of Canadian Exports of Pulp and Paper, 1983



Source: Canadian Pulp and Paper Association, *Reference Tables 1984* (Montreal, 1984), 9.

Figure 10: Composition of Total Canadian Pulp and Paper Production, 1983



Source: Canadian Pulp and Paper Association, *Reference Tables 1984* (Montreal, 1984), 7.

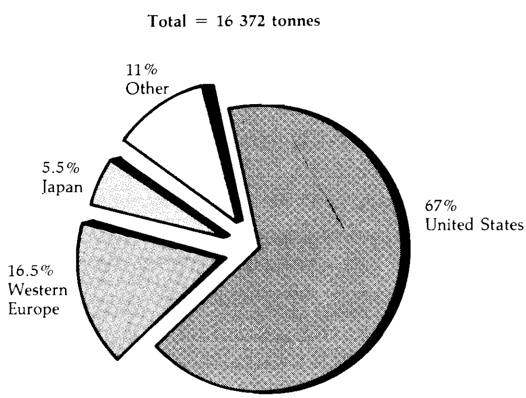
Foreign Competition in the Export Market

Canada produces more than one-fifth of the world's total exports of manufactured forest products. Of these exports, two-thirds come from paper and allied industries. More than 80 000 jobs are directly involved in these industries. Products include pulp, newsprint, and a number of different specialty papers. However, newsprint is the largest single product sector and Canada generates one-third of total world output and accounts for more than 60 per cent of international trade.[7]

Today, the Canadian pulp and paper industry faces a high level of competition from countries such as Sweden, the United States, the Soviet Union, and New Zealand. Not only are they competing in the production of softwoods that have been the mainstay of the Canadian industry, but they are also experimenting with new, untried wood and plant species, materials other than wood, and reconstituted wood products.

Two-thirds of Canada's pulp and paper exports go to the United States (Figure 11). However, the United States can produce pulp and paper at a lower cost than any other country in the world and is able to supply most of its own newsprint. In 1970 the United States produced only 35 per cent of its newsprint needs. Two years later, this proportion had increased to 40 per cent, and by 1990 it is expected to reach 60 per cent.[8] At the same time, the Scandinavian countries are competing with Canada for European markets and even for the expanding markets of South and Central Asia, Latin America, and the Middle East. In these areas, Canada has failed to hold its market share.

Figure 11: Exports of Canadian Pulp and Paper by Area, 1983



Source: Canadian Pulp and Paper Association, *Reference Tables 1984* (Montreal, 1984), 8.

Trade restrictions aggravate Canada's market problems.[9] Under the New Zealand-Australia Free Trade Association, supplies of pulp and paper from New Zealand have replaced Canadian exports to Australia. The United Kingdom's membership in the European Economic Community has made it less open to Canadian exports because Scandinavian suppliers have been given favoured access to the Community's members. This has also lowered the quota for imported Canadian newsprint in other European countries. Protectionism in the United States and the possibility of trade barriers threaten Canadian pulp and paper exports there.

Environmental Problems

The pulp and paper industry has substantial requirements for water for various uses, including waste disposal. Historically, enormous quantities of water were used in pulp and paper mills—for moving wood within the mill, for power generation, and in the processing of wood into pulp and paper. The water was used only once. The result was large losses of chemicals, fibre, and heat. Large amounts of water are still used in the pulp and paper industry, but recycling has greatly reduced the amount of waste water and the volume of effluents requiring treatment.

Even so, waste disposal problems continue to plague the pulp and paper industry. The volume and nature of the wastes vary with the type of processes involved. Most of the wastes are in the form of suspended or dissolved solids, including wood and pulp fibres, and pulping and papermaking chemicals. Other wastes include gases and vapours, and solid wastes such as bark, sand, and dirt. These wastes generate environmental problems ranging from discoloured rivers and noxious fumes to toxic waste waters and hazardous environmental emissions. Such problems cause adverse public reaction and serious environmental damage. Their control imposes a high cost on the industry and on society as a whole.

How Biotechnology Can Help the Pulp and Paper Industry

Biotechnology is only one among many approaches needed to tackle the problems facing the pulp and paper industry. Potential applications cover all aspects of the industry from the supply of pulpwood through wood preparation, pulping, papermaking, and the conversion of waste cellulose, to the treatment of waste water.[10] However, the time-frame for transferring each new technique from the laboratory to the industry can only be surmised (see Table 4).

Improving the Natural Resource Base

Biotechniques can be used to breed trees that are straighter, more vigorous, and resistant to disease, and that have better pulp properties.[11] These characteristics will affect the way pulp and paper are produced. In New

Area of Impact	Near-Term Potential < 10 yrs.	Long-Term Potential > 10 yrs.
Growing of trees	Cloning of superior trees varieties via tissue culture. Improved nitrogen nutrition via nitrogen-fixing bacteria, including actinomycetes. Improved nutrition and field hardiness via mycorrhizal fungus selection and management. Greater use of microbial insecticides.	Rapid laboratory selection from cell cultures of trees with some superior traits such as resistance to disease, frost, and drought. Trees with properties outside the species limit, such as lowered lignin content, increased fibre length, and high turpentine content. New "species" of trees with combined features of several current species. Symbiotic N_2-fixation in trees that do not naturally fix nitrogen. Genetically improved mycorrhizal fungi and N_2-fixing bacteria. Development of new microbial insecticides.
Processing		Biopulping. Biobleaching. Biotechnical improvement of mechanical pulps.
Alternative uses of wood	Use of low-value trees and wood residues via mushroom production. Fermentation of wood hydrolysates.	Biological pretreatment of wood for fermentation.
Using by-products and managing wastes	Fermentation of waste carbohydrate streams. Improvements in existing waste treatment processes. Biological decolorization of bleaching effluents.	Waste treatment systems microbially "tailored" to pulp and paper industry needs. Biological conversion of by-product lignins.

Table 4: Some Biotechnology Opportunities in the Canadian Pulp and Paper Industry

Zealand,[12] for example, researchers have developed a genetically superior radiata pine. Its higher yield makes it possible to plant fewer trees per hectare, thereby saving on pruning, increasing the yield of pulpwood, and lowering extraction costs.

Biotechnology also promises to cut the time needed to identify and propagate selected varieties of trees. Biotechniques such as tissue culture may speed up the process of cloning genetically superior varieties developed using conventional breeding techniques.[13] Transferring specific genes could allow the development of trees with selected characteristics such as rapid growth, improved pulping qualities, or resistance to disease, frost, drought, or herbicides. New techniques could increase the range of biological pest controls, thereby saving some of the timber that would otherwise be lost because of infestation.

Cutting Production Costs

The direct effects of biotechnology on the production of pulp and paper include the development of energy-efficient, cleaner processes. New uses could also be found for tree species hitherto considered unsuitable for pulping and for wood waste from harvesting and manufacturing.

The value of biotechnological techniques in the pulp and paper industry is well illustrated in the seasoning (storage) of wood before pulping. This is an established, simple biological process that reduces the problem of pitch deposits in paper machines. Uncontrolled, these deposits can disrupt production and spoil the paper produced. Slime deposits that have a similar effect can also be reduced by certain biotechnological techniques.

Biotechnology also offers alternatives to the expensive, polluting fungicides currently used to prevent wood rot. Biotechniques that separate bark from wood could reduce the cost of timber by allowing the industry to use all of the tree, including branches and leaves, for pulp. Moreover, biological pulping uses neither expensive equipment nor large amounts of chemicals or energy. The process would avoid pollution, because waste would be reduced to carbon dioxide and water.

Estimates of the potential returns from the application of specific biotechnological techniques to the pulp and paper industry vary. A study sponsored by the Science Council identified 17 opportunities for the application of advanced biological processes of interest to the Canadian pulp and paper industry.[14] The five most promising are wood protection, slime control, glucose production, colour removal from bleach-plant effluent, and anaerobic fermentation of liquid waste. The results of the economic analysis of each of these opportunities are summarized in Table 5.

The full application of the new technology to the industry remains some years off and unexpected successes, breakthroughs, or failures could make current projections invalid. The adoption of new bioprocesses will be strongly influenced by the availability of capital and the success of pilot

Table 5: Potential for Some Biotechnology Opportunities in the Canadian Pulp and Paper Industry

Biotechnology Opportunity	Present Situation	Reasonable Expectations from Biotechnology	Necessary Conditions for Realization of Expectations
Wood protection during outside chip storage	Wood losses: $32.6 million/year Additional brightening chemicals: $15.8 million/year Total cost: $48.4 million/year	Potential net savings: $28.4 million/year	Biological fungicide must be effective in achieving 80% reduction in wood losses at a charge of 1 kg per oven-dry metric ton of wood. Fungicide must cost less than $0.52/kg
Control of slime in pulp and paper operations	Slimicide cost: $3.5 million/year Cost due to lost production and other factors could be considerable.	A competitive biological treatment is commercially available. An increase in paper production worth $50 million/year might be achieved.	Realization of benefits depends on mill circumstances.
Glucose via enzymic hydrolysis of primary clarifier sludge	Minimum sludge disposal cost: $.4 million/year	Not promising for glucose production. SCP or edible mushroom production might be more attractive.	Further analysis of business opportunities needed.
Colour removal from pulp bleaching E_1 stage effluent	Industry could spend $96 million to $290 million in capital costs, and $13 million to $39 million/year in operating costs to resolve the colour problem.	May be preferable to the alternatives in some circumstances. Capital and operating costs appear to be similar to existing, external colour removal processes.	80–95% colour removal would be required for all bleach plants having an E_1 stage.
Anaerobic fermentation of liquid waste	Industry could spend an extra $16.5 million in capital costs, but gain operating cost savings of $9.9 million/year on expansion of existing secondary treatment. Would be similarly attractive for new secondary treatment.	Potential savings of $1.6 million in capital costs and $1 million/year in operating costs.	Expansion of existing secondary treatment is required. Advanced biological techniques must reduce capital costs by 10% and increase operating costs savings by 10%.

trials. The severity of environmental legislation may also affect acceptance of the new technology. The pulp and paper industry spent $1.1 billion between 1960 and 1983 on capital equipment for pollution abatement in waste water.[15] Biotechnology could help reduce such costs by replacing existing technologies with new techniques that are environmentally sound.

Tailoring Production to Consumer Demand
Biotechnology makes it possible to save on energy and raw materials and to use less polluting processes. It can also increase the quality and quantity of paper produced. Fungal treatment of pulp improves paper strength and at the same time reduces pollution, cuts water consumption by up to 90 per cent, and saves energy and space. Slime deposits on pulp equipment can cause transparent spots on paper that weaken it, and may cause the paper to tear on the machine. Existing methods of slime control are expensive and can poison mill effluents; biological controls could obviate these problems too.

Retaining Canada's Market Share
In 1983 pulp and paper accounted for exports valued at $8 billion or over 9 per cent of the total earned by Canadian exports.[16] To maintain or increase these vital earnings and protect its share of expanding world markets, Canada must counteract its growing shortage of mature, marketable timber. By speeding up the improvement of timber reserves and by increasing timber stocks, biotechnology could take on a crucial role in the national economy.

Reducing Pollution from Pulp and Paper Mills
For the most part, current applications of biotechnology in the pulp and paper industry involve the treatment of effluents. Approximately 50 per cent of the wood that enters a mill leaves it in waste water as pieces of wood and pulp particles. In a large mill, hundreds of tonnes of waste accumulate daily. This waste is often discoloured and toxic. Biotechnological techniques could transform this costly waste disposal problem into a valuable source of raw materials for the production of chemicals and liquid fuel, as well as protein for animal feed and human consumption.

