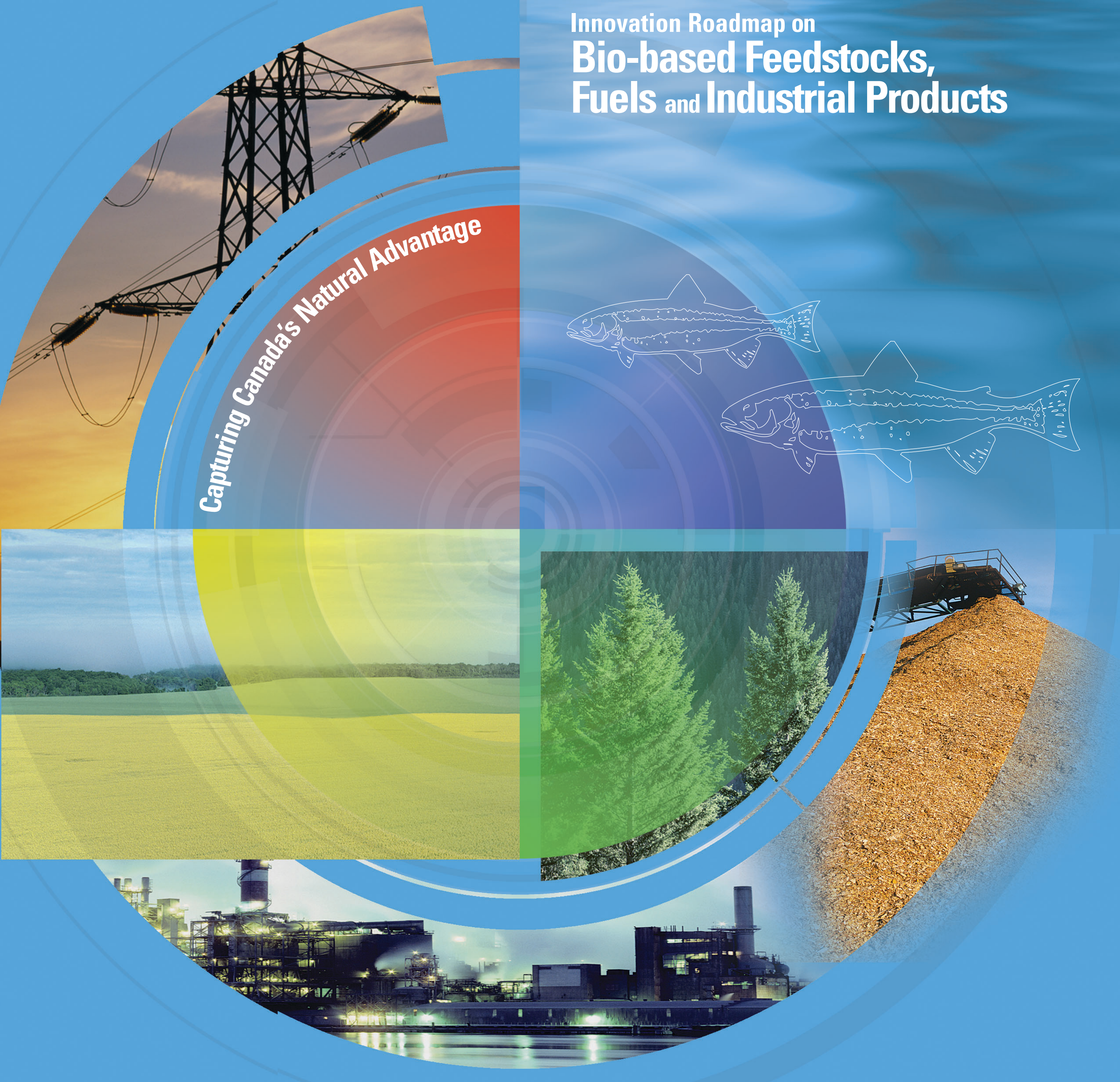
Innovation Roadmap on

Bio-based Feedstocks, Fuels and Industrial Products



Capturing Canada's Natural Advantage

BioProducts Canada

Canada

This publication is available upon request in multiple formats.
Contact the Information Distribution Centre at the numbers listed below.

For an electronic copy on ID-Rom of this publication, please contact:

Information Distribution Centre
Communications and Marketing Branch
Industry Canada
Room 268D, West Tower
235 Queen Street
Ottawa ON K1A 0H5

Tel.: (613) 947-7466
Fax: (613) 954-6436
E-mail: **publications@ic.gc.ca**

To obtain additional information about this report please contact:

Manufacturing Industries Branch
Industry Canada
235 Queen Street
Ottawa ON K1A 0H5

Tel.: (613) 954-3342
Fax: (613) 954-3107
E-mail: **bioproducts@ic.gc.ca**

or

BioProducts Canada
600 Peter Morand Crescent, Suite 250
Ottawa ON K1G 5Z3

Tel.: (613) 739-3900
Fax: (613) 741-2313
E-mail: **info@bio-productscanada.org**

Cat. No. Iu44-11/2004E-HTML
ISBN 0-662-36411-2
54124E/F

Innovation Roadmap on

Bio-based Feedstocks, Fuels and Industrial Products

Capturing Canada's Natural Advantage

Contents

Preface

A network of business people, academics, government personnel and consultants who have expertise and a strong interest in the bio-based economy (see Annex A) and “Thinking Green” have developed this *Innovation Roadmap on Bio-based Feedstocks, Fuels and Industrial Products: Capturing Canada’s Natural Advantage*. These individuals have participated in the steering committee, the working groups and workshops to develop and chart the way forward.

The objective of the innovation roadmap is to identify technology-based opportunities for utilizing Canada’s abundant bioresources in order to grow the economy while protecting the environment and our quality of life. The roadmap report covers a number of chemical and bioconversion technologies, and identifies both immediate and future markets for the bio-based economy. A recurring theme in this roadmap is that new biotechnologies have the potential to capture economically viable materials and energy from virgin biomass such as primary crops (agricultural, forestry and marine) and from their residual by-products. Another recurring theme is “your waste is my feedstock.”

Special thanks go to Randal Goodfellow, of BioProducts Canada Inc., for assistance in engaging participants, and also to David Layzell and Susan Wood of the BIOCAP Foundation, who worked miracles to document extensively the biomass inventories that are available as feedstocks and to convert this inventory into both dry carbon equivalents and potential energy. This innovation roadmap would not have been possible without funding from the Canadian Climate Change Action Plan 2000, the support and collaboration of departments on the Federal Working Group on Bioproducts, and the high energy and active participation of our workshop participants and project manager Joseph Cunningham.

The Way Ahead — It Is Already Happening!

Energy is central to Canada's sustained economic growth, and it is becoming progressively harder or more costly to extract from fossil sources. Demand for energy worldwide is expected to continue to grow rapidly in the foreseeable future.

The International Energy Agency (IEA) forecasts that the world will require 50 percent more energy over present consumption levels by 2020. Global pressure is building to allocate fossil fuels more wisely and to develop ways to diminish existing dependencies and vulnerabilities. As the amount of readily available oil, especially in OPEC countries, is depleting, oil prices will increase, and spikes in energy prices will become even more pronounced. The conflict between demand and availability could conceivably become more severe in the next 20 years, resulting in a major shift into future fuels and highly efficient energy systems such as fuel cells, small- to medium-scale distributed cogeneration systems and biofuels (biogases, biodiesel, bio-oils and alcohol).

Biofuels and bioproducts are strategically important to Canada. There are several successful Canadian companies actively engaged in this field. Canada is in an excellent position to benefit with its resource base, expertise and developing community-based eco-industrial clusters. The biomass opportunity will provide new revenue streams for the traditional agricultural, forestry and marine resource sectors and communities.

Major benefits can be derived from Canada's exceptionally large biomass resource — Canada's Natural Advantage. For instance, the BIOCAP Foundation estimates that our standing forests have an energy content that is equal to 69 years of Canada's current energy demand now being met by fossil fuels.

Due to a highly unstable global energy market as well as large spikes in oil and natural gas prices, Canada is at a tipping point regarding future fuel developments. Action must be taken now. Substantial biofuel opportunities both now and in the near-term future are ours to lose despite our abundant biomass resources and strong competitive advantages, especially in the physical, chemical and thermal conversion of primary and residual biomass to bio-based energy and industrial products.

The business case for future biofuel and bioproduct developments, however, needs to be better developed and communicated widely. The roadmap focusses on taking advantage of commercial opportunities, increasing biomass productivity and capturing value from agriculture, forestry, marine industries and municipal solid waste. Canadian companies are exceptionally well positioned to capture strong financial and economic returns from these materials. The return on investment is healthy for many Canadian companies in this business. Industry research and development is close to the market and is, in many cases, at a strong commercialization phase.

A transition is occurring in Canada from our current excellence in physical, chemical and thermal conversion technologies to a greater longer-term emphasis on bioprocesses and “green” chemistry, which are much less energy intensive and less polluting. The body of this innovation roadmap discusses this transition and multidisciplinary approaches involving biotechnology, nanotechnology, biology, chemistry, physics, engineering, rheology and mathematics in greater detail. The specific working group reports, which have been circulated to all participants, provide more comprehensive discussions on both chemical and biological technologies.

This innovation roadmap recommends several specific actions that should take place in order to grow the biofuels and bioproducts industries. The following key action items are elaborated in the main body of the report:

- community-based eco-industrial clusters pilot project
- government procurement
- creation of a **BioProducts Industry Council**
- greater capital availability
- greater migration of the technology platforms to market-driven commercialization initiatives
- greater engagement and awareness of the public.

This roadmap is a “living” process that allows industry players to work with governments and academia to design their own longer-term plans. This report suggests various technology and market-driven pathways. It also suggests specific actions for both the short and the long term that could be followed. The production of this document is one point on the road in a long journey. New technologies and innovative uses of biomass will continue to evolve from the discussions that our network or community of practice has initiated.

The roadmap brought together a group of individuals (see Annex A) representing a wide range of different interests comprising chemical conversions, combustion, bioprocesses, harvesting and distribution technologies, agriculture, forestry, municipalities and marine life. The synergy developed through this roadmap needs to be continued and developed further through sustained interactions and networking among the participants, who have contributed an enormous amount of their time and resources to this effort. We are forming the **BioProducts Industry Council** to focus the efforts of industry, the research community and government on the implementation of the roadmap. The council proposes to meet with the Minister of Industry and officials to review progress on a regular basis, identify barriers and provide advice on policies that can help grow a sustainable bioproducts industry in Canada.

> *The Stone Age did not end for a lack of stones, and the oil age will end not for a lack of oil.*
>
> —Sheik Yamani, Saudi oil minister, 1973

> *We stopped using stone because bronze and iron were superior materials, and likewise we will stop using oil when other energy technologies provide superior benefits.*
>
> —Bjørn Lomborg, *The Skeptical Environmentalist* (New York: Cambridge University Press, 2001), p. 120

Thank You!

Rick Smith, President and CEO of Dow AgroSciences Canada Inc., Chair of BioProducts Canada Inc. and Innovation Roadmap Champion

David C. Boulard, Executive Vice President, Ensyn Technologies Inc. and Chair of the Innovation Roadmap Steering Committee

Executive Summary

More than 300 Canadians from industry, academia and government have participated in this industry-led exercise, championed by Rick Smith, President and Chief Executive Officer, Dow AgroSciences Canada Inc.

The Vision

The overarching vision is to make Canada a leader in environmental and sustainable technologies through its Natural Advantage and to grow the economy while improving our environment and quality of life through the development and commercialization of industrial bioproducts and processes from our abundant biomass resources.

Biofuels and bioproducts are potentially cleaner and cheaper than fossil-based products. They are also renewable, unlike fossil-based products. Biofuels and industrial bioproducts contribute to sustainability and growth in meeting burgeoning world demands for energy, chemicals and materials. This trend is already happening among member countries of the Organization for Economic Co-operation and Development, where highly educated populations and advanced communications accelerate global adoption.

A theme running though this roadmap is the potential for new biotechnologies to capture economically viable materials and energy from biomass, including virgin biomass from primary crops (agricultural, forestry and marine), and from underutilized materials and land. The production of high-value by-products can be an incentive to recover and recycle waste energy and organic residues. At the same time, there is strong potential for greater synergy and resource conversion efficiencies in production through effective use of co-products.

Residual biomass represents low-hanging fruit that comes free or has a negative economic value such as a material that costs money to dispose of it in landfills, like municipal solid waste, waste wood and mill residues such as bark, sawdust, planer shavings, end cuts, paper sludge or slabs.

With more biomass resources per capita than any other nation, Canadians husband a diverse treasure house of crops, trees, animals, marine life, microorganisms, and industrial and municipal organic residues. Renewable resources challenged Canadians to create sustainable economic, environmental, and social benefits as their 21st-century hallmark. We are now well positioned for the paradigm shifts in industrial feedstocks to future fuels and industrial products in the new millennium.

Sustainability comes from leaving future generations with knowledge, capacity and capital to obtain a quality of life at least as good as ours while reducing their external vulnerabilities. Sustainability provides a context for corporate objectives directed to the triple bottom line of meeting financial, environmental and social needs.

Steadfast ties to their renewable resources ensure ongoing economic opportunities for Canadians. Pollution and greenhouse gas emissions will decrease. New employment will be created and the quality of life for all Canadians will steadily improve.

Achieving the Vision

Government, industry and academia must work collaboratively to achieve this vision. This roadmap contains concrete targets and time lines, a realignment of policies among all levels of government, effective approaches to stimulate innovation, promotion of stewardship and improved public outreach. Effective stewardship safeguards prompt use of safe and novel products in a sustainable environment.

