NON-FOOD/NON-FEED INDUSTRIAL USES FOR AGRICULTURAL PRODUCTS

PHASE 1

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EXECUTIVE SUMMARY

This report reviews the market opportunities for Canadian bioproducts and technology manufacturers in the North American marketplace. It is the first of a three-phase project designed to increase knowledge and awareness about these sectors and provide the basis for industry and government initiatives that will promote success in this rapidly expanding market.

Non-food, non-feed use of agricultural products offers three potential advantages for the Canadian economy:

- important potential to contribute to high technology manufacturing, thereby increasing gross domestic product and employment
- diversification opportunities for Canada’s farmers
- opportunities for rural economic development
- renewable alternatives to manufacturing industrial commercial and household chemicals from fossil fuels.

The methodology employed interviews with experts and industry representatives, as well as extensive document review using government, industry, and Internet sources. The study team included experts with a broad range of knowledge and experience involving public policy, agriculture, economics, chemistry, engineering, and food science. The team supplemented these strengths by involving a set of advisors with detailed knowledge and experience in business development, international raw material flows, university and government R&D, European bioproduct trends, and agricultural commodity markets. We used the Strategic Marketing Model (SMM) developed by Adler as the theoretical framework for examining 15 non-food/non-feed industrial sectors that are based on agricultural outputs. Not included in the terms of reference are bioproducts that are derived from forest or marine sources.

Phase 1 is a “scoping” exercise, designed to identify five most promising sectors for further and more intensive study in Phase 2. Therefore, the conclusions and policy direction are preliminary and tentative, pending the completion of Phase 2.

Study findings generally identified the value of integrated processing. Both the biorefinery concept and cluster-based development came through as common themes in many of the sectors. In fact, co-products from one-processing operation are often the raw materials for products finding markets in all together different sectors. Clearly the need for flexibility and processing/marketing options are important factors for the successful development of a biobased industrial economy.

As the work of this initial phase progressed, a tone of overall urgency began to appear. In many sectors, key informants indicated the technology relating to the expanded use of biobased materials was available, but neither the business nor the political climate in Canada had kept pace.

In other cases, the dearth of both basic and applied research in Canada had become a severe constraint to our ability to become a significant player in this industry of the future.

Many key informants indicated global supply chains are falling into place. A competition is forming among at least three global supply chain alliances: Pioneer Hi-Bred/DuPont; Cargill/Dow; and, ICI/National Starch/Novamont. In each case, complimentary technical and business strengths are being used to forge strong corporate entities which will allow rapid entry into what is anticipated to be a new era of industrial development. The window of opportunity for new players could close within three years as these giants plan future capital investment and make strategic alliances with downstream manufacturers.

In response to this situation, four major recommendations have been proposed. First, Canada should seriously consider the use of regulatory and market incentives to expand the ethanol, biodiesel, and lubricants industries. Second, Canada should create a more positive business and investment climate by developing a forward-looking capital investment strategy designed to attract one or more of the chemical global supply chain conglomerates. Third, the federal government should place a high priority on Industry Canada's technology road-mapping exercise. Fourth, Canada should develop a coordinated R&D strategy aimed at supplying much needed support for Canadian companies and players in this new economy.

The study team's key findings for the 15 different market sectors covered in this study appear immediately below. Additional detail on each sector may be found in the body of this report and in the associated technical reports filed with Agriculture and Agri-Food Canada.

Biofuels

The current market for **ethanol** in the United States is 6.1 billion litres, and it could dramatically increase to 28.4 billion litres by 2016 if the US proceeds, as expected, with tax exemptions, other financial incentives, and a new renewable fuel standard. Canada currently produces about 240 million litres of ethanol using corn and wheat as feedstocks. Ethanol is a mature industry in that consumer acceptance exists for ethanol blends in fuel and manufacturing technologies are well understood. A growing number of studies clearly demonstrate that government investment in this industrial sector produces significant net economic, environmental, and social benefits. The Canadian market could grow to one billion litres by 2010, provided that governments (federal and provincial) develop financial and regulatory supports parallel to those implemented in the US.

The market for **biodiesel** fuel in the US is currently 132 million litres, but tax incentives and a mandatory fuel standard in the US could drive the market to around 3,028 million litres by 2016. No commercial biodiesel market exists in Canada, but a pilot plant has been built in Foam Lake, Saskatchewan, and a world-scale commercial plant is planned for Oakville, Ontario. A mandatory 2% biodiesel fuel standard could result in a 400 million litre market opportunity for Canadian canola and soybean growers. To develop biodiesel production at the same pace as ethanol requires implementation of the same proactive public policy initiatives as currently being discussed for ethanol (i.e., a renewable fuel standard, plus tax and other financial incentives).

Biochemicals

Lubricants and hydraulic fluids are expected to provide major market opportunities for vegetable oils. Significant market penetration is expected in "total loss" oils like chain bar lubricants, greases, mould release agents, hydraulic fluids, and metal working oils. The huge motor and gear oil market could also open up to vegetable oils, with some studies predicting a capture of up to 35% of the European lubricants market. This would represent a market value of about 4.3 billion £ but assumes strong regulatory support. Canadian markets for vegetable-based lubricants and hydraulic fluids lag behind in North America. However, complete supply chains have now formed that include two dozen manufacturing companies ranging from farm co-ops to large multi-national petrochemical and agri-business companies. New advances in biotechnology, chemical processing techniques, and performance additives are helping to make vegetable-based lubricants more competitive.

Vegetable oil-based **inks** made from soybean, canola, and linseed are another market success story. One fourth of the 50,000-plus commercial printers in the US currently use soy ink, as do one-third of US newspapers. Overall, vegetable-based inks have captured about 25% of the North American inks market. Recent research suggests significant growth potential in traditional areas like newsprint and sheet-fed printing, and in new application areas like ballpoint pen ink, toner for office printers and copiers (using soy protein), and UV curable lithographic inks. Sun Chemicals, a multi-national leader in developing vegetable-based inks, has a production plant in Weston (Toronto), Ontario. Flint Inc., another industry leader, has various offices in Canada and a research facility in Toronto. Note that this market is growing as a result of the technical and economic advantages of using vegetable-based inks.

The **bioplastics** sector has evolved into a highly competitive and dynamic market involving large multi-nationals and integrated global supply chains. Market projections for bioplastics in Europe range between 20-30% of the total plastics market, and worldwide, multi-nationals are actively seeking plant locations to complete their supply and distribution chains. For example, in North America, Cargill Dow is now producing polylactic acid (PLA) made from corn starch in a plant located in Blair, Nebraska. The product, called NatureWorks,™ is the foundation for industrial and apparel fibres, packaging, and loose-fill, with an estimated world market of over USD$10 billion. Creating the economic environment to attract these production facilities requires aggressive policy such as targeted capital tax reduction for plant construction and operation, accelerated depreciation allowances, and other financial incentives. Although competition to land one of these new bioplastics plants will be fierce, such a facility will provide access to a global supply chain and participation in scientific and technical expertise, manufacturing know-how, and a global network.

Platform chemicals offer important opportunities for economic, environmental, and social benefits. The commercialization of lactic acid is well advanced. Cargill Dow believes that the world market could be as much as 1.4 million tonnes. One of the derivatives of lactic acid is the “green” solvent ethyl lactate. Cargill Dow is producing ethyl lactate for use in microelectronics component manufacturing, coatings formulation, cleaners, degreasers, and paint strippers. Archer

Daniel Midlands and USANTEC Inc. also produce ethyl lactate under the brand name Versol and are targeting high performance solvent markets. The market potential for sorbitol, another important platform chemical, is 226,800-272,200 tonnes. It provides the basis for glycerol (used in soaps, cosmetics, pharmaceuticals, alkyd resins, etc.) and propylene glycol (used, for example, as a non-toxic antifreeze). Yet another derivative, ethylene glycol (used in antifreeze, plastic bottles, brake fluid, and synthetic fibres), has a potential world market of 7.7 million tonnes per year. Other platform chemicals, like succinic acid, also show promise. Succinic acid and its intermediates and derivatives can be used to produce a vast range of products including solvents, polyesters, detergents, surfactants, and pharmaceuticals. The US government has focused its research efforts on forming public/private sector partnerships aimed at developing new technologies that can reduce production costs and improve product development. A similar approach to R&D could be an important element of a Canadian strategy.

While the consumption of low-cost **adhesives** and sealants is likely to remain flat or even decline, niches in higher performance components of the industry have good prospects for growth. For example, hot-melt packaging adhesives suitable for high-speed processing lines are expected to grow. In the construction industry, the use of adhesive for flooring, wall board, and paneling installation can improve performance and aesthetics. Further, in the automotive and aerospace industries where polymeric composites are replacing metals, adhesives will replace mechanical fasteners. Conventional metal construction, adhesives, and sealants can overcome corrosion and vibration noise associated with conventional fasteners and spot welding.

Perhaps the field of greatest interest in adhesives is the use of ultraviolet light and electron beam technologies to cure. Significant high-end markets exist in the medical/dental field where in many cases, adhesives are replacing sutures. Growth rates in these niches are typically 5 to 10% per year compared to the industry average of 2 to 4%. The extent to which this expansion occurs in Canada will depend on regulation to limit harmful volatile organic solvents inherent in conventional adhesives.

In the case of **surfactants**, a trend toward oleochemicals is appearing. Of the one MMT of surfactants used in the 1998 manufacture of cleaning products in Western Europe, 45% were of oleochemical and 55% were of petrochemical origin. This compares with a ratio of 30:70 in 1990. The situation in Japan is similar, while the growth rate in the US is expected to be slower.

Palm kernel oil, coconut oil, and palm oil are the principal sources of oleochemical surfactants, but virtually any oil-bearing crop could potentially provide the detergent-range carbon chain. In Canada’s case, current canola varieties that work well in certain industrial markets are not particularly suited for the surfactant industry. However, through genetic engineering, or perhaps intermediate processing, the desired chemical structure may possibly be achieved. A dual processing approach, with part of the crop intended for food and the other part for industrial use, has the potential to both produce a higher quality food oil and improve overall returns to the crusher.

Opportunities may exist to develop competitively priced oils that are either naturally suited for use in niche surfactant markets or that can be bred to produce oils that meet unique requirements. Flax, sunflowers, mustards, and crambe (Abyssinian mustard) have a solid history of production on the prairies, and all are capable of producing oils of interest to the surfactants industry. The big marketing challenge for any of these options will come from the very competitive prices found for palm, coconut, and soya oils and for petrochemical feedstock.

The Canadian **paints and coatings** industry is mature, and growth will match the pace of the economy in general, but industry shifts may alter this picture. Environmental health and safety considerations and costs associated with environmental and hazardous waste handling or disposal will continue to increase. Although the use of volatile organic compounds (VOCs) in paints has been reduced from 55% to approximately 25% over the past two decades, continued increases in VOC-generated smog will force regulation to reach additional reductions in allowable paint solvent emissions over the next decade.

The paints and coatings industry in the North American Free Trade Agreement (NAFTA) region is approximately USD$40 billion in total, including both domestic and export sales, with an annual growth rate of approximately 2%. The US accounts for nearly 90% of total production. The major use segments include original equipment manufactures (OEMs) and architectural paints, which together make up approximately 75% of total paint volume. Special purpose and miscellaneous coatings account for the remaining 25%. The major international paint companies serving in the region are located in the US; R&D initiatives for the industry originate from these companies. Only limited potential exists for expansion of Canadian participation in this industry.

The **cosmetics** industry has the ability to introduce new products that expand the bounds of the market. For example, new "cosmeceuticals," which are marketed for both medicinal and cosmetic properties, are currently in vogue. Although Canada may be seen as an attractive location for cosmetics manufacture due to the competitive business climate, the international nature of this industry and the absence of head offices of major corporations are difficult hurdles to overcome. Although niche production and processing opportunities exist, limited potential exists for Canadian manufacturing to capture significant new markets.

The Canadian **pharmaceuticals** manufacturing segment currently generates approximately CAD$2.9 billion in sales per year. Over the 1990 to 1998 period, Canadian shipments increased by 4.2%, while US shipments increased by 11.7%. The bright spot for Canada has been the export market—Canada’s exports within North America rose from CAD$102.5 million to CAD$961.9 million, a very impressive cumulative annual rate of 32.3%. Canada’s world exports rose through the 1990s from CAD$250.4 million to CAD$1,491.9 million, which amounted to an annual rate of 25.0%. Imports over this period rose at a rate of 17.9%, but because imports started at a level greater than four times that of exports, the negative trade balance rose at an annual rate of 15.2% to CAD$2,660 million.

Canada has some important strengths in this field. For example, on a per capita basis, our medical and biotechnology research communities have demonstrated an ability to provide world-class results. Unfortunately, Canada seems to be weak in converting research accomplishments into commercial enterprises. The lack of head offices of major pharmaceutical corporations and the small quantities of raw materials required to saturate the market restrict this opportunity to niche opportunities for both farmers and processors.

Many different types of **biopesticides** exist in North America and globally. As an example, a natural pesticide consisting of a simple peptide in the protein fraction of pea flour may hold promise for Western Canada. The pea insecticide has been patented, and it will take about three more years to develop a commercial product. To illustrate market potential, if a quarter of the annual small cereal grain production in Canada (roughly 40 million tonnes) were treated with the new pea insecticide during storage, it would create a market of 10,000 tonnes per year requiring about one million tonnes of peas to be processed.

Bioproducts (made from nonwood fibres)

A wide variety of **paper** and paperboard products can be produced using nonwood plant fibres. At present, the market for nonwood printing and writing papers is about 50,000 tonnes per year. Market size is limited by the cost of nonwood fibres, which is about five to eight times the cost of wood-based papers. Specialty papers like currency paper, cigarette paper, etc. are small niche markets with high entry-level requirements. The immediate potential large-scale use of nonwood fibres in the Canadian and US paper industry remains limited, but a worldwide shortage of fibre for paper making is emerging. Some projections estimate that this shortage will likely hit 100-125 million tonnes by 2010. In all likelihood, all fibre sources including fast-growth wood plantations, increased paper recovery, and nonwood plant fibres from crop residues as well as dedicated fibre crops will be required to meet the rising demand. Sufficient market potential in Canada and the US justifies at least one word-class integrated pulp and paper mill in each country, provided the mill can compete in both price and product quality.

The opportunities for using nonwood fibres in the **fibreboard** industry are not encouraging. Few market opportunities exist for new particleboard plants in North America using either wood or nonwood fibres. There are possible opportunities for new medium density fibreboard (MDF) capacity amounting to about 69.7 million square metres per year. However, one should keep in mind that three to five large wood-based MDF plants could fill this market need. Five years ago, the markets for fibreboard made from crop residues looked very attractive. However, many of the business investments in this sector have led to bankruptcy. Future research needs to focus on the development of efficient raw material acquisition, handling, and storage systems, with more attention being paid to process economics and the development of markets.

Nonwoven applications in the automotive industry and three-dimensional **composites** in the construction sector have interesting market opportunities for natural fibres. In each of these areas, the cost and unique performance characteristics of natural fibres offer a comparative advantage over wood fibres and fibreglass. In addition, these market opportunities do not require radical technological breakthroughs. Companies in Europe have taken existing technologies and processes and adapted them to the use of natural fibres, and this technology and industrial know-how is making its way to North America. Although interest within the industrial, academic, and agricultural sectors in North America has been high, market demand has only recently begun to emerge.

The recent success of the natural fibre/nonwoven fibre industry in Europe was the result of strong government support at all stages of the production chain, i.e., fibre production, processing, manufacturing, and market development. Whether this success can be applied to North America without active government support remains uncertain. The Durafibre plant in Canora, Saskatchewan that was producing flax fibres for use in the automotive industry has recently closed down following Cargill's decision to withdraw financial support from the project.

Potential in Canada's regions

All regions of Canada hold potential for attracting and developing biobased industries. Interest is high among people interviewed. However, certain sectors, such as platform chemicals, will likely prove to be viable only in the heavily industrialized regions of Ontario and Quebec. Other sectors, such as biofuels, lubricants, and perhaps fibre products may be best exploited on the Prairies where commodity availability and pricing are key elements of success. Niche products such as selected pharmaceuticals and other low volume/high value raw materials are needed, may find production opportunities in Atlantic Canada and British Columbia. Where the market pull of existing industry is not present, communities and regions will need to carefully assess their strengths and weaknesses and focus on opportunities within their particular capabilities.

Priorities for Phase 2

The selection of the priority sectors for Phase 2 depends on judgements about selection criteria, performance within a criterion, and the relative importance of the criterion. The selection model uses four basic criteria: economic multiplier, environmental benefit, potential for farm income, and regional distribution. Based on our analysis, we recommend that Phase 2 concentrate on biofuels (ethanol and biodiesel), platform chemicals, adhesives, bioplastics, and biopesticides. Other sectors including, paints and coatings, and lubricants also scored high on our evaluation matrix and therefore warrant further analysis as time and funding permits.

1.0 Purpose and scope of the study

1.1 Overview

Non-food/non-feed uses of agricultural products represent an exciting potential for increasing Canada's gross national product, enhancing the environment, and promoting international trade. Whether it is using corn and wheat to produce ethanol or using other agricultural products to produce biofuels, inks, pharmaceuticals or cosmetics, the non-food/non-feed uses for farm products offer a wide range of opportunities for Canadian producers and expanded activity in manufacturing.

The research aligns with recent statements by the government on the future of agriculture. For example, the speech from the throne in January 2000 committed Canada to

> *help Canada's agricultural sector move beyond crisis management — leading to more genuine diversification and value-added growth, new investments and employment, better land use, and high standards of environmental stewardship and food safety.*

This report surveys the market opportunities for Canadian bioproducts and technology manufacturers in the North American marketplace. It is the first phase of a three-phase project designed to increase knowledge and awareness about these sectors and provide the basis for industry and government initiatives that will promote success in this rapidly expanding market.

1.2 Structure of the research

Phase 1 of the research that is reported here starts from the findings and projections of an earlier market study conducted for Agriculture and Agri-Food Canada (AAFC) in 1997.[1] The specific goals of this Phase 1 research are to:

- analyse and summarize selected public policy, literature, and research data
- where possible, acquire/analyse information gathered from senior management of Canadian companies, associations, and experts from various sectors and sub-sectors in all regions of Canada
- interview technical experts involved in the agricultural bioproducts, biomass, and biofuels industries to gain insight into the current thrusts of these important sub-sectors
- evaluate selected previous research of specific relevance to this study
- where possible, provide market projections by sector to the year 2010
- select five specific sub-sectors for in-depth analysis in Phase 2.

Phase 2 reviews the five sectors in more detail with special attention on the current state of research and the identification of public policies that can promote the growth of these sectors.

[1] Ashmead Ralph, "Non Food / Non Feed Uses of Agricultural Products."

Phase 3 presents an in-depth review of the potential of hemp fibre and a comparative analysis of hemp fibre in relation to other synthetic and natural fibres used in North America.

1.3 Scope of the Phase 1 study

Long-term market projections in interdependent and emerging market sectors is risky. The rate of technological innovation, access to venture capital, the limited view that outsiders are afforded to the strategy of large multinational interests, and the complex nature of public policy in an evolving federalism can subvert projections.

Where appropriate, and possible, this study also includes an analysis of market structure, vertical supply chain integration, and economic competitiveness. However, much of the information that would improve the projections often falls into the area of trade secrets. Many companies will not release technical information or production cost data, or disclose information about either their suppliers or customers.

This study is limited to bioproducts related to agriculture. Bioproducts made from forestry and marine biomass have not been examined. Nutraceuticals have also been omitted because it is the focus of study by another branch within AAFC.

The time horizon of 2010 also delimits the scope of the study. In addition, technologies that are in the conceptual stage or basic research stage and could not become commercially viable for two to three decades have not been addressed. The study is grounded on techniques that are currently technically feasible and that have commercial potential.