Pulp mills that use an alkaline pulping process require treatment plants that act as enormous fermenters in which microorganisms purify the waste water. Mills that use an acid pulping process produce an effluent rich in fermentable sugars. These sugars can be fermented into ethanol, which after distillation becomes industrial alcohol. An alternative process converts the sugars into single-cell protein for animal or human consumption. Biotechnological techniques also offer new ways of treating toxic effluent, by decreasing waste sulphur compounds to eliminate toxic and foul-smelling emissions from mills.

Stimulating Biotechnology in the Pulp and Paper Industry

The Need for Public Awareness
Canadians must not ignore the fundamental economic importance of the forestry industries to the national economy. Industrial efforts to secure a market advantage through fuller use of new technologies can be increased by promoting a political and social climate conducive to technological change and to investment in research. The recent designation of a Minister of State for Forestry as recommended by the Science Council[17] is an encouraging move to this end. However, the Canadian Pulp and Paper Association, the Canadian Forestry Service, and provincial departments of forestry share a responsibility to raise awareness among politicians and the public of the benefits of using new technologies in the pulp and paper industry.

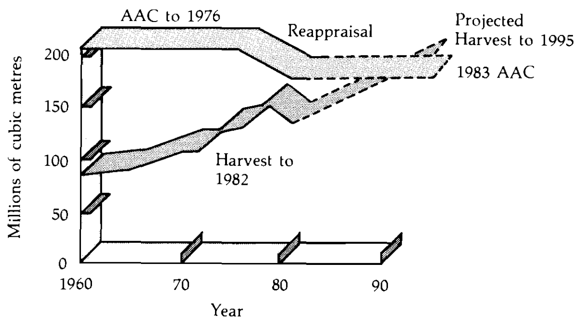
The Need for Research Priorities
World markets for pulp and paper offer expanding opportunities for the Canadian industry. However, the capacity of the pulp and paper industry to sustain itself and to grow will hinge on the continued availability of timber of suitable quality at a reasonable price. Additional constraints are imposed by the industry's ability to develop a new product mix and to tailor production to meet market needs in terms of quality, type, and price.

As an initial step, Canadians must improve forest management. Current projections indicate a significant decline in softwoods by 1995, although a sizable surplus of hardwoods will remain (Figures 12 and 13).[18] New, more intensively managed forests must be developed and existing forests protected against insects and disease. More efficient harvesting must be introduced and new technologies developed so that the use of hardwoods in pulp and paper manufacturing can be increased.

The use of biotechnology could relieve the pressures on the pulp and paper industry. However, its successful development requires a concerted effort to set priorities and establish research goals. Since the Canadian Pulp and Paper Association and its research arm, the Pulp and Paper Research Institute of Canada (PAPRICAN), are responsible for almost all the R&D in the industry, they should take the lead in meeting the industry's R&D needs. As an immediate step,

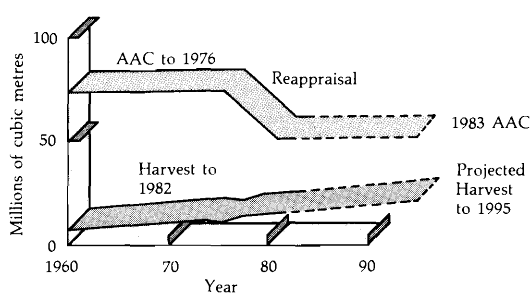
13. The Canadian Pulp and Paper Association, through its associate research group, the Pulp and Paper Research Institute of Canada, should establish a 10-year program of biotechnological research and development.

Figure 12: Trends in Allowable Annual Cut and Harvest of Canada's Softwoods (millions of cubic metres)



Source: Canadian Pulp and Paper Association, *Submission to the Royal Commission on the Economic Union and Development Prospects for Canada* (Montreal, 1983), 52.

Figure 13: Trends in Allowable Annual Cut and Harvest of Canada's Hardwoods (millions of cubic metres)



Source: Canadian Pulp and Paper Association, *Submission to the Royal Commission on the Economic Union and Development Prospects for Canada* (Montreal, 1983), 52.

This program should include specific objectives such as:

- improving chip storage with biological fungicides;
- reducing the amount of fibre leaving the mills in waste to 20 per cent of waste;
- increasing paper production with biological slime control.

The Need for Research Commitment

The overall research effort in biotechnology related to the pulp and paper industry is weak in view of the importance of this industry for Canadians. It involves fewer than 30 small research groups.[19] There is little direct communication among groups and little, if any, communication between them and the pulp and paper industry itself. Almost all the research effort is directed at the decolorization and detoxification of waste water and at the bioconversion of pulp and paper wastes to useful products such as ethanol fuel or single-cell protein for livestock feed or human food. Canada has only one plant that converts waste sugars into ethanol, and only one group looking at uses for converted mill sludge.[20] Several very important areas amenable to biotechnological approaches, such as wood preparation, pulping, and papermaking, are either neglected or ignored.

An important factor influencing the level of Canadian biotechnology R&D is the structural characteristics of the Canadian pulp and paper industry. R&D in the industry is dominated by corporate funding, and work is concentrated primarily at PAPRICAN. Individual companies do little research and several rely heavily on technology transferred from foreign parent laboratories.[21] Government involvement in R&D in the forest products sector has always been concentrated in forestry (silviculture and forest management) and its participation in R&D in the pulp and paper industry is relatively small.

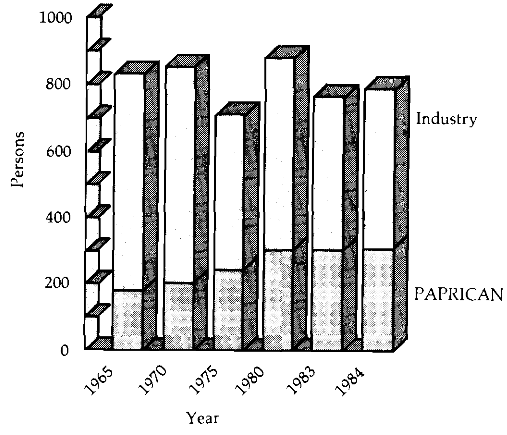
Traditionally, the Canadian pulp and paper industry has been slow to adopt new technology.[22] Moreover, joint ventures between Canadian and foreign firms have no mandate to undertake high-risk research in Canada, so that attempts to gain a technological advantage are thwarted.[23] Canadian firms usually employ researchers to screen developments elsewhere, rather than to do the research themselves. This situation is increasingly inadequate in the face of changing production costs and shifting market requirements. A new focus on technological innovation is required in which indigenous biotechnology oriented to domestic conditions could play a key role. The changing structural characteristics of the pulp and paper industry, including growing levels of Canadian ownership,[24] give grounds for hope that this is possible.

Two cooperative research establishments supported jointly by the industry and by the federal government are of particular importance to R&D in biotechnology: Forintek Canada Corporation in Ottawa and Vancouver; and PAPRICAN in Montreal and Vancouver. PAPRICAN accounts for nearly half of all R&D expenditure in the pulp and paper industry, but has only three scientists working on biotechnology. Moreover, as with all corporate R&D in the industry, much of this expenditure is related to short-term problem solving rather than to basic research. A number of different groups, including equipment manufacturers, federal and provincial governments, universities, and wood-product firms (often through the firms' affiliated research organizations) also have some R&D involvement.

In relation to the importance of the pulp and paper industry, the size of the total research effort is meagre. Of total sales in 1983 in excess of $8 billion, only about 0.3 per cent was reinvested by the industry in research[25]; of this, about half was spent by PAPRICAN. In Sweden, the comparable commitment to R&D is triple that level (0.9 per cent of sales) and two-thirds of that is spent by individual companies. Given this sparse overall commitment to R&D in the Canadian pulp and paper industry, the low level of support for research in biotechnology is less surprising.

Furthermore, since 1965 the number of R&D personnel has declined; in particular, the ratio of research performed in corporate laboratories to that in affiliated research organizations has decreased sharply (Figure 14). At present, there may not be enough qualified staff in individual firms to take up and adapt the research generated by the affiliated research groups.

Figure 14: R&D Personnel in the Pulp and Paper Industry and PAPRICAN, 1965-84



Source: Canadian Pulp and Paper Association

Yearly fluctuations in R&D investment in the industry correspond to fluctuations in corporate profits. In recent years, weak demand and poor prices have accentuated the decline in R&D funds. However, what might at first glance be considered a cyclical downturn is in fact the continuation of a long-term trend brought about by the closure of some R&D laboratories by foreign subsidiaries in Canada, as American companies in the United States centralize their R&D.[26] Consequently, although the pulp and paper industry is of the greatest importance to the Canadian economy, its research efforts trail behind those of competing countries. This is unacceptable. More direct involvement by federal and provincial governments may be necessary to initiate increased industrial R&D activity and to modernize the technology used by Canadian firms, but ultimately the responsibility for R&D must lie with the industry itself.

The time for investment in biotechnology R&D is now, even though the major returns from biotechnology in the pulp and paper industry may be some years off. Investment now could help the Canadian industry sustain its competitive position or even gain a technological advantage over competitors. This requires a much greater sense of commitment to R&D as a first step. To this end,

14. The Canadian pulp and paper industry should double the level of R&D to 0.6 per cent of sales by 1992, and increase to 5 per cent the proportion devoted to biotechnology research.

The Need for Cooperation

The total scientific research system in support of Canada's forest industries is small and fragmented.[27] Links among different research groups and institutions are poorly developed. Forging such links will become more important to the health of the pulp and paper industry as biotechnology, now primarily at a research level, grows more crucial to the development of the industry.

An exception to the overall pattern is PAPRICAN, which maintains close links with McGill University and the University of British Columbia. Funding of university research by PAPRICAN is now around 15 to 20 per cent of the institute's total budget. For the most part, however, Canada's university research community has little involvement with the country's key source of exports, the pulp and paper industry. Of the six professional forestry schools in Canada, only one has any research in place directly related to the pulp and paper industry. At most five universities, usually as part of their chemical engineering program, conduct pulp and paper research. A few other research groups are involved, such as B.C. Research and the Ontario Research Foundation, but no federal or provincial forestry department has made any commitment.[28] The National Research Council's Program for Industry/Laboratory Projects (PILP) has no active participation by any Canadian pulp and paper firm, yet offers an ideal framework for strengthening corporate-university research links.

In other countries, such as Sweden and the United States, there is much greater intrasectoral cooperation among R&D groups in the pulp and paper industry, machinery companies (a common source of new ideas), engineering consultants, and universities. The Canadian industry should develop similar communication links. This goal should be pursued even if it requires increased provincial government support with tax write-offs of more than 100 per cent. In view of the continuing importance of basic research to the development of biotechnology, an initial step should be to stimulate biotechnology research in the universities to meet pulp and paper industry needs.

15. Canadian pulp and paper firms should fund contractual research at Canadian universities to a level of 20 per cent of the industry's R&D funding.

Conclusion

Worldwide consumption of pulp and paper is expected to increase substantially in the coming years, boosted by increasing literacy, rising standards of living, and the widespread use of computers. Although the rate of increase in demand may be slower than in the past, good opportunities exist for Canada to expand trade, generate income, and create jobs. However, the recent economic slump has highlighted fundamental weaknesses in the industry that demand a reassessment of its long-term R&D commitment.