The BIOCAP Canada Foundation study has provided data on gross resource availability. Annual biomass residues are equivalent in energy content to about a quarter of the fossil fuel used in Canada.

The Canadian Climate Change Action Plan 2000 has established the following production targets:

- 1.4 billion litres of ethanol by 2010 (up from 200 million in 2001)
- 500 million litres of biodiesel by 2010 (up from essentially zero in 2001).

Set Targets for Greater Production and Use of Biofuels

1. Increase production of alternative fuels that help reduce greenhouse gases. Canada currently produces 240 million litres of ethanol. The Canadian ethanol industry including companies such as Iogen is

evaluating more than ten proposals to use alternative inputs to ethanol production such as starch or cellulosic plant materials. Scheduled to commence production between 2006 and 2010, production from these sources is expected to exceed current ethanol production targets. With 10 percent blending and no additional exports, this output would meet one-third of Canada's expected gasoline consumption and save three million tonnes of carbon dioxide emissions, which is equal to 3 percent of the Canadian transportation industry's gasoline emissions.

2. Increase the output of biodiesel and biodiesel blends to reduce airborne emissions.

3. Improve the cost competitiveness of producing biofuels by:
   a. utilizing high-end molecules in feedstocks to produce valuable by-products to defray energy costs
   b. adopting cogeneration practices to fully utilize all fuels and all heat generated in production processes
   c. minimizing heat requirements in production processes through catalysis, enzymes and innovative membranes
   d. reducing biomass transportation costs through bundling or compacting, or by treating residues and using them in close proximity to the resource
   e. supporting and integrating the disparate sciences listed below.

4. Encourage the growth of research and development in biofuels and industrial products, similar to the level achieved in fossil fuels.

Improve Networking

1. Recognize that intermediate demand (e.g., chemicals used as inputs in manufacturing) represents important markets for most biochemicals.

2. Participate in clusters or, if sufficiently small, incubators housing complementary companies to:
   a. minimize supply chain costs
   b. share management approaches
   c. innovate faster
   d. access markets sooner
   e. make better use of scarce intellectual resources through networks of scientists and laboratories among our companies, universities and governments

   f. learn innovative management practices and "lean manufacturing"
   g. improve access to capital and global markets in the bio-based economy for venture capitalists.

3. Keep the roadmapping process evergreen to:
   a. raise the profile of bioproducts
   b. promote the establishment of eco-industrial clusters
   c. utilize government procurement to establish initial markets
   d. expand research networks
   e. include research and development projects involving biofuels and bioproducts as eligible categories for investment under all federal programs, including Technology Partnerships Canada, Program for Energy Research and Development, Climate Change (Technology and Innovation) and Industrial Research Assistance Program.

Support and Integrate Disparate Sciences

1. The roadmap identifies the following areas for potential support and investment in the development of science, technology and skilled human resources:
   a. plant science, soil microbial ecology and bioprospecting
   b. GIS systems to locate biomass concentrations including both current manufacturing sites and legacy waste sites
   c. biocatalysis, especially enzyme optimization
   d. new chemistries to take advantage of the properties of biomass constituents (carbohydrates, lignin and oils)
   e. more work in cellulose, chitin, alginate and starch research for industrial uses such as fuels and chemicals
   f. additional work on cellulose chemistry to develop new uses for cellulose and co-products such as lignin
   g. cogeneration.

2. The roadmap identifies the following innovative feedstock platforms:
   a. carbohydrates, including cellulose, chitin, starch and alginates
   b. oil
   c. lignin
   d. protein
   e. ruminant digestive systems.

It *is our dreams that will decide and we (the people) are their Shapers.*
—Earle Birney, "The Shapers: Vancouver," 1973

1 Introduction and Vision

Canada is endowed with abundant natural resources and has among the world's most productive agriculture, forest and marine sectors. These sectors export grain, meat, fish, lumber, paper and other products to almost every corner of the globe. At the same time, Canadian energy, transportation and manufacturing sectors are being encouraged to increase productivity within acceptable boundaries of environmental stewardship by decreasing pollution including emissions of greenhouse gases. The harnessing of bioproducts derived from renewable bioresources — crops, trees, animals, marine life and microorganisms as well as industrial and municipal organic residues — challenges Canadians to build on their resources and to expand their capabilities to create industrial, economic, environmental and social benefits.

Up to the end of the nineteenth century, the demand for lubricants and illuminants was serviced by vegetable and animal oils, which were displaced by products derived from fossil fuels.

Sustainability is inexorably linked to the ongoing ability of society to innovate. Sustainability comes not in securing all specific resources for all future generations — for that is impossible — but in leaving future generations with knowledge and capital that allow them to maintain a quality of life at least as good as ours[1] without adding to external vulnerabilities.[2] This view of environmental stewardship provides a structure for corporate objectives that are directed to the triple bottom line; that is, the practice of corporations working to meet financial, environmental and social needs.[3] This technology roadmap is concerned with the availability of biomass and innovative biotechnologies to contribute to both sustainable development and growth. Some products from these innovations are already on the market while others are still at early stages of research and development.

FERIC delivers engineering and technological solutions for forest harvesting and management.

[1] Bjørn Lomborg, *The Skeptical Environmentalist: Measuring the Real State of the World* (New York: Cambridge University Press, 2001), p. 119.

[2] David E. Minns, "Challenges for Technology, Innovation and Industry," paper presented at a symposium on The Bio-based Economy, sponsored by Industry Canada and the Chemical Institute of Canada, Vancouver, Oct 2002.

[3] Luciano Respini (President of Dow Europe), "The Corporation and the Triple Bottom Line," paper presented at the symposium on Euro Environment 2000, sponsored by the Danish Ministry of the Environment and the World Business Council for Sustainable Development, Aalborg, Denmark, Oct. 18, 2000

Canadians can envision a bright future:

> *With sustainable production and use of biomass to produce fuels, chemicals and materials, economic opportunity and value-added will increase, pollution and greenhouse gas emissions will decrease, new employment will be created and the quality of life in Canada will improve.*[4]

The bioproducts industry uses renewable raw materials to produce fuels, chemicals and materials that are used throughout the economy. Most of the companies in the bioproducts sector are small and are focussed on niche market opportunities. A few others including Cargill, Archer-Daniels-Midland and Tembec are large.

A preliminary study by Statistics Canada has yielded some partial data for 2001 on the Canadian bioproducts industry. An estimated 133 Canadian firms are involved in making or developing industrial bioproducts. These firms employ 39 000 people and have revenues of $15.3 billion. In 2001, they invested $598 million in research and development and had exports worth $564 million.

The Vision

The overarching vision is to make Canada a leader in sustainable technologies through its Natural Advantage and to grow the economy while improving our environment and quality of life through the development and commercialization of industrial bioproducts and processes from our abundant biomass resources.

Tembec Chemical Products Inc. is an integrated Canadian forest products company producing wood products, market pulp and paper along with value-added wood products like resin and alcohol.

Before 1920, biomass supplied most of our needs for energy and industrial raw materials. Since then, readily available and inexpensive fossil-based hydrocarbons have been our main source of energy, chemicals and industrial materials. This petroleum-based economy has stimulated a great deal of growth and has helped increase our standard of living, but it has come at a cost to the environment. The dependence on fossil-based energy systems has resulted in considerable pressures on sustainable development and environmental stewardship. Security of supply, political issues, and large imbalances in supply and demand of fossil fuels are also creating havoc across the political and economic spectrum.

A new industrial revolution is under way. We are now starting to think “sustainable” and “green.” A fundamental change is occurring from utilizing

[4] Industry Canada, “Vision for the Bio-based Economy in Canada,” draft report, Industry Canada, Ottawa, February 13, 2003.

fossil carbon for energy to renewable carbon or biomass as a feedstock for energy and manufacturing industries.

The "green" bio-based economy offers viable solutions for a range of systematic problems including climate change, persistent organic pollutants, municipal, industrial and farm waste, decline of chemical process industries, and struggling rural agriculture and forest-based economies.

The export of new Canadian biotechnologies and the establishment of peace in many of the world's "hot spots" have the potential to improve the world's food supply where it is needed the most, including Sub-Saharan Africa in its "breadbasket" between the tributaries of the Nile River. Despite the growth in world population numbers, the proportion of people receiving insufficient food to carry out light work has fallen from 35 percent in 1971 to 18 percent in 1997, and the United Nations expects this proportion to fall to 12 percent by 2010.[5]

Marinard Biotech Inc. produces chitosan from shellfish for the cosmetics, pulp and paper, horticulture and food industries.

A theme running though this roadmap is the potential of new biotechnologies to capture economically viable materials and energy from residues including biomass from underutilized materials and land. The production of high-value by-products or co-products makes viable the harvesting of heretofore waste energy and residues. Alternatively, there is strong potential for increased manufacturing synergies and resource conversion efficiencies in production through the effective use of co-products.

[5] Op. cit. Lomborg, p. 61. As Lomborg notes, the absolute number of people facing these dire straits has fallen from 920 million in 1971 to 792 million in 1997 and is expected to drop to 680 million in 2010. While the former is still unacceptably high, it should also be noted that, given the increase in the world's population since 1971, an additional two billion people are not eating less than the minimum caloric intake recommended by the United Nations.

2 Technology Roadmap Process

Many stakeholders are needed to undertake this roadmapping activity, as described below.

Industry Champion

The Industry Champion is Rick Smith, Chief Executive Officer, Dow AgroSciences. As ultimate leader and client, he is using the roadmap to recommend government research priorities, policy, regulatory and skill requirements as well as outreach and implementation plans. Our champion is helping our network unite and focus the industrial sector on bioproducts, while providing economic and social benefits for Canada in advancing the bio-based economy.

Executive Committee

The Executive Committee is an industry-focussed subset of the Steering Committee, established to oversee, vet and approve the roadmap plans, resources and final report.

Steering Committee

The Steering Committee, with its larger membership reviews, provides direction and input to the roadmap processes, action plans, resources, outputs of workshops and preparation of the final report. Representatives are drawn primarily from industry, with links to the research community and non-governmental organizations such as BioProducts Canada.

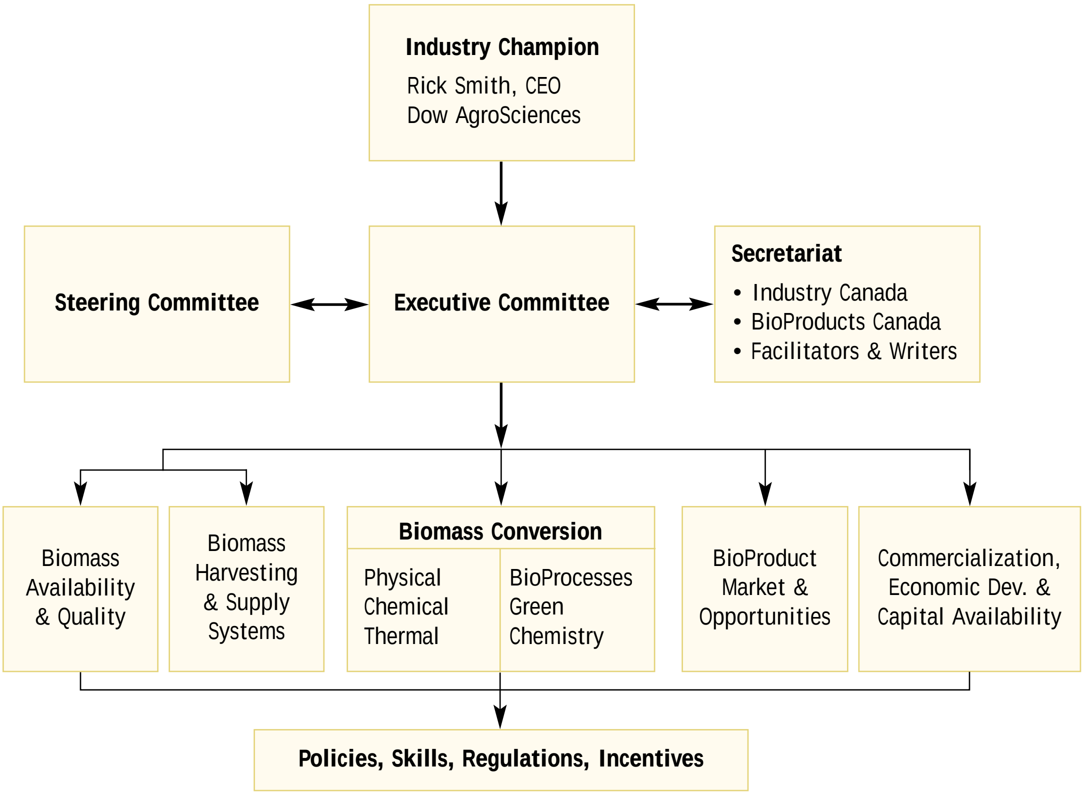
Working Groups

Working groups have been established for the following areas:

- biomass availability and quality
- biomass harvesting and supply systems
- biomass conversion technologies
  - physical, chemical and thermal-advanced combustion
  - bioprocessing and "green" chemistry
- bioproduct market and opportunities
- commercialization, economic development and capital availability
- policies, skills, regulations and incentives
- communications strategy.

These working groups met, either in person, by phone or electronically on several occasions. Each group produced a report on its findings. These reports were instrumental in producing this document.