Finally, this study reflects effort that could be marshaled over three months, beginning in January of 2002. Each of the 15 product sectors being examined in this study are complex areas in and of themselves. Separate technical reports for each product sector are available as companion reports to this document.

2.0 Study methodology

2.1 Overall framework: the Strategic Market Management System (SMMS) approach

The research team employed an adapted version of David Adler's Strategic Market Management System (SMMS) as a heuristic device to guide the collection of data and assist in analysing each product sector. Table 1 (next page) lists and categorizes the market factors considered in the SMMS approach.

In this phase of the study, we are concerned with market factors external to an individual company or industry. We focus on broad classes of data involving customer needs; competition from other products or countries; market size, growth, and profitability; and factors considered to be "exogenous" influences, like science and technology and public policy stances on regulations and market incentives.

Other phases of the project will look at the company or industry level, which includes additional factors like management strength, employee knowledge and skills, access to capital, industry R&D investments, and intellectual property (i.e., patents, trade secrets, etc.).

An integrated examination of both external and internal market factors will assist in defining Canada's strengths and weaknesses; help identify our sources of competitive advantage; and assist individual companies, industries, and governments to develop business/industry strategies based on sustainable competitive advantage.

To our knowledge, this model has not been used previously in Canada to assess the market potential of bioproducts.

<table>
<tr><th colspan="2">Table 1: Strategic Market Management System (SMMS)</th></tr>
<tr><th>1.0 The market (external)</th><th>2.0 The farm / firm / industry (internal)</th></tr>
<tr><td>1.1 Customer analysis
< identify market size, structure
< segmentation (i.e., identify sub-markets)
< customer motivation
< user’s unmet needs
< identify opportunities/threats
< identify source of competitive advantage

1.2 Competitor analysis
< from other products (e.g., natural, petrochemical)
< from other countries

1.3 Market analysis
< actual and potential market size
< market growth
< market profitability
< cost structure
< distribution systems
< market trends
< key success factors

1.4 Environmental or “exogenous” influences
< science and technology
- plant biotechnology
- bioprocessing
- new material science
< public policy
- legislation and regulations
- tax policy
- investment in R&D
- investment in human resources
- affirmative government purchasing
< other economic, social, cultural, or demographic influences

1.5 Define market opportunities

1.6 Define market strategy

1.7 Opportunities and threats</td><td>2.1 Performance analysis
< product
- total sales
- product cost
- product quality
- product availability
- profitability
< human resources
- management strength
- employee skills/motivation
< access to capital
< access to distribution channels
< R&D investment/new product development
- patents, licensable technologies, trade secrets
- strategic alliances (e.g., product development)

2.2 Sources of competitive advantage

2.3 Determine performance strategy</td></tr>
<tr><th colspan="2">3.0 Determine overall business strategy</th></tr>
<tr><td colspan="2">Notes: External analysis conducted during Phase 1.
Internal analysis - product performance conducted during Phase 1.
Balance of internal analysis conducted in Phase 2 for selected supply chains.
1.6, 2.3, and 3.0 denote actions by government/industry.</td></tr>
</table>

2.2 Sustainable development — meeting the "triple bottom line"

In addition to using the SMMS approach as a heuristic device, the study team also considered issues of sustainability, or what some businesses refer to as the "triple bottom line." A growing number of public and private organizations want to pursue market strategies that have positive economic, environmental, and social impacts. Where possible, we report the benefits that biobased markets may have on the economy and on the government's own revenues and budget. We also consider potential impacts on the environment, including the effects on energy consumption, the reduction of greenhouse gas (GHG) emissions, and the prevention of air and water pollution. Finally, we were especially interested in the impact on farm income and the potential for rural economic development.

2.3 The study team

The core study team included six experts with a broad range of knowledge and experience involving public policy, economics, chemistry, engineering, and food science. The team supplemented its strengths by involving a set of advisors with detailed knowledge and experience in business development, international raw material flows, university and government R&D, European bioproduct trends, and agricultural commodity markets. Several advisors have knowledge and experience working within multinational companies that are closely related to the emerging biobased economy. These individuals are listed in Appendix A.

2.4 Focus groups

The study team also conducted three focus group sessions with experts.

- The first dealt with the topic of ethanol and biodiesel fuel co-products and how they might improve the economics of biofuel production. An ethanol industry already exists in Canada, and it may be possible to leverage this existing asset. Brazil, for example, uses ethanol as a "platform" chemical for producing other commodity organic chemicals.

- The second focus group session dealt with surfactants. Vegetable oils hold a significant market share in the surfactant market, but it is dominated by palm oil. This focus group linked domestic oil seed developers with industry experts to discuss future opportunities for the use of domestic oil seeds in the global surfactants market.

- The third focus group session focused on fibre markets. Both Canada and the US have actively pursued the fibreboard market. Unlike the situation with ethanol, this market sector has met with some stunning financial failures. Several hundred million dollars in capital investments were jeopardized after 12 of 18 fibreboard mills in North America closed their doors. The third focus group session was aimed at discussing the lessons learned from this experience and using that knowledge to minimize future risks.

3.0 Summary of market potential by product sector

Section 3 summarizes some of our key findings for the 15 different market sectors covered in this study. Additional detail on each sector may be found in the associated technical reports. Note that these sectors are presented in no particular order of importance.

3.1 Ethanol

3.1.1 Market analysis

As a measure of overall market demand, US ethanol production rose steadily from 643.5 million litres in 1980 to approximately 6.1 billion litres[2] in 2000. Over 15.2 million tonnes of corn were used to produce ethanol in 2000, or about 6.5% of the US corn crop.[3] As of March 2000, 45 companies in the US were operating 58 ethanol plants in 19 states.[4] Farm cooperatives accounted for 40% of the 6.1 billion litres produced in 2000.[5]

Most of the ethanol production in the US is currently concentrated in five states:[6]

- Illinois — 2,178.5 million litres
- Iowa — 1,709.1 million litres
- Nebraska — 1,263.2 million litres
- Minnesota — 847.9 million litres
- Indiana — 333.1 million litres.

The four largest processors are:[7]

- Archer Daniels Midland (4 plants) — 2,839.1 million litres
- Williams Energy (2 plants) — 492.1 million litres
- Minnesota Corn Processors (2 plants) — 461.8 million litres
- Cargill (2 plants) — 397.5 million litres.

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[2] We use imperial measure for US data and metric measures for Canadian data. These will be harmonized in a subsequent revision.

[3] National Corn Growers Association web site.

[4] John M. Urbanchuck. AUS Consultants. Ability of the US Ethanol Industry to replace MTBE. March 2000.

[5] Statement of the National Corn Growers Before the Subcommittee on Conservation and Credit, Rural Development and Research, April 25, 2001.

[6] John M. Urbanchuck. AUS Consultants. Ability of the US Ethanol Industry to replace MTBE. March 2000.

[7] Ibid.

Six additional ethanol plants are under construction in the US, which will produce 507.2 million litres of additional capacity. A further 32 plants, accounting for just over 3.8 billion litres, are in the planning and final development stages (as of March 2000).[8] Clearly, this is a rapidly expanding market.

Corn remains the feedstock of choice for new plants, but a trend may discerned toward using other raw material inputs such as: wheat and barley in Montana, Oregon, and Washington; wood wastes and forest residues in Oregon, California, Wyoming, and Arkansas; rice straw in California; sweet potatoes in North Carolina; and municipal solid waste in New York State and Pennsylvania.

Current ethanol production in Canada is 238 million litres or about 4% of US production. As part of the federal government's Action Plan 2000, announced October 2000, the government is committed to increasing ethanol production in Canada by 750 million litres by 2010.[9]

The six ethanol plants in Canada are located in Ontario, Manitoba, Saskatchewan, and Alberta. Corn is used as a feedstock in the east while wheat is used in the west. Future plants totalling over 400 million litres in capacity are being considered in Ontario and Quebec.[10] The Saskatchewan Hibernia (Ethanol) Strategy Task Force has suggested that five world-class facilities be built in Saskatchewan between 2003 and 2006. The plan includes two 25 ml, one 30 ml, one 50 ml, and one 80 ml plant totalling 222 million litres of capacity. Where feasible, these ethanol plants would be integrated with beef feedlot operations similar to the existing Pound-Maker Agventures plant in Lanigan, Saskatchewan.[11]

The Canadian retail distribution system for ethanol is also evolving. The retailing of E10 (a blend of 10% ethanol and 90% gasoline) is simplified, to some extent, by the fact that all automobiles made since 1970 can use E10 without requiring engine modifications.[12] There are about 1,000 ethanol refueling stations in Canada serving the four western provinces and Ontario and Quebec. One of the most significant recent announcements was the intention of Commercial Alcohols to build a CAD$100 million, 120 million litre ethanol plant in Varennes, Quebec. The project should be completed in early 2002. The production capacity from the Varennes plant will be used to supply Petro-Canada stations in Quebec. Petro-Canada will then join Sunoco in Ontario and Husky Oil in the West as part of Canada's network of fuel ethanol retailers.

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[8] Ibid.

[9] Margaret Bailey. "Ethanol Policy and Programs: Status, Issues and Next Steps." The Real World of Ethanol Symposium. January 30, 2002.

[10] Canadian Renewable Fuels Association web site.

[11] Saskatchewan Hibernia (Ethanol) Strategy Report. February 18, 2002.

[12] Ibid.

It is important to emphasize that ethanol plants do not divert corn and other feedstocks, like wheat, from food uses. Ethanol production uses the relatively low-value starch component while leaving behind vitamins, minerals, fibre, oil and protein, which can be used in higher value food and feed markets. Ethanol plants actually produce industrial fuels and chemicals plus other co-products for human and animal consumption. Ethanol plants act as "bio-refineries" that maximize the use value of agricultural crops.

The cost of processing grains to ethanol has been declining over time. According to the US National Renewable Energy Laboratory (NREL), the cost of producing one gallon of ethanol in 1978 (in 2000 US dollars) was USD$2.47. By 1994, the price had dropped to USD$1.43 per gallon (current dollars). Current costs are USD$0.88 cents per gallon for dry mill operations while the industry average is about USD$0.95 to USD$1.10 per gallon in the US.[13]

3.1.2 Public policy

Although the cost of producing ethanol has been decreasing over time, ethanol still requires federal and provincial tax rebates to be commercially viable in Canada.[14] In Ontario, for example, the average wholesale price in 2000 for both diesel and gasoline fuel was CAD$0.35 per litre. The average price of ethanol was CAD$0.38 per litre, after federal and provincial tax rebates of CAD$0.25 per litre.[15]

An important market opportunity also exists in the regulation of various additives and conventional fuels. For example, if the blending agent methyl tertiary butyl ether (MTBE) is banned in California and other major jurisdictions in the US, and ethanol is selected as the replacement, current ethanol demand in the US could double to 12.1 billion litres by 2004.[16]

In a related development, various bills in the US Congress advocate a renewable fuel standard. One of the proposed bills calls for a refiner, blender, or fuel importer to ensure that motor vehicle fuels contain not less than 0.8% renewable fuel beginning the calender year 2002 and then increase in percentage every year until reaching 5.0% in 2016. A renewable fuel standard could drive the US market for ethanol to 28.4 billion litres per year. The economic impacts[17] from the standard would:

[13] Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks. A joint study by the US Department of Energy and the US Department of Agriculture. October 2000. Statement of the National Corn Growers Before the Subcommittee on Conservation and Credit, Rural Development and Research, April 25, 2001.

[14] Neil Levine. An Ontario Perspective: Ethanolized Gasoline at Sunoco. Presented at "The Real World of Ethanol" Symposium. Sponsored by the Saskatchewan Agrivision Corporation. January 30, 2002.

[15] Ibid.

[16] John M. Urbanchuck. AUS Consultants. Ability of the US Ethanol Industry to Replace MTBE. March 2000.

[17] John M. Urbanchuk. AUS Consultants. An Economic Analysis of Legislation for a Renewable Fuels Requirement for Highway Motor Fuels. November 2001.

- reduce US crude oil imports by 11.0 billion litres (302 million barrels annually)
- decrease oil imports and reduce the US trade deficit by USD$63.4 billion
- create 300,000 new jobs in the US
- increase US household income by USD$71 billion
- increase corn prices by USD$0.28 per bushel and soybean prices by USD$0.68 per bushel
- create USD$10.5 billion in new investment in renewable fuel facilities
- increase net farm income by USD$99 billion (USD$6.6 billion annually)
- reduce farm program payments by USD$7.8 billion.

In North America, the ethanol industry is an important component of the new biobased economy. It adds more than USD$2 billion to the US economy each year and has created almost 200,000 jobs, added over USD$450 million in sales tax receipts, and increased net farm income by USD$4.5 billion.[18]

In addition to these economic and social impacts, ethanol-blended fuels also provide positive environmental impacts. Ethanol contributes toward a net energy balance and produces 32% fewer greeenhouse gas emissions than gasoline for the same distance travelled.[19] Ethanol use can also help to reduce smog, which is a growing health issue in urban areas. The Ontario Medical Association, for example, claims air pollution costs Ontario citizens more than CAD$1 billion a year in hospital admissions, emergency room visits, and absenteeism.[20]

Regulatory reforms can clearly create market demand for ethanol-blended fuels, but market incentives are also required to ensure that ethanol is economically competitive and that the industry can attract investment capital. Both the US and Canada have reduced the gasoline excise tax on ethanol-blended fuels. Without this exemption, ethanol could not compete against petroleum fuels. The US also offers an additional USD$300 million in market incentives over the 2001 and 2002 fiscal years to encourage ethanol and other bioenergy plant expansion. They also have a small ethanol producer tax credit that allows a USD$0.10 per gallon production income tax credit on up to 56.8 million litres annually.

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[18] Dr. Michael K. Evans. The Economic Impact of the Demand for Ethanol. Kellogg School of Management. February 1997.

[19] Statement of the National Corn Growers Before the Subcommittee on Conservation and Credit, Rural Development and Research, April 25, 2001.

[20] "Clean Air," Green Land. Environment Canada web site.

More recently, an energy bill in the US Senate calls for an additional USD$0.219 per gallon equivalent federal income tax credit for E85 sold at retail and increasing by a further USD$0.146 by 2005. This incentive, plus the USD$0.510 per gallon ethanol producers' incentive will ultimately make ethanol less expensive per gallon equivalent than motor gasoline.[21] The Seante bill also calls for up to USD$30,000 in federal income tax incentives of retail fueling sites to install E85 infrastructure.[22]

Although these market incentives forego government tax revenues, the longer-term cost-benefit to the government remains positive. An economic impact study conducted by Dr. Michael K. Evans, Kellogg School of Management (February 1997), found that the ethanol tax incentives amounted to a budget loss of USD$648 million, but the net gain was USD$3.5 billion dollars through increased personal and corporate income taxes, and reduced costs for social security and unemployment benefits.

3.1.3 Science and technology

Ethanol is produced from the fermentation of sugars. The feedstocks can include corn, wheat, and other cereal grains, as well as lignocellulosic materials like crop residues (e.g., corn stover and wheat straw), forestry residues, fast growing poplars, and switch grass.

The conversion of starch-based crops like corn and wheat using an enzymatic hydrolysis process that converts starch to sugars is well established and has been in commercial production for more than two decades in the US. There are two major types of processing technologies used to convert corn grain to fuel-grade ethanol: wet mills (commonly known as corn refineries) and dry mills.

Corn wet mills produce:

< starch (used in food and industrial applications)
< ethanol
< corn sweeteners
< corn oil
< corn gluten feed (used for animal feed)
< corn gluten meal (used for animal feed)
< carbon dioxide (CO_2) (used in the beverage industry).

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[21] National Ethanol Coalition Newsletter, April 30, 2002.
[22] Ibid.

Corn dry mills produce:

- ethanol
- bran and gluten (used as a baking ingredient and meat extender)
- distillers dried grains with soluables (DDGS) — sold as a high quality animal feed ingredient for cattle and, more recently, for swine and poultry[23]
- CO_2.

The conversion of lignocellulosics like crop residues (e.g., corn stover and wheat straw), forestry residues, fast growing poplars, and switch grass can yield:[24]

- ethanol
- pulp fibre (which could be used in pulp and paper)
- protein for human and animal feed
- gypsum (used in construction material)
- CO_2 (used in the beverage industry)
- lignin
- acetic acid (used in industrial chemicals)
- furfural
- xylitol (used as a sweetener).

The conversion of lignocellulosic materials is more complex and is not as well advanced. The cellulose and hemi-cellulose components are essentially long, molecular chains of sugar held together by lignin. The technology hurdles include:

- the separation of the lignin from the cellulose and hemi-cellulose so that the latter can be treated by hydrolysis

- the hydrolysis of cellulose and hemi-cellulose takes place at different rates

- the hydrolysis process yields a variety of sugars, with pentose sugars being difficult to ferment

- the yeast used in grain fermentation cannot ferment all the different sugars

- the various types of feedstocks present different types of problems — agricultural residues and hardwoods have lower amounts of lignin but higher amounts of pentose sugars while the situation for softwoods is just the reverse.

[23] See the work currently being conducted at the University of Minnesota http://www.ddgs.umn.edu/general-info.htm.

[24] Mark Stumborg. Fuel Ethanol Industrial Development. AAFC Draft Report. October 1995.

In 2000, the US NREL held a series of colloquies around the US to assess the prospects for commercializing biomass in the next two to five years.[25] The results of the industry consultation were as follows:

- Validation of the processing technology on a large scale (45.4 tonnes per day feedstock) is the primary obstacle to biomass commercialization. Potential sites for validation include existing fermentation plants (like Iogen's), wet and dry corn mills, or an existing pulp mill.
- Collection, storage, and delivery must be between USD$25-40 per dry ton delivered to the processor. This may be achievable through the emergence of organized "biomass suppliers."
- Plant science can improve biomass yields by developing new "biomass" hybrids where the cellulose component is increased and the lignin content is decreased.
- Significant improvements are still possible in machinery, transportation, and storage.
- Further process improvements can be made in integrating pre-treatment, hydrolysis, and fermentation.
- Enzyme improvements can be achieved to lower enzyme cost by a factor of 10 with sufficient investment in research.
- The economics can be improved by costing externalities such as GHG emissions at USD$10 per ton of carbon equivalent.
- A biorefinery approach to corn stover may lead to higher-valued products.

Although there are at least six different technologies now being studied for the conversion of cellulosics to ethanol, only two technologies are optimized for crop residues: those of Iogen Corporation in Canada and BC International Corporation in the US.[26]

[25] Biomass Commercialization Prospects in The Next 2-5 Years. NREL. November 2000.

[26] These and other processing technologies have been reviewed in B. W. McCloy and D. O'Connor. Wood-Ethanol: A BC Value-Added Opportunity. December 1998.

The expansion of co-products from ethanol production is also a major area of R&D. Recent biorefinery research includes:[27]

- research on new markets for existing co-products (e.g., DDGS)
- fractionating corn and wheat for nutraceutical and pharmaceutical applications
- further processing ethanol into intermediate and derivative chemicals like ethylene
- co-processing ethanol and succinic acid (which is another platform chemical)
- linking ethanol and beef feedlots/meat packing into a broader value added chain that includes the production of biodiesel, biogas, and/or fertilizers from waste meat processing streams.

3.1.4 Conclusions

The creation of ethanol markets in both Canada and the US depend fundamentally upon public policy. A program of well-designed tax exemptions and other financial incentives combined with a new renewable fuel standard will shape market expansion between now and 2010. A growing number of economic impact studies clearly demonstrate that government investment in this industrial sector produces significant net economic, environmental, and social benefits.[28]

The new international trend to leverage the existing ethanol industry into a platform[29] for the production of commodity organic biochemicals simply increases the strategic importance of expanding the Canadian ethanol industry.