The Canadian pulp and paper industry will not regain its former competitive strength if it expects to rely on abundant, cheap sources of wood and massive exports of pulp and newsprint. Canada's forests are shrinking. No longer is there a large surplus of cheap softwoods, and the hardwoods, which are more readily available, require the adoption of new processing techniques. Serious environmental issues persist. Good opportunities exist on world markets for the Canadian pulp and paper industry, but growth is concentrated in higher value-added products, such as quality printing papers, which are not in Canada's traditional product mix.

Although biotechnology could meet many of the needs of the pulp and paper industry, Canada's commitment to R&D in biotechnology for the industry is very weak. The industry's traditional reliance on imported technologies will not allow Canada to compete successfully on world markets with higher value-added goods. In the next five to 10 years, biotechnology is more likely to improve existing processes than to revolutionize production techniques or dramatically alter the goods produced. It is not too late for Canada to enter the race and carve out its own research niche.

Biotechnology cannot be developed in isolation, but must be viewed as part of a technological package. The new technology's interdisciplinary nature requires a strong commitment to basic research. This commitment is sadly lacking. Without it, the revitalization of the industry will be at the mercy of shifts in world economic conditions. Biotechnology offers a means to gain better control of the fluctuating fortunes of the industry. Such control requires identification of research priorities, an increased commitment to R&D, and improved intrasectoral links.

Chapter 4

Biotechnology in Canada's Resource Industries: The Road Ahead

The examples of agriculture and pulp and paper show that biotechnology could increase efficiency and productivity in these industries, both of which are very important to the Canadian economy.[1] Although the Science Council has not looked at biotechnology in relation to other resource industries in detail, it is clear that industries such as mining, forestry, and aquaculture[2] could also take advantage of the new technology to develop new products and new methods of processing.

Other resource industries have special needs and a study of these industries would produce specific recommendations to stimulate their use of biotechnology. However, the two case studies of agriculture and pulp and paper suggest certain general directions that should be followed in developing biotechnology for the benefit of all resource industries. The key is to ensure that an adequate level of research in biotechnology is maintained and that there is nothing to hinder the commercialization of the results of that research. The implementation of these two precepts will require national commitment and the cooperation of government, industry, and the universities. A firm commitment to research and clear channels for technology transfer will enable Canada's resource industries to use biotechnology to respond to the pull of the market for value-added products and inexpensive, efficient processing methods.

Research in biotechnology has all the same needs as any other type of scientific research — personnel, funding, communication, and so forth — but, in addition, it has specific needs arising from its interdisciplinary character and from its use of living organisms. The Science Council's recommendations deal with both the general needs of the research community and those specifically pertaining to biotechnology. In particular, the recommendations for research focus on:

- the need to establish specific objectives for biotechnology research;
- the vital role of culture collections in biotechnology research;
- the need to control the release of genetically engineered organisms into the environment.

The commercialization of research, especially that done by the university community, is also a problem in many fields other than biotechnology. However, it is worthwhile examining this issue in the context of biotechnology, because technology transfer is crucial to the health of this high-technology field. In particular, the Science Council's recommendations deal with:

- defining the role of the Department of Regional Industrial Expansion in stimulating the commercial development of biotechnology;
- using the patent system to disseminate information about biotechnology and to prevent the duplication of research efforts in biotechnology;
- encouraging university scientists to patent their research where possible;
- increasing industrial participation in NSERC's strategic grants program.

A Firm Commitment to Research

Providing Direction and Focus

A national mission requires well thought-out objectives that challenge Canada's biotechnology community. Suggested objectives for biotechnological research in agriculture and forestry might include (a) the development of genetically improved conifers resistant to spruce budworm infestation by 1992; or (b) the development of an alfalfa capable of productive growth after three degrees of frost by 1995. Such targets would offer stimulating challenges to the research community and lead to marketable technologies.

The report of the Task Force on Biotechnology to the Ministry of State for Science and Technology, *Biotechnology: A Development Plan for Canada*,[3] recognized the potential of biotechnology applied to Canada's natural resource industries. Several provincial initiatives mirror similar concern for biotechnology and natural resources, yet there is an absence of overall focus and there are no goals. Where plans are in place, the commitment is often short-term.

The National Biotechnology Advisory Committee was established to advise the Minister of State for Science and Technology on the development of biotechnology. Since it is the only central body concerned exclusively with biotechnology, it should take on the role of guiding all federal departments and agencies involved in biotechnology research and of helping them contribute to overriding, national objectives.

16. The National Biotechnology Advisory Committee should set goals and objectives for the natural resource sector under the national biotechnology programs.

Objectives for biotechnology research might be set as follows:

- for pulp and paper: effluent and waste water treatment to produce marketable by-products;
- for plant agriculture: increased stress tolerance (resistance to salinity, drought, and frost) to increase the cost competitiveness of agriculture.

The Need for Well-Trained Personnel

The lack of trained and experienced personnel may be the greatest constraint on the success of biotechnology in Canada. This was the conclusion reached in a survey by the Canadian Society of Microbiologists in conjunction with the Science Council. The availability of skilled personnel must be assessed as a precondition to the successful development of a long-term biotechnology program and to the identification of major research opportunities for Canada.

Homegrown talent is vital to the strength of Canada's resource industries. The shortage of well-trained personnel in such areas as agriculture and forestry has caused widespread concern in Canada.[4] Applying biotechnology to these industries will put an added strain on human resources.

A Task Force formed by the National Research Council in 1984[5] has estimated the total demand for doctoral graduates in disciplines related to biotechnology at about 600 to 800 over the next five years. Universities, industry, and government all need staff trained in areas such as process and systems engineering, genetics, molecular biology, microbiology, biochemistry, cell biology, and chemistry.

Biotechnology is not labour-intensive. It requires a relatively small number of highly qualified personnel. Crucial shortages may emerge temporarily only in highly specialized areas, such as biochemical engineering or molecular biology. Personnel needs will depend on the success of programs that commercialize the new technology. In anticipation of industrial requirements for highly qualified scientists and engineers, NSERC has established Industrial Research Fellowships,[6] intended primarily for new doctoral graduates seeking employment in industry in Canada for the first time. This program includes biotechnology and is a companion to the University Research Fellowships program. Both fellowship programs should help ensure the creation and maintenance of a pool of expertise for the long-term development of biotechnology in Canada.

Those skilled scientists already employed in Canada are themselves a vital natural resource. Many work for the federal government. To maintain their expertise and keep abreast of a fast-moving field such as biotechnology, these scientists rely on conferences and meetings, possibly more than on any other means of communication. Attendance by government scientists at scientific meetings is also a valuable means of promoting communication between federal scientists and their peers in universities and industry.

A report issued in 1982 mentioned that federal scientists find current government policy toward attendance at scientific meetings capricious and that the regulations are applied in such a way as to make plans for attendance difficult.[7] Requests have to be submitted up to a year in advance and even when government scientists are prepared to pay their own travel costs and expenses, leave may still be refused. These problems continue and many government scientists can only keep up communication with others in the same field by using their vacation time and spending their own money for conference travel.

Since 1982 efforts to curb government expenses have led to new Treasury Board guidelines on conference travel that limit attendance by federal scientists usually to one person from each federal department per conference. These guidelines, which have always been subject to the specific needs of the individual department's program objectives, have recently been relaxed. The rigid interpretation of these guidelines by some departments contradicts efforts by the government to encourage greater communication in biotechnology as an essential element of the national strategy. Administrators in line departments and agencies such as Agriculture Canada, Fisheries and Oceans, and the National Research Council must recognize the need to reduce the isolation of federal scientists from the rest of the scientific community and must adopt more flexible policies toward the attendance of federal scientists at scientific meetings.

Maintaining Cell Culture Collections

The research community has not succeeded in obtaining suitable funding to maintain and catalogue cell culture collections. These collections are a prerequisite to biotechnology research.

Biotechnologists need access to a wide variety of microorganisms and other types of cells for their research, so that they can select the most appropriate strain to meet their purposes. Their chances of finding what they need in Canada are slim. Only one or two of Canada's collections can boast a full-time curator. Most collections are maintained by hard-pressed scientists and technicians who use them for their own research programs. As a result, many collections are poorly maintained, and each year many strains are lost.

On each criterion of a successful, permanent collection system — accession, authentication, preservation, documentation, and distribution of strains — Canadian collections are inadequate.[8] Scientists across the country need access to national and international cell banks.[9] The integration and upgrading of cell culture collections is long overdue.

17. The Minister of State for Science and Technology should establish a national program for the long-term development of culture collections.

Meeting Regulatory Needs

Biotechnology has very specific needs for regulation. The form of these regulations will help determine the economic and social impact of the new technology on society.

Examination of the risks associated with biotechnology exceeds the mandate of this study. However, in reviewing the adequacy of existing mechanisms to control risks, most federal and provincial authorities agree that existing legislation, with certain adaptations, can meet most of the special needs of the new technology. For example, a number of laws and regulations at various levels of government deal with the hazards that may result from the commercial application of biotechnology.

There are, however, no federal laws and few regulatory guidelines that specifically deal with genetically engineered organisms. Such guidelines could help allay any public concern about the new technology and could promote an environment conducive to commercial development. A working group co-chaired by Health and Welfare Canada and Environment Canada is examining the safety and regulatory aspects of biotechnology. Changes in legislation would be premature at this point. However, as part of a long-term strategy,

18. The Working Group on the Safety and Regulatory Aspects of Biotechnology should monitor research in genetic engineering and related activities with a view to developing guidelines and standards for the release of genetically engineered products to the environment.

Opening the Channels to Technology Transfer

Financing the Commercialization of Biotechnology

Any effective attempt to commercialize research findings requires both a rich flow of ideas and the availability of adequate funds. The absence of investment funds can impede development or even prevent it altogether. At present, Canada's venture capital system is not particularly conducive to the formation of new enterprises, including new biotechnology firms.

Canada has a two-tier financing system for venture capital.[10] The first tier is funding for pre-start-up and start-up enterprises. Second-tier financing is reserved for new companies that have matured beyond the seed-capital phase and entered a period of expansion. There are claims that Canada has plenty of second-tier money available and too few good ideas to spend it on, whereas the scarce first-tier financing is swamped with too many good ideas.[11] Recently, some provincial governments have taken measures to provide vehicles to help innovators get seed capital. For example, the government of British Columbia created Discovery Foundation; Ontario, the IDEA Corporation; and Alberta, Vencap Equities Ltd.

Although the venture capital situation has improved in Canada, it is still hard for any company, let alone a new biotechnology company, to obtain funding for the early stages of its corporate life. Unlike the situation in the United States or some parts of Europe, Canadian venture capitalists are generally unwilling to get involved in first-stage financing.

In Canada the majority of such funds still comes from private, individual investors.[12] The result is an acute shortage of funds for start-up enterprises.

A source of venture capital that could help start-up companies in high-technology areas such as biotechnology might be pension funds. A study commissioned by the Science Council has shown how pension funds have been successfully used for venture investments, especially in small and medium-sized enterprises, in the United States.[13] Pension fund managers should be encouraged to investigate venture capital opportunities.

Better tax benefits for venture capital are also needed to increase the amount of venture capital available for start-up enterprises. Apart from the Canada Development Corporation's $45 million for the establishment of Allelix, only $10 million of Canadian venture capital has gone into biotechnology firms in Canada. An equal amount of Canadian funds went to companies in the United States, where the tax benefits are greater. Unless Canada offers more incentives to venture capitalists to reverse this trend, there will continue to be a shortage of venture capital to support high-risk, start-up companies that offer a long-term payoff in terms of innovative products, exports, and jobs.