Figure 1 — Management Structure of the Roadmap



3 Biomass Availability

Globally, the annual production of biomass from plant vegetation is equal to five times the world's annual consumption of energy and chemicals. The volume of fossil carbon used for energy and fuels is ten times that used for the production of chemicals and plastics. It is possible and even plausible that all global chemical markets could be supplied using biomass and that a major portion of global energy and fuel needs could be met using biomass in combination with other sources of renewable energy such as wind power.

BIOCAP Inventory Study

Canada is well endowed with natural bioresources. It has 10 percent of the world's forests. The BIOCAP Canada Foundation estimates that Canada's reserve of timber resources is equivalent to 69 times its annual consumption of fossil fuels. On an annual basis, the renewable resource residues from forestry, agriculture and related manufacturing industries are equivalent to approximately 18–27 percent of the energy Canada derives from fossil fuels.

A detailed analysis was carried out by the BIOCAP Foundation to assess the capacity of Canada's biological resources — in particular, agriculture and forestry — to support a bio-based economy. In a bio-based economy, the agriculture and forestry sectors are involved in the large-scale production of bio-based energy (e.g., fuels), industrial chemicals and feedstocks in addition to the production of food, feed and fibre.

The analysis explored forest production, agricultural production and municipal waste streams.

Land Area: Of Canada's 998 million hectares of total land area, about 42 percent is forested, with about 245 million hectares or 25 percent of the total considered timber productive forest. A further 67.5 million hectares (6.8 percent) make up agricultural land, of which 36.4 million hectares (3.6 percent of total) are cropland.

DuPont Canada Inc.'s products include resins, films, automotive finishes, crop protection products and industrial chemicals. One of its goals is to lower its environmental footprint through energy efficiency and biofeedstocks.

Standing Biomass / Bioenergy Stock:
The 245 million hectares of timber productive forest in Canada have a biomass carbon stock of about 15 835 million tonnes of carbon. The energy content of this resource amounts to 566 exajoules, or about 69 times Canada's annual energy demand met by fossil fuels.

Annual Harvest: The annual biomass harvest from Canada's forestry and agricultural sectors is about 143 million tonnes of carbon. This level is similar to the annual atmospheric emissions of carbon from fossil fuel use in Canada, which amounted to about 150 million tonnes of carbon in 1998.

The annual energy content of the biomass harvest in Canada amounts to 5.1 exajoules, which is 62 percent of the energy derived from fossil fuel combustion. A 25-percent increase in forestry and agricultural production in Canada could provide about 1.25 exajoules a year in biomass energy, an amount equal to about 15 percent of the energy that Canada now derives from fossil fuels.

Residue Biomass: There are large residual or residue biomass carbon streams that are associated with existing agriculture and forestry or with municipalities:

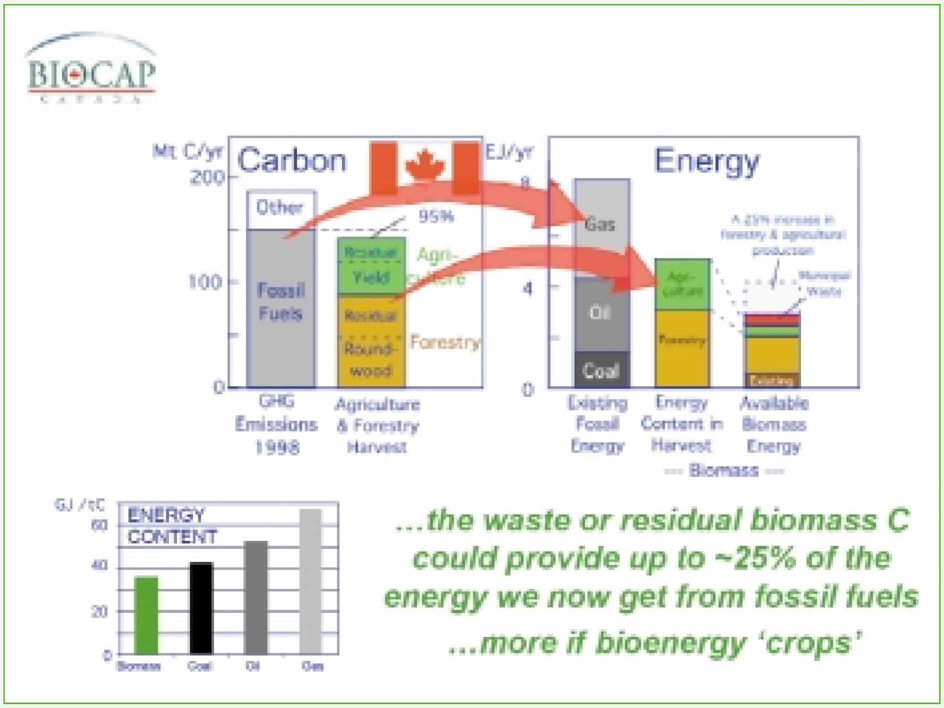
- Of the more than 66 million tonnes of carbon a year in the residual or waste biomass carbon stream, about 60 million tonnes may be considered “available” feedstock for a bio-based economy. This represents about 42 percent of the entire forestry and agricultural harvest.
- The energy content of this biomass resource, conservatively estimated to be in the range of 1.5–2.2 exajoules a year, is equivalent to 18–27 percent of the energy that Canada derived from fossil fuels in 2000.

These facts illustrate the major potential of Canada's vast forestry and agricultural resources to provide a renewable and sustainable supply of bio-based energy, chemicals and materials to help meet the needs of society. In addition, residue products from fisheries and aquaculture could provide considerable amounts of valuable fish oils, fatty acids and chitin. The potential of alginates in conversion to energy and chemicals requires further study and could be significant.

Dow AgroSciences Canada Inc. produces pest management and biotechnology products that improve the quality and quantity of the earth's food supply and contribute to health.

An economy based on biomass feedstocks would help the nation meet its international climate change commitments while stimulating the rural economy and encouraging innovation and economic growth. Certainly, when it comes to a bio-based economy, Canada has a Natural Advantage relative to other developed countries of the world.[6]

Figure 2 — The Energy Potential of Canada's Biomass Carbon



[6] David B. Layzell and Susan M. Wood, *Canadian Biomass Inventory: Feedstocks for a Bio-based Economy*, report prepared for Industry Canada (Kingston, ON: BIOCAP Foundation, 2003).

4 Conversion Technologies

Biomass is converted into useful fuels by direct combustion as well as by thermal, chemical and biological processes. Direct combustion involves burning untreated biomass material in boilers or furnaces. Thermal processes involve heating the biomass material. Chemical processes involve breaking down or converting the feedstocks through chemical reactions, membranes, metal catalysts and other physical separation technologies. Biological conversion uses microbiological action to convert the biomass material into usable fuel and other bioproducts.

The bioenergy cycle, depicted in Figure 3, occurs as photosynthesis and biomass growth draw carbon from the atmosphere, which is subsequently returned to the atmosphere when the biomass is consumed.[7] Similarly, nutrients taken from the soil as the biomass grows are later returned to the soil when it is consumed. The carbon dioxide gases released by the use of biofuels result in little or no net addition of carbon to the atmosphere, whereas the use of fossil fuels adds considerably more carbon to the atmosphere.

This vegetation or biomass growth, when harvested, can produce a variety of products including energy, food, feed and industrial products produced in petrochemical factories. Technologies used in biofactories include thermal conversion, biological processes such as fermentation and chemical conversions using membrane separations, catalysts, etc.

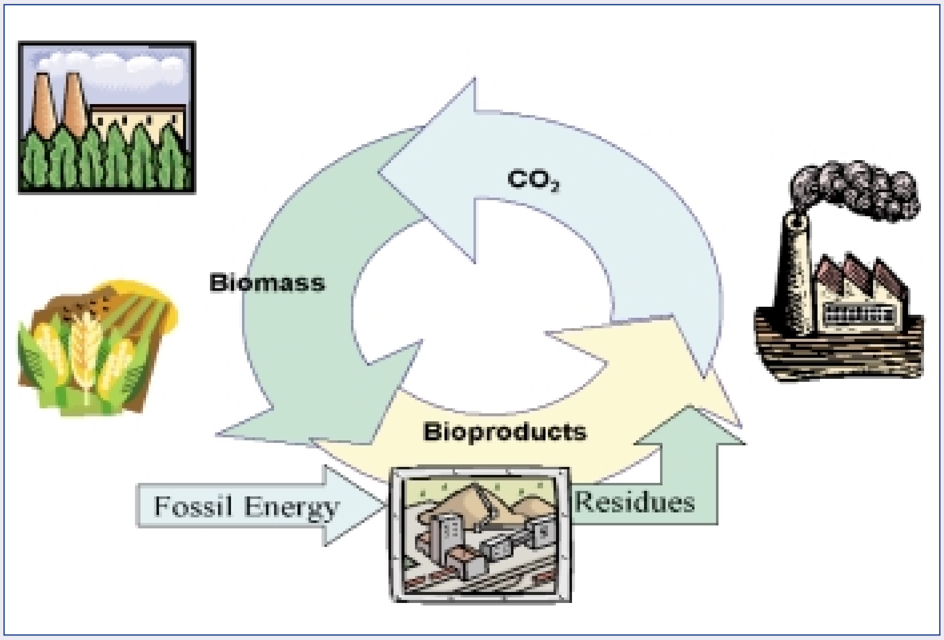
While biomass production can produce energy through chemical and bioprocess conversion technologies, it also consumes large amounts of energy in planting, fertilizing, tilling, harvesting, distribution and processing the crops. Clearly, a long-term goal of the innovation roadmap is to reduce fossil fuel inputs through more efficient bioenergy technologies and to recycle some of the nutrients from organic by-products and residues back into the land.

Canadian Kelp Resources Ltd. operates a kelp farm, markets health food sea vegetables and advises on kelp industrialization.

Forinteck Canada Corp. delivers engineering and technological solutions to the wood products industry.

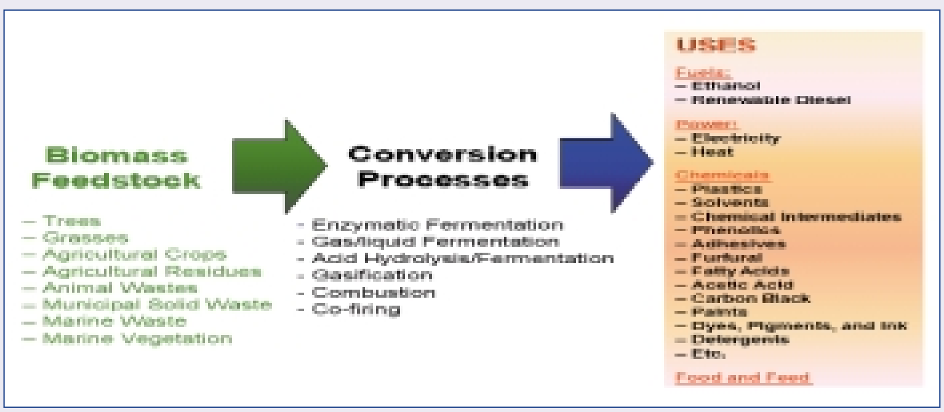
[7] See the Biomass Research & Development Initiative Web site at: **http://www.bioproducts-bioenergy.gov**.

Figure 3 — The Bioenergy Cycle



Source: Prepared by Acton White Associates Inc., Ottawa, 2004.

Figure 4 — The New Industrial Biorefinery



Source: Adapted from material from U.S. Department of Energy, Washington, D.C., February 2004.

Catalysts

Catalysts are becoming more prevalent in manufacturing. Catalysis is the process by which chemical reactions are either accelerated or slowed by adding a substance that is not changed in the chemical reaction. Catalysis lowers the energy required to activate a process, resulting in lower energy demands. Sixty percent of chemical products and 90 percent of chemical processes are based on catalytic chemical synthesis. General advances in the discipline of catalysis could have a major impact on Canada's chemical industry as well as on chemical processes in manufacturing and mining.

Catalysis involves the use of chemicals, metals or enzymes. When enzymes are used as catalysts, the term biocatalysis is used. A more common definition of biocatalysis is the use of biological systems or their components for chemical synthesis or transformation.

Chemical and metal catalysts are important in the production of biodiesel, and biocatalysis is employed in anaerobic digestion processes as well as in many other manufacturing processes.

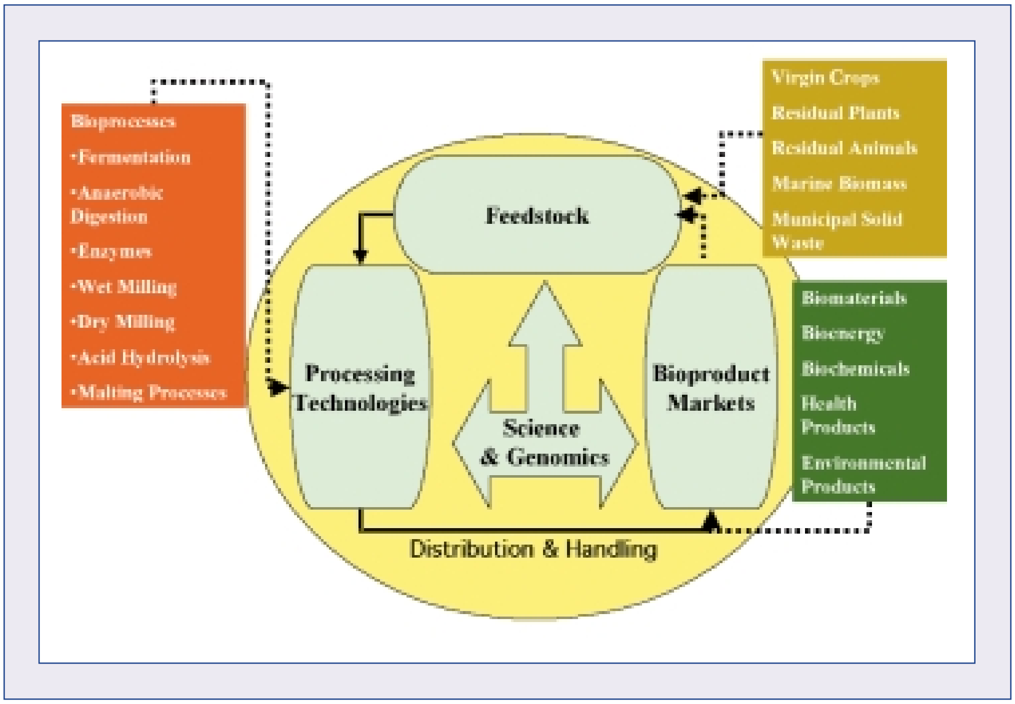
Biological and chemical processes are described in the following pages. In some cases, the distinction between chemical and biological processes is clear.