The tremendous growth now taking place in the US ethanol industry will not occur in Canada without commensurate public policy and market incentives. The current federal policy in Canada is a good first step, but it is not considered adequate by the ethanol industry, which looks with envy at the more proactive public policy support south of the border.[30]

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[27] See the SMMS reports for ethanol, biodiesel, and platform chemicals for more details.

[28] Dr. Michael K. Evans. The Economic Impact of the Demand for Ethanol. Kellogg School of Management. February 1997.

[29] Platform chemicals will be discussed in a later section.

[30] See, for example, the Canadian Renewable Fuels Association web site where Bliss Baker the president of the CRFA is quoted as saying: *"If they (the federal government) want this industry to succeed they will have to commit to a clear national strategy that includes a Renewable Fuels mandate and tax parity with the United States."* One of the demands they are making to the federal finance department is a 2-cent per litre tax credit.

3.2 Biodiesel

3.2.1 Market analysis

Biodiesel, created from renewable sources such as animal fats and vegetable oils (soy, canola, etc.), is a replacement for conventional diesel fuel. It contains no petroleum but may be blended with conventional diesel in the same way that ethanol is blended with gasoline. The idea for using vegetable oils as combustion fuels dates from the original inventor (Rudolf Diesel) in 1895.

The US is the largest soybean producer in the world. It produces an annual crop of 73.5 million tonnes, the equivalent of about 15 billion litres of oil.[31] Almost one-twelfth of the soybean oil production (453,600 tonnes) is surplus and carried over into the following year.[32]

Many see biodiesel fuel as offering an important market for surplus soybean oil. At present (2001), the US produces 132.5 million litres of biodiesel, but a mandatory renewable fuel standard could push production as high as 3.1 billion litres by 2016.[33]

There is no commercial production of biodiesel in Canada, notwithstanding the fact that Canada planted 500,000 hectares of soybean and 3.3 million hectares of canola in 1995. In total, the two crops produced 8.6 million tonnes of oil. Over 40% was exported. Milligan BioTech Inc. has been operating a biodiesel pilot plant in Saskatchewan since March 2001. The biodiesel is being used as a fuel conditioner, and they are test marketing it across Canada. The plant capacity is approximately 450,000-500,000 litres per year.[34]

The use of biodiesel as a total substitute for diesel fuel is not practical in Canada. It would require 11 times the current acreage of canola to satisfy current highway transport diesel fuel requirements. The future markets for biodiesel will likely focus on B20 blends and B2 fuel additives.[35]

3.2.2 Public policy

Market growth for biodiesel in Europe and North America will depend heavily on government regulatory and taxation policies.

Limitations of sulphur content in diesel fuel and a renewable fuel mandate are two key regulatory initiatives that could have a major impact on markets.

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[31] Soy Lubricants Technical Background. United Soybean Board. February 2000.

[32] Personal communication, Dr. Sevim Z. Erhan, USDA. Peoria, Illinois.

[33] Establishing a Renewable Fuels Standard as Part of a National Energy Policy. Renewable Fuels Association.

[34] Personal communication, Zenneth Faye, March 17, 2002.

[35] SARD Report #4. March 2001.

Diesel fuel in the US typically contains sulphur levels of about 350 ppm in on-road fuel and 3,500 ppm in off-road fuel. Sulphur has been found to reduce engine life and pollute the air.

The US Environmental Protection Agency (EPA) intends to reduce the sulphur content in on-road diesel fuel to 15 ppm starting June 2006. The sulphur content for off-road diesel transportation fuels will be lowered to less than 500 ppm starting with the 2006 model year, and it intends to lower the standard further to 15 ppm beginning in 2009 or 2010.

Reducing sulphur levels affects lubricity and can result in high rates of fuel injection component wear and potential premature failure. Field experience with these fuels has led to widespread use of fuel additives. The use of biodiesel as a lubricity additive for solving the problems of low sulphur content has been supported by the fuel injection equipment industry.

Under Canada's Clean Air Campaign, launched in May 2000, Canada is now committed to aligning its regulatory controls to the more stringent air quality standards of the US.[36]

The European Union's (EU) Directorate for General Transport and Energy is advocating the implementation of a renewable fuel standard. It has drafted a proposed rule that would require each member state to use a minimum of 2% biofuels in their transportation fuels by 2005 and increase to 5.75% by 2010. Each member state must approve the rule before it goes to the EU Council of Ministers and the EU Parliament for final approval. This is a process that could take several years.

The US is also considering legislating renewable fuel standards. The US Congress has introduced legislation calling for the mandatory use of renewable fuels, like biodiesel and ethanol, in motor vehicle fuels sold in the US. One of the proposed bills calls for a refiner, blender, or fuel importer to ensure that motor vehicle fuels contain not less than 0.8% renewable fuel beginning the calendar year of 2002 and then increase in percentage every year until reaching 5.0% in 2016.

Canada's decision to align its air quality regulations with the US will also create pressure on Canada to adopt renewable fuel standards similar to the US.

The total Canadian diesel fuel market in 1999 was 22,171 million litres. The transition to a low sulphur content in transportation fuels (i.e., down from 500 ppm to 15 ppm in the US; 30 ppm in Canada by 2006), combined with a renewable fuel standard starting at 0.8% and rising to 2.0% by 2010, would create an initial market demand for biodiesel in Canada of 170 million litres and a mature market of 424 million litres by 2010. Using canola as an example, the market demand in 2010 for B2 would require 424 million litres of biodiesel, the equivalent of 879,800 tonnes of canola seed or 10.2% of the 8,798,000 tonnes produced in Canada in 1999.[37]

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[36] Providing Cleaner Air to Canadians. Environment Canada. February 2001.
[37] Ibid.

The economic and social impacts[38] in the US from implementing a low sulphur content and a 1.5% renewable fuel standard have been estimated to:

- increase the price of one bushel of soybeans by USD$0.17 annually over a ten-year period
- boost total crop cash receipts by USD$5.2 billion cumulatively by 2010
- increase average net farm income by USD$300 million per year
- add 13,000 jobs in the farm, food processing, and manufacturing and service sectors.

In addition to these positive economic and social impacts, biodiesel has important environmental impacts. A US government study by the Departments of Energy and Agriculture found that biodiesel reduces CO_2 emissions by 78% over its life cycle compared to petroleum diesel, and it has a positive energy balance of 3.2 to 1 compared to diesel fuel's 0.83 to 1.[39]

Biodiesel offers significant consumer benefits as well. Research conducted in Saskatchewan using canola oil has found that small amounts of canola biodiesel, less than 1%, can be used successfully as a lubricant additive, particularly in winter diesel fuel. Even these small amounts of biodiesel have resulted in substantial improvements to fuel efficiency (2 to 13%) and reduction in engine wear (9 to 57%). Economic modelling based on the findings of laboratory studies have found that a large diesel truck running 250,000 km per year using a 0.5% canola biodiesel lubricant additive would result in almost CAD$4,000 per year in net economic savings for the owner, based on a 4% improvement in fuel economy and reduced engine wear of 50%.[40]

The cost of pure biodiesel (B100) in the US has fallen from USD$4.50 per gallon in 1997 to USD$1.00 per gallon in 2001.[41] The cost premium for biodiesel becomes even smaller if it is used in a B20 blend or a B2 fuel additive. If government excise tax exemptions are extended to biodiesel, as they have been for ethanol, biodiesel fuel (as an additive) will become cost competitive.

3.2.3 Science and technology

Biodiesel processing technology is well advanced in Europe and could easily be licensed and applied to Canada.

There are also several important Canadian technological innovations in biodiesel processing. For example, the BIOX Corporation in southern Ontario has patented a technology that it claims can dramatically reduce the costs of biodiesel production. By the fall of 2002, the company intends to build a biodiesel plant in Ontario using soybean oil, animal fats, and recycled cooking oil. BIOX

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[38] Washington DC press release. Posted on the National Biodiesel Board web site. July 17, 2001.

[39] Reported in The New Diesel Fuels: They Are In Your Future for Nonroad Equipment. Equipment Manufacturers Institute. November 2001.

[40] SARD Report #4. March 2001.

[41] K. S. Tyson, J. Brown, and M. Moora. Industrial Mustard Crops for Biodiesel and Biopesticides. NREL.

claims they can build one of the world's largest biodiesel plants if an excise tax exemption can be extended to biodiesel fuels and access to capital financing can be secured.[42]

Another potential source of biobased diesel fuel is yellow grease and tallow (and possibly poultry fat and waste water plant-generated lipids), which can be converted to a low sulphur, high cetane premium diesel blending stock called AGTANE (AGricultural ceTANE)[43] *"When AGTANE is blended with regular diesels, the resulting fuel burns more efficiently and with cleaner emissions. Particulate matter and* NO_x *emissions are significantly lowered."*[44]

A second technology worth monitoring is the Thermal Depolymerization and Chemical Reforming (TDP) process, which converts organic wastes (like manure, slaughterhouse wastes, and food processing wastes) into oils, gases, and carbon using water pressure and temperature. A USD$15 million, 181 tonne per day demonstration plant is being built in Carthage, Missouri, next to ConAgra's Butterball turkey processing plant. The US EPA has provided a USD$5 million grant and ConAgra Foods Inc. has entered into partnership with Changing World Technologies to commercialize the technology. The US oil industry is reported to be supportive of the technology because they can take the crude oil from the TDP process and refine it into gasoline and other products.[45]

Neither AGTANE nor the crude oil from the TDP process are biodiesel fuels, but they impinge upon the biodiesel market and may compete with biodiesel technologies (i.e., BIOX) for the same organic waste streams.

Automotive industry acceptance of biodiesel fuel is critical for future market expansion. Original equipment manufacturers now support the use of biodiesel as a lubricant additive, provided it meets industry standards (i.e., American Society for Testing and Materials (ASTM) provisional standard PS 121 and those of original equipment manufacturers).[46] The Canadian General Standards Board has also announced that it will approve in principle the adoption of the ASTM standard for biodiesel.[47]

The Office of Fuels Development at the US NREL is currently searching for a crop that could produce 23-45 billion litres per year at USD$0.10 per pound. At that level, biodiesel could supply 10-20% of the total diesel market at under USD$1.00 per gallon.

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[42] http://www.bioxcorp.com/

[43] A. Spartaru, J. Monnier. AGTANE (AGricultural ceTANE): An economically viable bioenergy product for compression ignited engines. CANMET Energy Technology Centre.

[44] Ibid.

[45] "ConAgra Signs Environmental Technology Agreement with Changing World Technologies." ConAgra news release. December 5, 2000. Also see Oil from offal...a poultry plus. *Kansas City Star*. July 28, 2001.

[46] The New Diesel Fuels: They Are In Your Future for Nonroad Equipment. Equipment Manufacturers Institute. November 2001.

[47] Reported in the Canadian Renewable Fuel Association Newsletter, January 2002.

NREL is currently in the middle of a three-year study of the potential use of industrial mustard as a source of biodiesel and biopesticides. So far, their research seems promising:

- The defatted meal (after the oil is removed) can be used as a pesticide without further processing.
- In vitro breeding can improve the glucosinolate concentration in the meal to reduce costs.
- Specific varieties can be bred to act as fungicides, insecticides, herbicides, or nemacides.
- Oil content varies between 25 and 40%.
- Depending on the variety, the oil is 90% monosaturated or more in some cases.
- The oil is inedible and not suitable for high value industrial purposes, so its market price will not be tied to increases in food crop prices or other markets.
- Crop yields of 1.8 tonnes per acre of seed appear to be achievable in rotation with dry land wheat production without irrigation.
- Wheat yields have increased as much as 20% when grown in rotation with industrial mustard.
- The mustard crop can be planted and harvested with existing wheat equipment.
- The mustard crop appears to resist many of the pests common to canola.
- Application trials with mustard meal have shown it to be highly effective with fungus, nematodes, cut worms, wire worms, crab grass, and other agricultural pests.

Western Canada is currently growing edible varieties of mustard as a specialty crop. The NREL research on industrial mustard may (or may not) have applications to western Canada.

3.2.4 Conclusions

Biodiesel fuel, particularly when used as a 2% fuel additive, offers an enormous market opportunity for Canadian agriculture. However, for these markets to expand, the same proactive public policy initiatives currently being discussed for ethanol (i.e., a renewable fuel standard, tax incentives, etc.) must be extended to biodiesel fuel production. Canada already owns several technology patents that have commercial potential. One biodiesel pilot plant already exists in Saskatchewan and a large commercial scale biodiesel plant is being proposed in Ontario.

3.3 Lubricants and hydraulic fluids

3.3.1 Market analysis

The potential European market in 2010 for vegetable oil-based lubricants is estimated to be 35% of the total lubricants market. Vegetable oil-based lubricants are considered to be one of the largest and fastest growing industrial use markets. Vegetable-based lubricants currently account for 100,000 tonnes of production but are expected to rise dramatically to 1.7 million tonnes by 2010, when they will equal the combined volume of renewables used in polymers, solvents, surfactants, and composites.[48] The potential European market for vegetable oil-based lubricants is projected to be worth 4.3 billion £ by 2010 (close to CAD$10 billion).[49]

Significant market penetration is expected in "total loss" oils like chain bar lubricants, greases, mould release agents, hydraulic fluids, and metal working oils. The huge motor and gear oil market could also open up to vegetable oils. Table 2 identifies the potential European market share and value according to sub-market, assuming EU legislation is enacted that is supportive of biolubricants.

Table 2: Potential European market for biodegradable lubricants

	Lubricants ('000 tonnes)	2000 market ('000 tonnes)	2010 market ('000 tonnes)	Share % by 2010	Market (£ million)
Hydraulic fluids	750	34	250	33	890
Greases	400	1	180	45	320
Chain bar lubricants	125	11	120	96	210
Mould release agents	225	4	180	80	320
Motor and gear oils	2,400	48	480	20	1,730
Metal working oils	1,000	2	500	50	870
TOTAL	4,900	100	1,710	35	4,340

Source: Reported in Realizing the Economic Potential of UK-Grown Industrial Crops. Annex - Key Statistics, Table 1. Alternative Crops Technology Interaction Network (ACTIN). June 6, 2001.

The market potential in North America is also considered to be high. The United Soybean Board has rated lubricants and hydraulic fluids as one of the top five industrial market opportunities for soybeans.

Price competitiveness varies according to the quality of the product. Vegetable-based chainsaw lubricants, for example, cost about 30% more than comparable petroleum oils; hydraulic fluids cost about 50-200% more; and rapidly biodegradable synthetic esters are about 400-800% more. In areas where there is a smaller price differential, e.g., chain bar lubricants, vegetable-based oils are likely to completely capture the market by 2010.

For some applications, vegetable oils may be more competitively priced if one uses full cost accounting methods (capital + operating + "external or environmental costs"). The greater lubricity of vegetable oils results in lower friction wear and longer tool and equipment life. Evaporative losses from vegetable oils are significantly lower. Greater adhesion to metal surfaces results in less oil loss. For example, in the case of chain bar oil, cutting 100 m^3 of wood consumes

[48] Table 3 in Realizing the Economic Potential of UK-Grown Industrial Crops. Alternative Crops Technology Interaction Network (ACTIN). April 2001. The data are based on information supplied to the European Commission for the Renewable Raw Materials Working Group of the European Climate Change Programme (2000).

[49] Reported in Realizing The Economic Potential of UK-Grown Industrial Crops, Annex - Key Statistics, Table 1. ACTIN. June 6, 2001.

34 litres of rapeseed oil compared to 56 litres of mineral oil. By comparing total costs (capital + operating), mineral oils may actual cost more — up to 23% more in some applications.

Vegetable-based oils have the advantage of being inherently biodegradable and non-toxic, as well as having higher lubricity and a higher flash point. They are also a renewable resource and contribute to lower CO_2 emissions.

However, vegetable oils have low temperature limitations (pour point and Brookfield viscosity) and will freeze at higher temperatures. Either mineral oils or synthetic oils can be used as an additive to improve low temperature performance.

Vegetable oils also have lower oxidative stability and breakdown (polymerize) at higher temperatures. The lower hydrolytic and oxidative stability of vegetable oils can be improved by genetically modifying vegetable oils to have higher oleic content and enhancing the oil further through the addition of additives, such as antioxidants, which can improve hydrolytic stability.

North American companies currently manufacturing vegetable oil-based lubricants include:

- Archer Petroleum, Omaha, Nebraska
- Cargill, Minneapolis, Minnesota
- Environmental Lubricants Manufacturing, Inc., Waverly, Iowa
- Great Lakes Oil Company, Concord Township, Ohio
- Greenland Corporation, Calgary, Alberta
- Husqvarna, Charlotte, North Carolina
- International Lubricants, Seattle, Washington
- John Deere, Moline, Illinois
- Lubrizol Corporation, Wickliffe, Ohio
- Renewable Lubricants, Hartville, Ohio
- Safe Lube/Gemtek, Phoenix, Arizona
- Terresolve Technologies, East Lake, Ohio
- The Fanning Corporation, Chicago, Illinois
- TyTek Equipment, Mobile, Alabama
- West Central Soy, Ralston, Iowa.

At least sixteen types of lubricants, hydraulic fluids, and greases have been commercialized using soybeans, including products employing a genetically modified organism (GMO) variety.

3.3.2 Public policy

Vegetable-based lubricants address the increasing public concern about the impacts of petroleum oil-based lubricants and hydraulic fluids, particularly where these oils come in direct contact with the environment, food, or people.

< Approximately 47%[50] of lubricants and hydraulic fluids are lost into the environment. So-called "total loss" lubricants like off-shore drilling muds, concrete parting agents, chain bar oils, railroad flange oils, drip oils, and wire rope lubricants are completely lost into the environment. The loss rate for lubricants in two-stroke engine oils is 34%. Much of this loss goes directly into the marine environment. The loss rate for hydraulic fluid is 8%.[51]

< Petroleum-based oils can contaminate ground water for up to 100 years, and as little as 0.1 ppm mineral oil can reduce the life span of shrimp by 20%.[52] As a result of these concerns, non-toxic biodegradable vegetable oils have become attractive, notwithstanding their higher market prices. While the overall growth in the lubricant market is expected to remain fairly constant, the biodegradable lubricant sector was expected to grow by 6.8% in 2000.[53]

< A life cycle analysis (LCA) study[54] has demonstrated considerable environmental benefits from using vegetable oil-based lubricants compared to mineral oil-based products.

< When the environmental, health, and safety costs (which are typically treated as "externalities") are folded into life cycle costs, the price advantage for vegetable oil applications becomes stronger. A number of industry sectors are now becoming concerned about potential clean-up costs and legal liabilities associated with total-loss oils.

Regulatory pressures are likely to drive the markets for vegetable-based lubricants and hydraulic fluids in both Europe and North America over the next decade.

There are calls in the EU for tougher volatile organic compound (VOC) regulations and the application of a carbon tax to promote greater use of biodegradable lubricants (as well as adhesives, paints, coatings, and inks).[55] Vegetable-based oils produce fewer emissions, have better skin compatibility (i.e., produce fewer dermatological problems), and provide improved fire safety because of their higher flash point.[56]

Many petroleum-based metalworking oils contain chlorine, sulfonates, and other chemicals that may be harmful to workers. The US Occupational Safety and Health Administration (OSHA) has

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[50] Reported in the IENICA National Report for Germany, 1999.

[51] Reported in the IENICA National Report for the United Kingdom, 1999.

[52] Dr. Amaya Igartua. Behavior of Vegetable Oils: Biodegradability, Toxicity, Recycling. CTVO-net Workshop. 2000.

[53] The biodegradable lubricant market includes some synthetic lubricants as well as vegetable oil-based lubricants. See Lubricants from Vegetable Oils. The Carbohydrate Economy. Institute for Local Self-Reliance. 2001.

[54] Dr. Patricia Wightman. Environmental Benefits to be Derived from the Use of Vegetable Oils in Place of Existing Petrochemical-Derived Materials. Chemical-Technical Utilization of Vegetable Oils (CTVO-net) Workshop. 2000.