In its report 37, *Canadian Industrial Development: Some Policy Directions*, the Science Council examined the problems of financing new ventures and made several recommendations to support the growth of new, high-technology firms.[14] These recommendations apply directly to the growth of small, indigenous biotechnology companies. If the federal government wants to assist the formation of such firms it must review its efforts to provide start-up funding and give priority to addressing the problem of pre-venture capital financing.

Clarifying Federal Government Responsibilities for Commercializing Biotechnology

The Department of Regional Industrial Expansion (DRIE) has a particular responsibility to promote and facilitate industrial activities. However, it has been slow to develop a strategy to support industrial biotechnology. In a recent discussion paper it outlined a framework for its initiatives in biotechnology. These included:

- taking a strong lead with science-based and other departments on the commercial development of biotechnology;
- exploring the feasibility of establishing a private-sector biotechnology association;
- pursuing provincial economic and regional development agreements on biotechnology;
- developing agreements with large Canadian companies, provincial and municipal governments, and other government departments as a means of fostering government-industry cooperation.

The success of these initiatives requires that DRIE accept its responsibilities as the lead agency in support of the industrial development of biotechnology. This means that DRIE must improve its links with federal science-based departments and agencies now involved in biotechnology, and strengthen its communication role among federal government departments, industry, and the universities. However, the existing organizational structure of DRIE militates against an effective implementation of its own planned initiatives in biotechnology. DRIE is organized into various industry sectors, whereas biotechnology cuts across many different business sectors. There is no one source of information within DRIE from which a company can obtain assistance to commercialize biotechnology.

19. The Department of Regional Industrial Expansion should coordinate its strategy in support of industrial biotechnology.

Biotechnology is a high-risk activity, especially in the innovation and commercial stages. The returns to biotechnology are long-term; development costs are enormous. It is crucial that DRIE recognize these characteristics and that its support programs be flexible enough to respond.

DRIE faces a dual mandate of industrial and regional development and the two are sometimes incompatible. For the maximum commercialization of biotechnology, the major DRIE funding mechanism, the Industrial and Regional Development Program (IRDP) must be made more flexible by de-emphasizing the rigid geographical tier system of funding that is designed to support business development in special regions. New biotechnology firms are most likely to spring up in major centres, such as Vancouver and Montreal, that already have the appropriate infrastructure, including a supply of qualified personnel. The constraints of the tier system should be removed to allow the maximum funding for biotechnology projects. To this end,

20. The Department of Regional Industrial Expansion should budget, by reallocation from the Industrial and Regional Development Program, $10 million a year to fund commercial scale-up of biotechnology by Canadian firms.

Using the Canadian Patent System to Stimulate Commercial Biotechnology
The Canadian patent system is a source of technical information that can be used to stimulate biotechnology research. Although the primary function of patents is to protect the intellectual property of the inventor, a good patent system can also encourage the rapid diffusion of new ideas and prevent the squandering of research funds on problems already satisfactorily resolved elsewhere. Canada's shortage of researchers and limited research budget makes any repetition of research particularly wasteful. Yet duplication occurs. Although it is impossible to estimate the waste

of resources caused in this way, the case of VIDO (Veterinary Infectious Disease Organization) is illustrative. After investing approximately $1 million in research on a vaccine to protect calves from viral neonatal diarrhoea, VIDO found that existing patents blocked the commercial exploitation of its own findings.[15]

Patents are a valuable source of technological information, much of which is unavailable elsewhere.[16] The Canadian patent office is a repository of information covering the whole spectrum of technology and represents a resource of great potential use in technology transfer. To realize this potential, the Patent Office recently implemented a publicity program to promote the use of patented technologies by Canadian businesses, research organizations, and government agencies.[17] Although the program purports to be national in scope, its effectiveness is severely limited by the fact that Canadian patent data are not fully computerized, making access to the data inconvenient and slow.

The Patent Act requires a complete technical description of each invention. However, it includes no effective measures for the dissemination of that technical information.[18] Section 27 of the Patent Act gives the Commissioner of Patents discretionary power to disseminate information but places no obligation on the Commissioner to do so. The effective dissemination of patent information would result in more efficient use of scarce R&D resources and quicker transfer of new technologies. An R&D bulletin that could be organized and distributed by the private sector would be a useful form of information dissemination. It would initially require some government funding and would depend on a fully automated patent system. Although the patent office has drawn up long-term plans for automation, their implementation requires additional funding. Canada urgently needs a modern patent system.

21. The Department of Consumer and Corporate Affairs should accelerate the automating of the patent system and establish contracts with the private sector to publicize patent information.

The patenting of life-forms is an issue that must also be examined. Intellectual property rights play a key role in determining the speed and focus of commercial development because few companies will embark on expensive R&D programs in biotechnology without some assurance that the results of that research can be patented. Although previous technological advances were readily incorporated into the existing patent system, biotechnology's dependence on new life-forms means that past experience may not apply in this instance.

The freedom to patent life-forms in Canada was first recognized when the Commissioner of Patents awarded a patent on a live organism to Abitibi-Price (1982). However, because the patent was awarded by the patent examiner and not by the courts, the decision remains open to legal challenge. Consequently, although the principle of patenting a life-form is accepted, the legal status of such patents is moot and unsatisfactory for firms anxious to exploit biotechnology R&D. Continued uncertainty could constrain the commercial exploitation of the new technology.

The patenting of life-forms is a thorny issue and the subject of international concern. Canada is an active participant in the debate to develop a coordinated policy for patenting useful life-forms.[19] However, a clear legal position on this issue is needed before firms can move ahead with confidence.

Patenting the Results of University-Based Research

Encouraging academics to apply for patents could also give a boost to commercial biotechnology in Canada.

Few Canadians apply for patents. Of the patents issued in Canada in the past 10 years, only 6 per cent were issued to Canadians.[20] To some extent, this testifies to the limited amount of R&D carried out in Canada, but it also reflects the tradition among Canadian academics to view the commercialization of research as crass and to give their findings to the world community as a "free good," usually produced from research supported by Canadian public funding. Failure to patent in Canada can result in an innovation being profitably developed elsewhere with no return to the Canadian economy. Praiseworthy as it may be for individuals to forgo personal gain from their research, the failure of Canadians to protect their intellectual property may mean that Canada is losing income and jobs to other parts of the world.

Interest in biotechnology is rapidly increasing at a time of shrinking public funding for research. This leaves Canadian academics vulnerable to exploitation by firms that offer small amounts of money in return for all of a project's research findings. Many are not aware of the possibility of patenting life-forms. Even if researchers are aware of this possibility, they usually lack good advice. For the most part, Canadian universities have failed to recognize the value of patents as a potential source of additional funds. Even in those universities that retain patent counsel, individual scientists rarely use the facilities available. Access to good, private counsel (always expensive) is generally blocked by lack of funds. The Canadian Patent Office cannot fill the need, since it too lacks the requisite expertise, personnel, and funds.

A recent report by the Quebec government on intellectual property and biotechnology summarized the issues facing the Canadian intellectual community.[21] Two recommendations stand out: (a) universities must clarify their policies on inventions and patents with respect to research that is supported by industrial funding and (b) granting councils must accord a greater value to patented inventions in evaluating research proposals. Canadian universities need to update their intellectual property guidelines in response to the powerful commercial drive behind biotechnology. The three national granting bodies should take the initiative in proposing guidelines for the commercialization of research supported with public funds.

22. The Natural Sciences and Engineering Research Council, the Medical Research Council, and the Social Sciences and Humanities Research Council, in consultation with the university community, should draw up guidelines for university scientists for securing intellectual property rights.

Involving Industry in Biotechnology Development

The development of biotechnology depends on the involvement and interaction of universities, government, and industry. Encouraging the participation of representatives from industry in granting councils and disseminating reports of government work on biotechnology to the private sector could improve the cooperation of these three sectors.

The Natural Sciences and Engineering Research Council (NSERC) provides strategic grants to support projects or programs in certain areas of national concern, including biotechnology. The strategic grants program is intended to support basic research projects that relate to the selected topic area, based on the applicant's track record and the merit of the proposed research.

To demonstrate the commercial value of proposals for strategic grants, applicants must (1) identify industry or government users who could benefit from their results, (2) describe contacts made with potential users, (3) discuss the potential significance and implications of the results to the strategic area, and (4) discuss plans for promoting the results to users. To improve the dissemination of research findings, NSERC also funds workshops and seminars for the joint participation of university and industrial personnel.

In 1984/85, 68 strategic grants worth $3.6 million were awarded for biotechnology. The total number of requests for strategic grants in biotechnology was 81, the same as in the previous year. NSERC had hoped to achieve a 30 per cent funding rate and did, in fact, achieve a 25 per cent rate in the overall strategic grants program. The success rate for the biotechnology sector was somewhat lower. Close to 75 per cent of submissions were not considered sufficiently relevant. In part, this may be attributed to the very low participation rate of industrial members on the review panel. Proposals that may not appear relevant to academic peers may be seen in a different light by the industrial sector. The biotechnology strategic grants committee currently has only one representative from industry, despite attempts by NSERC to correct this imbalance.

NSERC's attempts to introduce industrial relevance within its strategic grants program provide valuable support for industrial development in biotechnology. Canadian universities have a pool of expertise that could be used by industry to strengthen its position on domestic and world markets. Because there are so few people in Canada with experience in industrial biotechnology, NSERC might consider requesting that the National Biotechnology Advisory Committee cross-appoint some of its industrial representatives to the biotechnology strategic grants committee.

Business groups that include representatives of firms involved in biotechnology should also support NSERC's attempts to promote industrial relevance in its strategic grants program and seize the opportunity to encourage commercially useful research in the universities.

23. The Canadian Chamber of Commerce and the Canadian Manufacturers' Association should encourage their members to participate fully in the strategic grants committees of the Natural Sciences and Engineering Research Council.

Exchanging Information with Other Countries

Improved liaison among the different agencies within Canada is vital to ensure the commercial success of Canadian biotechnology. However, the rapid development and commercialization of biotechnology in other countries must also be monitored if Canadian industry is to carve out its own market niche and avoid duplication of effort. The Science Council has already recognized the need for science counsellors to become more deeply involved in assisting the acquisition of technologies from foreign sources.[22] Industry in Canada should have a "one-stop" service to obtain this information.

To aid in marketing Canada's biotechnology expertise worldwide, a close liaison between the Ministry of State for International Trade (through the science counsellor network) and the Department of Regional Industrial Expansion is needed to strengthen the gathering of market intelligence and the dissemination of news about international activities in biotechnology to Canadian companies.

Conclusion

Biotechnology has the potential to invigorate a declining resource base and help meet increasing competition and new market demands. However, the strengthening of R&D in biotechnology, although essential, is not enough. Canada is ill-prepared to develop technologically based industries or to take an aggressive marketing stance. Well-trained personnel and improved university-industry links are urgently needed. Research gaps must be filled. Above all, academics, industrialists, and government officials must recognize their mutual responsibility to promote technological change, collaborate to remove unnecessary barriers to growth, and secure a focused effort to market their research findings.

Chapter 5

Conclusions and Summary of Recommendations

Biotechnology is an important area of high technology; Canada's resource industries need the benefits it can bring. Until now, the abundance of Canada's natural resources has allowed these industries to monopolize a large portion of world markets without relying on R&D or new technologies. However, Canada's share of world markets in resource commodities is shrinking and its natural resource base is becoming depleted. Other countries, particularly in Western Europe, that have never had abundant natural resources have adapted to scarcity by using R&D and technology to tailor their production to consumers' needs.