Domtar Inc. is developing separation and enzymatic processes to save energy in pulp and paper and other manufacturing.

Bioprocesses

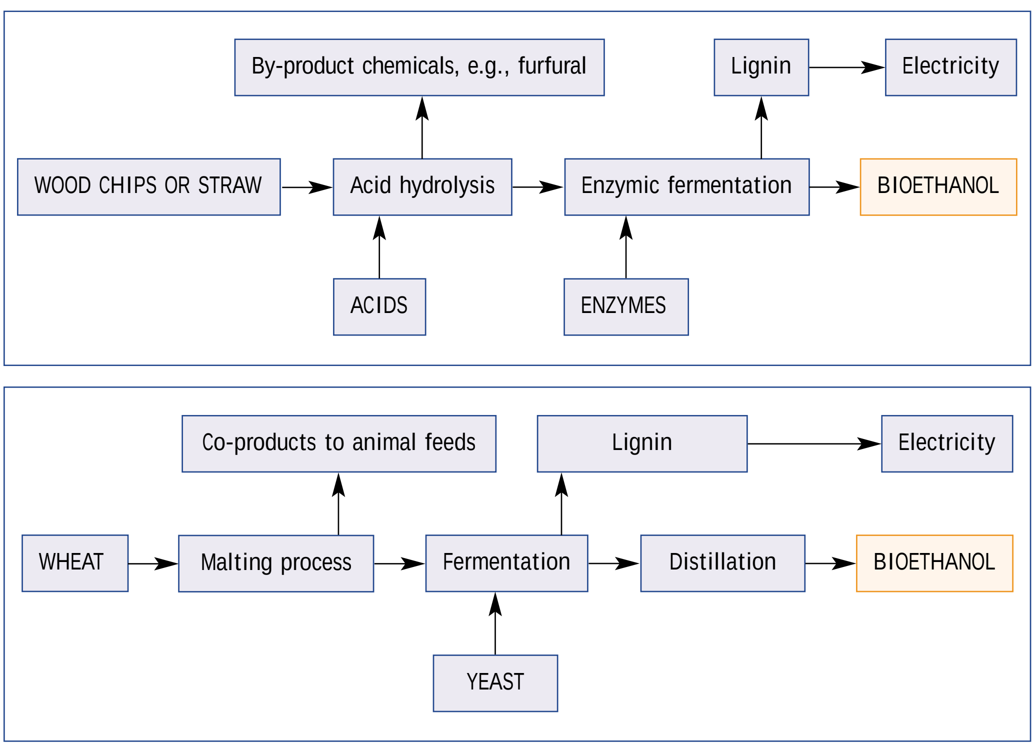
Several bioprocesses are depicted in Figure 5. Figures 6 and 7 provide value chains for technologies and products for ethanol.

Figure 5 — Bioprocess Generic Value Chain



Source: Prepared by Acton White Associates Inc., Ottawa, 2004.

Figure 6 — Bioethanol Value Chains



Source: United Kingdom, Department of Transport, *International Resource Costs of Biodiesel and Bioethanol* (London, UK: Department of Transport).

4 Conversion Technologies

New technologies have evolved to more efficiently derive ethanol from feedstocks such as agricultural and forestry residues, municipal solid wastes, other industrial wastes and crops grown solely for energy purposes.[8]

In Canada, an estimated 1000 retail locations are selling ethanol-blended gasoline in all provinces west of New Brunswick. Approximately 7 percent of gasoline sold in Canada is blended with ethanol.[9] The current annual output of ethanol from five production facilities is 240 million litres, of which 65 million litres are industrial ethanol and 175 million litres are fuel ethanol. Canada imports 90–100 million litres a year from the United States. Most of these imports are destined for Ontario and Quebec.

Dow Bioproducts Ltd. produces agri-fibre-based construction materials.

More than ten proposals based on current technologies are being evaluated by the Canadian ethanol industry. A few proposals for ethanol production from cellulosic plant materials are also being seriously considered. These production facilities are expected to be in operation by between 2006 and 2010, which would bring fuel ethanol production in Canada in 2010 to over 1.4 billion litres a year. If all of this ethanol were consumed in Canada, 35 percent of the gasoline consumed would meet the E-10 quality standard targeted by the Canadian Climate Change Action Plan for 2010.

The use of ethanol to replace 1.2 billion litres of fossil-based gasoline would result in a reduction of three million tonnes of carbon dioxide or carbon emissions to the atmosphere, which is equal to 3 percent of the Canadian transportation industry's gasoline emissions.

Casco Inc. produces corn-derived products — starches, fermentable sugars, sweeteners, feed and oil used by more than 60 different industries.

Ethanol production typically involves the conversion of starch from corn, wheat and barley to sugar followed by the fermentation of this sugar to ethanol. U.S. output of ethanol currently amounts to about 10 billion litres a year in 76 production facilities. The U.S. Energy Bill has targeted production in 2012 to reach 19 billion litres.

DynaMotive Energy Systems develops pyrolysis technologies that convert lignocellulosic residues to bio-oils, carbon, biogas and other products.

Ethanol made from cellulosic feedstocks has the potential for even greater reductions in greenhouse gas emissions than ethanol made from grains. Cellulose is derived from forest products and agricultural processes, making it the most abundant biomaterial in Canada. Research is progressing on cellulosic technology to produce ethanol from agricultural residues (such as straw and corn stalks), dedicated grass crops and forestry products like wood residue or short-rotation plantations.[10]

---

[8] See U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "History of Biofuels" at **http://www.ott.doe.gov/biofuels/**.

[9] **http://www.climatechange.gc.ca/english/newsroom/2003/bg_ethanol.asp**

[10] *Ibid*.

Traditionally, cellulose has been used in the manufacture of paper products, non-woven fabrics and insulation. Secondary transformations have led to a variety of higher-valued products such as baby diaper absorbents, textile yarns, plastic films, high-gloss coatings, food additives, and reinforcing carbon fibres. Cellulose is ideal for paper making because the polysaccharide links in it force the cellulose chain into a rigid straight orientation. Hydrogen bonding between chains creates flat sheets or rods that add strength and stability.

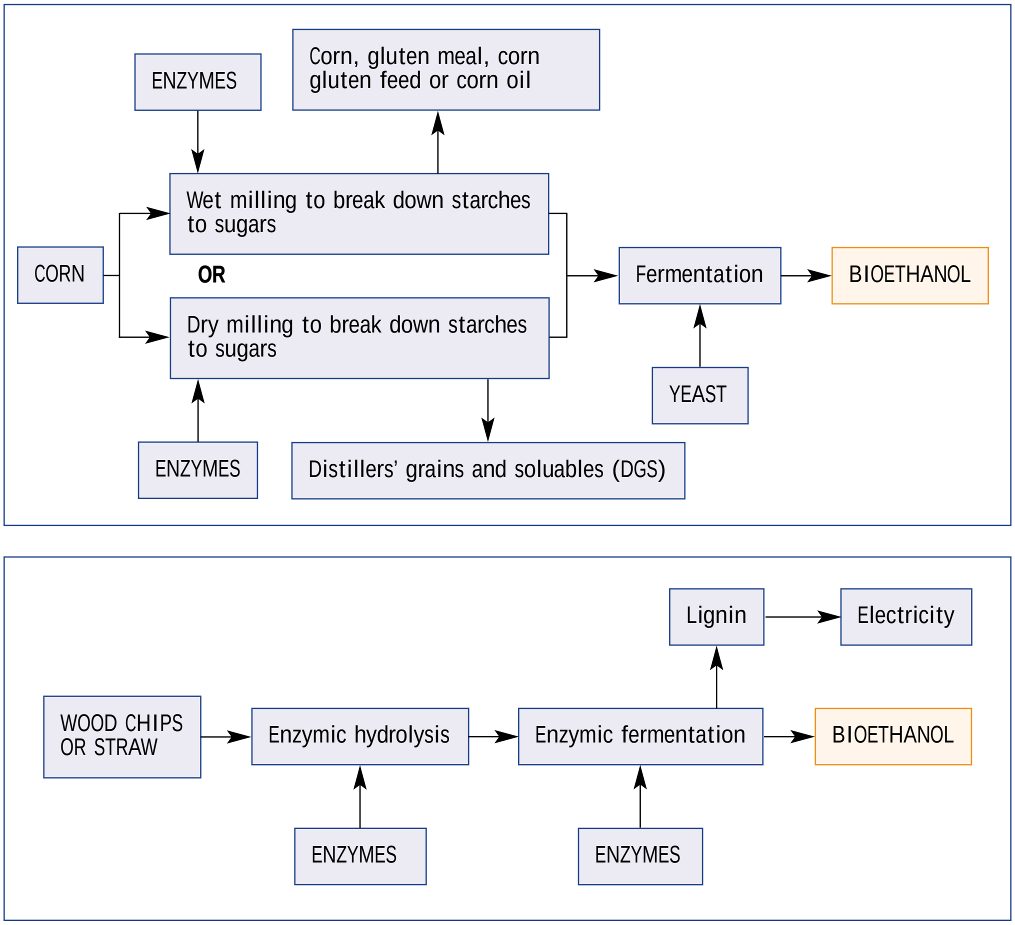
Lorama Chemicals Inc. manufactures polysaccharide resins to modify decorative enamel formulae to reduce raw material costs in coating technologies.

Cellulose structures survive pulping processes, which involve aggressive chemical digestion and high temperatures. The isolation processes used for cellulose transformation in Canada generate waste biomass, which in turn produces enough process bioenergy for cellulose isolation as well as chemical recovery. In terms of cellulose recovery and energy efficiency, established pulping processes such as sulfite and kraft need to be optimized with newer technologies in order to maintain the advantage of cellulose over products derived from fossil deposits. Forest product processing systems use residual biomass for energy and co-products; kraft mills, for example, are at or near energy self-sufficiency. However, there are potentially more biomass residual sources that require identification through audits such as the recovery of cellulose fibres from pulping effluents and conversion to “biodust”-type fuels.

Emerging technologies have used cellulose’s natural tendency for self-assembly at the molecular level to introduce exciting third-generation cellulosic biomaterials. Derek Gray of McGill University in Montréal has discovered cellulosic optical materials and cellulosic liquid crystals. Derek Gray and Laurent Heux at Centre national de recherche scientifique (CNRS) at Grenoble, France, have explored chiral-nematic self-ordering cellulose microcrystals and their interaction with light. This new biomaterial technology leads to potential communication pathways that can transmit more information than is currently available from fibre optics or optical switching devices. You-Lo Hsieh of the University of California at Davis has developed bio-functionalized cellulose nanofibres and cellulose-derived carbon nanofibre porous networks that may lead to selective membrane technologies for directed molecular separations, hydrogen sequestration and ion partitioning.

The demand for natural-based polymers is increasing at an accelerated rate because of increased costs and shortages of fossil-based chemicals. The United States government has recently proposed rules for the federal procurement strategy to include more bio-based products, including 50 percent minimum natural-source fibre and 10–40 percent natural-source plastics. This policy will further increase the demand and value of cellulose as a biomaterial.

Figure 7 — Bioethanol Value Chains



Source: United Kingdom, Department of Transport, *International Resource Costs of Biodiesel and Bioethanol* (London, UK: Department of Transport).

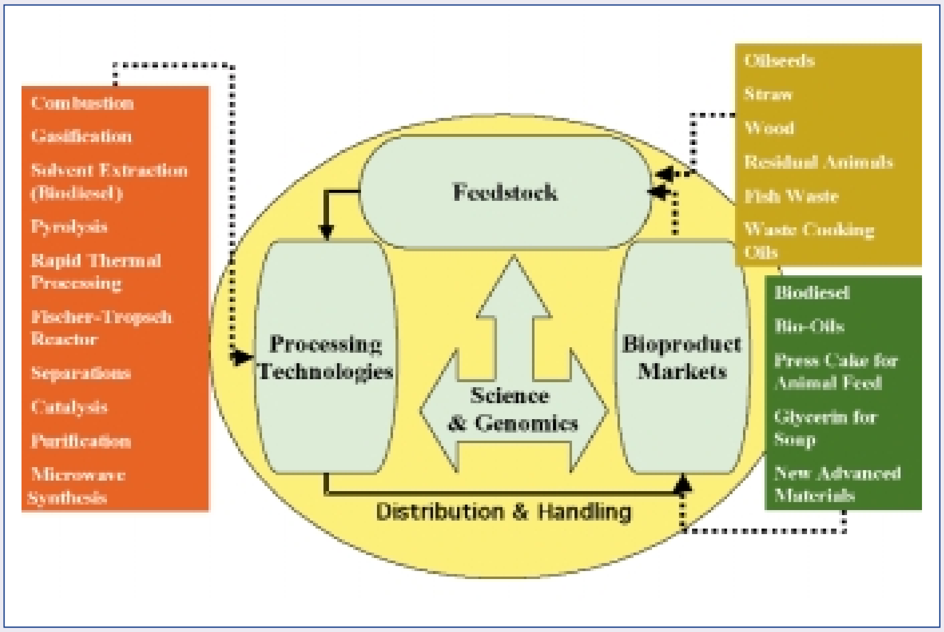
Chemical Conversions

Biomass is also converted into useful fuels by direct combustion, thermal processes and biological processes. Direct combustion involves the burning of untreated biomass material in boilers or furnaces. Thermal processes entail heating the biomass material. Biological conversion uses enzymatic and microbiological action to convert the biomass material into usable fuel and/or potable water. Direct combustion is a common method of capturing the biomass energy and involves burning the biomass material, including wood residue and municipal solid waste, in boilers or furnaces. The resultant steam is then used to generate electricity.