[55] Dr. Amaya Igartua. Behavior of Vegetable Oils: Biodegradability, Toxicity, Recycling. CTVO-net Workshop. 2000.

[56] Lubricants from Vegetable Oils. The Carbohydrate Economy. Institute for Local Self-Reliance. 2001.

designated metalworking/machining fluid exposure as a priority for future rule making.[57] Petroleum-based chain bar oils can also present a health hazard because the movement of the chain flings a mist of oil around the worker.

3.3.3 Science and technology

Advances in biotechnology are increasing the yields of lubricant oils and opening up opportunities to design oils with fatty acid profiles that more closely meet industry specifications. In the US, a high-oleic soybean oil, originally developed for food purposes, is now being used as a lubricant by some companies. For example, Environmental Lubricants Manufacturing based in Waverly, Iowa, is manufacturing and retailing lubricants, greases, and hydraulic fluids made from soybeans that have been genetically modified by DuPont. Additional modifications are being studied to reduce the number of additives and/or reduce the number of manufacturing steps, both of which will further reduce the costs of vegetable oil production.

Although great advances have been made with soybean oils, canola remains the dominant North American oilseed crop used for industrial lubricants. About 85% of vegetable oil-based lubricants come from canola. Soybean and other oils like sunflower provide the balance. There is some experimentation with safflower and castor oils. High oleic corn varieties are also being investigated. Agriculture Canada in Lethbridge has developed a high linoleic acid safflower that could provide high performance characteristics compared to other oils. The technology could also be used to develop high linoleic sunflower varieties.[58]

3.3.4 Conclusions

In summary, lubricants and hydraulic fluids are expected to provide tremendous market opportunities for vegetable oils in this decade. From a full cost accounting and life cycle perspective, vegetable-based oils are becoming quite competitive with petroleum-based oils. The performance of vegetable-based oils is improving as a result of performance additives, new chemical processes, and new varieties of bioengineered vegetable oils. Complete supply chains have developed in both Europe and North America. Manufacturers of vegetable-based lubricants and hydraulic fluids include large multinational oil companies (e.g., Burah Castrol, Exxon, Pennzoil, Texaco, Quaker State, Mobil, and Witco) as well as Lubrizol, Cargill, and a host of smaller companies in both the US and Canada.

Assuming that agriculture-based lubricants in North America achieve a 12% market share of the lubricant market by 2010 — about one-third of the rate of growth predicted in Europe — the value to Canada will be about CAD$114 million in sales. If North America reaches the same market potential (35%) as Europe, sales will be about CAD$350 million.

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[57] See Lubricants from Vegetable Oils. The Carbohydrate Economy. Institute for Local Self-Reliance. 2001.
[58] Personal communication with Dr. Martin Reaney. AAFC. Saskatoon Research Centre.

3.4 Inks

3.4.1 Market analysis

During the late 1950s and early 1960s, linseed, soy, corn, and canola vegetable oils became common ingredients in inks, but they quickly gave way to faster drying[59] petroleum-based inks in the 1960s. Then the oil crises of the 1970s and 1980s caused widespread concerns over the future price and availability of petroleum-based inks. Regulatory controls over printing chemicals were also being passed at the federal and state levels, and these changed the cost balance within the industry.

As a result of these pressures, the industry was ready to innovate. The American Newspaper Publishers Association instructed its technical staff to develop an alternative ink. After studying over 2,000 formulations, they settled on a soybean oil-based formulation, and in 1987, the General Printing Ink Division of Sun Chemicals agreed to produce the new ink.[60] Within the last ten years, over 3,000 newspapers in the US have begun using soy ink.

Over time, customer demand led to other formulations for sheetfed, heatset, coldset, business forms, and flexographic inks.[61] Vegetable-based inks have not penetrated some markets. For example, the gravure and screen printing markets use little soy ink.[62]

The percentage of vegetable oil that can be used in printing inks varies according to manufacturer, press type, paper type, and ink colour. Non-heatset inks, absorbent (uncoated) papers, and black ink can use higher amounts of soy oil. Table 3 summarizes the percentage of soy oil according to ink type.

In 10 years, the market share for vegetable oil-based inks in the US has gone from 5% in 1989 to 22.5% in 1999, equal to 244,900 tonnes of soybeans.[63] The estimate for 2002 is 25%.[64] If soybean inks capture the entire ink market, 1.1 million tonnes of soybeans, less than 2% of the US soybean crop, would be required.

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[59] Faster drying inks boost productivity because print jobs can run faster.

[60] National Soy Ink Information Center, http://www.soyink.com

[61] Ibid.

[62] Ibid.

[63] Markets for vegetable-based inks are also growing in Europe and Japan. Belgium, the Netherlands, several Scandinavian countries, and parts of France and Germany have moved to vegetable-based inks. Raw materials include rapeseed, linseed, sunflowerseed, and soybeans. The current consumption of vegetable-based printing inks in Europe is between 12,000 and 15,000 tonnes per annum. The potential market is estimated at 100,000 tonnes of oil seed. See R. Garofalo. "Fediol Manifesto on Non-food Oils Seeds" in Chemical-Technical Utilization of Vegetable Oils: Final Conference Proceedings. June 2000. The Soy Ink Information Center reports that Japan already has over 900 registered soy ink users and 23 soy ink manufacturing companies. Almost 25% of colour newsprint uses soy ink. About 680,000 bushels of soybeans were used in Japan to make inks in 1999, and soy ink usage was expected to increase threefold in 2000.

[64] Personal communication. Jo Patterson. National Soy Inks Information Center.

Table 3: Customer needs by type of ink

Ink type	Minimum % soy oil	Maximum % soy oil	Cost/benefits of using soy oil	Notes
Newsprint (web presses)	< 30% for colour < 40% for black	< 50% for colour < 75% for black	< brighter colours < better colour control < less rub-off < greater coverage < better stability < no capital cost difference < black ink can cost 30% more	< higher % oil content due to greater absorbency < 100% soy formulations possible < higher costs for black ink may be offest by greater coverage and reduced newsprint spoilage due to smoother flow
Sheetfed	< 20%	< 20-30% on coated paper		< small presses that print one sheet at a time using coated and uncoated paper
Heatset (web presses)	< 7%	< less than 20%	< no capital cost difference < ink cost 5-8% higher	< heatset inks rely on volatile organic compounds (VOCs) to increase the evaporative rate < increasing soy oil % increases dryer temperature requirements and can scorch paper and dull ink finish < requires 25-35% solvent use
Non-heatset (web and sheetfed presses)	< 20% sheetfed inks < 30% web inks		< better print quality < brighter colours < no capital cost difference < higher costs but expected to decrease	< soy colour inks contain less oil than soy black inks and therefore dry faster < higher soy oil can be used on uncoated paper because of absorption
Form inks (non-heatset web presses)	< 20%	< 40-50%	< brighter colours < slightly higher ink cost	< forms generally use uncoated stock
Flexographic ink	< 15% soy protein < 0% oil	< 15-25%		< water or solvent based and does not contain oil < flexographic inks used primarily for packaging

Source: National Soy Ink Information Center web site and Alternatives to Petroleum and Solvent-Based Inks, Massachusetts Toxics Use Reduction Institute. EnviroSense, Environmental Protection Agency.

One-fourth of the 50,000-plus commercial printers in the US currently use soy ink as do one-third of US newspapers. More than 90% of US newspapers use coloured soy ink.

Table 4 breaks down the soy ink market by sector. Although the figures are dated, they clearly indicate the relative size of potential markets. Newsprint is the largest potential market and accounts for about 227,000 tonnes, heatset has a potential market size of 136,000 tonnes, and sheetfed 45,000 tonnes. Table 4[65] also indicates that soy inks have made significant market penetration across all areas. The average percentage of market captured by soy inks was about 9% in 1997. In practice, ink manufacturers use both soy and linseed oil. Canola can also be substituted for soy oil. By 2002, the use of all vegetable oil-based inks had climbed to 25%.[66]

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[65] Source: National Printing Ink Research Institute. Lehigh University, Bethlehem, Pennsylvania. Referenced in Biochemicals for the Printing Industry. Institute for Local Self-Reliance. 1997.

[66] The ink manufacturing plant in Weston (Toronto) Ontario uses about 60% linseed oil and 40% soy oil. Linseed oil is used is used where faster drying times are required. Personal communication, Sun Chemicals.

Table 4: Soy ink market penetration			
Ink types	**Total consumption ('000 tonnes)**	**Usage of soy ink ('000 tonnes)**	**% of market captured by soy inks**
Newspaper	213	22	10.2
Black	170	10	6
Colour	43	11	27
Sheetfed	48	5	9.3
Heatset	130	10	7.3

Colour soy ink and commercial soy-based printing inks are cost-competitive with petroleum-based inks. Because soy ink provides more intense colour, printers may not use as much ink. As a result, more materials can be printed with less ink. Some printers report 10-15% more coverage.

Black soy ink for newsprint is priced about 25% higher than black petroleum ink. (USD$0.60 per pound vs USD$1.76 per pound), but increased mileage may offset some of the difference in cost.[67]

The performance benefits of vegetable-based inks include:[68]

< considerably improved abrasion resistance and less "rub-off"
< excellent machine stability — less spoilage
< more intense colours
< less ink usage
< no dry-back
< no VOCs
< no need for labelling
< vegetable oils are not carcinogenic while many petroleum oils are
< no unpleasant mineral oil smell — vegetable oils are almost odour-free
< no carcinogenic PCAs (polycyclic aromatic hydrocarbons)
< improved lifting properties
< improved print characteristics
< considerably less pollution to the environment
< no recycling problems with waste paper.

[67]Biochemicals for the Printing Industry. Institute for Local Self Reliance. 1997. Also see R. Garofalo. "Fediol Manifesto on Non-food Oils Seeds" in Chemical-Technical Utilization of Vegetable Oils: Final Conference Proceedings. June 2000.

[68]See chapter on "Oil Crops" in IENICA European Overview. 2000.

3.4.2 Public policy

Like many other biobased products, public policy has also played an important role in the development of vegetable-based inks. Regulations governing the release of VOCs and the control of toxic chemicals have played an important role. However, concerns about petroleum oil price shocks caused by the oil embargo in the 1970s, proactive leadership by the newspaper and printing industry, and aggressive marketing by national and state soybean associations have also been important factors in market development.

The 1990 amendments to the US Clean Air Act, which required a 15% reduction in VOCs, acted as a strong market driver. Further market incentives came in the form of the US Vegetable Printing Act of 1994, which mandated that printers under government contracts use vegetable-based inks whenever possible. Following the federal government's lead, ten states have passed soy ink legislation requiring state agencies to use soy ink.[69]

Canada has not passed a regulation to require the use of soy-based printing inks in government printing. However, the use of vegetable-based printing inks is widely supported in Canada and is included in numerous green guides and checklists, including:

- Guide to Green Purchasing (1995), published by The National Roundtable on the Environment (1995)
- Environment Canada's Green Meeting Guide (1996) and Green Publications Checklist
- GIPPER's Guide to Green Procurement, published by the City of Toronto, Province of Ontario, Ontario Hydro, etc.

3.4.3 Science and technology

There is still considerable potential for increased use of vegetable-based oils. Dr. Sevim Erhan, at the United States Department of Agriculture (USDA) Research Lab in Peoria, Illinois, has patented two ink formulations that allow for increased use of soy oil. Using her patented formulations, the current 40% oil content used in black newsprint applications could be extended to about 80%; the current 30% used for colour newsprint could be increased to 60-70%; and the current 20% used in sheetfed coated paper printing applications could be increased to up to 60%.[70]

Other market opportunities that could be created from advances in new technology include:[71]

- birth certificates
- toner for office printers and copiers
- ballpoint pen ink
- UV curable lithographic inks

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[69] Biochemicals for the Printing Industry. ILSR. 1997. Available at http://www.pneac.org/sheets/all/Biochemicals_for_the_Printing_Industry.pdf

[70] Personal communication.

[71] National Soy Ink Information Center and Illinois Soybean Association.

- faster curing conjugated soybean oil
- textile printing ink.

3.4.4 Conclusions

Vegetable-based inks now account for approximately 25% of the printing inks market. New advances in technology offer the potential to further increase market share.

Opportunities to promote the production of vegetable-based inks in Canada do exist. Sun Chemicals has a production plant in Weston (Toronto) Ontario that uses both linseed and soy oil in its formulations. Linseed oil has the advantage of faster drying times. Canola oil can also be substituted for soy oil. The differing performance characteristics of vegetable oils are matched to meet specific customer needs. In some applications, a variety of vegetable oils may be used.[72]

Linseed, canola, and soy are all grown in Canada. Further follow-up in this growing market sector is recommended.

3.5 Bioplastics

3.5.1 Market analysis

Bioplastics are derived entirely or almost entirely from renewable agricultural resources, thereby displacing nonrenewable resources — petroleum, natural gas, and coal. Many pathways exist for the creation of bioplastics:

- Synthetic biopolymers are made by Eastman Chemical Company (Eastar Bio), BASF (Ecoflex), Bayer (BAK), and DuPont (BioMax and Sorona).
- Starch-based polymers are made by Novamont S.p.A. (Mater-Bi), National Starch and Chemical Company (the ECO line of bioplastics), and Mazin International.
- Polylactic acid (PLA) is used as the feedstock for Cargill Dow's new polymer (NatureWorks™).
- PHAs are used by ICI (BIOPOL) and Metabolix.
- Protein polymers made from soy, wheat, and milk products are made by Urethane Soy Systems, DuPont Soy Polymers, and two Canadian firms — BioEnvelope Technologies and Nexia Biotechnologies Inc.

The range of current and potential applications is extensive:

- personal care items — diapers, sanitary napkins, cotton swabs, soap holders, containers for cosmetics
- textiles — apparel, home furnishings, man-made leathers and suedes, shoe linings, carpet backing, protective clothing
- catering — plates, cutlery, cups, straws, cup lids

[72] Personal communications. Sun Chemicals (Toronto).

- packaging materials — food trays, lunch boxes, packaging for instant foods, films for dry food, foamed items, yogurt cups
- stationery — pens, cartridges, pencil sharpeners, rulers
- biomedical technology — sutures, drug delivery systems, screws, biodegradable woven patches for use inside the body, dressings, glues, ligaments
- agricultural materials — mulch films, seedling pots for transplanting, vegetation nets
- cosmetics — (monomers) moisturizer, skin rejuvenator, pH control, anti-microbial
- automotive parts — automotive and truck panels
- construction materials — building insulation
- everyday consumer products — trash bags, plastic bags for shopping, drainer nets.

Decision Resources, Inc. estimated that the world demand for biodegradable polymers in 1998 was 25,000 tonnes or USD$120 million.[73] Growth through to 2003 has been projected at 29% per year. Production and sales in 2003 were estimated to be 91,000 tonnes and USD$380 million respectively.[74] These projections have quickly been overtaken by recent events involving Cargill Dow Polymers' new NatureWorks™ product.

In Europe, bioplastics are viewed as a large potential market for starch-based crops like corn, wheat, potatoes, and peas. Currently, bioplastics accounts for only a few ten thousand tonnes that are mostly used to produce low-end loose fill packaging, high-end surgical/medical devices, and cosmetic packaging. However, if mandatory biodegradable regulations and a carbon tax on fossil fuels are enacted, the European markets could expand quickly to about one million tonnes per year.[75] Most European experts estimate that the potential market for biodegradable plastics in Europe is about 20%, although Germany believes that it could exceed 30%.[76]

In the US, Cargill Dow and DuPont are focusing on producing fibres that go well beyond the boundaries of biodegradable plastic markets. Their goal is to make high performance, cost-competitive fibres that may become, in time, major fibres comparable to synthetic PET or nylon. As a result, the market opportunities and potential for growth could be very significant.

Both Dow and DuPont represent a new breed of bioproduct company that is developing sophisticated supply chains that operate at a global scale.

- Cargill Dow Polymers is constructing a polylactic acid (PLA) plant in Blair, Nebraska. The plant will produce up to 140,000 tonnes when it reaches capacity (expected in 2003). Although PLA is biodegradable and based on corn, its unique performance qualities and its competitive price are what make the polymer so attractive.
- Cargill Dow plans to build five additional PLA plants. There are discussions about a plant in Europe and another in Asia. That leaves two plants whose locations are still undecided. One attractive site could be in southern Ontario, close to the chemical and plastics industries near Sarnia. The world wide market for PLA is estimated to be USD$10+ billion.[77]

- DuPont is following a similar approach with their new Sorona™ fibre. Sorona™, or 3GT, is made by combining 1,3 propanediol, which can be produced by micro-organisms using a carbohydrate sugar feedstock like corn and the synthetic terephthalic acid. One half of the new polyester is based on renewable resources, the other half is petroleum-based. Sorona™ is not even designed to be biodegradable. It is a high performance fibre that is cost-competitive. Sorona™ has unique performance properties. It is soft; has good stretch and recovery, improved fit and comfort, easy dyeability; and can be spun into apparel-grade textile fibres. A new plant has been built in Kinston, North Carolina, to produce the new fibre. The initial plant capacity is expected to be 10,900 tonnes per year with the ability to expand to 45,400 tonnes per year at the same site. The Sorona™ fibre technology has also been licensed to a number of fibre manufacturing companies in Asia

[73] Jay Dwivedi. Trends in Biodegradable Polymers Market. Decision Resources, Inc. 1999.
[74] Ibid.
[75] IENICA report for the European Union, 1999.
[76] IENICA report for the European Union, 1999. IENICA report for Germany, 1999.
[77] Presentation by Pat Gruber, Cargill Dow LLC.

who are interested in product development. Sorona™ represents a family of polymers that DuPont claims is the most advanced polymer platform in their company's science portfolio.

3.5.2 Public policy

Although regulations governing biodegradability have been important in Europe, public policy has not played a large role in the development of bioplastics in North America.

US chemical companies like Dow and DuPont have focused on creating new products that offer their customers superior price and performance advantages. Their R&D is emphasizing new bioprocessing manufacturing technologies that have the potential to dramatically lower capital and operating (e.g., energy consumption) expenses. These new products and bioprocessing technologies contribute to their goal of developing a product portfolio mix that results in higher corporate profits and greater shareholder value.

3.5.3 Science and technology

A full discussion of the science and technology behind biodegradable plastics is well beyond the scope of this project. For an excellent overview of the area, the reader is referred to "Biopoymers: Making Materials Nature's Way," published by the US Senate Committee on Energy and Natural Resources in 1993. For a more recent review, see "The Green Plastics Model: Biodegradable Synthetic Plastics," a paper prepared for Industry Canada in 2002.[78]

The main point we wish to emphasize in this report is that many different technologies along the supply chain ranging from seed development to production, processing, and product development and marketing must be harnessed to successfully launch a commercially viable product. A number of multinational firms are in the process of assembling these technologies within integrated global supply chains that are held together by acquisitions, research alliances, joint ventures/partnerships, and licensing agreements. Their goal is to achieve a strategic competitive advantage by combining knowledge and skills throughout the value chain.

DuPont/Tate and Lyle/Genencor, Cerestar/Cargill/Dow, and ICI/National Starch/Novamont are three examples of global supply chain alliances involving bioplastics production.

Table 5 highlights some of the complex supply chain relationships created by DuPont.

[78]Emily Cranston, Jumpei Kawada, and Robert H. Marchessault. McGill University, Department of Chemistry, Pulp and Paper Centre.

Table 5: Some elements of DuPont's biobased products supply chain

Science and technology

< 1996 — research partnership with Genencor, the world's second largest developer and manufacturer of industrial enzymes

< 1998 — research partnership with the United Soybean Board

< 1998 — purchase of the Cereals Innovation Centre, Cambridge UK from Dalgety; expertise in wheat milling, structure, and function; dedicated team studying biorefining for paints, detergents, oils, adhesives, cosmetics, and absorbents

< 1998 — purchase of Hybrinova SA, a hybrid wheat subsidiary from Lafarge; Hybrinova is located near Paris, France; it has established research relationships with leading seed companies throughout Europe.