In general, Canadian resource industries have not responded effectively to major changes in world demand. The growth in demand for medium-hard and soft wheats has evoked a belated response from the agricultural industry. The pulp and paper industry contributes to an oversupply of newsprint but has not responded effectively to the increase in world demand for higher quality paper. Old strategies are inadequate in the modern world. Market growth is occurring in new products that Canada is ill-qualified to supply.

Canada is not yet in a position to carry out the revitalization of its resource sector using biotechnology. A number of important changes must occur before that happens. These changes are the underlying objective of the Science Council's recommendations for biotechnology.

- Basic research must be strengthened and focused to achieve a critical mass.
- If government and university research laboratories are to be more responsive to market pull, firms in the resource sector, especially the large domestic resource firms, must provide them with the necessary direction.
- Links between industry and researchers in government and universities must be strengthened.
- The regulatory environment must be made more conducive to the development of biotechnology and existing legislative gaps must be filled.

The recommendations in this report are geared to these ends and are directed at the three key players: universities, industry, and government. Universities will be responsible for research on the basic science of biotechnology. To perform this task, they will require adequate levels of funding and a supply of trained personnel. Industries that can benefit from biotechnology must accept responsibility for the commercialization of research and for applying the basic science to specific problems defined by the market. This requires that they cooperate with the universities and use their knowledge of the marketplace to help focus research. Governments, both federal and provincial, must act as facilitators in these processes. This will involve clarifying the aims of their already-stated commitment to biotechnology and supporting efforts to link the other two sectors. A national commitment by all three sectors is needed to channel the total research effort in biotechnology to meet national needs.

Summary of Recommendations

The development of biotechnology in Canada's resource industries has two essential conditions for success: research and commercialization. The Science Council's first two recommendations deal with these conditions and are prerequisites to the rest of the recommendations.

1. The Natural Sciences and Engineering Research Council should receive extraordinary funding of $15 million each year for 10 years for the creation of from five to 10 interdisciplinary teams, each with a research focus on some topic of fundamental importance to the advancement of biotechnology.

2. The National Research Council should establish a $10 million contract research program to support biotechnology research by small and medium-sized firms.

Strengthening Basic Research

3. Agriculture Canada should publish its strategic interests and long-term research plans in biotechnology and increase by reallocation its research funding for biotechnology to 20 per cent of its total research budget.

6. Agriculture Canada and provincial governments that fund biotechnology research in agriculture should award funds regardless of the institutional or disciplinary affiliation of the applicants.

13. The Canadian Pulp and Paper Association, through its associate research group, the Pulp and Paper Research Institute of Canada, should establish a 10-year program of biotechnological research and development.

14. The Canadian pulp and paper industry should double the level of R&D to 0.6 per cent of sales by 1992, and increase to 5 per cent the proportion devoted to biotechnology research.

15. Canadian pulp and paper firms should fund contractual research at Canadian universities to a level of 20 per cent of the industry's R&D funding.

16. The National Biotechnology Advisory Committee should set goals and objectives for the natural resource sector under the national biotechnology programs.

17. The Minister of State for Science and Technology should establish a national program for the long-term development of culture collections.

Responding to Market Pull

19. The Department of Regional Industrial Expansion should coordinate its strategy in support of industrial biotechnology.

20. The Department of Regional Industrial Expansion should budget, by reallocation from the Industrial and Regional Development Program, $10 million a year to fund commercial scale-up of biotechnology by Canadian firms.

Linking Researchers and Industry

5. In order that the Canadian Agricultural Research Council can continue updating its review and directory of biotechnology research, Agriculture Canada should provide it with sufficient resources.

7. Agriculture Canada should reintroduce a plant breeders' rights bill to Parliament.

10. The provincial departments of agriculture and Agriculture Canada, in their current review of technology transfer, should propose mechanisms for increased cooperation and coordination with the private sector.

21. The Department of Consumer and Corporate Affairs should accelerate the automating of the patent system and establish contracts with the private sector to publicize patent information.

22. The Natural Sciences and Engineering Research Council, the Medical Research Council, and the Social Sciences and Humanities Research Council, in consultation with the university community, should draw up guidelines for university scientists for securing intellectual property rights.

23. The Canadian Chamber of Commerce and the Canadian Manufacturers' Association should encourage their members to participate fully in the strategic grants committees of the Natural Sciences and Engineering Research Council.

Filling Legislative Gaps

4. The federal cabinet should establish phyto-protection and veterinary products testing facilities.

8. Agriculture Canada should review the existing varietal licensing system as it affects the development and introduction of all new varieties, including those developed through biotechnology, with a view to encouraging the rapid introduction of new crop varieties.

9. Agriculture Canada should increase the range of wheat varieties licensed to be grown in Canada.

11. Agriculture Canada, in collaboration with Health and Welfare Canada and Environment Canada, should establish guidelines for the registration of pest-control agents that are not found naturally in the environment, including pest-control agents that are genetically engineered microorganisms.

12. Agriculture Canada, in collaboration with Health and Welfare Canada and Environment Canada, should develop policy guidelines on field testing of genetically engineered seeds intended for commercial applications.

18. The Working Group on the Safety and Regulatory Aspects of Biotechnology should monitor research in genetic engineering and related activities with a view to developing guidelines and standards for the release of genetically engineered products to the environment.

Notes and References

Chapter 1

1. D. Webber, "Biotechnology Moves into the Marketplace," *Chemical and Engineering News* 62(1984), 16: 11-15, 18-19.
2. United States Congress, Office of Technology Assessment, *Commercial Biotechnology: An International Analysis* (Washington, D.C., 1984), 217-233.
3. National Research Council of Canada, *Biotechnology Research Institute Preliminary Strategic Plan* (Ottawa, 1984), 26.
4. Canadian Fertilizer Institute, unpublished data.
5. For a full discussion of the implications of biotechnology for the restructuring of agriculture and agricultural research, see M. Kenney et al., "Genetic Engineering and Agriculture: Exploring the Impacts of Biotechnology on Industrial Structure, University-Industry Relationships, and the Social Organization of US Agriculture," *Cornell Rural Sociology Bulletin* 125(1982): 1-94; and M. Kenney and J. Kloppenburg, "The American Agricultural Research System: An Obsolete Structure?" *Agricultural Administration* 14(1983): 1-10.
6. United States Congress, Office of Technology Assessment, op. cit.
7. C.G. Edwards, J. Elkington, and A.M. Murray, "Japan Taps into New Biotech," *Bio/technology* 2(1984): 307-321.
8. J.R. Murray, "Patterns of Investment in Biotechnology II: 1983 Financing for Health Applications Increases over Agriculture," *Bio/technology* 2(1984): 332-333.
9. See C.H. Bigland, *Potential for the Application of Biotechnology in the Development and Production of Animal Vaccines and Monoclonal Antibodies in Canada*, manuscript report (Ottawa: Science Council of Canada, 1984).
10. Statistics Canada, Science and Technology Statistics Division, *Federal Scientific Activities 1984/1985* (Ottawa, 1984), 62.
11. Labatt is developing novel yeasts for converting a wide variety of feedstocks; Canada Packers is studying growth factors for mammalian cell cultures; and George Weston is conducting research on biopolymers and microbial lipids. In addition, one corporation, Canadian Pacific, has endowed a chair in biotechnology and is sponsoring agricultural research at several Canadian universities.
12. Ministry of State for Science and Technology, *Biotechnology: A Development Plan for Canada*, Report of the Task Force on Biotechnology to the Minister of State for Science and Technology (Ottawa, 1981).
13. Ministry of State for Science and Technology, *A National Biotechnology Strategy*, background notes to *Towards 1990: Technology Development for Canada* (Ottawa, 1983).
14. National Research Council of Canada, *Annual Report 1983-84* (Ottawa, 1984), 32.
15. National Research Council of Canada, *Biotechnology Research Institute*.
16. Natural Sciences and Engineering Research Council of Canada, *Report of the President 1983-84* (Ottawa, 1983), 10.
17. Natural Sciences and Engineering Research Council of Canada, "Report on the 1984-85 Competition for Strategic Grants," *Contact* 10(1985), 1: 10-13.
18. Natural Sciences and Engineering Research Council of Canada, *Report of the President 1983-84*, 11.

19. This view is in line with NSERC's own findings on university research resources. The Task Force on Research Infrastructure appointed by NSERC in 1984, for example, recommended an increase in the research infrastructure grants program from $12 million to $60 million. *Contact* 10(1985), 1:18.
20. Gouvernement du Québec, Groupe de travail pour la préparation d'un rapport de conjoncture sur la recherche et le développement dans le secteur forestier au Québec, *Le secteur forestier: bilan et perspectives* (Québec, 1983).
21. Conseil des universités, *Rapport du Comité sur la formation en biotechnologie* (Québec, 1984).
22. K.A.J. Hay and R.J. Davies, "Declining Resources, Declining Markets," *International Perspectives* March/April 1984, 13-18.
23. See J.N.H. Britton and J.M. Gilmour, *The Weakest Link: A Technological Perspective on Canadian Industrial Development*, Background Study 43 (Ottawa: Science Council of Canada, 1978). Also, Science Council of Canada, *Forging the Links: A Technology Policy for Canada*, Report 29, and *Canadian Industrial Development: Some Policy Directions*, Report 37 (Ottawa, 1979 and 1984).
24. The Science Council has already identified aquaculture as one resource area amenable to biotechniques and with considerable potential for Canada. See Science Council of Canada, *Aquaculture: A Development Plan for Canada*, Final Report of the Industry Task Force on Aquaculture (Ottawa, 1984).
25. For a useful review of the research currently under way in Canada, see The Canadian Agricultural Research Council, *Biotechnology: Research and Development for Canada's Agriculture and Food System*, mimeographed (Ottawa, 1983).
26. See L. Jurasek and M.G. Paice, *Biotechnology in the Pulp and Paper Industry*, manuscript report (Ottawa: Science Council of Canada, 1984).
27. S. Stewman, D. Lincoln, et al., "Recombinant DNA Breakthroughs in Agriculture, Industry, and Medicine: A Delphi Study," *Futures* 13(1981): 128-140.
28. See National Research Council of Canada, *Biotechnology Research Institute*, 26-27.
29. Ministry of State for Science and Technology, *Biotechnology:A Development Plan*. This report drew the same conclusion. The situation has changed little since then.
30. See, for example, R.E. Cape, "On Deserving Awe and Envy," *Bio/technology* 2(1984): 912; A. Klausner, "'Prioritizing' Biotechnology," *Bio/technology* 2(1984): 1007; S. Yanchinski, "Industry Wants a Role for Government," *New Scientist* 1396 (1984): 29-30.
31. United States Congress, Office of Technology Assessment, op. cit., 11.
32. W.G. Hutchinson and Company Ltd., *Directions: Canada's High Tech Industry, 1985-90*, mimeographed report (Toronto, 1985), 91.
33. This is the conclusion of research on the SBIR program by the National Science Foundation (personal communication, R.R. Tibbetts, Program Manager); for a broader discussion of the merits of the SBIR program and of its impact on biotechnology, see J. Van Brunt, "Researchers Praise Phase I and II SBIR," *Bio/technology* 3(1985): 287-288.

Chapter 2

1. Canadian Agricultural Research Council, *Biotechnology: Research and Development for Canada's Agriculture and Food System*, mimeographed (Ottawa, 1983) and *Inventory of Biotechnology*, mimeographed (Ottawa,

1985); Ministry of State for Science and Technology, *Biotechnology in Canada*, MOSST Background Paper 11 (Ottawa, 1980); Science Council of Canada, *Biotechnology in Canada: Promises and Concerns*, proceedings of a workshop sponsored by the Institute for Research on Public Policy and the Science Council of Canada (Ottawa, 1980).