Iogen Corporation manufactures enzyme products for the pulp and paper, textiles and animal feed industries, and is a leading developer of technology to make clean fuels from plant fibre.

In the extraction of chemicals from biomass, moisture content in the biomass hampers the direct combustion approach. To facilitate transportation and combustion, biomass can be chipped, compressed or pelletized. Ash that remains after burning the biomass material must be disposed of. A diagram of key chemical and thermal technologies is shown in Figure 8.

Figure 8 — Combustion, Thermal and Chemical Value Chain



Biodiesel

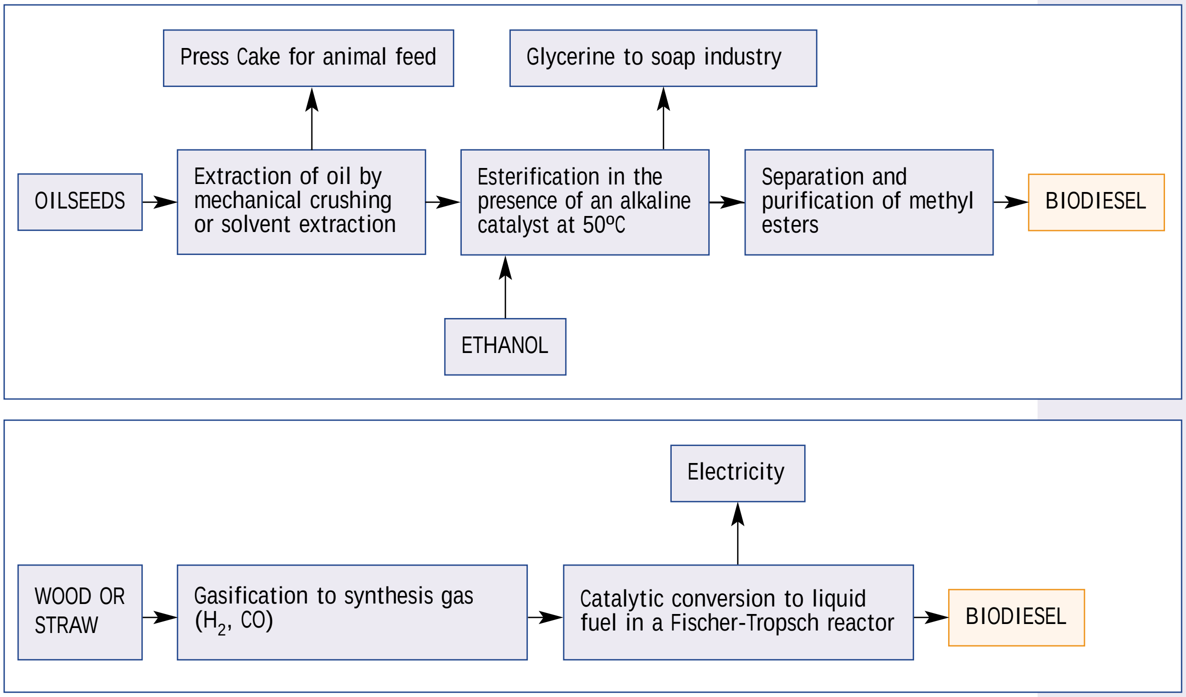
Biox Corporation seeks to produce high-grade biodiesel from plant and animal oils.

Biodiesel is produced by chemically reacting alcohol with vegetable oils, fats or greases. Metal carbonate and other chemical catalysts facilitate the conversion process. Biodiesel production involves the esterification of fats and oils. Esterification is the chemical preparation of methyl esters of fatty acids from triglycerides. Fat and oil are mixed with methyl alcohol and a catalyst (sodium hydroxide). Circulation and mixing help the reaction proceed to completion, generally with around 95 percent conversion to methyl esters.[11]

[11] *Biodiesel Production*, Dr. John W. Goodrum and Daniel Geller, Biological and Agricultural Engineering Department, The University of Georgia, 2003

Biodiesel production technologies are shown in Figure 9.

Figure 9 — Biodiesel Value Chains



Source: United Kingdom, Department of Transport, *International Resource Costs of Biodiesel and Bioethanol* (London, UK: Department of Transport).

Pyrolysis is a process used in producing bio-oils. It involves the irreversible thermal degradation of organic composites in biomass, mostly lignocellulosic polymers, in the absence or near absence of oxygen to make products like bio-oil, carbon and other products. The steel industry is seeking biomass-derived energy and carbon feedstocks.

Ensyn Technologies Inc. develops pyrolysis technologies that convert lignocellulosic residues to bio-oils, resins, carbon, biogas and other products.

Membranes

Membrane research focusses on non-thermal processing applications as well as refining, purifying and concentrating process streams. Membranes can provide manufacturing industries with energy-efficient processes that can use fewer chemicals and produce high-quality, value-added products. Membrane separation technologies using solvents and catalytic processing can reduce the need for thermal-driven applications. The end result can be lower cost, lower emissions and less energy consumed.[12]

[12] For more information, see the National Research Council's Institute for Chemical Process and Environmental Technology Web site at: **http://icpet-itpce.nrc-cnrc.gc.ca/research_fm_em.html**.

Biochemicals

The biochemicals sector produces a wide range of bulk and specialty chemicals that find use as:

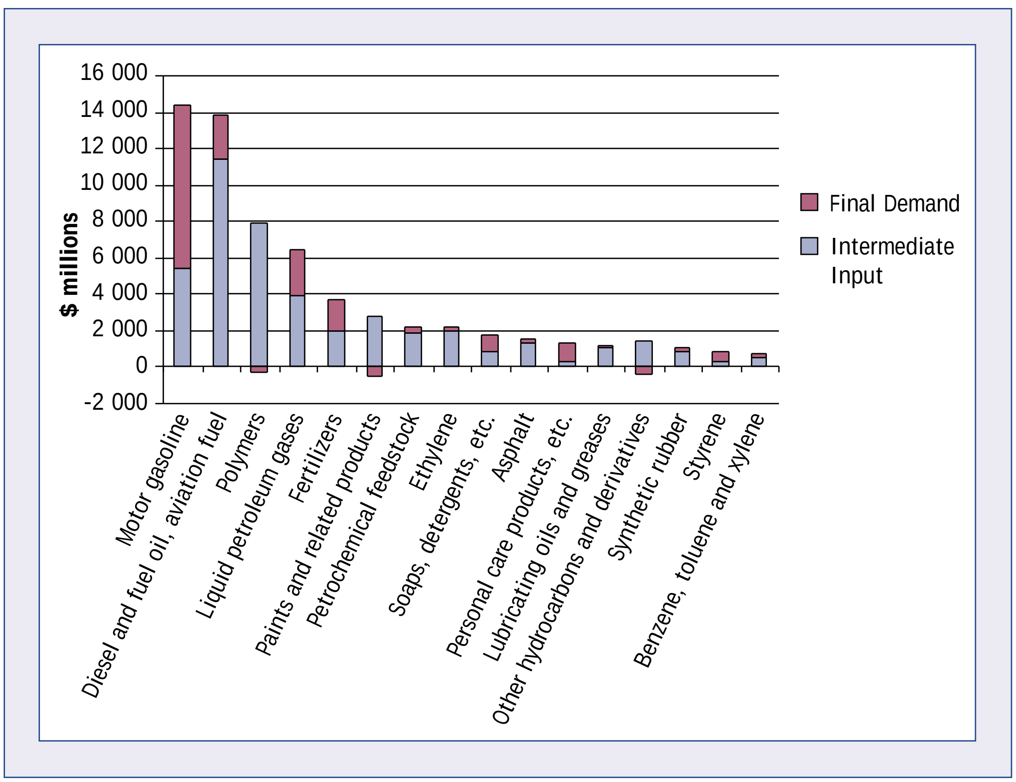
- ingredients for synthesis of other chemicals
- monomers for production of polymers and resins
- adhesives
- lubricants
- surfactants
- pest control agents
- paints and coatings
- pigments and inks
- ingredients for cosmetics, fragrances and food
- ingredients for pharmaceuticals and medical devices
- fertilizers.

Nexia Biotechnologies Inc. manufactures complex recombinant proteins in the form of biomaterial, biopolymers and biopharmaceutical products with industrial and medical applications. The company's most advanced biopolymer is its BioSteel recombinant spider silk.

Approximately 730 billion pounds of chemical products are manufactured in the United States each year. Sixty billion pounds of chemicals are fabricated in Canada annually.

Figure 10 identifies a number of key organic chemicals produced in Canada that could be produced from biomass rather than from fossil fuels.

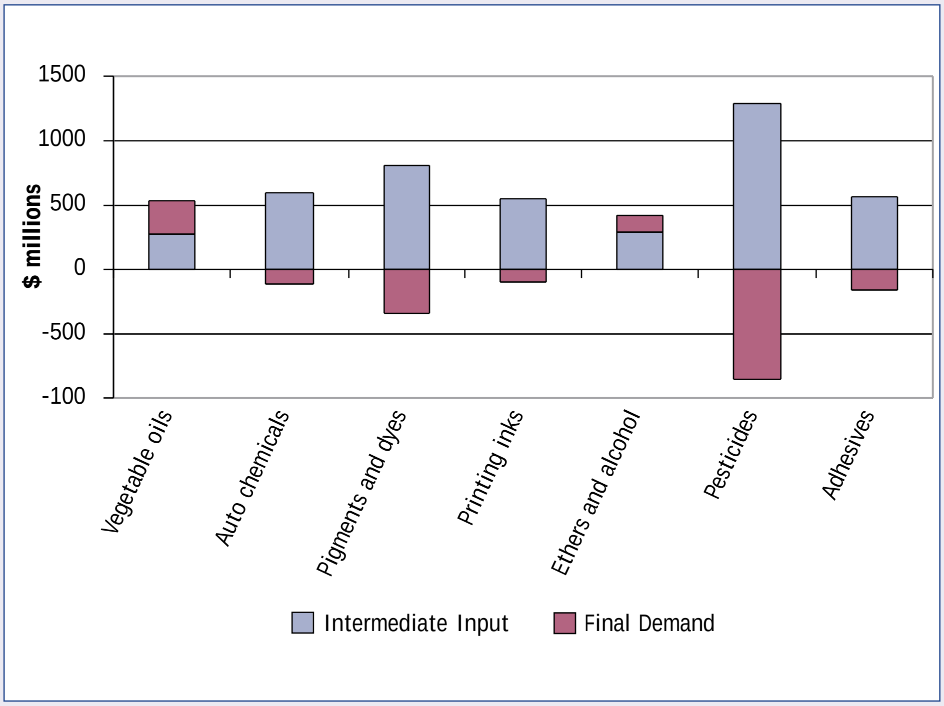
Figure 10 — Top Canadian Chemicals, 2000



Source: Derived from Statistics Canada, Input/Output Data.

Other important chemicals that could be produced from biomass feedstocks are identified in Figure 11 separately, since their volumes were considerably lower than those displayed in Figure 10. They nevertheless represent strong market opportunities for bioproducts.

Figure 11 — Other Important Chemical Markets Relevant to the Biofactory



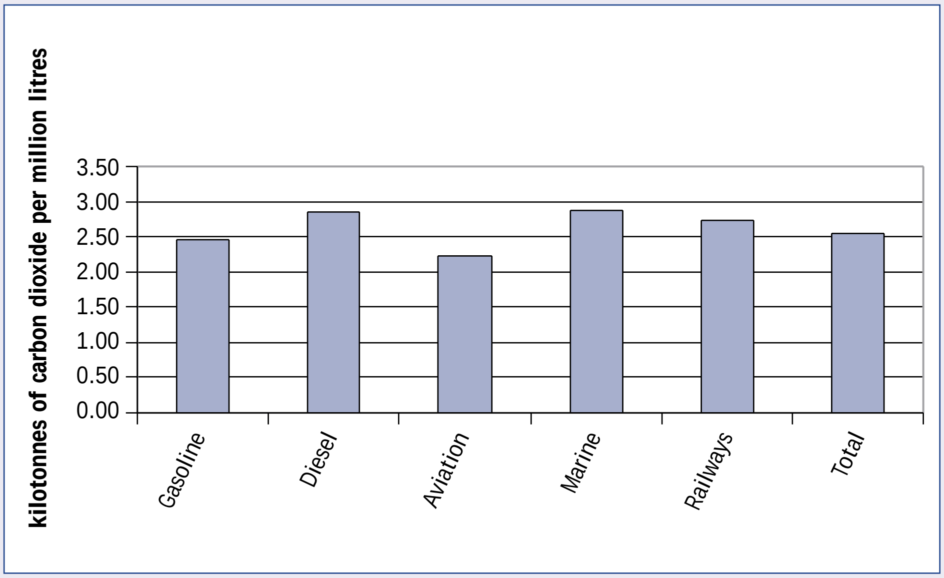
Source: Derived from Statistics Canada, Input/Output Data.