< 1998 — formation of the Wheat Research Alliance with John Innes Centre, The Sainsbury Laboratory and Plant Bioscience Ltd. (Norwich, England); goal is to generate knowledge and intellectual property and provide a clear path to commercialization

< 1998 — licensed 3-Dimensional Pharmaceuticals' proprietary DirectedDiversity technology, which blends computational tools and combinatorial chemistry to accelerate the chemical discovery process

< 1998 — a genomic research collaboration with Lynx Therapeutics to isolate genes that would otherwise be inaccessible with current technologies; designed to accelerate their gene discovery and breeding programs

< 1999 — USD$35 million, five-year research and development alliance with MIT; brings together DuPont's and MIT's strengths in materials, chemical and biological sciences to develop new processes for new materials directed at bioelectronics, biosensors, biomimetic materials, alternative energy sources, and new high-value materials

< 1999 — purchase of CombiChem Inc., which has technology that links sophisticated computer technology with chemistry to identify potential new applications in medicine, agriculture, and the material sciences. The computer-based methods shorten the time of discovery, identify potential drug development problems early, and point the way to new compounds not previously considered; CombiChem will operate as part of DuPont Pharmaceuticals Research Laboratories[1]

< 2000 — a research and development agreement with Affymax whereby DuPont gains access to their chemical libraries

Seed development

< 1999 — USD$7.7 billion spent purchasing Pioneer Hi-Bred International

< the DuPont Wheat Enterprise (this includes DuPont's research facility in Wilmington Delaware, the Cereals Innovation Centre, Hybrinova SA, the John Innes Centre, and the Sainsbury Laboratory)

Starch, sugar, and protein production

< 1997 — purchase of Protein Technologies International (PTI) from Ralston Purina. PTI is the leading global supplier of soy proteins for the food and paper processing industries. It has 1,200 employees, USD$430 million in annual sales, and numerous technology centers around the world; DuPont Soy Polymer created out of PTI.

< 2001 — DuPont acquires Hubel Longyun Protein Food Group's soy protein facility in China and renames it the DuPont Yun Meng Protein Company Ltd.; facility to produce high quality (90+%) soy protein isolate for the healthy food ingredients market; example where local product development and processing combined with world-class processing and distribution.

< 2000 — a joint development agreement with Tate & Lyle to produce biobased polymers; Tate & Lyle is a global leader in carbohydrate processing (17,500 employees); Tate & Lyle also owns the Amylum Group which operates in 12 countries throughout Europe and holds leadership positions in a wide range of cereal sweetener and starch products.

< Tate & Lyle also has a minority interest in Staley. Staley is a world leader in the production of corn sweeteners and starches and controls about 20% of the US corn sweetener and starch market. It manufactures over 350 starch products for the food, building, and paper industries. Staley operates out of four major plants located in Decatur, Illinois, Louden, Tennessee, and Lafayette, Indiana.

Table 5: Some elements of DuPont's biobased products supply chain
Manufacturing capacity < 1998 — acquisition of 1,3 propanediol (PDO) technology from Degussa AG; Degussa also agreed to construct and operate a 9,000 metric tonne PDO plant in Wesseling, Germany; the German plant, which produces PDO based on petroleum feedstocks, is intended to give DuPont a head start in developing products from PDO and 3GT and provide a "bridge to market" for DuPont's bio-PDO. The biobased technology is expected to dramatically lower the cost of PDO production as well as downstream products. < 2001 — DuPont and Tate & Lyle announced that they had successfully manufactured PDO using a fermentation process based corn sugar. PDO is an important component of DuPont's Sorona™ 3GT which can be spun into apparel-grade textile fibres. < 2001 — a new continuous polymerization plant for the production of Sorona™ has is built in Kinston, North Carolina. It will use PDO from the Wesseling plant and then switch over to corn-based PDO once process economics and market demand can justify the switch-over.
Downstream product development alliances for Sorona™ (2001) < Far Eastern Textile Ltd., based in Taiwan — it is one of the largest polyester producers in Asia. It has over 7,000 employees. < Teijin is based in Japan. It is becoming one of the largest polyester producers in the world. Teijin has over 22,000 employees and has production facilities in Japan, Thailand, Indonesia, Mexico, China and Italy. < Toray is also based in Japan. It is a major world manufacturer of synthetic fibres and textiles, films, resins, chemical products, and advanced composite materials. Toray employs over 18,000 people. It has 27 textile, fibre, and apparel companies and affiliates and five plastics companies within Japan alone. It also operates in 17 additional countries around the world. < Saehan is based in Korea and is a producer of textiles (both synthetic and natural) and apparel. It has eight offices/plants in Korea and a "global network" of facilities in Japan, Hong Kong, Indonesia, Phillippines, China, and Vietnam. < DuPontSA is based in Europe and is the product of a joint venture between DuPont and Haci Omer Sabanci Holding A.S. The new company, DuPontSA, will develop, make, and sell polyester filament, staple, resins, intermediates, and related products throughout Europe, the Middle East, and Africa. It is the largest polyester company in the region with USD$1 billion in sales and over 4,500 employees.
[1]DuPont Pharmaceuticals is a worldwide business that focuses on research, development, and delivery of medicines to treat unmet medical needs in the fights against HIV infection, cardiovascular disease, central nervous system disorders, cancer, arthritis, and related disorders. DuPont Pharmaceuticals was sold in October 2001 to Bristol-Myers Squibb Co. The USD$7.8 billion sale was used, in part, to fund growth opportunities. Conoco Inc., a petroleum company purchased for USD$8 billion in 1981, was sold earlier in 1999.

3.5.4 Conclusions

In summary, the technology has been developed, complete product supply chains have been established, and product applications have been developed that are cheaper, better performing, and more environmentally safe than traditional petroleum-based plastics. These new technologies and products will have a profound impact on Canada's manufacturing sector.

This is a highly competitive and dynamic market involving large multinationals and integrated global supply chains.

To compete successfully, Canada's strategy must focus on developing a more positive business climate. Targeted reduction in taxes on plant capital construction, accelerated depreciation allowances, and other financial issues must be re-examined. Competition to land one of these new bioplastics plants will be fierce and will provide the "winner" with access to a global supply chain with enormous scientific and technical expertise, manufacturing know-how, and a global network of product manufacturers.

3.6 Platform chemicals[79]

3.6.1 Market analysis

Five key platform chemicals — ethanol, lactic acid, sorbitol, succinic acid, and luvulenic acid — have become a focus of interest in the US. These platform chemicals are of great potential importance because they can be used to create intermediate chemicals and derivatives with additional product and market potential. For each platform chemical, we have summarized in Table 6 (next page) some of the intermediate chemicals and derivatives, their applications, price per pound, potential market size, and impact on the environment.

- Lactic acid has a potential worldwide market of 1.4 million tonnes.
- The potential US market for sorbitol is 226,800-272,100 tonnes with a world market estimated to be 544,300 tonnes. Polyols like glycerol, propylene glycol and ethylene glycol can be made from sorbitol. Glycerol and propylene glycol each have a market of 544,300 tonnes/yr. Ethylene glycol has a market of 7.7 million tonnes/yr.
- Succinic acid is still a number of years away from commercialization. Two attractive chemical derivatives are polyvinyl pyrrolidinone (PVP), used in pharmaceuticals, toiletries, paper, beverages and detergents, and itaconic acid which is used in polymeric fibre blends to add toughness and abrasion resistance. The market for PVP is estimated to be 23,000 tonnes/yr and itaconic acid is estimated to be 9,000 tonnes/yr worldwide.
- Levulinic acid derivatives MTHF (a fuel oxygenate) and DALA (a biopesticide) are thought to have 91,000-181,000 tonnes/yr markets.

[79]For further details see: Utilization of Corn-Based Polymers: Plastics from Renewable Resources Offer Significant Commercial and Environmental Benefits. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 2001; Products from Wheat Milling By-Products: Mill Feed Can be A Source of Renewable Feedstock for High-Value Chemicals. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 2001; Catalytic Upgrading of Glucose: Water-Based Catalytic Processing of Corn-Derived Glucose Will Offer a New Route to Commodity Chemicals. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 2001; New Continuous Isosorbide Production from Sorbitol. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. September 2001; Production of Succinic Acid From Wood and Plant Wastes: New Bacteria Will Be Used as a Biocatalyst to Produce Succinic Acid From Biomass. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 1999; Chemicals from Lignocellulose: Biomass Feedstocks Will Be Used to Produce A Variety of Chemical Products. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 2001; Manufacturing of Industrial Chemicals From Levulinic Acid: A New Feedstock for the Chemicals Industry: Inexpensive Biomass Material to Be Developed Into A Variety of Products. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 1999; Fractionation of Corn Fibre for Production of Polyols: Corn Fiber Fractionation Will Provide Low-Cost Chemical Feedstock. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 1999; Dennis J. Miller and Brian Doidge. Biochemicals from Corn: Developing a Biochemical Industry Based on Corn in Ontario. Ridgetown College, University of Guelph. March 31, 2000.

Table 6: Examples of major platform biochemicals

Intermediates and derivatives	Market applications	Price per lb (USD$)	Potential market size
Lactic acid			
Lactic acid is created through the fermentation of glucose; other chemical pathways: < polymerization to polylactic acid < dehydration to acrylates < dehydration then hydrogenation to propanoic acid < hydrogenation to propylene glycol < condensation to 2,3-pentanedione < oxidation to pyruvic acid.	< lactic acid used as a food acidulant < lactic esters used as a solvent < polylactic acid used for plastic fibres, packaging, and films < acrylic acid (and its esters) used for acrylate polymers and plastics < PG used as a nontoxic antifreeze, and monomer for plastics < 2,3-pentanedoine used as a flavour agent, biodegradable solvent, photoinitiator, and < chemical intermediate < pyruvic acid used as a food acidulant	< polylactic acid sells for $1.00-$1.50/lb (projected) < $0.50/lb for acrylic acid < $0.65/lb for propylene glycol < $30-50/kg for 2,3- < pentanedione (as a < flavour agent)	< 50 million lb/yr for lactic acid food uses < 300 million lb/yr for polylactic acid (short term) < potential 3 billion lb/yr for acrylic acid if lactic acid production costs can be reduced from USD$0.25/lb to USD$0.15/lb < potential 1.2 billion lb/yr for PG if lactic acid production costs can be reduced to USD$0.15 - USD$0.18/lb < <50,000 lb/yr for 2,3-pentanedione (as a flavour agent)
Sorbitol			
Sorbitol is created through the catalytic hydrogenation of glucose.	< confectioneries < oral care products < pharmaceuticals < vitamin C < polymers < surfactants	< 70% wt. aqueous solution $0.25/lb < crystalline solid - $0.73	< US - 500-600 million lb/yr < worldwide - 1.2 billion lb/yr < annual growth of 3-4%
Commodity polyols including: < glycerol (G) < propylene glycol (PG) < ethylene glycol (EG) < are created through catalytic hydrogenolysis (hydrocracking).	< PG applications: - nontoxic antifreeze - monomer for plastics - copolymerization of isosorbide and PET to sPET	< PG - $0.65/lb < EG - $0.26/lb (price is low) < G - $0.60	< not commercialized at present < PG - 1.2 billion lb/yr (the most promising) < EG - 17 billion lb/yr worldwide < G - 1.2 billion lb/yr (market is unstable) < 20% of world PG market would require 20-25 million bushels of corn

Table 6: Examples of major platform biochemicals

Intermediates and derivatives	Market applications	Price per lb (USD$)	Potential market size	
Succinic acid				
Fermentation of glucose to succinic acid derivatives: < salts, esters, anhydride < 1,4-butanedoil (BDO), tetradydrofuran (THF), and < gamma-butyrolactone (GBL) < 2-pyrrolidinones < itaconic and citraconic acids	< succinate salts used as deicing agents and in food applications (HaloSalt) < esters used as industrial solvents and paint removers < BDO, THF, and GBL used as monomer precursors for polybutylene terephthalate (PBT) and polytetramethylene ether glycol (PTMEG) < 2-pyrrolidinones used as solvents, plasticizers, and coalescing agents for polymer emulsion coatings and polyvinyl pyrrolidinone (PVP) < PVP is used in pharmaceuticals, cosmetics, toiletries, textiles, paper, beverages, and detergents < itaconic acid used as an additive in polymeric fibre blends to add toughness and abrasion resistance < polyitaconic acid is a < "superabsorbent"	< $0.43/lb for maleic anhydride which is a starting chemical for PBT and PTMEG < PVP sells at $3.00- < $8.00 depending on grade < itaconic sells for $2.00/lb	< PVP estimated at 50 million lb/yr < itaconic has 20 million lb/yr market worldwide	
Levulinic acid				
Levulinic from waste cellulose < acid hydrolysis to C5 and C6 sugars < dehydration using H2SO4 < three technologies: - Arkenol Inc. - DOE Battelle North West Labs - Biofine, Inc. < hydrogenation of levulinic acid results in methyltetrahydrofuran (MTHF) < oxydation of levulinic esters results in organic acids: - succinic - malonic	< alpha- and beta-angelicalactones, levulinate esters, which are used as plasticizers and flavoring agents < MTHF is fuel oxygenate and octane enhancer that may be a replacement for MTBE < delta-amino levulinic acid (DALA)	< levulinic acid sells for $2.00/lb (cost of production projected to be $0.20) < new research aimed at reducing costs to $0.04 to $0.10/lb	< MTHF and DALA expected to increase the market for levulinic acid by 200 to 400 million lb/yr	'

3.6.2 Public policy

Platform chemicals offer a number of public economic, environmental, and social benefits.

The new bioprocessing production processes for biochemicals offer chemical companies significant economic benefits, including:

- lower capital costs
- lower operating costs (fewer and safer wastes, reduced energy consumption, reduced number of processing steps)
- reduced cycle time to process improvements and new products
- new products that cannot be made now using traditional chemistry
- higher performing, lower cost products for downstream manufacturers
- higher profit margins
- greater shareholder value.

The environmental benefits include:

- use of renewable feedstocks from agriculture
- less raw material per unit product
- lower energy use
- fewer toxic wastes
- reduced GHG emissions.

Because agricultural feedstocks are bulky and therefore expensive to transport, future processing plants are likely to locate close to the source of raw materials (i.e., agricultural areas). The Cargill Dow PLA plant, for example, was located in Blair, Nebraska, close to corn production.

The rural economic development benefits are also likely to grow over time as the initial biochemical plant evolves into a biorefinery that produces many biochemicals and products. An example would be the Archer Daniel Midlands biorefinery in Decatur, Illinois, which produces ethanol and a host of other biochemicals.

An example of the kinds of direct rural economic development impacts that will follow from the location of platform chemical manufacturing has been described by Pat Gruber of Cargill Dow Polymers. In the case of a PLA plant, these benefits would include:

- a series of regional feedstock plants
- chemical, energy, and biofuel plants
- fibre, film, and sheet converting plants
- waste and water treatment plants
- additional warehousing
- increased transportation.

Economic multiplier effects will add even greater benefits for rural economic development.

For all these reasons, the US government has invested in R&D aimed at improving markets for biobased chemicals. The focus has been on reducing production costs and improving product development. The US Department of Energy's Office of Industrial Technologies, for example, has sponsored a considerable amount of R&D involving research partnerships among university and government laboratories and industry. Some examples are summarized in Table 7.

Table 7: US universities and government laboratories and companies engaged in biochemical research and development

Universities/government	Industry associations/companies
< Colorado School of Mines — (PLA) < from dextrose; multi-disciplinary graduate-level biobased R&D program < NREL — PLA from dextrose; high grade cellulose; MTHF and DALA from crop residues; polyols from corn < Pacific Northwest National Laboratory — propylene glycol from glucose; propylene glycol from sorbitol or lactic acid; sPET from copolymerization of isosorbide and PET < Michigan State University — propylene glycol from sorbital or lactic acid; multi-disciplinary graduate-level biobased R&D program < Pittsburg State University — polyaldehyde from soybean and other vegetable oils < Argonne National Laboratory — succinic acid from crop residues; green solvents (lactate esters); ethyl lactate from rice straw < Oak Ridge National Laboratory — succinic acid from crop residues; polyphenols < MIT — polyphenols < Polytechnic Institute — polyphenols < UCLA (Berkeley) — polyphenols < California Institute of Food and Agricultural Research (UCLA, Davis) — ethyl lactate from rice straw < California Energy Commission — ethyl lactate from rice straw	< Cargill Dow LLC — PLA from dextrose < Mennel Milling Company — propylene glycol from glucose < Pendleton Flour Mills, Inc. — propylene glycol from glucose < US Corn Growers Association — propylene glycol from sorbital or lactic acid; polyols from corn < Iowa Corn Promotion Board — sPET from copolymerization of isosorbide and PET < BF Goodrich Performance Materials Division — polyaldehyde from soybean and other vegetable oils < Arkenol, Inc. — succinic acid from crop residues < Applied CarboChemicals, Inc. — succinic acid from crop residues < Altus Biologics, Inc. — polyphenols < Dow Chemical Co. — polyphenols < Eastman Chemical Company — polyphenols; high grade cellulose < Enzmol International, Inc — polyphenols < NTEC — green solvents (lactate esters) < BC International Corporation < Collins Pine Company — ethyl lactate from rice straw < VerTec BioSolvents — ethyl lactate from rice straw < Biofine Corporation — MTHF and DALA from crop residues < Chemical Industry Services — MTHF and DALA from crop residues

3.6.3 Science and technology

New advances in the use of waste products (e.g., mill feed, crop residues, etc.), the development of new catalysts and biocatalysts, new membrane and separation technologies, and chemical purification and recycling of waste streams are some of the areas being studied in the US.

Mennel Milling Company, Pendleton Flour Mills, Inc., and the US Pacific Northwest National Laboratory have formed a partnership to develop economical methods to recover starch from mill feed and convert it (starch) to either lactic acid or propylene glycol.[80]

Michigan State University, the US Corn Growers Association, and the Pacific Northwest National Laboratory have formed a partnership to synthesize and characterize catalysts and determine the process economics for producing propylene glycol from either sorbital or lactic acid.[81]

The Iowa Corn Promotion Board and the Pacific Northwest National Laboratory are studying the copolymerization of isosorbide and PET (polyethylene terephthalate) to form sPET, a product that is stronger and more rigid. Because of these performance qualities, food and beverage containers now made with PET could be redesigned to use less material.[82]

The Argonne National Laboratory, Arkenol, Inc., Applied CarboChemicals, Inc., and the Oak Ridge National Laboratory have formed a cooperative research and development agreement (CRADA) to ferment sugars from wood and crop residues using a new E. coli strain called AFP111. The micro-organism's metabolic pathways are being genetically engineered to efficiently convert different types of sugars into succinic acid.[83]

MIT, Oakridge National Laboratory, Rensselear Polytechnic Institute, UCLA (Berkeley), Altus Biologics, Inc., Dow Chemical Co., Eastman Chemical Company, and Enzmol International, Inc. are involved in a pre-competitive research project involving the enzymatic processing of polyphenols. Currently, formaldehyde (a toxic and carcinogenic chemical that is difficult to recycle) is used for producing polyphenols.[84]

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[80] Products from Wheat Milling By-Products: Mill Feed Can be A Source of Renewable Feedstock for High-Value Chemicals. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy. US Department of Energy, February 2001.

[81] Catalytic Upgrading of Glucose: Water-Based Catalytic Processing of Corn-Derived Glucose Will Offer a New Route to Commodity Chemicals. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 2001.

[82] New Continuous Isosorbide production from Sorbitol. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. September 2001.

[83] Production of Succinic Acid From Wood and Plant Wastes: New Bacteria Will Be Used as a Biocatalyst to produce Succinic Acid From Biomass. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 1999.

[84] Biocatalysis Under Extreme Conditions for the Chemical Industry: Enzymatic Transformations Will Be Applied to Critical Chemical processes. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 1999.