2. For a useful summary, see J.H. Hulse, "Biotechnology: New Horns for an Old Dilemma," *Food Technology in Australia* 36(1984), 6: 271-277.
3. Canadian Agricultural Research Council, op. cit., 75.
4. Ibid., passim.
5. Ibid., 23.
6. C.H. Bigland, *Potential for the Application of Biotechnology in the Development and Production of Animal Vaccines and Monoclonal Antibodies in Canada*, manuscript report (Ottawa: Science Council of Canada, 1984), 16.
7. One encouraging sign is the creation in 1984 of the Canadian Embryo Transfer Association based in Saskatoon.
8. See J.N.H. Britton and J.M. Gilmour, *The Weakest Link: A Technological Perspective on Canadian Industrial Development*, Background Study 43 (Ottawa: Science Council of Canada, 1978); Science Council of Canada, *Forging the Links: A Technology Policy for Canada*, Report 29 (Ottawa, 1979); F. Longo, *Industrial R&D and Productivity in Canada*, manuscript report (Ottawa: Science Council of Canada, 1984); Science Council of Canada, *Canadian Industrial Development: Some Policy Directions*, Report 37 (Ottawa, 1984).
9. T.F. Funk, *An Examination of Policy Issues Related to the Adoption of Biotechnology Research by the Canadian Seed Industry*, manuscript report (Ottawa: Science Council of Canada, 1984), 72.
10. M. Kenney et al., "Genetic Engineering and Agriculture: Socioeconomic Aspects of Biotechnology R&D in Developed and Developing Countries," *Proceedings of the First World Conference and Exhibition on the Commercial Applications and Implications of Biotechnology* (London, 1983), 475-488.
11. A. Ulrich, H. Furtan, and K. Downey, *Biotechnology and Rapeseed Breeding: Some Economic Considerations*, manuscript report (Ottawa: Science Council of Canada, 1984).
12. In this context, it is interesting to note that the United States National Academy of Sciences has identified research in plant biology as an area likely to return the highest scientific dividends, given sufficient federal investment. "US Plant Biology Research Totals $200m," *Outlook on Science Policy* 7(1985): 9.
13. E.J. LeRoux, "Payoff from Research," *Proceedings of the Agricultural Outlook Conference* (Ottawa: Agriculture Canada, 1983), 18.
14. D.G. Hamilton, *Evaluation of Research and Development in Agriculture and Food in Canada* (Ottawa: Canadian Agricultural Research Council, 1980), 24-25.
15. Canadian Agricultural Research Council, op. cit., 66.
16. See, for example, S.W. Martin, "Vaccination: Is it Effective in Preventing Respiratory Disease or Influencing Weight Gains in Feedlot Calves?" *Canadian Veterinary Journal* 24(1983): 10-19; J. Wilson and A.D. Osborne, "Antibiotic Therapy for Experimentally Induced *Hemophilus pleuropneumoniae* in Pigs," submitted to *Canadian Veterinary Journal*, 1984; D. Waltner-Toews, S.W. Martin, and A.H. Meek, "A Field Trial to Test the Efficacy of a Combined Rotavirus-Coronavirus-*E. coli* vaccine in Dairy Cattle," proceedings of VIDO's Fourth International Symposium on Neonatal Diarrhoea, October 3-5, 1983, 456-478; L.J. Saif, D.R. Redman, L.L. Smith, and K.W. Theil, "Pas-

sive Immunity to Bovine Rotavirus in Newborn Calves Fed Colostrum Supplements from Immunized or Non-Immunized Cows," *Infection and Immunity* 41(1983): 1118-1131.

17. See, for example, W.H. Furtan, "Agricultural Research and Bill C-32," departmental working paper (Saskatoon: University of Saskatchewan, Department of Agricultural Economics, 1980); R.M.A. Loyns and A.J. Begleiter, "An Examination of the Potential Economic Impacts of Plant Breeders' Rights on Canada," unpublished report (Ottawa: Consumer and Corporate Affairs, Bureau of Intellectual Properties, 1982); C.J. Dias and Y.P. Ghai, "Plant Breeding and Plant Breeders' Rights in the Third World: Perspectives and Policy Options," unpublished report (Ottawa: International Development Research Centre, 1983).
18. Agriculture Canada, "A Survey of Effects of Plant Breeders' Rights Legislation in Other Countries," unpublished report (Ottawa, 1980).
19. T.F. Funk, op. cit., 71.
20. W. Bushuk, "Plant Science: Summation," prepared for *The Prairie Production Symposium*, sponsored by the Canadian Wheat Board Advisory Committee, Saskatoon, October 1980, 18-19.
21. R.M.A. Loyns et al., "Constraints on Biotechnological Developments in Canadian Grains with Special Reference to Licensing of Varieties," unpublished report (Ottawa: Science Council of Canada, 1984).
22. One conservative estimate of the cost to Canada of not licensing HY320-type wheat (a medium-hard wheat variety) is approximately equal to the 1982 realized net farm income from farming of all farmers in Manitoba (i.e., $200 million to $400 million). A. Ulrich and W.H. Furtan, *An Economic Evaluation of Producing HY320 Wheat on the Prairies* (Saskatoon: University of Saskatchewan, Department of Agricultural Economics, 1984), vi.
23. See H.R. Baker, "Agricultural Extension and Biotechnology," unpublished report (Ottawa: Science Council of Canada, 1984).
24. W. Smith, "Production et consommation dans le système agro-alimentaire québécois: une approche géographique," *Cahiers de géographie du Québec* 25(1981): 323-341.
25. H.G. Coffin, R. Dupuis, and L. Fischer, "An Evaluation of Technology Transfer Through Contractual Agreements in Agriculture: Case Studies in Sweet Corn and Pedigreed Seed Production in Quebec," unpublished report (Ottawa: Science Council of Canada, 1984).
26. See, for example, Canadian Environmental Law Research Foundation, *Biotechnology and the Environment: A Regulatory Proposal*, discussion paper (Toronto, 1984).
27. Science Council of Canada, *Biotechnology in Canada: Promises and Concerns*, Proceedings of a Workshop Sponsored by the Institute for Research on Public Policy and the Science Council of Canada (Ottawa, 1980); Science Council of Canada, *Regulating the Regulators: Science, Values and Decisions*, Report 35 (Ottawa, 1982); H. Eddy, *Regulation of Recombinant DNA Research: A Trinational Study*, discussion paper (Ottawa: Science Council of Canada, 1983); S. Krimsky, *Regulatory Policies on Biotechnology in Canada*, manuscript report (Ottawa: Science Council of Canada, 1984).
28. S. Krimsky, op. cit., 5.
29. For a valuable discussion of the problems, opportunities, and policy options facing Canadian agriculture, see J.C. Gilson, "The Canadian Agricultural Industry: Issues, Challenges and Policy Options," paper presented to the National Economic Conference, Ottawa, March 22-23, 1985.

Chapter 3

1. Woodbridge, Reed and Associates Ltd., *British Columbia's Forest Products: Constraints to Growth*, prepared for the British Columbia Ministry of State for Economic and Regional Development (Vancouver, 1984), 75.
2. See, for example, Science Council of Canada, *Canada's Threatened Forests* (Ottawa, 1983).
3. R. Hayter, "The Canadian Forest Industries," in *Canada's Resource Industries*, edited by I. Wallace (Toronto: Wiley, in press).
4. Ibid.
5. Canadian Pulp and Paper Association, *Reference Tables 1984* (Montreal, 1984), 8.
6. Woodbridge, Reed and Associates Ltd., op. cit., 74.
7. Canadian Pulp and Paper Association, *The Canadian Pulp and Paper Industry* (Montreal, 1984), 1-2.
8. Woodbridge, Reed and Associates Ltd., op. cit., 84.
9. See R. Hayter, op. cit.
10. See T.K. Kirk, T.W. Jeffries, and G.F. Leatham, "Biotechnology: Applications and Implications for the Pulp and Paper Industry," *Tappi Journal* 66(1983), 5: 45-51; and L. Jurasek and M.G. Paice, *Biotechnology in the Pulp and Paper Industry*, manuscript report (Ottawa: Science Council of Canada, 1984).
11. For these reasons, the Science Council sponsored a national workshop in February 1985 to identify opportunities for the application of biotechnology in forest sciences.
12. See T.M. Powledge, "Biotechnology Touches the Forest," *Bio/technology* 2(1984): 763-772.
13. For a comprehensive discussion of the subject see J.M. Bonga and D.J. Durzan, editors, *Tissue Culture in Forestry* (The Hague: Martinus Nijhoff/Dr W. Junk Publishers, 1982). See also E. Mason and F.W. Maine, *Tissue Culture and Micropropagation for Forest Biomass Production: Literature Review*, prepared for the National Research Council of Canada, Division of Energy (Guelph: Frank Maine Consulting Ltd., 1984).
14. B.C. Garner, M.F. Davy and K.M. Thompson, "Opportunities for Biotechnology in the Canadian Pulp and Paper Industry," unpublished report (Ottawa: Science Council of Canada, 1984).
15. Canadian Pulp and Paper Association, personal communication.
16. Canadian Pulp and Paper Association, *Reference Tables 1984*, 5.
17. Science Council of Canada, op. cit., 3.
18. Canadian Pulp and Paper Association, *Reference Tables 1984*, 5.
19. A list of these groups can be found in L. Jurasek and M.G. Paice, op. cit., 47-51.
20. See T.E. Tautorus and P.M. Townsley, "Biotechnology in Commercial Mushroom Fermentation," *Bio/technology* 2(1984): 696-701.
21. F. Amesse, "The Canadian Pulp and Paper Industry: A Preliminary Analysis of a Technological Gap Situation," unpublished PhD thesis (Montreal: Université de Montréal, École des Hautes Études Commerciales, 1979).
22. R. Hayter, "Research and Development in the Canadian Forest Product Sector—Another Weak Link?" *Canadian Geographer* 26(1982): 256-263.
23. Ibid.
24. R. Hayter, "The Canadian Forest Industries."
25. Various unpublished data sources.

26. R. Hayter, "Research and Development," and "The Evolution and Structure of the Canadian Forest Product Sector: An Assessment of the Role of Foreign Ownership and Control," *Fennia*, in press.
27. R. Hayter, "Evolution and Structure."
28. O.M. Solandt, *Forest Research in Canada* (Ottawa: Canadian Forestry Advisory Council, 1979).