A key argument for producing chemical products from biomass feedstocks is that the plants during their photosynthesis growth consume carbon from the atmosphere. Therefore, the net carbon emissions that occur when biofuels are combusted are zero, although other greenhouse gases are emitted.

In contrast, Figure 12 shows carbon emissions for various fossil-based transportation fuels.

Robustion produces fire logs from recycled coffee grounds.

Figure 12 — Carbon Emissions for Fossil-based Transportation Fuels



Source: Derived from data available on Government of Canada's Climate Change Web site **www.climatechange.gc.ca**.

Biomaterials

The biomaterials sector produces biomass-derived fibres, plastics and resins that find use in:

- building and construction materials
- automotive and aerospace composites
- advanced membranes
- biomedical devices
- textiles
- packaging and containers.

Hempline Inc. produces high-quality hemp fibre for textiles.

Biomaterials have very diverse markets including building materials, automotive/aerospace composites and industrial textiles. The overall global market for automotive/aerospace biomaterials is based mostly on plastics and composites. A strong driver for the biomaterials industry is the replacement of glass fibres in composite plastics for automotive and aerospace applications.

5 Challenges and Constraints

Bio-Products Saskatchewan Inc. conducted a survey of 168 bioproducts firms in June 2003. While the response rate was poor (11 percent), the results are interesting and are summarized below.

International regulations were not considered a serious impediment for 80 percent of the respondents. The remaining 20 percent were concerned about the restrictive Japanese regulations and a high fructose corn syrup tax that is imposed by Mexico.

Two-thirds of respondents indicated that federal regulations were not restrictive. The remaining one-third felt that environmental approvals on applications of new technologies were restrictive. The regulations under the *Canadian Environmental Protection Act* were considered to be restrictive regarding the development of the use of microbial applications of bioproducts.[13]

Eighty-seven percent of those surveyed indicated that provincial regulations were not restrictive and they had no difficulty in meeting them. Municipal regulations were similarly not seen as an impediment.

Regarding the impact of industry standards on their firm's operations, 73 percent replied that there had been no effect. The remaining 27 percent indicated that they were adversely affected by industry standards, citing the following reasons:

- lack of industry standards for flax straw and fibre quality
- requirement to use American-based construction and technology engineering
- stiff regulations required by the local power company.[14]

In addition, workshop participants raised concerns over too few inspectors at major points of entry into the United States to process traffic as being a non-tariff barrier against the export of perishable commodities such as fermentable sugars.

[13] Stuart Smyth, "A Preliminary Analysis of the Barriers to the Development of the Bio-Products Industry in Canada" (Saskatoon, SK: Bio-Products Saskatchewan Inc., October 2003).

[14] Ibid.

Financing Issues

All of the respondents indicated that they were having difficulties in acquiring capital. Lending financial institutions were perceived as viewing the bioproducts industry as too new and risky an industry in which to invest. Risk factors included:

- newness of the technology
- new products
- new markets
- newness of the company.

With many firms engaged in the early commercialization stage, a number of respondents indicated that the financial institutions' requirement to have high sales volumes were unrealistic.

The survey asked if there had been problems in acquiring funding from government investment programs; 60 percent of respondents indicated they had experienced problems. When asked to provide comments, the range of responses was quite varied:

- The application process is cumbersome.
- There is funding for pure research, but little for product feasibility.
- It is very challenging at times to have the required 50 percent matching funds.
- It is hard to get funds for basic research.[15]

Other Hurdles

When asked how they were helping Canada meet its Kyoto Accord commitments, respondents cited the following activities:

- reducing greenhouse gas emissions
- increasing carbon sequestration in plants
- reducing the burning of flax straw and lowering carbon dioxide emissions.

[15] Ibid.

Overall, the survey respondents felt that to facilitate the development of the bioproducts market, governments should be carrying out the following activities:

- developing public education programs
- helping the industry deal with an environmental benefit using transgenic products
- implementing policies that encourage the commercialization of new research and development
- providing better tax incentives
- encouraging industry and government to work better together
- supporting environmental actions.

The following specific barriers regarding the development of bioproducts or bioprocesses were cited:

- insufficient market awareness
- inadequate capital and financing at all stages of company development
- lack of clear standards in some sectors of the industry
- uncertainty about how to qualify for carbon credits in the future.

6 Innovation Roadmap Targets

The BIOCAP study concluded that annual biomass residues are equivalent to 18–27 percent of the fossil fuel used annually in Canada. Canada could supply all of its current production of organic chemicals and a major portion of its liquid fuel needs from available biomass.

Schweitzer-Mauduit Canada Inc. produces flax fibre for fine paper.

Cellulose-based biomass will be the predominant source of future biofuels, biochemicals and biomaterials. In North America, a significant portion of corn and soy is already being used for industrial purposes. New strains and global warming may expand corn's growing range.

The Canadian Climate Change Action Plan 2000 has established the following targets:

- produce 1.4 billion litres of ethanol by 2010 (up from 200 million litres in 2001)
- produce 500 million litres of biodiesel by 2010 (up from essentially zero in 2001).

One tonne of dry cellulose biomass yields about 350 litres of ethanol, and about half the biomass will be a lignin residue. Therefore, 1.4 billion litres of ethanol, if it came from cellulose, would result in 2 million tonnes of residual lignin that could be converted into chemical feedstock. The residual stocks provide opportunities for research and development to discover marketable by-products to provide additional revenues for the entire production stream, thereby lowering the overall costs of producing the biofuel.

Research and Development Targets

The research and development target is to reduce by 50% or more the cost of technologies and systems for biomass harvesting and conversion into bioproducts and bioenergy. Achieving this target will require, among other things, development of a robust capacity to discover and optimize enzyme biocatalysts and to design and optimize biomass-processing systems that use these biocatalysts.

A possible list of research and development actions by federal science-based departments and agencies is identified below:

- The National Research Council Canada, the Canadian Forestry Service, Agriculture and Agri-Food Canada and other science-based departments could work with Industry Canada and the roadmap network to begin implementing a national research and development capacity for development and commercialization of industrial bioproducts (biofuels, biochemicals and biomaterials).
- Agriculture and Agri-Food Canada could develop a suite of enzymes from current work on bacteria in ruminants that will be able to break down lignin into its constituent aromatic and phenolic compounds.
- Agriculture and Agri-Food Canada could identify and develop industrial crop species that produce large amounts of biomass and are pest and drought resistant (e.g., mustard for oil, triticale for starches and sugars, flax for fibre and oil).
- The Canadian Forestry Service could develop forest management practices and more pest- and drought-resistant varieties of trees, which would contribute to 25 percent greater productivity from Canada's managed forests including forest plantations and policies related to forest fuel "loadings."
- Fisheries and Oceans Canada could identify new marine species that provide the basis for novel chemicals and materials.
- The National Research Council could develop practical tools for researchers and companies to assess products, processes and production systems for sustainability throughout the research and innovation process from conception to commercialization.

Bioproduct Industry Targets

The roadmap identifies major opportunities to reduce emissions of greenhouse gases and toxic chemicals by changing to biomass feedstock, adopting eco-efficient biomass processing technologies and organizing industrial production in eco-clusters. Ten percent of the greenhouse gas reduction potential has been targeted to come from biofuels (16 million tonnes of carbon dioxide equivalent per year). In addition, a 33-percent reduction in energy use by chemical process industries (7 million tonnes of carbon dioxide equivalent per year) has been targeted. Achieving these targets will require research, planning, measuring and improving performance, as well as understanding the limits imposed by the requirement for sustainability.

Two possible future scenarios were considered, including "business as usual" and a "policy alignment" of biofuel and bioproduct issues to facilitate rapid growth in this strategic sector. Under the "business as usual" scenario, biofuels and industrial products grew modestly. Under the "policy alignment" scenario, this sector grew annually from 12 to 15 percent. These scenarios are described in Table 1.

Almost half of this growth occurred in rural areas and nearby communities, not only from supplying and preprocessing of raw materials but also from developing bio-refineries similar to the Cargill-Dow operation, which produces 140 000 tonnes of polylactic acid plastic from corn in Blair, Nebraska. In addition to exporting bioproducts, Canadian companies became exporters of turnkey biomass processing systems and services related to their design, construction and further development.

Specific targets are outlined below in Table 1.

Table 1 — Bioproduct Industry Targets for 2010

	Biofuels	Biochemical	Biomaterials
Annual revenue growth	15%	12%	14%
Market priorities	penetration of North American transportation fuels (ethanol 10% and biodiesel 5%)	agricultural and forest value chains linked with emerging chemical platforms	building materials (strawboard, fibreboard, fibre, resins) for domestic and export markets
Commercial targets	full-scale implementation of Iogen technology for ethanol from straw designing cellulose ethanol production facilities to ferment sugar into ethanol and platform chemicals industrial-scale demonstration of BIOX and Rothsay biodiesel technologies	capacity to produce platform chemicals (sugar, lactic acid, etc.) in millions of tonnes per year at internationally competitive costs at least one major new facility producing polymers from sugar or oil platform chemicals major new wood pyrolysis facility producing phenol ingredients for manufacture of adhesive resins	creation/attraction into Canada of at least one major manufacturer of bioplastics from sugar or oil as raw material 2–3 automotive/ aerospace parts suppliers (e.g., Magna, Bombardier) to begin using flax and hemp fibres to replace glass fibres in their products 2–3 additional agri-fibre production facilities for western Canada

Table 1 — Bioproduct Industry Targets for 2010 (continued)

	Biofuels	Biochemical	Biomaterials
Annual R&D targets	new technologies to maximize conversion of carbon to ethanol and to extract ethanol from fermentation liquid, without distillation (reduce energy cost by 30%) new high-efficiency technology (e.g., semi-permeable membranes) to separate high-value biochemicals from biofuel feedstock and bio-oil development of pyrolysis/gasification technology for production of hydrogen from biomass via value capture from co-products so net cost is competitive with hydrogen derived from natural gas	need to identify and develop 2–3 new chemical platforms that are compatible with Canadian sources of biomass (e.g., convert canola oil into plastic) need to develop patented technology for cost-competitive production of intermediate chemicals development of a suite of enzymes from current work on bacteria in ruminants that will be able to break down lignin into its constituent aromatic and phenolic carbon compounds to enable an aromatic chemicals platform	need to identify high-performance biofibres that can compete with carbon fibres in plastic composites development of protein fibres that improve on spider silk performance characteristics biotechnology–nanotechnology opportunities for catalytic surfaces, smart materials, etc.
Market share	domestic: high penetration of domestic market (>90%) international: access to U.S. market for excess Canadian regional capacity	domestic: high penetration of intermediate chemicals that are incorporated into the supply chain for Canadian products for domestic and export markets (e.g., phenols for resins that are used in wood particle and strawboard construction materials; composite plastics in automotive and aerospace components, etc.) in support of a Canadian "green" product export strategy international: access to U.S. market and 3–4% penetration of global markets (i.e., nearly double the current Canadian penetration of global chemical markets of ~ 1–2%)	domestic: high penetration of agricultural fibre into building materials and composites for automotive/aerospace products, manufactured in Canada (look for raw material synergies among materials from agriculture, forestry and marine sources; look for synergies with Canadian manufacturers of consumer and industrial products that can use these materials) international: increase by 50% Canadian suppliers' share of international markets for raw materials (fibres, bioplastics) and finished parts in building materials, automotive, aerospace and consumer products sectors

7 Key Nuggets Extracted from the Roadmap Process

The technology roadmap involved seven major working groups and 22 workshops on key themes and conversion technologies, a detailed literature review on chemical and bioprocesses based on biomass feedstocks and a validation workshop attended by the roadmap participants held February 16–17, 2004. A number of nuggets or key themes have emerged from the research and discussions. These nuggets are described below.

Strategic Positioning

Canada has higher biomass endowments relative to its population than most other countries. Canada also has strong science and technology capabilities to refine and develop biomass conversion technologies or adapt technologies from abroad to enable bioproduct manufacturing.

There is a need to focus not only on development and application of specific technologies but also on how these technologies come together and are networked and more effectively integrated into systematic production systems by the private sector on a balanced playing field.

Education and skills training is needed to facilitate scientists and engineers in working with and integrating the capabilities of a range of disciplines that traditionally have not worked together (biology, chemistry, engineering).

Critical reforms are needed to set price signals straight in the following areas:

- accelerated capital cost allowances commensurate with those extended to companies exploring and proving up petroleum reserves and other close substitutes
- clear rules for internationally tradable environmental tax credits
- reductions in non-tariff barriers by trading partners inclusive of availability of Food and Drug Administration personnel around the clock at key border crossings
- land tenure systems that reward those responsible, including local communities, for husbanding forestry lands and ocean resources
- clearly delineated private and social benefits, with appropriate government policies to generate societal benefits for all Canadians.

These reforms are necessary to establish viable and cost-effective technologies that are acceptable to Canadians.

Investing in People and Science

The following areas are identified for possible investment in the development of science, technology and skilled human resources:

- plant science, soil microbial ecology and bioprospecting
- GIS systems to give the locations of biomass concentrations, including both current manufacturing sites and legacy residues such as grandfathered municipal landfills and wood-chip burials, relative to roads and processing infrastructure
- mapping of flows of residues within communities including waste energy
- biocatalysis, especially enzyme optimization
- new chemistries that take advantage of the properties of biomass constituents (carbohydrates, lignin, oils).