Cellulose is already a high volume renewable feedstock used by the chemical industry to produce chemicals, plastics, food additives, fibres, and textiles. Over 680,300 tonnes of highly pure cellulose are required each year. The traditional methods of separating cellulose from other wood components (lignin and hemicellulose) include sulfite and prehydrolysis kraft pulping. The Eastman Chemical Company, the NREL, and a major US producer of chemical grade cellulose are working on a new technology called Clean Fractionation,[85] which uses an organic solvent and water to make the separation.

The Argonne National Laboratory and NTEC, Inc. have formed a partnership to produce nontoxic "green solvents" from lactate esters. Carbohydrates are fermented to form lactic acid, which is then esterified to form lactate esters. The process uses a new membrane-based process for producing lactate esters. Electrodialysis and pervaporation are used to avoid salt formation, increase product purity, and reduce undesired by-product formation. This process won the 1998 Presidential Green Chemistry Challenge Award and the 1998 Discover Magazine Award for Technology Innovation — Environment.[86]

The Argonne National Laboratory and NTEC EDSep, Inc. are working together to expand the application of electrodeionization, an established technology, to the chemical industry for the purpose of economically purifying products, recovering waste, and recycling water. Electrodeionization has been applied primarily to purifying water for the pharmaceutical, semiconductor, and biotechnology sectors.[87]

3.6.4 Conclusions

Platform chemicals offer significant opportunities for economic, environmental, and social benefits. The commercialization of lactic acid is well advanced. Other platform chemicals, like succinic acid, also show promise.

The US government has focused their research efforts on forming public/private sector partnerships aimed at developing new technologies that can reduce production costs and improve product development. A similar approach to R&D should be considered in Canada.

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[85] Clean Fractionation for the production of Cellulose Plastics: Economical Separation Technology is More Energy-Efficient and Produces Valuable Co-Products. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. September 2001.

[86] Novel Membrane-Based Process for Producing Lactate Esters - Nontoxic Replacements for Halogenated and Toxic Solvents. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 1999.

[87] Advanced Electrodeionization Technology for Product Purification, Waste Recovery, and Water Recycling: Electrotrodeionization has the Potential for Numerous Industrial Applications. Project Fact Sheet. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy. February 1999.

3.7 Adhesives

3.7.1 Market analysis

The global adhesives industry represented over USD$20 billion of sales in 1998. US sales were over USD$8 billion in (1998), with a 3% average annual growth rate. The Canadian adhesive and sealants industry is broken into two classifications — industrial and consumer. The industrial segment is estimated to account for about 80% of the Canadian market. Total shipments in 2000 were CAD$470 million, and 2,350 people were employed at 40 establishments.

Canadian export shipments totalled CAD$225 million. Over 90% of both import and export trade occurred with the US. Exports grew from 15% of total shipments in 1990 to 48% of total shipments in 2000. Imports grew from approximately 40% in 1990 to 65% of domestic consumption in 2000. The complete elimination of tariffs under NAFTA on January 1, 1993 has aided the increase in Canada-US adhesive and sealants trade.

Future markets are being driven by industry's need for low VOC content, use of annually renewable resources (natural materials), biodegradability, repulpability, recyclability, and compatibility with waste management infrastructure.

3.7.2 Public policy

Restrictive legislation governing the use of harmful VOCs has been introduced in Europe and in several states in the US. Canadian legislation is following along similar lines, but law makers and company officials face a difficult situation. Until suitable replacements are found to these functionally effective solvents, tighter legislation in Canada will certainly drive production elsewhere.

3.7.3 Science and technology

New product developments in the adhesive and sealants industry have been driven by environmental, health, and safety concerns. Many conventional adhesives contain VOCs. When combined with nitrogen oxide in the atmosphere and exposed sunlight, VOCs are known to cause smog (ground level ozone). Ozone is a major cause of respiratory problems in humans, and efforts are under way to reduce its concentration in populated regions throughout North America.

Water-borne and hot-melt adhesives and sealants offer a solution to VOC emission problems, and their use is likely to expand at the expense of solvent-borne products. A more recent initiative likely to impact the adhesive and sealants industry is the move by industry and government to support the development and use of biomass materials to replace the dependence upon fossil-based resources for fuels, power, and chemical products. While in its earliest stages, this initiative has the support of chemical industry leaders and government energy and agricultural agencies in the US.

3.7.4 Conclusions

While the consumption of low-cost adhesives and sealants is likely to remain flat or decline, higher performance components of the industry have good prospects for growth. Hot-melt packaging adhesives suitable for high-speed processing lines are expected to grow. In the construction industry, the use of adhesive for flooring, wall board, and paneling installation can improve performance and aesthetics. Further, in the automotive and aerospace industries where polymeric composites are replacing metals, adhesives will replace mechanical fasteners. Conventional metal construction, adhesives, and sealants can overcome corrosion and vibration noise associated with conventional fasteners and spot welding.

Few Canadian adhesive and sealant companies perform R&D for advanced adhesive materials. Many depend on the efforts of research centers of parent companies located in the US and Europe for the products that will define future adhesive and sealant compositions. As the effects of industry globalization and technology advancements driven by environmental, health, and safety concerns are felt by the general industry, Canada could find itself at a disadvantage as a technology follower.

However, a developing international trend to increase the utilization of biobased materials in the manufacture of industrial products could bode well for the Canadian adhesive and sealants industry. A concerted effort by industry and government to develop and implement "sustainable products" from biomass resources is likely to create a demand for agriculturally produced feed stocks. Canada, with an abundance of natural resources and high level of agricultural technology development, is well positioned to respond to this developing opportunity.

Prime target materials for biobased adhesives include starch, protein, fats, lipids, and complex carbohydrates, all of which are found in abundance in Canada's major crops. Wheat, barley, canola, flax, soybeans, corn, field peas, etc. are all candidates. Of great interest is that in many cases, waste streams of both plant and animal processing can be used as either a primary source of raw material or, in some cases, a low-cost adjunct in adhesive formulations.

The potential to use locally produced adhesives in composite boards and construction materials using Canadian straw and forest resources provides what would appear to be an attractive business opportunity provided that the quality and price of the local biobased adhesives are competitive with petrochemical-based products. The fact that vegetable protein-based adhesives were used as standard practice in the first third of the 20th century bodes well for their reintroductions in the 21st century as environmental concerns regarding the current products escalate.

3.8 Surfactants

3.8.1 Market analysis

According to a recent report by ACTIN, the worldwide market for surfactants in the year 2000 was slightly over £8 billion, or about 9 million tonnes, and growing at an annual rate of about 7.2% per year. A breakdown of that market, as presented in Table 8, shows that household detergents account for almost half of the surfactant market.

Table 8: Global surfactant market

	Value (£ million)	Volume ('000 tonnes)
Household detergents	3,200	4,240
Industrial and institutional cleaning	490	570
Personal care	1,130	960
Crop protection	310	200
Oilfield	440	460
Paints and coatings	160	170
Textile spin finish	230	170
Textile auxiliaries	510	530
Construction	220	500
Emulsion polymerization	280	310
Food	225	220
Plastic additives	65	40
Pulp and paper	110	120
Other	830	630
TOTAL	8,200	9,120

Source: Based on information from Unichema (2000).

Over this same nine-year period, the oleochemical portion of the surfactant market rose in the EU from 30% to 45%, bringing the world average up to about 50%. This significant swing would appear to be a result of European consumers choosing biobased products in the important consumer markets and increased use of soaps, cleaning compounds, and detergents in far eastern countries where oleochemical-based surfactants are the starting material of choice. The most recent data for manufacturing in the Canadian and US soap and cleaning compounds industry indicates that manufacturing shipments from 1990 to 1998 actually declined by more than 10% (CAD$1.7 billion to CAD$1.5 billion) for Canada while increasing 72% (CAD$28.9 billion to CAD$49.8 billion) in the US (average growth of 7% per annum). As of 1998, US production was more than 33 times that of Canada. During the period from 1990 to 1998, the net negative balance of trade for Canada (vs the US) rose from CAD$32.6 million to CAD$238.3 million.[88] The North American market is still dominated by petrochemicals where price advantage is chosen over environmental concerns.

Although dozens of large national and international corporations are involved with surfactants, a few multinational enterprises (MNEs) dominate the industry. Shell Oil is the major player in surfactant production whereas Procter and Gamble is the dominant player in the manufactured products sub-sector. Virtually all Canadian manufacturers are subsidiaries of US or international corporations and therefore, as such, have little influence over development of the industry.

The Canadian surfactant industry may present a few opportunities. For example, the current overcapacity in the oilseed crushing industry may make it possible to satisfy the demands of the food industry with the two-thirds of oil production normally recovered by pre-pressing while targeting industrial markets, and with the remaining one-third, which is now recovered by the undesirable hexane extraction.

3.8.2 Public policy

In the US, the most likely policy makers with specific impact on the production of oleochemical surfactants (and other derivatives) are state legislatures in the US farm states. The bold measures in limiting the release of VOCs, which were taken by the California legislature, had a very marked impact on the surfactants industry.

At the federal level, both Canada and the US have placed restrictions on the use of VOCs, but have fallen short of banning these substances. Both nations are relying more on the threat of legislation to encourage manufacturers to change their formulae. This is not the case in Europe where legislated banning of VOCs has occurred.

3.8.3 Science and technology

Surfactants are organic chemicals whose structure is characterized by the presence of an oil-loving ("hydrophobic") and a water-loving ("hydrophilic") part. The hydrophobic portion, usually a long hydrocarbon chain, is the more important for the behaviour of surfactants. Oil (which is all hydrophobic) and water do not mix. Surfactants are mostly hydrophobic and have only a limited solubility in water. If the solubility limit is exceeded, the surfactant molecule is "desperate" to leave the inhospitable aqueous environment and adsorbs at any surface that is less polar than water: the air-water interface, the walls of the vessel, fabric, etc. When these surfaces are covered and can accommodate no additional surfactants, the latter form a "wagon train camp" structure in water, with the hydrophobe at the centre and the hydrophilic portions facing outward toward the aqueous environment. These structures are called micelles.

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[88]Source: Statistics Canada, Industry Canada, and the US Department of Commerce.

The most important consequence of the above is that surfactants are effective at extremely low concentrations in the range of 100 ppm or so and hence find application in almost all industrial processes in addition to their use in cleaning products.

Major starting materials for surfactants include ethylene, benzene, normal paraffins, and natural fats and oils. The first three are petrochemicals, and the fats and oils are oleochemicals derived from renewable plant and animal sources. From these basic materials, several different chemicals are produced that are converted to surfactants. In turn, these surfactants become the key active ingredients in a wide range of consumer products.

3.8.4 Conclusions

Palm kernel oil, coconut oil, and palm oil are the principal sources of oleochemical surfactants, but virtually any oil bearing crop could provide the detergent-range carbon chain. In addition to the petro- and oleochemical feedstocks, proteins and carbohydrates can be used for certain specialty surfactants, although at higher production costs.

Current canola varieties that work well in certain industrial markets are not particularly suited for the surfactant industry. However, through genetic engineering, or perhaps intermediate processing, the desired chemical structure may be achieved. This dual processing approach, if adopted, has the potential to produce a higher quality food oil and improve overall returns to the crusher.

Opportunities may exist to develop competitively priced oils that are either naturally suited for use in niche surfactant markets or that can be bred to produce oils that meet unique requirements. Flax, sunflowers, mustards, and crambe (Abyssinian mustard) have a history of production on the prairies, and all are capable of producing oils of interest to the surfactant industry. The big challenge for any of these options will come from the very competitive prices found for palm, coconut, and soya oils and for petrochemical feedstock.

Predictions of future markets and supply opportunities are always difficult to make with certainty. However, given the trends in Europe toward replacement of petrochemical-based surfactants with oleochemical-based products, there is reason to believe that the oleochemical segment of the North American surfactant industry will continue to expand at a rate well above that of population growth.

3.9 Paints and coatings

3.9.1 Market analysis

Paints and coatings are formulated products. The base material, known as the binder or vehicle, is the film-forming ingredient that largely determines the performance of the coatings. In the past, binders were largely based on natural products such as linseed oil and natural resins. Today, to achieve higher performance, almost all binders are based on synthetic polymers.

Other ingredients in the manufacture of commercial paint include pigments to impart colour, inert fillers to extend the product, liquid diluent to control the viscosity, and a variety of small quantity additives needed for application or performance reasons. The diluents for liquid paints can be volatile organic material (solvents) or water.

The paints and coatings industry in the North American Free Trade Agreement (NAFTA) region is estimated at approximately CAD$40 billion in total, including both domestic and export sales, and has an annual growth rate of approximately 2%. The US is estimated to account for nearly 90% of total production. The major use segments include original equipment manufactures (OEMs) and architectural paints, which together make up approximately 75% of total paint volume. Special purpose and miscellaneous coatings account for the remaining 25%. The major international paint companies serving in the region are located in the US. R&D initiatives for the industry originate at these companies.

A decline in solvent-borne paints and coatings over the past decade has resulted in a reduction in the demand for vegetable oils used in the manufacture of solvent-based paints. However, a recent chemical industry initiative to make greater use of biobased raw materials may reverse this trend in the coming decade. Additionally, the US government has enacted legislation supporting the development and use of biobased products for industrial use. It seems that US chemical industry members and the US government will have a major influence on the direction of new biobased raw material development and commercialization.

The Canadian paint industry is mature, and growth will match the pace of the economy in general, but industry shifts may potentially have an impact. For example, environmental health and safety considerations are driving the product development efforts of paint industry members, and costs associated with environmental permitting and hazardous waste handling or disposal will continue to increase. Although progress in the reduction of VOCs from paints has been made, continued increases in VOC-generated smog will force additional reductions in allowable paint solvent emissions over the next decade. Paint industry R&D labs continue to search for cost-effective routes to lower VOCs from paints and coatings.

Another change in the paint industry is the significant increase in large mass market retail sales channels like Wal-Mart and Home Depot. The convenient, low-cost availability of paint at the mass marketers will continue to reduce the demand for independent paint stores. Additionally, because of the powerful purchasing leverage of mass market channels, paint manufacturers face slimmer margins in transactions with these companies. In fact, a consolidation of the paint industry segments resulted from the cost of environmental and regulatory compliance and profit loss due to mass marketers competition. This consolidation is likely to continue.

In their global industry analysis published in January 2002, MarketResearch.com projects that world demand for paints and coatings will rise at a rate of 3.4% per year to 28.5 million tonnes in 2005 and that the global paint industry will be valued at more than USD$138 billion. MarketResearch.com further reports that the US domestic market was USD$14.9 billion in the year 2000, having grown at an average annual rate of about 2.7% over the previous five years.

The Canadian paints and coatings industry grew through the 1990s at a compound annual growth rate of 1.58%, while US manufacturing shipments grew at 8.51%. Clearly, with a US domestic industry of USD$14.9 billion (2000) and manufacturing shipments of USD$37.3 billion (1998), US companies are exporting more than half of their production. The bright spot in the Canadian industry is in exports, which during this period, increased from CAD$65.5 to CAD$389.3 million. This represents a compound annual growth rate of 25.0%. Imports grew at 11.9%. However, the growth in Canadian exports has levelled off during the past two years.

3.9.2 Public policy

The elimination of harmful organic chemicals in paints and coatings is a high priority for both industry and government. As suitable ingredients are found, industry will no doubt be quick to adapt.

3.9.3 Science and technology

Existing air pollution regulations require that vegetable oil derivatives used in paint binder formulations provide finished paints that are low in organic solvent emissions. Conversion to water-borne paint binders is a possible route to success, although the inherent water sensitivity of vegetable oil binders must be overcome first. Coating research centers are currently searching for solutions to this technical challenge.

Vegetable oil-based binders can provide improved performance in some paint applications, and where the cost and availability of the preferred oil are in balance, the possibility of new entries is very good.

Recent industry and government initiatives to promote "sustainable development" are expected to have a positive long-term effect on the use of vegetable oils in paints. New biogenetically engineered paths to vegetable oils better suited for paint manufacture are possible. However, research in this area will require substantial funding from government and industry sources.

Of existing vegetable oils used in paint polymers today, safflower oil and dehydrated castor offer a good balance of cure and colour stability. Linseed oil cures very rapidly but discolours badly. Canola oil, while having excellent colour stability, does not cure effectively at ambient temperature. Soya oil has some cure potential, but its tendencies to discolour make it a poor compromise for performance. Its primary attractions are availability and low cost.

The most unpredictable result of changes likely to occur over the next decade is the nature of biobased raw materials resulting from the genetic engineering of plants to produce oil. Past efforts in genetic engineering have sought to enhance production or improve food quality. As research is directed to genetically engineered new industrial chemicals, a fundamentally new technical platform is likely to be created. It now appears that the US chemical industry and the US government will largely determine the direction of this new science and resulting products.

Current R&D is unlikely to have a major impact on the level of vegetable oils used by the Canadian paints and coatings industry in this decade. Limited gains in the use of vegetable oils in water-borne paints and coatings will be offset by the continued reduction in the use of solvent-borne paints and coatings based on vegetable oil-containing binders. The net result is that there will be little or no growth in the use of vegetable oil by the paints and coatings industry in this decade.

3.9.4 Conclusions

Canada offers excellent production opportunities for several oilseeds (flax, canola, sunflower, soybean, mustard, crambe). Any one of these has the potential to become a major ingredient in the new generation of paints and coatings. Canada's research and farming communities are both experienced in developing new seed varieties, including genetically engineered products.

Where new agricultural crops become the raw material of choice, Canada offers pricing advantages, and where appropriate, isolated growing locations that ensure that genetic purity can be maintained and identity preserved supplies can be assured.

One old "stand-by" product, which has renewed potential for expanding the flax market, is linoleum, which is made of natural materials including linseed oil, resins, wood, cork powder, calcium, vegetable pigments, and hessian (jute). There are new interests in this material worldwide, especially in the EU, where the market is expected to increase from 36 millions m^2 in 1995 to 56 million m^2 in 2003. Linoleum has particular benefits in “high-tech” situations because it is anti-static. One kilogram of linseed oil is required for each m^2 of linoleum.[89]

The Canadian paints and coatings industry grows at the rate of the general Canadian economy. New product developments come primarily from US paint industry research centers and are highly influenced by prevailing air pollution regulations. Paint imports continue to become a larger percentage of domestic consumption.

The change from solvent-borne paint binders to water-borne binders has eliminated growth in the use of vegetable oils in the manufacture of paints and coatings. There are currently no new vegetable oil-based binder technologies that are likely to reverse this trend.

Commercial uses of new vegetable oil-based products are likely to begin to play a significant role in commercial paints and coatings manufacture by the end of this decade. The type of vegetable oil feed stocks used and the goals and objectives of the research projects funded in this decade will determine the paints and coatings application to which they will be adapted. Canadian government and industry research is required for Canada to have an influence on the long-term direction and impact of vegetable oil use in future paint and coating products.

With the prospect of major changes in paint and coating formulations in the coming decade, opportunities will likely arise for the supply of new, environmentally friendly raw materials and attract new processing plants geared to handle and process the new materials.

[89] IENICA (ref 1495) Summary Report — Oil Crops.doc August 2000.

3.10 Cosmetics

3.10.1 Market analysis

Crops such as oats, canola, and wheat are all used in the cosmetics industry. Numerous special crops and wild species also produce unique materials of interest to this industry. The sector is of further interest to the agricultural community as vegetable oils, starch, and proteins. Derivatives of these three basic components of plant materials also make up a significant portion of many cosmetics. The potential for GM plants further heightens the interest in this sector.