Chapter 4

1. S.L. Smith, "High Tech: Agriculture's Long-Term Future," *Agrologist* 13(1984), 2: 12-13.
2. See, for example, Science Council of Canada, *Aquaculture: An Opportunity for Canadians* (Ottawa, 1985).
3. Ministry of State for Science and Technology, *Biotechnology: A Development Plan for Canada.*
4. See, for example, A. Zimmerman, "Investment in Foresters," *Policy Options* 3(1982), 1: 20-21; and P. Hohenadel, "Heirs Unapparent," *Saturday Night*, August 1983, 9-10.
5. National Research Council, *Task Force on Human Resources for Biotechnology* (Ottawa, 1984).
6. Natural Sciences and Engineering Research Council, *Awards Guide 1985-86* (Ottawa, 1984), 55.
7. K.G. Davey, *Biological Research in Federal Laboratories*, prepared on behalf of the Biological Council of Canada (Ottawa, 1982), 11. Subsequently, other scientific bodies, such as the Canadian Society of Microbiologists, have raised the issue of attendance by federal scientists at scientific meetings.
8. This was the conclusion reached by the participants in the Science Council's workshop on national culture collections held in March 1985.
9. For a discussion on the vital role of culture collections for biotechnology, see B. Kirsop, "Culture Collections — Their Services to Biotechnology," *Trends in Biotechnology* 1(1983): 4-8.
10. See P. McQuillan and H. Taylor, *Sources of Venture Capital in Canada*, revised edition (Ottawa: Department of Industry, Trade and Commerce, 1978); B. Marshall and R. Forbes, "Venture Capital Financing of New Technologies," *Business Quarterly* 48(1983), 4: 105-109.
11. "Funding Still Hard to Find for 'Little Guys,'" *The Financial Post*, 10 December 1983, 24; M. Tefft, "Canadian Risk Capitalists Having a Very Good Year," *The Financial Post*, 22 September 1984, S10; P. Kemball, "Venture Capital and Capital for Ventures," unpublished report (Ottawa: Department of Regional Industrial Expansion, Small Business Secretariat, 1983).
12. See Calgary Council for Advanced Technology, *Brief for the Royal Commission on the Economic Union and Development Prospects for Canada* (Calgary, 1983); P. McQuillan and H. Taylor, op. cit.; Association of Canadian Venture Capital Companies, *Annual Report 1983-84* (Toronto, 1984).
13. Mary Macdonald, *Pension Funds and Venture Capital*, discussion paper (Ottawa: Science Council of Canada, forthcoming).
14. Science Council of Canada, *Canadian Industrial Development: Some Policy Directions*, Report 37 (Ottawa, 1984), 22-25.
15. See C.H. Bigland, *Potential for the Application of Biotechnology in the Development and Production of Animal Vaccines and Monoclonal Antibodies in Canada*, manuscript report (Ottawa: Science Council of Canada, 1984), 42.

16. See K. Omae, "Patents: Key to Business Growth," *Canadian Business Review* 10(1983), 3: 35-38; Economic Council of Canada, *The Bottom Line: Technology, Trade, and Income Growth* (Ottawa, 1983).
17. See, for example, Consumer and Corporate Affairs Canada, "The Canadian Government Patent Office: The Information Edge," information sheet, January 1984.
18. Economic Council of Canada, op. cit., 60.
19. See, for example, Organisation for Economic Co-operation and Development, Committee for Scientific and Technology Policy, "Patent Protection in Biotechnology: An International Review," unpublished paper (Paris, 1984).
20. Canadian Patent Office, unpublished data.
21. Québec, Ministère de la Science et de la Technologie, *A l'heure des biotechnologies: rapport des missions sectorielles* (Québec, 1984).
22. Science Council of Canada, *The Canadian Science Counsellors* (Ottawa, 1984), 20.

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No. 35. **The Role and Function of Government Laboratories and the Transfer of Technology to the Manufacturing Sector**, by A.J. Cordell and J.M. Gilmour, April 1976 (SS21-1/35, Canada: $6.50, other countries: $7.80), 397 p.

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No. 53. **The Uneasy Eighties: The Transition to an Information Society**, by Arthur J. Cordell, March 1985 (SS21-1/53, Canada: $7.00, other countries: $8.40), 150 p.

Occasional Publications

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Energy Scenarios for the Future, by Hedlin, Menzies & Associates, 423 p.
Science and the North: An Essay on Aspirations, by Peter Larkin, 8 p.

A Nuclear Dialogue: Proceedings of a Workshop on Issues in Nuclear Power for Canada, 75 p.

1977

An Overview of the Canadian Mercury Problem, by Clarence T. Charlebois, 20 p.
An Overview of the Vinyl Chloride Hazard in Canada, by J. Basuk, 16 p.
Materials Recycling: History, Status, Potential, by F.T. Gerson Limited, 98 p.

University Research Manpower: Concerns and Remedies, Proceedings of a Workshop on the Optimization of Age Distribution in University Research, 19 p.
The Workshop on Optimization of Age Distribution in University Research:
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Background Papers, 338 p.
Living with Climatic Change: Proceedings, 90 p.
Proceedings of the Seminar on Natural Gas from the Arctic by Marine Mode: A Preliminary Assessment, 254 p.
Seminar on a National Transportation System for Optimum Service: Proceedings, 73 p.

1978

A Northern Resource Centre: A First Step Toward a University of the North, by the Committee on Northern Development, 13 p.
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Proceedings of the Public Forum on Policies and Poisons, 40 p.
Science Policies in Smaller Industrialized Northern Countries: Proceedings, 93 p.

1979
A Canadian Context for Science Education, by James E. Page, 52 p.
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Canadian Food and Agriculture: Sustainability and Self-Reliance: A Discussion Paper, by the Committee on Canada's Scientific and Technological Contribution to World Food Supply, 52 p.

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An Engineer's View of Science Education, by Donald A. George, 34 p.
The Limits of Consultation: A Debate among Ottawa, the Provinces, and the Private Sector on an Industrial Strategy, by D. Brown, J. Eastman, with I. Robinson, 195 p.

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1984

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Continuing Education for Scientists: Suggestions for Integrating Learning and Research, by Richard P. McBride, 34 p.

1985

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Science Council of Canada
Conseil des sciences du Canada

Summary of Report 38

Seeds of Renewal

Biotechnology and Canada's Resource Industries

The Science Council of Canada is Canada's national advisory agency on science and technology policy. Created in 1966, its primary functions are to

- analyse science and technology policy issues;
- recommend policy directions to government;
- alert Canadians to the impact of science and technology on their lives;
- stimulate discussion of science and technology policy among governments, industry and academic institutions.

Summary of Report 38

Seeds of Renewal

Biotechnology and Canada's Resource Industries

September 1985

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Report 38 (SS22-1985/38E)

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A new technological revolution is under way. By applying biological techniques to industrial processes, biotechnology is creating new products, enhancing the productivity of traditional industries, and helping to protect the environment.

Biotechnology is creating a new technological revolution.

All around the world, countries are investing in biotechnology. Some are using it to develop new industries such as bioelectronics, others are using it to modernize traditional industries such as agriculture, food processing, fisheries, or forest products by making these industries more efficient and productive. These developments directly threaten some of Canada's most important industries — agriculture, pulp and paper, and fisheries. To retain and, if possible, increase its existing share of world markets, Canada must participate fully in the biotechnology revolution.

Biotechnology offers a wide array of opportunities for improving the products and processes of the natural resource industries. It makes it possible to breed more nutritious crops and increase forest yields. Biotechnology can also help strengthen the natural resource base by breeding crops that are more resistant to drought or disease or by developing biological pest controls to protect forests from insect infestation. Moreover, biotechnology can treat some of the negative effects of established industries, such as oil spills or toxic wastes.

Biotechnology can help strengthen the natural resource base and can counteract some of the negative effects of established industries.

The Science Council of Canada believes that if Canada is to profit from biotechnology, it must focus efforts in biotechnology on the natural resource sector. This requires a national commitment to strengthen the research base and commercialize research findings.

In its two-year study of biotechnology, the Science Council examined how biotechnology could be applied to two resource-based industries: plant agriculture and pulp and paper. It identified obstacles to the use of the new technology and made recommendations to deal with some of these problems. The recommendations presented in Report 38 and summarized here were arrived at after consultation with key business people, researchers, and policy makers in the resource industries, universities, and government.

Stepping Up Biotechnology Research

Biotechnology involves an interdisciplinary mix of the biological sciences and engineering. The Council believes that the best way to carry out this research is to bring together

By drawing researchers together into teams and coordinating their efforts into an overall biotechnology research plan, overlaps could be avoided and gaps filled.

teams of biologists, biochemists, and bioengineers to work on long-term projects in specific research areas (for example, breeding crops that can tolerate high levels of salinity). Its first recommendation* proposes that the Natural Sciences and Engineering Research Council fund 10 teams, each with at least five scientists, to help develop a critical mass in Canadian biotechnology research.

Canada already has many highly qualified researchers who could participate in these teams (there are over 100 small groups working on agricultural biotechnology and 30 studying biotechnology in the pulp and paper industry) but these researchers are scattered across the country. Some of them may be duplicating the work of other researchers, whereas certain topics, such as the improvement of cereal crops or the preparation of wood for processing into pulp, are being neglected. By drawing researchers together into teams and coordinating their efforts into an overall biotechnology research plan, overlaps could be avoided and gaps filled.

National targets for government research into biotechnology should be identified and published by the National Biotechnology Advisory Committee. This is a group of experts who advise the Minister of State for Science and Technology on the development of biotechnology in Canada. As the only central body representing all three sectors and concerned exclusively with biotechnology, it should coordinate the work of federal departments and agencies involved in this area and use the expertise of its members to develop long-range goals for research (recommendation 16).

Agriculture Canada and the National Research Council have the greatest involvement in government research into plant biotechnology. This research is important and should continue. However, the proportion of Agriculture Canada's funds devoted to this type of research is inadequate and the department has never publicly announced its long-term research plans. By reallocating its existing budget, Agriculture Canada could provide an appropriate level of funding for biotechnology, and by publishing its research plans, it could participate more fully in a comprehensive national strategy (recommendation 3).

*A complete list of recommendations appears on pages 10-12.

Research on biotechnology in pulp and paper is conducted largely under the aegis of the Canadian Pulp and Paper Association through its associate research group, the Pulp and Paper Research Institute of Canada (PAPRICAN). Like Agriculture Canada, this institute should set long-term goals for its research in biotechnology (recommendation 13). PAPRICAN, however, should not take responsibility for all pulp and paper research. Corporate and university research are needed to keep the industry up to date and competitive. Research on topics such as biological fungicides to protect stored wood chips, methods of controlling pitch and slime in pulp and paper machinery, or ways to decrease the amount of waste fibre that leaves a mill should be undertaken by groups in industry or universities. Funding for this research could be found if the Canadian pulp and paper industry doubled the level of funding for R&D from 0.3 per cent to 0.6 per cent of sales, and if 5 per cent of these funds were set aside specifically for corporate biotechnology research and 20 per cent for university-based research (recommendations 14 and 15).

Traditional research structures are not always suitable for biotechnology. Solutions to problems may come from completely unexpected quarters — for example, a bioengineer may provide the missing piece of information to solve a puzzle that has plagued botanists for years, or a biochemist may discover a process that could be used by geneticists. Barriers between the disciplines that contribute to biotechnology must be broken down. One barrier that hinders research in plant biotechnology is that between researchers in agricultural faculties and those in regular university departments. Funding for biotechnology from federal and provincial sources should be available to any researcher in any institution who is making a contribution to plant science (recommendation 6).

Traditional research structures are not always suitable for biotechnology. Barriers between the disciplines that contribute to biotechnology must be broken down.

Researchers need more than just money. Biotechnologists use living cells for their research, and these cells must be kept alive in special storage facilities. Canadian collections of cell cultures are poorly maintained — most are kept by scientists who have little time to spare for all the tasks needed to build up complete, permanent collections, tasks such as cataloguing, preserving, and authenticating strains, or responding to requests from other scientists for particular strains. Canada needs a national system of culture collections that could be used by biotechnologists all across the

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country. The Ministry of State for Science and Technology should organize a program to set up such a system (recommendation 17).

Applying Research Findings

Research that stays in the laboratory and circulates only to other researchers will not immediately benefit the economy. Biotechnology must also be put into practice in industry where it will be commercially useful and will generate new ideas for development.