There is a need to develop a range of tools for assessing the sustainability of biotechnologies, bioproducts and bioprocesses at different stages of development — from concept to scale-up and demonstration — in order to guide their development and derive optimal economic, environmental and social benefits. These tools could greatly increase the efficiency of our innovation system as well as the productivity and sustainability of a major portion of our industry.

At present, many bioproducts are more costly to produce than their petroleum-derived counterparts. With decreasing costs of recovery of oil from shale and recovery of hydrogen from crude petroleum being more than offset by OPEC cartel pricing practices, the economical feasibility of biofuels remains an uncertain and moving target.[16] The key to economic viability is to increase the overall value obtained from the processing of a given biomass resource by selecting products of high value and by reducing wasted energy and residues to as near zero as possible.

Linnaeus Plant Sciences Inc. is developing plant-based oils for the manufacture of industrial and transportation lubricants.

[16] Lomborg, op. cit., Chapter 11. He notes that prices are controlled by OPEC and do not reflect costs such as the falling costs of producing oil from Canada's tar sands from $28 a barrel to under $11 recently. Writing in 2000, he found that, net of taxes, the real price of gasoline at the pump in the United States was lower than before the OPEC cartel. The forecasts of known recoverable reserves from conventional sources had risen from 10 years in 1914, to 13 years in 1939 and 1953, to 35 years in 1955 and over 40 years more recently. Oil shales contain 242 times the reserves of conventional sources, without considering coal and nuclear potential.

Emerging Issues

Many current applications focus on the use of biotechnologies for the conversion of biomass from landfill, agricultural operations and forestry to valuable products. However, the increasing scale of production required for the bio-based economy will require alternative biomass sources of feedstock, likely from intensive agricultural practices. Production on such a scale will raise questions of security of annual supply and will be accompanied by its own set of sustainability and vulnerability issues.

Examples of emerging issues have been cited by ICSU 2002:[17]

- The intensification of agriculture in favourable areas comes at the cost of damage to the environment, with increasing salinity problems in irrigated areas, and damage to human health, ecology and wildlife due to misuse of pesticides.
- Other agricultural-associated practices, including deforestation, overgrazing, overfishing and water pollution will increasingly threaten the sustainable use of natural resources.
- Decreasing water availability for agriculture is one of the most important trends. There will be a need for more efficient use of water in agriculture, including the development of drought-tolerant crop varieties.
- Pressure on agricultural land for urbanization and industrialization will increase further. There are limited prospects for expanding the land available for agriculture, except by moving into forests or marginal areas with poor soils and little water.
- Deforestation and loss of biodiversity by the clearing of land for agriculture may occur in areas of mega-terrestrial biodiversity and consequentially threaten species.
- Natural disasters could pose a continuing threat to the supply of feedstock, and the long-term effects of climate change are unknown.

Answering the Global Challenge

In both North America and Europe, timely development of bio-based industries requires a multidisciplinary, focussed and coordinated approach to research, development and commercialization. Specifically, there should be a closer working relationship among researchers, especially between plant biotechnologists, process engineers, chemists and biochemists. The study of gene regulation in plants, for example, must be tied with the study of the

[17] International Council for Science (ICSU), Series on Science for Sustainable Development No. 6: Biotechnology and Sustainable Agriculture 45 pp., 2002.

functionality of polymers, and both must be coordinated with the work of process engineers who specialize in the area of separation technologies and reactor design. Coordinated advances must be made in all three areas.[18]

Raising the Profile of Bioproducts

The research and the workshops on this roadmap clearly demonstrated the strong benefits of sustainable development to the rural economy and of a value-added chain of integrated and distributed systems.

By-products support each of the three pillars of social, financial and environmental stewardship. Governments need to create a national demonstrations facility to establish and network key technologies. The biotechnology industry needs to be marketed or branded better. Our message needs to be widely communicated. A strong communications program must accompany the action plan from this roadmap.

Eco-industrial Clusters

A bio-industrial park is a cluster of companies that together function as a biorefinery (the biomass equivalent of an oil refinery), producing an array of bioproducts from one or more bioresources with maximum value-added and minimum environmental footprint. This form of industrial organization is known as an eco-industrial cluster. Such clusters are designed so that the by-products and waste energy of one company form the inputs of other companies, and together the companies achieve an overall eco-efficiency beyond what they could achieve separately.

Clusters can also benefit participating firms in the following ways:

- accessing intellectual capabilities in the immediate area
- attracting the best and the brightest from other areas of the world
- minimizing adjustment costs for workers and employers in moving from one job to another within the confines of the cluster
- using the good auspices of leading firms in the cluster to enter international markets
- working with local schools and institutions of higher learning to develop curricula to meet industry research, development and personnel needs
- developing mentoring models to assist start-up companies
- attracting world recognition for technical and commercial excellence

[18] Agriculture and Agri-food Canada, Background papers and notes on Bioproducts, 2003

- initially attracting international venture capitalists and eventually generating funds within the cluster to fund and to assist in the management of start-ups
- founding and operating the social infrastructure that attracts world leaders in business practices to speak and to contribute intellectually to the ongoing growth of the cluster.

In addition to bio-industrial parks, greater networking linking of university researchers across Canada is needed to build a critical mass of research for development of new environment-friendly chemicals and process technologies as well as new varieties of crops and trees as potential sources of biomass.

Public and private incubators that specialize in biotechnologies can be viewed as microcosms of clusters, with a mission focussed on the commercially successful launches of resident biotechnology companies. The incubator's task frequently is to guide innovators with potentially good products in their transition to either becoming business persons or finding purchasers of their intellectual property. Depending on the ownership philosophy of the incubator facility, incubator personnel can access additional scientific expertise as well as provide laboratory and computer facilities, business acumen, assistance in the development of business plans, access to venture capitalists, and synergistic opportunities among residential and other firms including cluster leaders.

Strategic Procurement

Governments could make a tremendous difference in helping Canada's biofuel industry reach the needed market size and economies of scale for commercial success. For example, the Government of Canada operates eight E85 (85 percent ethanol) fuelling stations and approximately 800 flexi-fuel vehicles, which can use up to 85 percent ethanol.[19]

Governments at all levels in Canada consumed 130 petajoules of energy in 2002 or nearly 2 percent of the fossil-based total energy consumed. Governments consume almost as much energy annually as does the agriculture industry (201 petajoules). Their consumption profile could facilitate commercialization and financing of biotechnologies.

[19] *Op. Cit.* **climatechange.gc.ca**

Research Networks

The roadmap is dynamic and evergreen, not static. The production of this document is only one step in the process. The network needs to continue to spread and to establish additional champions.

A high-powered council or organization is needed to facilitate synergy, grow the community of practice and raise the profile of bioproducts.

A blue ribbon committee or **BioProducts Industry Council** could be created, with senior-level representation from the private, public and academic communities. A governance and financial structure for this council should be developed and submitted as a proposal to the federal government.

Technology Partnerships Canada

Bioproducts technologies are eligible for assistance from Technology Partnerships Canada, as are other enabling technologies. The strong commercial opportunities associated with industrial fuels and bioproducts coalesces nicely with the business case requirements of Technology Partnerships Canada. This roadmap including the workshops provides numerous examples of technologies with strong commercial potential.

Resource Management

Comparisons with fossil fuels are made relative to a stock, whereas biomass is really a flow. Canada has a substantial amount of fringe lands, some owned by governments and others privately held. These fringe lands may have the potential to produce large quantities of fast-growing poplar trees or perennial switch grass, which could be used as feedstocks to the biofactory.

Several forests in Canada would grow considerably more product if they were thinned and managed properly. One possible solution is for Canada to work with the provinces to give communities greater control in resource management practices for public lands and pastures, which may be better utilized as woodlots or farms to grow lignin products.

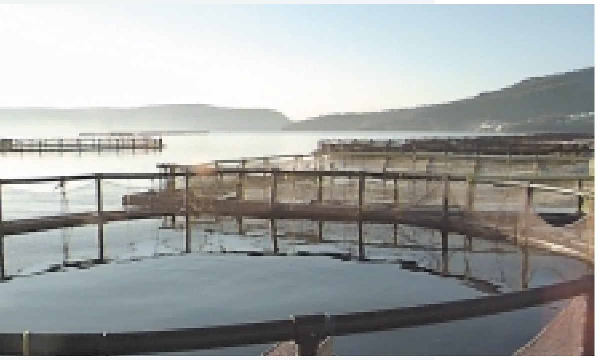
Future Conversion Technologies

Extensive discussions have occurred through the roadmap workshops on future feedstock pathways and conversion technologies. Feedstock platforms include:

- carbohydrates, including cellulose, starch, chitin, alginates
- oil
- lignin
- protein.

The specific technologies involving these platforms were extensively discussed in the working group reports.

Strong opportunities lie in cellulosic ethanol production with Iogen's technologies and bio-oil production technologies being used by Topia Energy, Dynamotive and Ensyn. Iogen's technologies involve considerable energy savings, as the non-fermentable material is used as energy feedstocks. Ensyn's approach involves small-scale distributed systems operating at the site of wood wastes, converting the residues to easily transportable bio-oils.



Canada has a Natural Advantage in all sources of these major carbohydrates. Extensive research should be focussed on identifying products that can be made from these feedstocks and the relevant conversion technologies.

Another strong technology opportunity may be found in ruminants' digestion systems. Animals eating barks and other forest vegetation, such as beaver and moose, are able to break down cellulose and lignin into its constituent carbon compounds and energy.

Cost-effective methods of biomass production require a confluence of technologies, since they need to be applied throughout innovative supply chains, such as the following:

- genetically improved species tailored to meet demands for bioproducts while lowering risks of crop failure, such as hybrid poplar, industrial mustard, grasses and faster-growth marine species for cold water
- efficient harvesting technologies that minimize soil compaction and infrastructure damage — collection, reduction, bundling and drying of residues to provide a flow of biomass to bioprocessors for conversion to products

- a range of large- to small-scale or mobile and distributed biorefineries capable of extracting as much high-end material and molecules as possible for use in communities, thereby reducing transportation costs and creating an export opportunity for Canadian technology
- GIS mapping of all biomass inventories and availabilities of all forestry, agricultural, marine, MSW and residues from industrial processes including low-grade heat
- GIS and community mapping of residue inventories and flows to delineate possible synergies among industries operating in close proximity to each other so as to make one establishment's residues another's material inputs.

Building on Strengths and Networks

Unlike the pharmaceutical industry with its long research pipeline and expensive trial exercises, most bioproducts are on the market or are about to be launched. There is potential for immediate and sustained economic impacts in terms of private sector revenues, employment and government revenues.

The likelihood of manufacturing occurring in Canada, rather than abroad, is higher in biotechnologies than in the pharmaceutical industry. This is because biotechnologies rely on relatively heavy biomass, whereas pharmaceuticals use relatively light materials. In addition, market concentration in the United States requires prolonged pharmaceutical testing on a demographically determined sample, whereas most bioproducts move more rapidly to market. The natural resources are Canadian and are becoming increasingly expensive to move; they will therefore be an important attractor.

8 Action Items

The action items that are described in this roadmap document are based on the validation workshop on the roadmap that was held in Ottawa on February 16–17, 2004. All the participants in the roadmap were invited to this session, and over 80 participated. The action items are summarized into short-term items requiring prompt attention and longer-term suggestions requiring action over the next five to ten years.

Bioproduct Technologies

An overriding priority, which cuts across both short- and long-term horizons is for private and public research and development investments to create commercial benefits and increased productivity.

Short-term Action

The industry consultations initiated by the roadmap need to continue over the next few years and must involve customers, governments and academia. The emphasis must be on solutions rather than processes, to meet market criteria.

Long-term Action

The long-term action items on biotechnologies include:

- improved coordination among researchers and communities including electronic and personal linkages
- improved biochemical and complementary separation and conversion technologies
- strengthening, where appropriate, existing programs supporting research and development, with an emphasis on development and commercialization
- increased awareness and application of international innovations
- addressing skill shortages
- ensuring that human resources — scientists, financiers, regulators, industrial clients, and consumers — are well trained and up-to-date
- alerting students to emerging intellectual challenges and opportunities.

Markets

A theme throughout the roadmap is that innovations will increasingly facilitate development of higher-valued products from fibres and higher-end molecules. An improved understanding of viable markets for biomass by-products is essential for lowering overall costs of operations. The participants in the validation workshop strongly reiterated that the private sector — and not government — needs to take the lead in identifying and taking advantage of market opportunities.

Short-term Action

Marketing of bioproducts needs to be improved through:

- better access to major markets and product standards
- establishment of community centres showcasing biotechnology innovations
- mapping of flows of residues from local production facilities of potential users within communities as an element in developing eco-industrial clusters
- development of an effective media campaign to accentuate the positive and correct consumers' false perceptions of risks
- development of pilot and case studies to illustrate the above
- attraction of additional potential receptors to the roadmap process and open other marketing avenues for close substitutes for chemical processes
- opening of government procurement
- enhanced marketing of Canadian expertise and related equipment.

Long-term Action

Over the longer term, Canada needs to establish a cross-linked bioproducts database for renewable and legacy feedstocks, products and consumers by region. This mapping needs to be consistent among main biomass sources so that feedstocks may be drawn from both agricultural and forestry resources, thereby facilitating risk minimization of shortages. As a by-product, this process should assist in quantifying value chains and making resource management choices regarding the biograin and forestry interface.