Over the past 50 years, the cosmetics sector has experienced phenomenal growth in sales and rewarding financial returns for industry leaders. World sales in the cosmetics and personal care industry in 1998 were reported to be USD$166.2 billion, of which North America consumed USD$35.8 billion or 21.5%.[90] Canada's manufacturing total of about CAD$1.1 billion and domestic disappearance of about CAD$1.8 billion each represent less than 1% of world production.[91]

The Canadian market has grown through the 1990s at an annual rate of 4.7%, while domestic manufacturing of cosmetics has only increased at an average annual rate of 1.4% per year.[92] Clearly, imports have satisfied the increased demand. On the positive side, domestic exports have risen at an average annual rate of 22.0% from 1990 to 1998, while imports have risen at an average annual rate of 19.1%. Free trade appears to have allowed both Canada and the US to specialize based on competitive advantage.

Substantial growth potential for this industry exists globally. As emerging nations generate wealth and personal income rises, personal care products will likely show relatively higher sales increases than many other manufactured goods. In contrast, for developed nations such as Canada, markets will remain stable. Year-to-year swings in disposable income, fads, and corporate marketing programs will all contribute to variations in sales, but market growth in the developed world will remain modest. This creates a barrier to entry since profit margins remain relatively low in a mature and increasingly competitive North American market.

Smaller companies have had difficulty breaking into the more lucrative segments of this industry because the Canadian and world markets are dominated by multinational corporations. Entry may depend not only on introducing something new and exciting, but also on cultivating a relationship with one of the MNEs for both marketing protection and product development resources.

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[90]Chemical Market Reporter. April 5, 1999.

[91]Care must be taken in comparing figures for different countries as there may be discrepancies in the classes or types of products that are included in this category.

[92]Statistics Canada.

3.10.2 Public policy

Health and safety issues are of major concern to the cosmetics industry. In recent years, the fears of animal-borne disease being spread through cosmetics has resulted in a rapid change in many formulations in which plant-based ingredients are used in replacement of animal-based substances. This action was led by the dominant companies in the industry, whom some would accuse of using the "threat" of a problem to introduce new product lines using a safe product marketing approach. Current focus is on the topic of GMOs and their safety. It is still not clear what stance the industry or governments will take on this matter.

Labelling issues are currently receiving considerable regulatory attention. Due to the globalization of this industry, companies are pressing governments for a standardized approach to product labelling and ingredient standards.[93]

3.10.3 Science and technology

This industry is marked by its ability to introduce new products that expand the bounds of the market. One possibility, for example, lies in the potential for new "cosmeceuticals," which are marketed for both medicinal and cosmetic properties. Unfortunately, little R&D is occurring in Canada as corporate research is largely done close to head offices.

3.10.4 Conclusions

There is potential to attract industry leaders to invest in new processing facilities based on Canada's generally supportive business climate and competitive cost structures. In particular, opportunities will exist for niche products and identity-preserved production for special applications. However, the potential for Canadian farmers to capture significant new markets currently appears limited due to the low volumes of farm production required and the limited processing that currently occurs in Canada.

3.11 Pharmaceuticals[94]

3.11.1 Market analysis

Like other sectors based on industrial chemicals, predictable shifts have occurred since the implementation of the Canada-United States Free Trade Agreement (CUSTA). Over the past decade, both imports and exports have risen dramatically. Canada's exports amounted to CAD$1.5 billion, or roughly one-third of production, in 1998. This is up from 1990 with an annual growth rate of 25% worldwide or 32.3% within North America. Despite this sterling export performance, Canada's trade deficit of CAD$2.7 billion has grown throughout the 1990s. Imports in 1998 were almost CAD$4.2 billion, increasing at an annual rate of 17.9% since 1990.

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[93] Personal communication with Carl Carter, Cosmetics Association of Canada.

[94] This brief overview of the pharmaceuticals sector only scratches the surface of this complex and important field. With the limited time and resources for this study, focus has been placed on those sectors where it was believed greatest benefit could accrue to the farming community in general. This does not imply that the pharmaceuticals sector should not receive a high level of attention with regard to its potential contribution to the overall Canadian economy.

One interesting sub-sector is self-care products, in which not only the active ingredient but also some of the carrying, or bulking, agents are derived from plant sources. The Nonprescription Drug Manufacturers Association of Canada (NDMAC) reports self-care product sales of CAD$2.9 billion or about one-quarter of the sector. It is reported that about half of these sales are manufactured in Canada.[95] As with many others, this sector is dominated by MNEs, virtually none of which have head offices in Canada. However, according to the NDMAC, the proliferation of products means that there is still a place for smaller firms. Unfortunately, most of the smaller companies serve only as marketing or sales agents for foreign companies.

3.11.2 Public policy

Concern for both personal and environment safety from both within and outside government has driven much of the research in this sector. This concern results in large measure from knowledge gaps relating to the genetic manipulation of plants and animals. There is need for a clear understanding of this topic as it relates to pharmaceutical preparations followed by the development of sound policy based on scientific fact.

Given the combination of the potential for high profits for the pharmaceutical companies and the very minimal impact that this industry might have on the farming community in general, it would appear that incentives for either the development of new products or the growing of target crops would be hard to justify from a Department of Agriculture perspective alone. However, given the overall importance of this sector to the Canadian economy, it appears prudent for all branches of government to work collaboratively in seeing that the research and investment climate is such that those individuals and corporations willing to invest in this sector give serious consideration to making their investments in Canada. A full harmonization of the Canada/US regulations concerning all aspects of this industry would surely be an important first step in causing this to happen.

3.11.3 Science and technology

There is expanding interest in using plants that, through traditional or genetic engineering methods, have been bred to produce increased quantities of biologically and chemically active molecules. One such class of molecules is sterols. These naturally occurring chemicals, found in cells and membranes of all oil-producing plants, have demonstrated the ability to lower blood cholesterol in humans.[96] The recovery of sterols along with other bio-active substances, such as linoleic acid, essential amino acids and perhaps even lignan from the waste or feed stream of oilseed crushing, or cereal fractionation, could add significantly to the profitability of that whole production/processing chain. Cereal starch in particular has the potential to be recovered and converted into a wide range of end products, including both carriers and active ingredients in many pharmaceutical preparations.

[95] Personal communication with Carl Carter, NDMAC.
[96] Forbes Medi-Tech web site.

3.11.4 Conclusions

From an overall business perspective, the pharmaceutical industry shows tremendous potential for growth, fuelled by increasingly sophisticated and demanding health care consumers. From an agricultural perspective, growth potential is limited because minimal acreage is required to supply this market. Additionally, much of the production will occur within factories and not in the farmers' fields because of the critical need for a secure supply of many of the higher-valued ingredients. Fermentation vats and controlled environment growing rooms will be the new "agriculture" for many of the supply items.

Niche opportunities also exist for the provision of contract growing services to drug companies for selected products. For example, Sembiosys, a Calgary-based company, has developed genetically engineered oilseed crops that produce "designer" proteins that can be recovered from the oil fraction during processing. These high-valued materials are being sold to both pharmaceutical and cosmetic companies. Contract field production of these new varieties could provide options for a few selected farmers. Experimentation in the US on genetically altered corn led to the production of human antibodies that could be used in attacking cancerous cells in humans. From a farming perspective, however, the scope is somewhat limited because 30 acres would satisfy all of the needs the US.[97] Further, crop land and conventional animal-rearing must compete against other options such as vat production of microbes, intensive controlled environment growing of plants, and high-tech animal facilities.

Undoubtedly, medical research represents a key Canadian strength. Several universities, including the University of Toronto, McGill, the University of Saskatchewan, and the University of Ottawa, have contributed greatly to the field. Ongoing efforts to convert this knowledge into marketable products have begun to pay significant dividends. Ongoing linkages among AAFC, Industry Canada, and leaders in medical research will be a critical determinant of any expanded role for Canadian farmers and investors in this potentially lucrative sector.

3.12 Biopesticides

3.12.1 Market analysis

Pesticides are used in crop protection, regulation of plant growth, control of insects, treatment of seeds, control of algae in swimming pools, and preservation of wood and textiles.

Sales of crop protection products in Canada amounted to CAD$1.31 billion in 2000.[98] Although sales had increased 53% in the eight years prior to 1998, 2000 sales were down 3.1% for the year, following a decline of 4.9% the previous year. Herbicides constituted 81% of sales, fungicides 9%, insecticides 5%, and specialty products 5%.

In 1996, 10 Canadian establishments, mostly subsidiaries of multinational companies, were identified as producers of pesticide chemicals. Most of the activity in Canada is in formulation

[97] W. Wayt Gibbs, *Scientific American*, November 1997.
[98] Crop Life Canada, http://www.croppro.org

and not in the development and production of active ingredients. Uniroyal is the only multinational producing active ingredients in Canada (an antifungal seed treatment chemical). The 10 establishments had shipments of CAD$262 million of which 44% was exported.

The British Crop Protection Council identifies five types of biopesticides:[99]

- **Natural products.** These are naturally occurring chemicals that have been commercialized for use in crop protection strategies.

- **Pheromones, insect repellents, and anti-feedants.** The term pheromone describes naturally occurring chemical attractants for insects used to disrupt mating, lure and kill, or monitor populations. Natural chemicals may also have the effect of repelling insects and discouraging them from feeding.

- **Living systems.** Examples are baculoviruses, protozoa, bacteria, fungi, and nematodes used in crop protection.

- **Insect predators.** These are insects that are sold commercially for use in controlling damaging insects and mites in greenhouses and outdoor agriculture. Both predators and parasites are included.

- **Genes.** Transgenic or genetically modified crops with benefits for pest control are those in which genetic material from another source than the genes normally present in the plant species has been inserted into the crop to (a) confer tolerance to a particular herbicide that would otherwise kill the crop or (b) confer resistance to attack by viruses or insects. An example is the introduction of a particular type of EPSP gene, obtained from the bacterium Agrobacterium tumefaciens, into canola plants. This gene, completely alien to the normal canola plant species, conferred resistance to the broad spectrum herbicide glyphosate in the transgenic canola plants. At the normal rates of application of glyphosate herbicide, weeds were controlled, while the transgenic canola showed no adverse effects.

Within the broader context of integrated pest management, biopesticides are but one of a range of strategies that producers may use for pest control. A typical integrated system could contain some of the following elements:

- synthetic pesticides
- natural pesticides
- pheromones, insect feeding deterrents
- conventional crop breeding to enhance resistance to a particular disease or insect pest

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[99]Copping, L.G., ed. 2000. The BioPesticide Manual. British Crop Protection Council, BCPC Publications Sales, Bear Farm, Binfield, Bracknell, Berks. RG 42 5QE, UK. Foss, K. 2002. Fewer Canadians working the land, farming report says. *Globe and Mail*, February 23, p. A7.

- bioengineering approaches or cell culture techniques to breed crops resistant to insects or resistant to specific herbicides
- forage crops and cover crops that reduce weed populations—e.g., a new bioherbicide forage barley is under development at Brandon AAFC
- physical collection of weed seeds by techniques such as chaff collection or the new harvest system called the McLeod Harvest system developed in Manitoba. There is potential for a new machinery manufacturing business in Canada.
- Least disturbance seeding methods that can leave weed seeds on the soil surface to be destroyed by insects or disease. The stubble residue may be used as a substrate for growth of a specific micro-organism to kill weeds. Zero till equipment manufacture is already a significant business in Canada.
- Selected spraying of weeds using new techniques such as global positioning systems (spray only patches of weeds) or photoelectric weed detection systems that only turn on the weed sprayer when weeds are detected.
- Agronomic techniques such as crop rotations, tillage timing, depth and type, seeding rate, timing of spraying.
- Physical barriers that reduce insect and disease damage, enhance crop growth, and reduce the effects of drought and frost. Special kaolin clay sprays have been developed in the US that show considerable promise for protection of orchard crops such as pears and apples. Products are now commercially available.
- Computer programs and other information type aids to assist farmers in designing improved pest control systems.

3.12.2 Public policy

To our knowledge, no major public policy initiative in Canada is focused on developing markets for **natural** biopesticides made from crops. The AAFC research stations in the prairies have informally worked their knowledge networks out west to piece together a number of very interesting possibilities for pea flour-based biopesticides. This research is discussed below.

3.12.3 Science and technology

Several recent pest control strategies may have development potential in Canada.

A natural insecticide and feeding deterrent in peas

Paul Fields of AAFC’s research centre in Winnipeg, Manitoba, is developing a biopesticide made from pea flour extracts. The extract, when applied at 0.1% to cereal grain, killed 90% of rice weevils and 50 to 70% of rusty grain beetles. The extract has been patented, but it may take about three more years to develop a commercial product. Health Canada then has to approve it.

If a quarter of the annual small cereal grain production in Canada (roughly 40 million tonnes) needed to be treated with the new pea insecticide during storage, it would create a market of 10,000 tonnes per year requiring about one million tonnes of peas to be processed. Pea production in Canada during 2001 (a drought year) was 2.2 million tonnes, so a production infrastructure already exists. The processed peas, after removal of the biopesticide fraction, would still be available for livestock feed (for example). Other potential markets include ethanol from the starch fraction and plastics from the pea protein. Interestingly, some pilot work suggests that the use of pea starch results in significantly higher ethanol yields than wheat. Recent research has also shown that peas, when planted in rotation with spring wheat, reduce the nitrogen fertilizer requirements of spring wheat and increase its yield.

This is an interesting product with potential to be developed in Canada.

Nep1: A selective herbicide protein isolated from a micro-organism

Studies conducted by the USDA found that a protein (Nep1) isolated from the micro-organism *Fusarium oxysporum* possessed selective herbicide properties.[100] The protein triggered a hypersensitivity reaction in certain weeds. Nep1 appears to target dicotyledon plants and have little effect on monocotyledon crops such as wheat. The protein is active at very low concentrations of about six grams per hectare. Since the protein is a natural product, it would probably be acceptable to the organic market. Development is likely to occur in the US, but it might have useful applications in Canadian agriculture.

Delta amino levulinic acid (DALA): a new broad spectrum herbicide derived from levulinic acid, a potential new platform chemical produced from waste paper

DALA is a broad-spectrum biodegradable herbicide that shows high activity toward dicotyledonous weeds while showing little activity toward monocotyledonous crops such as corn, wheat, and barley.[101] It may also have potential as an insecticide. Work in the US has found a simple route to synthesize DALA from levulinic acid. A new method has been found to produce levulinic acid cheaply from low cost lignocellulosic materials such as waste paper.[102] While it seems unlikely that it will be produced in Canada, it may be a useful broad spectrum herbicide for Canadian farmers, particularly if weeds develop herbicide resistance to present herbicides.

An interesting group of research organizations and companies is developing new routes for production of levulinic acid and DALA. They include the Pacific Northwest Laboratory of Battelle, the NREL, the New York State Research and Development Authority, Biofine Inc., and Chemical Industry Services Inc.

Use of high glucosinolate-content mustard seed meal as a herbicide, fungicide, or insecticide

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[100]Kleiner, K. 2000. Nature's assassin: weeds in organic fields are about to face a new enemy. New Scientist: March 4, p. 15; Jennings, J.C., Apel-Birkhold, P.C., Bailey, B.A., and Anderson, J.D. 2000. Industion of ethylene biosynthesis and necrosis in weed leaves by a Fusarium oxysporum protein. Weed Sci. 48: 7-14.

[101]Elliott, D.C., Fitzpatrick, S.W., Bozell, J.J., Jarnefeld, J.L., Bilski, R.J., Moens, L., Frye, J.G. Jr., Wang, Y., and Neuenschwander, G.G. 1999. Production of levulinic acid and its use as a platform chemical for derived products. Proceedings of the Fourth Biomass Conference of the Americas, p. 595-600. NREL, 1617 Cole Blvd., Golde, CO 80401-3393, U.S.A.

[102]Ibid.

The University of Idaho and the NREL in Colorado are investigating the development of industrial mustard crops for biodiesel and biopesticides. Selection of lines of mustard crops high in glucosinolates has found types that have high concentrations of glucosinolates in the seed meal after extracting the oil. These seed meals have been found to be highly effective against fungi, nematodes, cut worms, wire worms, and crab grass. The seed meals may also be able to be used as soil fumigants to replace methyl bromide. Projects are also underway investigating glucosinate pesticides in Italy, Denmark, and Austria.

Mustard breeding is proceeding in the opposite direction in Canada. Varieties are being developed that are low in glucosinolates and have an oil composition similar to canola.[103] These new mustard types are being developed to provide canola varieties that are more drought resistant than existing canola types based on rapeseed transformations.[104] Thus it seems unlikely that the high glucosinolate lines of mustard will be developed or grown in Canada unless there are clear ways to distinguish the lines from the canola types.

Development of spinosad, a new type of insecticide

In 1982, a scientist visiting a rum distillery in the Caribbean noticed that there were no insects in the soil around the distillery. Soil samples were taken, and it was found that a bacteria in the soil was acting as an insecticide.[105] The active natural chemical produced by the bacteria was isolated and identified. The active chemical is a complex organic compound called spinosad.[106] It has now been developed into the first of a new class of insecticides called naturalytes by the company (Dow AgroSciences) that has developed the product. The new class of insecticides has an excellent environmental record and human safety profile, similar to Bt. The new class of insecticide appears to fit in well with integrated pest management programs. The first commercial product is now registered for use on 170 different crops.[107]

Microbial organisms used as pesticides

Living organisms, such as bacteria, fungi, and insects, can be used to suppress, kill, or inhibit damage caused by pests.[108] Development of such products would fit well into integrated pest

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[103]McMillan, D. 2001. New canola tackles drought. *Western Producer,* August 30, p. 52.

[104]Angadi, S., Miller, P., McConkey, B., McDonald, C., Cutforth, H., and Gan, Y. 2002. Mustard is better suited to the semi-arid prairie than canola. Proceedings, Soils and Crops Workshop, University of Saskatchewan, February 21-22.

[105]Bell, I. 2001. Fermented bacteria produces new insect control. *Western Producer,* June 28, p. 22. Canadian Renewable Fuels Association. 2001. Ethanol brochure. Available from CRFA, 31 Adelaide Street East, Toronto, ON M5C 2J8.

[106]Copping, L.G., ed. 2000. The BioPesticide Manual. British Crop Protection Council, BCPC Publications Sales, Bear Farm, Binfield, Bracknell, Berks. RG 42 5QE, UK. Foss, K. 2002. Fewer Canadians working the land, farming report says. *Globe and Mail*, February 23, p. A7.

[107]Dow AgroSciences. 2001. Success - First Naturalyte Product Registered in Canada. News release of May 1st, 2001.

[108]Boyetchko, S. M. 1998. Bacteria and their use toward biological control of crop pests. AgBiotech Bulletin 6 (2): 5-6.

management programs. Work is under way in Canada to investigate a number of aspects of development of microbial pest control agents. Control agents for both weeds and crop diseases are being studied. Biofermentation methods to produce the microbial agents, formulation and application technology, and registration are being investigated.

The first product developed was BioMal, a microbial control agent for the weed round leaf mallow.[109] PhilomBios, the company selling the product, stopped producing the product by 1999 because the company found that it could not manufacture the product cheaply enough for general agricultural use.

Research studies are under way in a number of areas. For example:

- evaluation of bacterial strains for control of Fusarium pathogens in cereals[110]
- investigation of novel rhizobacteria to control pathogenic fungi infecting peas and lentils
- developing lines of arbuscular mycorrhizal fungi that improve the ability of selected lines of barley to out-compete the weed wild oats.[111]

Use of higher plants for weed control

There is renewed interest in the role of forage crops and green manure crops to control weeds. Studies in Alberta and Manitoba found that a tall, leafy barley that was seeded shallow and grown densely could eliminate or reduce the need for herbicide.[112] The barley would be harvested early for forage for livestock. Studies are being conducted by Mario Therrien at the AAFC centre in Brandon, Manitoba. According to Therrien: "*we have found that if you have a weedy field, it's best to plant to barley in the first year. In the second year, plant canola, and use proper control methods for the grass weeds. In the third year, a farmer should be able to grow herbicide-free wheat*." Therrien is planning to select forage barley lines that have high weed control ability. The plan is to register a barley variety specifically as a bioherbicide.