Biotechnology must be put into practice in industry where it will not only be commercially useful, but will also generate other new development ideas.

The United States is successfully using small and medium-sized enterprises to foster a lively biotechnology community. Its National Science Foundation operates a program called Small Business Innovation Research, which promotes technological innovation in small high-technology firms by providing 100 per cent research funding for a fixed period. Unlike Canadian programs, which are cost-sharing, the American program takes into account the high-risk, long-term nature of biotechnology and the fact that few small companies can afford to pay even for part of the research costs. The program has helped double employment in the firms sponsored and has encouraged small firms to link up with university researchers. Canada needs a program like this and the National Research Council would be the most appropriate agency to sponsor it (recommendation 2).

The Department of Regional and Industrial Expansion (DRIE) has already stated its intention to promote efforts to commercialize biotechnology. However, in order to foster industry-government cooperation, DRIE needs to draw together into a special section those of its personnel who have experience in dealing with biotechnology projects (recommendation 19). At the moment, these people are scattered among its many branches, each of which deals with a different business sector.

DRIE could also use the Industrial and Regional Development Program to stimulate commercial ventures in biotechnology. However, the rigid geographical system for allocating funds under the program should be relaxed for biotechnology, since new firms are most likely to spring up in large business centres, such as Montreal or Vancouver. By earmarking some of the program's funds for biotechnology, DRIE could give a powerful boost to biotechnology firms (recommendation 20).

The Research-Market Link

The recommendations discussed so far, if implemented, would build up a strong body of biotechnology researchers in universities, other research institutions, and corporate laboratories and provide funds for small and large firms to use that research in commercial ventures. However, links between researchers and entrepreneurs are needed. The best way to develop such links is for the two groups to come halfway to meet each other. Researchers have to learn to think like entrepreneurs, in terms of the commercial possibilities of their work, and entrepreneurs have to keep abreast of research developments in order to spot those with market potential.

Researchers have to learn to think like entrepreneurs and entrepreneurs have to keep abreast of research developments.

One important step that researchers could take would be to learn how to patent their work. Nowadays, even life-forms can be patented, along with biotechnological products, processes, and equipment. Patenting helps ensure that the returns from a Canadian innovation contribute to the wellbeing of the Canadian economy. Many university researchers are unfamiliar with patenting regulations, therefore they need guidelines and advice to help them secure intellectual property rights. Another barrier to patenting is the belief of many scientists that publicly funded research should remain public property. These barriers could be removed by having the three federal granting agencies (the Natural Sciences and Engineering Research Council, the Medical Research Council, and the Social Sciences and Humanities Research Council) draw up guidelines for patenting, thereby providing university researchers with the information they need and giving their support to the idea that patenting is an integral part of high-technology research (recommendation 22).

Agricultural biotechnologists, however, cannot yet patent the new crop varieties they develop. This deters private-sector breeders, especially seed companies, who will not do research if they cannot profit by it. By introducing a plant breeders' rights bill to Parliament, Agriculture Canada might stimulate more commercial R&D in agriculture (recommendation 7).

Patenting is an integral part of high-technology research, and could stimulate developments in biotechnology.

One advantage of researchers securing intellectual property rights is that information about products and processes that have been patented is available to the public. The Department of Consumer and Corporate Affairs is automating the patent system, which will permit computer searches for information. This process should be completed as quickly as possible. The department should also disseminate patent information regularly, perhaps through a bulletin produced by a private company under contract to the department (recommendation 21).

Such a move would complement the work of the Canadian Agricultural Research Council, which already publishes a review and directory of biotechnology research in progress. With support from Agriculture Canada, it could continue this work and circulate the review widely, not only to other researchers, but to entrepreneurs and industrialists interested in biotechnology (recommendation 5).

Companies can help ensure that research on subjects of potential commercial interest receives support.

Companies can do more than simply find out about what research is being done; they can help ensure that research on subjects of potential commercial interest receives support. Industrialists should accept the invitations of the Natural Sciences and Engineering Council to sit on strategic grants committees that choose the recipients of grants. Industrialists are needed who can evaluate the commercial significance of proposed projects. The Canadian Chamber of Commerce and the Canadian Manufacturers' Association should encourage their members to participate in the strategic grants committees of the Natural Sciences and Engineering Research Council in all high-technology areas (recommendation 23).

Coordination between government and industry should also take place at the level of local support systems for farmers. Agriculture Canada and the provincial departments of agriculture operate a nationwide system for the transfer of new technologies to farmers. Lately, however, this system has been allowed to run down. At the same time, private companies are competing to circulate information to farmers about their products and services. Farmers need objective, general advice about a wide variety of subjects, so that they can choose new technologies appropriate to their needs. Agriculture Canada and the provincial agriculture departments should cooperate with the private sector in establishing effective technology transfer organizations to provide this advice (recommendation 10).

Regulation and Legislation

The legal climate can affect what kind of biotechnology is developed in Canada and how quickly it develops. Legislation should protect the environment without slowing down the commercialization of research. This means that laws have to keep abreast of new developments in biotechnology. In some cases, the products of biotechnology are so unlike traditional products that existing laws do not describe them. In particular, genetically engineered microorganisms (including pest-control agents) and genetically engineered seeds are so new that there are no regulations governing their registration, testing, or release into the environment. Agriculture Canada, in collaboration with Health and Welfare Canada and Environment Canada, should draw up guidelines to deal with these issues (recommendations 11 and 12).

Legislation should protect the environment without slowing down the commercialization of research.

Health and Welfare Canada and Environment Canada have already created a Working Group on the Safety and Regulatory Aspects of Biotechnology. This group should monitor all Canadian research in genetic engineering as a prelude to enacting legislation and setting standards for this research (recommendation 18).

Facilities for testing biotechnology products are also essential. In 1983 the federal government made plans to create two testing facilities — one for plant protection products, including genetically engineered pest-control agents, and one for veterinary products. The government abandoned this idea as a cost-cutting measure, but it should be resurrected and implemented immediately (recommendation 4).

Regulations to control the safe development of biotechnology and to protect the environment fulfil the first function of legislation. However, legislation can also facilitate the development of biotechnology by officially recognizing some of the new products that are being developed. For example, new types of wheat may not fall into the traditional categories of varieties that can be licensed and sold in Canada. Wheat licensing regulations are linked to the nutritional content of wheat. However, if a new variety were specially bred, for example, to resist drought so that it could grow in an area formerly considered too dry for cultivation, it might not fall into one of the existing categories. In this case, it would be barred from licensing and commercial sale. New categories are needed that permit breeders to license such varieties. Agriculture Canada should review the varietal licensing system for all crops and re-evaluate it in light of new developments in biotechnology (recommendations 8 and 9).

Legislation can facilitate the development of biotechnology by officially recognizing some of the new products that are being developed.

Canadian producers in the natural resource industries must respond more quickly to changes in world demand.

A National Strategy for the Resource Industries

Canada must revitalize its natural resources if they are to remain competitive. Not only do Canadian producers have to contend with natural disadvantages such as soil infertility, permafrost, or a short growing season, but mismanagement has often added to their difficulties by depleting natural resources. Moreover, they have not responded quickly enough to changes in world demand. In agriculture, for example, demand for medium-hard and soft wheats is increasing, but Canada has until recently produced mainly hard wheats. In pulp and paper, markets for high-quality paper are growing, but Canada is still contributing to an oversupply of newsprint.

Biotechnology is not the only answer to these problems. However, it must play a part in any national strategy to improve the resource industries. The recommendations in this report support a four-pronged approach: basic research must be strengthened and focused; the commercialization of research results must be enhanced; links between researchers and industry must be forged; and gaps in the regulatory environment must be filled.

All three sectors involved in biotechnology must cooperate in this approach. Universities must supply the basic research on biotechnology. Industries that can use biotechnology must participate fully in the commercialization of that research and use their knowledge of the market to help set goals for research. Governments, both federal and provincial, must support efforts to link the other two sectors and provide the necessary legislation to create a suitable environment for the development of biotechnology. A full commitment by all three sectors will channel the total effort in biotechnology to meet national needs.

A full commitment by government, industry, and the universities will channel the total effort in biotechnology to meet national needs.

Recommendations

1. The Natural Sciences and Engineering Research Council should receive extraordinary funding of $15 million each year for 10 years, for the creation of from five to 10 interdisciplinary teams, each with a research focus on some topic of fundamental importance to the advancement of biotechnology.
2. The National Research Council should establish a $10 million contract research program to support biotechnology research by small and medium-sized firms.

3. Agriculture Canada should publish its strategic interests and long-term research plans in biotechnology and increase by reallocation its research funding for biotechnology to 20 per cent of its total research budget.
4. The federal cabinet should establish phyto-protection and veterinary products testing facilities.
5. In order that the Canadian Agricultural Research Council can continue updating its review and directory of biotechnology research, Agriculture Canada should provide it with sufficient resources.
6. Agriculture Canada and provincial governments that fund biotechnology research in agriculture should award funds regardless of the institutional or disciplinary affiliation of the applicants.
7. Agriculture Canada should reintroduce a plant breeders' rights bill to Parliament.
8. Agriculture Canada should review the existing varietal licensing system as it affects the development and introduction of all new varieties, including those developed through biotechnology, with a view to encouraging the rapid introduction of new crop varieties.
9. Agriculture Canada should increase the range of wheat varieties licensed to be grown in Canada.
10. The provincial departments of agriculture and Agriculture Canada, in their current review of technology transfer, should propose mechanisms for increased cooperation and coordination with the private sector.
11. Agriculture Canada, in collaboration with Health and Welfare Canada and Environment Canada, should establish guidelines for the registration of pest-control agents that are not found naturally in the environment, including pest-control agents that are genetically engineered microorganisms.
12. Agriculture Canada, in collaboration with Health and Welfare Canada and Environment Canada, should develop policy guidelines on field testing of genetically engineered seeds intended for commercial applications.
13. The Canadian Pulp and Paper Association, through its associate research group the Pulp and Paper Research Institute of Canada, should establish a 10-year program of biotechnological research and development.
14. The Canadian pulp and paper industry should double the level of R&D to 0.6 per cent of sales by 1992, and

increase to 5 per cent the proportion devoted to biotechnology research.

15. Canadian pulp and paper firms should fund contractual research at Canadian universities to a level of 20 per cent of the industry's R&D funding.
16. The National Biotechnology Advisory Committee should set goals and objectives for the natural resource sector under the national biotechnology programs.
17. The Minister of State for Science and Technology should establish a national program for the long-term development of culture collections.
18. The Working Group on the Safety and Regulatory Aspects of Biotechnology should monitor research in genetic engineering and related activities with a view to developing guidelines and standards for the release of genetically engineered products to the environment.
19. The Department of Regional Industrial Expansion should coordinate its strategy in support of industrial biotechnology.
20. The Department of Regional Industrial Expansion should budget, by reallocation from the Industrial and Regional Development Program, $10 million a year to fund commercial scale-up of biotechnology by Canadian firms.
21. The Department of Consumer and Corporate Affairs should accelerate the automating of the patent system and establish contracts with the private sector to publicize patent information.
22. The Natural Sciences and Engineering Research Council, the Medical Research Council, and the Social Sciences and Humanities Research Council, in consultation with the university community, should draw up guidelines for university scientists in securing intellectual property rights.
23. The Canadian Chamber of Commerce and the Canadian Manufacturers' Association should encourage their members to participate fully in the strategic grants committees of the Natural Sciences and Engineering Research Council.