Long-term markets also need to be established for internationally tradable environmental tax credits. This process is time consuming, since it requires international agreements defining the nature of the credits and structuring recipients to reduce environmental degradation. While it is advantageous to clarify other regulations in the short term, in reality some, such as those impacting on land tenure, will be adjusted only in the longer term.

More research and data mapping on eco-industrial clusters should take place. Key areas for this research include:

- local champions
- leaders in international trade
- local organizations to spread shared ideas and management techniques within and outside the supply chain
- internal trade synergies
- intellectual linkages with university and government laboratories.

Institutions

Divergent source of biomass, the heterogeneous nature of bioprocesses and the vast range of potential receptor industries engender complex and, at times, tenuous relationships within the biotechnology community and business, government and academic institutions.

Short-term Action

While the roadmap has provided a valuable network for some 300 participants from business, government and academia, this dynamic needs to be extended by creating a viable mechanism championing the bioproducts industry. This mechanism should build on networks created by the roadmap and encourage industry champions. A blue ribbon committee or **BioProducts Industry Council** should be created, with senior-level representation from the private, public and academic communities. This council would provide advice to the Minister of Industry. A number of different governance models were considered, and the creation of a blue ribbon **BioProducts Industry Council** to provide advice to the Minister of Industry was considered to be the most effective approach.

A policy review focussed on energy and related by-products needs to pinpoint inequities in the competitive environment in which biotech firms perform. The review should suggest policy, program and regulatory alternatives to level the playing field. Key issues include:

- communications
- non-tariff and tariff barriers
- regulatory issues including product standard development
- carbon credit certification
- energy pricing
- accelerated write-offs and other incentives and disincentives for all forms of energy and other products competing with bioproducts
- cogeneration policies in each province and constraints to market entry
- government procurement policies as an initial purchaser.

The requirement to improve research synergies among public, private and academic participants in biotechnologies is ongoing and may be stimulated by focussing on:

- commercial research
- virtual research networks
- targets for lowering cost-of-production research.

Long-term Action

A reformed policy would:

- improve coordination among government departments and agencies including science-based departments and Human Resources Development Canada and their related councils
- change consumer and corporate cultures to understand biofactory concepts and its commercial and sustainable development.

9 Concluding Remarks

The innovation roadmap is a journey where a network of participants from industry, academia and government discuss, study and seize opportunities on present and future technologies on biomass conversion to fuel and industrial products.

The roadmap is only one tool to get us "there" — we need a cohesive and collaborative tool. Our network needs to have active participants in influencing government levers such as future federal budgets in levelling the playing field for the bio-based economy. We need to know where we are going. We need to improve the receptor capacity. We need to actively lobby for the development and implementation of smart regulations (governments are listening). We need a marketing and communications plan. We need to implement our action items that have emerged through this exciting process.

It is a rewarding and stimulating journey!

Annex A Steering Committee and Working Group Participants[20]

Abitibi Consolidated Inc.
Francine Dorion
Martin Fairbanks

ABP Recycling Incorporated
Joe Kosalle

Acadian Seaplants Limited
K. Butler

Agriculture and Agri-Food Canada
Brian Freeze
Lori Heigh
Gary Nelson
Martin Reany
Dee Shute
Mark Stumborg
Fraser A. Sutherland

Ag-West Biotech Inc.
Muriel Adams

Air Liquide
Edward DaSilva

Alberta-Pacific Forest Industries Inc.
Ken Plourde

Alberta Research Council
Wade Chute

Association of Canadian Industries Recycling Coal Ash (CIRCA)
Anne Weir

AVAC Ltd.
Keith Jones*

BASF Corporation
J. Clarke

Bayer AG
William Buckner*
Richard Steevensz

BC Hydro
Bonny Hill

BioAtlantech
John Argall
Fraser A. Sutherland

Bio-Products Saskatchewan Inc.
Ron Kehrig*

BioAlberta
Myka Osinchuk

BIOCAP Canada Foundation
Tina Bailey
David Layzell*
Susan Wood

BioProducts Alberta
John Christensen

BIOTECanada
Betsy Bascom

BioTerre Systems Inc.
Richard Royer

Biox Corporation
Tim Haig
Kevin Norton

Bowater Newsprint
Brian Mooney

British Columbia Ministry of Agriculture, Food & Fisheries
John Schildroth

Brock University
H. L. Holland

Canadian Association of Recycling Industries
Leonard G. Shaw

Canadian Biotechnology Secretariat
Glenn Kendall

Canadian Chemical Producers' Association
David Goffin
David J. Shearing*
Brian Wastle

Canadian Construction Research Board
Ed R. Cuylits

Canadian Ecology Centre
Al Stinson

Canadian Electricity Association
Victoria S. Christie

Canadian Plastics Industry Association
Catherine Cirko
Pierre G. Dubois
Charmaine Entine

Canadian Renewable Fuels Association
Bliss Baker

Canadian Steel Producers Association
Lynne Ree

Canadian Wildlife Federation
Sandy Baumgartner

CanBio
Bruce McCallum

CANFOR Corporation
M. J. (Mike) Bradley
Barbara R. Hislop
Michael A. Jordan
Paul T. Wooding

---

[20] Steering Committee members are noted with an asterisk.

CAREER Biotechnology-South Western Ontario
John H. Oostveen

Carleton University
Pascale Champagne

CASCO Int.
Allan Ellingham*
Jim Grey
Colleen Lytton

Cement Association of Canada
Angela Burton
Sharon Daly*
Lawrence Loh

Centre d'études des procédés chimiques du Québec (CÉPROCQ)
Yacine Boumghar

Centre québécois de valorisation des biotechnologies
Michel E. Lachance
Geneviève Tanguay*

Centre de recherche en environnement UQAM Sorel-Tracy
Jacques Giguère

Centre for Sustainable Cities Canada
Greg Finnegan

CETAC–WEST
Lorna Shaw-Lennox
Donald G. Somers

Chemical Institute of Canada
Roland Andersson
Jean Bélanger

City of Edmonton
Jerry Leonard

City of Saskatoon
Eve Casavant

Columbian Chemicals Company
William Stafford

Commercial Alcohols Inc.
B. Gallant
M. Schwartz

Composite Panel Association
Patrice R. Tardif

The CROFT Alliance Inc.
Adam Bielecki

Crompton Corporation
Paul A. Thomson

Dalhousie University (Canadian Institute of Fisheries Technology)
Robert G. Ackman

Dofasco
Susan Olynyk

Domtar Inc.
Ghislain Dinel
Stewart Marcoux

Dow AgroSciences Canada Inc.
Rick Smith*

Dow BioProducts Ltd.
Wayne Karolat

Dow Chemical Canada Inc.
Allan James
Claude-André Lachance
Maury J. Smith

Ducks Unlimited
Douglas A. Chekay

DuPont Canada Inc.
David A. Berg
Howard Ng

DynaMotive Energy Systems Corporation
Andrew Kingston*

Enerkem Technologies Inc.
Esteban Chornet

Ensyn Technologies Inc.
David C. Boulard*
Barry A. Freel
Garth Gorsky

Environment Canada
Manfred Klein
Terry McIntyre
Mathew Schacker

Federation of Canadian Municipalities
Sandor Derrick
Doug Pollard
Sherry Watson

Forest Engineering Institute of Canada
Alex W. J. Sinclair
Jean-Francois Gingras
Enrie Hiedersdorfs

Fibrex
Gordon E. Bylo

Fielding Chemical Technologies Inc.
Darren Lawless

Fisheries and Oceans Canada
Dave Conley
Mark Burgham

Fisheries Products International
W. Fudge

Foragen Technologies Management Inc.
David Gauthier

Forest Products Association of Canada
Paul Lansbergen

Government of Alberta
Ronald J. Dyck
Peter Dzikowski*
Alan Hall
Scott Wright

Government of Manitoba
Allen Sturko*

Government of Ontario
George Cadete
Brad Defoe
David R. DeYoe
Anna Ilnyckyj*
George Mandrapilias
Oswald Zachariah

Government of Nova Scotia
J. Desmond Cousens

Government of Prince Edward Island
Richard F. Ablett
Gailene Murphy
Ron Skinner

Hempline
Geoff Kime

High Liner Foods Incorporated
Lynn Wagner

H. L. Blachford Ltd.
Matthew G. Parthun

Industry Canada
Margaret Bailey
Bruce Bowie
John Jaworski
Suzanne Keating
Bob McKenzie
Kash Ram

Iogen Corporation
Maurice Hladik
Jeff Passmore
Jeffrey Tolan

J. D. Irving, Limited
William (Bill) J. Borland

Jungbunzlauer Canada Inc.
Howard Roberts
Ryan Waines

Kinectrics Inc.
Francis H. Chang

Kingston Economic Development Corporation
Shelagh McDonald

Kruger Inc.
M. H. Lamarre
R. Jobin

Lignum Ltd.
W. W. (Bill) Bourgeois

Linnaeus Plant Sciences Inc.
Jack Grushcow

London Biotechnology Commercialization Centre
Peter Bruijns

Lorama Chemicals Inc.
Ruben Lenz

Manitoba Hydro
D. R. (Deny) St. George

Marinard Biotech
Patrice Element

Marine Institute of Memorial University
G. Rose

McCain Food Ltd.
Tom Kazas
Christine Thomas

McGill University
Wayne Brown
Tak Hang (Bill) Chan
Robert Marchessault
C. J. Li
Jim Nicell
Paul J. Thomassin

Magellan Aerospace Corporation (Orenda Turbines)
Raj Thamburaj

Menova Engineering Inc.
Dave Gerwing*

Mining Association of Canada
Pierre Gratton

Ministry of Natural Resources, Wildlife and Parks (Québec)
Georges B. B. Lê

National Aboriginal Forestry Association
Harry M. Bombay

National Renewable Energy Laboratory
Jim McMillan
Quang Nguyen

National Research Council
Gabrielle H. M. Adams
Michael Day
Richard Isnor
Kevin A. Jonasson
R. D. (Bob) Reichert
Donald L. Singleton
Jack Smith
Wing Sung

Natkem
Pierre Laborde

Natural Capital Resources Inc.
Kathryn A. Wood

Natural Resources Canada
Jody Anne Barclay
John A. Burnett
Errol T. N. Caldwell
W. H. Cruickshank
Safaa Fouda
J. Peter Hall
Ed Hogan
Hamid S. Mohamed
René Pigeon
Nicole Richer
Claude Robert
Joe Robert
Maria Wellisch
Suzanne Wetzel

Natural Sciences and Engineering Research Council of Canada
Suzanne Liou

Nexfor Ltd.
A. Potter

Norac Concepts Inc.
Benoit Caron*

NOVA Chemicals Corporation
Anita L. Arduini
Mike Francis
Pesh Patel

Ocean Nutrition Canada
Colin Barrow

Olds College
Paul Kolodziejczyk

Ontario Agri-Food Technologies
George Surgeoner

Ontario Corn Producers' Association
Don McCabe*
Ken Hough

Ontario Forest Research Institute
David R. DeYoe

Ontario Power Generation
John C. Flynn
Murray Patterson*
James Perry

Ottawa Biotechnology Incubation Centre
Rainer Engelhardt

Paper and Paperboard Packaging Environmental Council
John Mullinder

PAPRICAN Inc.
S. Lee Allen
Thomas Browne
D. Gray
Mike Paice
P. Watson

Parkland Industrial Hemp Growers co-op Ltd.
Joe Federowich

Petro-Canada
Bruno Francoeur

Pilot Plant Corp.
Robert E. Morgan

Pioneer Petroleum
Art Stirling

Pollution Probe
Ken Ogilvie

Prairie Agriculture Machinery Institute
H. Burke
Darrell Lischynski*

Pulp and Paper Technical Association
W. Robert Wood

Radient Technologies Inc.
Steven Splinter

Recycle Alberta
Christina Seidel

Robustion Products Inc.
Joanne Johnson

Rothsay
Ron Wardrop

Royal Dutch Shell
Dana Atwell
Gary Ertel

Sarnia–Lambton Economic Partnership
Mike Ireland

Saskatchewan Research Council
R. (Ranga) Ranganathan

Saskatchewan Power
D. W. (Dave) Smith

SaskFlax
Linda Braun

Schweitzer-Mauduit
Joe Hogue*

Soy 20/20
Gregory Penner*

Suncor Energy Inc.
Stephen A. Kaufman
Cam Schneider
Pat Visscher

Sustainable Development Technology Canada
Blaine Kennedy*
Andrée Mongeon

TechPEI
Richard F. Ablett
Gailene Murphy

Tembec Inc.
Bob Benson
David R. Cameron*
Leon Magdzinski

Université de Laval
Robert Romain

Université du Québec
Claude Dupont

University of Alberta
Ian Morrison
Suresh Narine

University of British Columbia
Gary Bull
Hadi Dowlatabadl
S. Duff
Paul N. McFarlane
Jack Saddler

University of Guelph
Nigel J. Bunce
J. Christopher Hall
Marcel Schlaf
Rickey Y. Yada

University of Lethbridge
Kurt Klein
Randall J. Weselake

University of New Brunswick
Thierry B. R. Chopin

University of Ottawa
Kevin Kennedy

University of Saskatchewan
Ernest M. Barber
Ajay K. Dalai
Jill E. Hobbs
Venkatesh Meda
Satya Panigrahi

University of Toronto
David G. B. Boocock
Mohini M. Sain

University of Waterloo
Murray Moo-Young

Weldwood of Canada Limited
R. W. (Rod) Beaumont

Western Economic Diversification
Doug Maley

Weyerhaeuser
Stuart McCormack
Alan Pelman

Wood Products Group of New Brunswick
Frederick Nott