Martin Entz and his students at the University of Manitoba have studied the use of perennial and annual forages for weed control (1999). In many cases, production of forage crops could reduce weed populations considerably. Thus forages could be a significant component of integrated weed control programs.

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[109] AgBiotech Bulletin. 1999b. Bioherbicides not competitive. AgBiotech Bulletin 7 (3): 5.

[110] Hanson, K.G. and Fernandez, M.R. 2002. Evaluation of bacterial strains for control of Fusarium graminearum and related cereal pathogens. Proceedings Soils and Crops Workshop, University of Saskatchewan, February 21-22 (in press).

[111] Xavier, L.J.C., Boyetchko, S.M. and Derksen, D.A. 2002. Arbuscular mycorrhyzal fungi influence competition between barley and wild oat. Soils and Crops Workshop, University of Saskatchewan, February 21- 22 (in press).

[112] MacAuthur, M. Tall, leafy forage barley gets job fighting weeds. *Western Producer*, January 3, p. 20

3.12.4 Conclusions

Further research should be undertaken to understand the potential market opportunities for natural insecticides. In particular, further support should be invested in understanding the various market opportunities for pea protein and starch fractions. This research might benefit from using a biorefinery approach to product development. Partnerships between private sector and government/university organizations should also be encouraged and supported.

3.13 Pulp and paper

3.13.1 Market analysis

A wide variety of paper and paperboard products can be produced using nonwood plant fibres. Markets and suppliers for Canadian and US nonwood fibre products are summarized in Table 9.

Table 9: Nonwood fibre paper and paperboard markets and suppliers in Canada and the US

Product	Market	Supplier(s)
Pulp	1999/2000 market potential was 50,000 admy/year.	Not available
Paperboard	No paperboard products are currently produced in Canada and the US using nonwood plant fibre materials.	Not applicable
Printing/writing papers	Estimated at 50,000-70,000 tonnes per year. The primary reason for the small market size is cost. Nonwood content printing and writing papers cost five to eight times more than wood-based papers. In 2001, Wal-Mart only ordered 360 tonnes of cotton content resume paper to meet the requirements of all of its stores.	Canada: Rolland Inc (QC); Spexel Inc. (QC); Domtar Inc. (ON) US: Gilbert Paper (WI); Crane & Co. (MA); Neenah Paper (WI) New entrants: Canada: Arbokem (AB) US: Living Tree Paper Co. (OR); Vision Paper (NM)
Currency paper	Canada produces currency paper from in-house produced rag pulp and supplies the Canadian government. The US produces currency paper from in-house produced rag pulp and supplies the US government.	Canada: Spexel Inc. (QC) US: Crane & Co. (MA)
Cigarette papers	Decorticated flax bast fibre from Manitoba and Saskatchewan is used for the production of cigarette burning tubes by two US-based pulp and paper mills.	US: Schweitzer-Mauduit International (NJ); RF Ecusta (NC) It is unlikely that there will be new entrants to this market segment due to market conditions, anti-smoking campaigns, and high market entrance requirements.
Other specialty papers	Small specialty pulp and paper mills produce a variety of specialty papers using nonwood fibre pulps from abaca, textile flax tow, oilseed flax bast, hemp bast, sisal, and cotton pulps. These and other specialty papers have very limited markets with high entry-level requirements.	There are a number of small specialty pulp and paper mills in the US, especially in the New England States. It is unlikely that there will be new entrants to this market segment due to smaller market size and difficult market entry.

As described in Table 9, the potential for future large-scale use of nonwood fibres in the Canadian and US paper industry is limited. Current usage tends to occur in specialty products with limited markets and high entry requirements. In the printing/writing papers sector, where new market entrants seem to have made some headway, market potential appears to be limited due to the high cost of the paper on the market.

Two recent unpublished studies[113,114] indicate that good market opportunities may exist for nonwood fibre-based papers under certain conditions:

- The quality of the nonwood content paper must be equivalent to or better than that of wood-based papers currently on the market.

- The prices of the nonwood content paper must be in the same range as the prices of equivalent wood-based papers — i.e., do not expect a premium for the nonwood content papers.

- Certain paper grades offer more potential market opportunity than other grades.

There appears to be sufficient market potential in Canada and the US to justify at least one world-class integrated pulp and paper mill in each location. Information from various sources also suggests that other mills could be built to serve a larger suppressed demand that has not been evident due to the higher cost of currently available nonwood papers.

Nonwood fibres are currently used to produce a variety of grades of paper,[115] including but not limited to:

- printing and writing papers
- linerboard
- corrugating medium
- newsprint
- tissue
- specialty papers.

Combinations of common and specialty nonwood pulps permit the production of a variety of grades of paper to meet quality requirements demanded in the global market. For example, softwood kraft is commonly used to add strength to paper produced from common nonwood pulps (hardwood substitutes). However, other nonwood pulps such as cotton linters or flax or hemp bast pulp may also be used. Additionally, wastepaper pulp may blended in the furnish. The nonwood portion can vary from 50 to 90%, and even up to 100%, depending on the grade and required quality. Specialty papers such as currency, cigarette papers, tea bags, dialectric paper etc. may be made from a furnish of 100% nonwood specialty pulps.

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[113] "Prefeasibility Study - Nonwood Pulp and/or Paper Mill, Manitoba, Canada," unpublished report. HurterConsult Incorporated. 2000 — to be made public in mid-2002.

[114] "Technical & Economic Feasibility Study for Nonwood Pulp & Paper Mill, Iowa, USA," unpublished report. The Optimum Group of Kellogg Brown & Root, Inc. 1999.

[115] Hurter, Robert W. "Nonwood Plant Fiber Uses in Papermaking." September 2001, http://www.hurterconsult.com/nonwood_uses.htm

Nonwood pulps can also be used as an additive to wood-based papers for a variety of reasons such as:

- to provide the papers with certain specific desired properties – e.g., production of ultra lightweight papers or papers with increased opacity or better bulk, etc.
- to offset higher wood costs
- to provide an incremental increase in mill capacity in a region where woods resources are finite.

3.13.2 Public policy

There is no strong public policy support in North America for nonwood pulp and paper making.

3.13.3 Science and technology

A vast body of knowledge has already been developed on the use of nonwood plant fibres. Many of the technical questions have been addressed in other countries by engineering consultants and equipment suppliers with expertise in the use of nonwood plant fibres. Since this expertise can be brought to projects in North America, it is not necessary to completely reinvent the technology for use in North America.

Some of the areas that require further research include "emerging" pulping technologies, the impact of press washing on nonwood fibres, desilication technology, and "emerging" black liquor recovery technologies.

A review of these technologies is beyond the scope and resource limitations of this report. Please refer to the pulp and paper SMMS report for more details on raw material preparation, pulping technology, and paper making.

3.13.4 Conclusions

There is a growing worldwide shortage of fibre for paper making. Some projections estimate that this shortage will likely hit 100-125 million tonnes by 2010. In all likelihood, all fibre sources including fast-growth wood plantations, increased paper recovery, and nonwood plant fibres from crop residues as well as fibre crops will be required to meet the rising demand.[116]

Agricultural residues offer a huge potential fibre resource for the pulp and paper industry. For example, as mentioned previously, all of the wheat straw in Canada would produce about 11 million tonnes of hardwood substitute pulp, assuming a 35% yield to account for storage, preparation, pulping and bleaching losses. Residues offer different types of fibres, which could be used for different applications. Adding fibre crops such as hemp further increases the potential to develop specific pulps to meet specific quality requirements.[117]

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[116] See the SMMS report for a detailed analysis of fibre market supply and demand.
[117] Ibid.

Although there are many potential uses of nonwood fibres in paper and paperboard production, each possible application needs to be assessed on both economic and technical terms.

Several potential projects appear to offer potential for the production of nonwood fibre-based papers or the use of nonwood fibres in wood-based papers. For example:

- < A stand-alone greenfield integrated pulp and a 200,000 to 250,000 tonne-per-year paper mill that would use cereal straw (likely a prairie project) or corn stalks (likely an Ontario project) as the major fibre raw material to produce printing and writing papers. The nonwood component of the paper could be 40 to 60% with the balance being purchased pulps including recycled fibre pulp and either softwood kraft or cotton linters pulp for reinforcing fibre.

  The key to success for this project will be to produce good quality paper at a cost comparable with wood-based paper.

- < The addition of a nonwood fibre pulping line (from raw material preparation to pulping and bleaching) to an existing integrated wood-based pulp and paper mill and then to blend the nonwood pulp with the woodpulp to produce nonwood content paper. The selection of the nonwood fibre would depend on the characteristics of the pulp required and availability and costs. Depending on these factors, the nonwood fibres selected could be flax straw, hemp straw, cereal straw, corn stalks, switch grass, or any other nonwood fibre raw material which is available.

Possible examples of this type of project include:

- < The addition of a cereal straw, corn stalks, or switch grass full chemical pulping and bleaching line to an existing pulp and fine paper mill to provide an incremental capacity increase in production or to substitute for some of the hardwood used in the mill. There will typically be little, if any, difference in the paper machine operation if the nonwood fibre content of the fibre furnish is less than 30%.

- < The addition of a cereal straw high-yield semi-chemical pulping line to a corrugating board or linerboard mill.

- < The addition of a flax/hemp pulping line (from raw material preparation to pulping and bleaching) to an existing wood-based pulp and fine paper mill to provide an incremental capacity increase in production or to substitute for some of the softwood used in the mill.

The market surveys referred to earlier clearly indicate that the general public would be willing to accept nonwood fibre content paper provided that the quality and price of the paper were equal to or better than that of wood-based papers. However, it may still be difficult to develop the potential market opportunities required to enable companies and entrepreneurs to justify taking the risks involved in developing a project that would incorporate nonwood fibres in the production of paper.

To help alleviate some of these risks, the Canadian federal government could develop preferential purchasing practices for nonwood content papers similar to the preference they now provide for recycled printing papers.

3.14 Fibreboard

3.14.1 Market analysis

The panel board industry divides into two broad categories: structural panels and non-structural panels. These broad categories can be further subdivided by end-product markets as listed in Table 10.

Table 10: Panel board classifications

Type of panel board	Sub-classifications	Markets	Possible fibre source
Structural panels	< plywood < chipboard < oriented strand board (OSB)	< housing	< hardwood < softwood
Non-structural panels	< particleboard < medium density fibreboard (MDF) < composite panels < lower density fibreboard (LDF)	< furniture < cabinets and partitions < counter tops < mobile home decking < wall panels < floor underlays	< hardwood < softwood < nonwood fibres

The most likely end-products for agricultural-based fibreboards are particleboard and MDF. However, the January 2002 RISI North American Wood Panels Forecast reported a 7% year-to-year decline for North American particleboard consumption to just below 557 million square metres in 2001, and they forecasted further declines in consumption in the next two or three years. Given that production capacity in 2000 was just below 647 million square metres, there do not appear to be any market opportunities for new particleboard plants in North America using either wood or nonwood fibres.

In the same RISI report, they noted that MDF consumption in North America was about 232 million square metres in 2001 and that a strong US economy will "*trigger considerable consumption increases in 2003 and 2004, when annual volumes of more than 311 million square metres will be more than 30% above the previous cyclical peak in 2000.*" Thus, if RISI forecasts are correct, there are possible opportunities for new MDF capacity amounting to about 70 million square metres per year. However, one should keep in mind that three to five large wood-based MDF plants could fill this market need.

The ability of ag fibreboards to compete with wood panel boards on cost and quality has been seriously called into question by a series of plant closures, sales, and financial reorganizations. Ten plants in North America have run into financial problems (see Table 11).

Table 11: Ag fibreborad ventures that have run into financial difficulties

Plants	Location	Current status
Vacherie	Louisiana	Closed in the 1970s.
CenKan Corporation	Kansas	Sold to Prairie Forest Products, who temporarily closed the plant and are in the process of selling it again to new owners.
Natuall Fiberboard	Texas	Sold line to Prairie Forest Products.
Agriboard Industries (stramit type)	Alberta	New owners or financing apparently in place. Planning to make structural SIP type panels.
AgraFibre	Alberta	Bankrupt - sold for $0.07 on the dollar. Converting to wood.
Compak/WestGrain	Minnesota	Closed - financial reorganization.
Phoenix Biocomposites	Manitoba	Under Chapter 11. Has received court approval to borrow new funds and to reopen on a limited basis to produce a structural panel they are developing. Apparently some litigation still pending.
Isobord International	Manitoba	Plant closed in early May. Dow Chemical bought for $0.10 on the dollar. Dow's plans are unknown. Plant now has a severe problem of rotting straw in storage.
Acadia	Louisiana	Closed.
Duragreen	Hawaii	Closed.

Source: Don Lengel. A Clarion Call for Common Sense and Reality in the Composite Panel Industry. Paper presented at the May 2001 meeting, Eastern Canadian Section, Forest Products Society.

The following four plants remain in operation:

- PrimeBoard in North Dakota (wheat straw)
- Fibertech in California (rice straw)
- Pacific Northwest Fibers in Idaho (bluegrass straw)
- Prairie Forest Products (wheat straw).

Their viability may be due to the cheap purchase of equipment from previously failed ventures and the receipt of government subsidies. In addition, all of these plants are small operations, which counters an industry trend toward economies of scale.

A high-level analysis of production costs offers few reasons for optimism.

- **Raw materials.** Crop residues are as expensive, and perhaps more expensive, than wood residues when ag fibre feedstock losses in storage and preparation are factored into the cost estimates. Contrary to popular belief, there is no shortage of forest residues. According to Don Lengel, wood residue supply will increase substantially when forest thinnings programs start in earnest, and other factors such as a switch from national forests to private forest lands, increased forest growth, and increased residuals from cutting smaller logs are considered. In terms of raw materials, there is no cost advantage to using straw.

< **Storage costs.** Unlike wood residues, which are available throughout the year, nonwood residues are harvested and collected once or twice a year and must be stored until needed. Since covered storage adds significant costs, ag fibreboard plants have had to store fibre in the open and protect the piles of straw against the threat of fire, spoilage from weather, and rodent infestations. Material handling during wet weather is also a challenge. In terms of storage costs, there is no cost advantage to using straw.

< **Production costs.** As of 2004, there will be 20 US and seven Canadian MDF mills in North America with an average mill capacity of 11 million square metres per plant. The size of MDF plants will have increased about 40% between 1994 and 2004. In the fibreboard industry, economies of scale are important. The same holds true for particleboard plants where small plants have had to close when faced with stiff competition from large mills. The small size of existing ag fibreboard plants does not confer a cost advantage. Ag fibreboard plants also use isocyanate adhesives, which cost 1.5-3 times more than wood-based adhesives. There is no cost advantage to straw panel production.

Although nonwood MDF fibreboard samples met industry standards, and lab tests showed improved machinability and reduced tool wear, production did not lead to consistent quality because of weather spoilage, rodent contamination, black mould, and other production-related quality control problems involving the inclusion of tramp material. Even if quality control could have been achieved, the market (both distributors and consumers) was reluctant to pay more for an "environmentally friendly" product. Straw panels, therefore, do not offer a price premium advantage to compensate for the higher production costs.

3.14.2 Public policy

There is no significant public policy agenda in North America supporting nonwood fibreboards.

3.14.3 Science and technology

The economics and technologies used throughout the production chain need to be re-examined.

Some of the lessons learned from a recent review of financial failures include:

< lack of due diligence reviewing past history and current operations

< lack of panelboard engineering and economic expertise, and experience that has resulted in faulty planning, design, operations, and market penetration

- lack of capital for the important initial engineering and financial functions discussed above.

- lack of understanding regarding raw material acquisition, handling, transport, storage, yield, and net cost

- additional, unnecessary risk incurred by adding unproven presses and other "new" technology often integrated with inflated patent claims that ultimately failed

- use of inferior fibrous geometry: ag particles instead of ag-fibres

- a lack of comprehension of many fundamental panelboard operating principles, namely:
  - the necessary economies of scale
  - the fierce competition from wood-based products, especially during tough economic times
  - the time and capital required to ramp-up necessary marketing, which can equal the cost of the physical plant

- strategic miscalculations:
  - expectations of large-scale markets willing to pay substantial premiums for environmentally friendly panels
  - imminent large-scale wood shortage.

3.14.4 Conclusions

For future projects, more attention needs to be focused on the development of efficient raw material acquisition, handling, and storage systems. Additionally, binder costs need to be reduced. One suggestion is to use linseed oil from oilseed flax to help extend the expensive isocyanate binder commonly used with straw. Alternative binders should also be examined. Dr. Richard Wool of Cara Plastics in Delaware and Dr. Shelby Thames of the resin group at the University of Southern Mississippi in Hattiesburg are working on soy-based resins that might prove useful in reducing binder costs.[118]

More attention also needs to be paid to process economics and the development of markets. One recent suggestion involves establishing a full-scale pilot plant that is integrated with an operating, profitable, wood fibre-based plant where "*panel processes, products, and economics can be optimized and proven, and where substantial quantities of panels can be produced for meaningful market studies*."[119]

Analysis of the fiberboard industry reveals a sector that is high cost and that lacks a compelling market rationale. These fundamentals are unlikely to reverse in the foreseeable future.

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[118] Communication with Erwin Lloyd, Biocomposite Solutions.

[119] Don Lengel. A Clarion Call for Common Sense and Reality in the Composite Panel Industry. Paper presented at the May 2001 meeting, Eastern Canadian Section, Forest Products Society.

3.15 Textiles/nonwovens/biocomposites

Technically speaking, textiles, nonwovens, and biocomposites may be separate supply chains, but in practice, they overlap considerably. Nonwovens is a large and rapidly growing sub-market of textiles. It accounts for 20% of the textile market and is growing at about 10% per year. Nonwovens can be made from natural fibres like hemp, flax, and cotton. Nonwovens can also be used to create composite materials by bonding the nonwovens with petrochemical resins or polymers using compression moulding processes. This is currently being done commercially in Europe where nonwovens made from jute, hemp, or flax are bonded in a 50:50 weight ratio with polypropylene to form interior car components. The petrochemical matrix, used in the example above, could be replaced by a biopolymer made from biomass feedstocks. This would produce a biocomposite that is made completely from renewable resources. For a discussion of biopolymers, read the related sections on bioplastics and adhesives.

3.15.1 Market analysis — textiles[120]

The total size of the world textile market in 1998 was just over 45 million tonnes. Half of the fibre market is composed of natural fibres like cotton, rayon (made from wood cellulose), wool, flax, silk, and hemp. The other half is made from non-cellulosic materials like polyesters, polypropylene, etc.

Natural fibres have gradually lost market share to non-cellulosic fibres over the 18-year period from 1980 to 1998. The production of non-cellulosic fibres has increased significantly from 10 million tonnes (34%) in 1980 to over 23 million tonnes in 1998 (50%).

Production of cotton, which is by far the most popular of the natural fibres, grew from just over 14 million tonnes in the early 1980s to a peak of 20 million tonnes in 1991. Its production has plateaued and even dropped slightly since then.

Of the natural fibres, cotton dominates with slightly less than 45% of the market. Rayon, wool, flax, silk, and hemp account for 10% of the textiles market. Rayon has steadily declined from just over 3 million tonnes in 1980 to just over 2 million tonnes in 1998. Wool, flax, and silk show no signs of market growth over the 18-year period. Hemp is a very small niche fibre with a production of only 69,000 tonnes in 1998.[121]

It is useful to look at market developments in Europe because they may provide clues about future trends in North America, but one must keep in mind that the public policy environment and consumer attitudes in Europe are quite different than those in North America.

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[120] Communications with Erwin Lloyd, Biocomposite Solutions.

[121] For similar conclusions on market trends for flax and hemp see Nicole Charest, "Industrial Hemp Markets: The Next Challenge" in Alberta Hemp Symposium Proceedings. Alberta Agriculture, Food and Rural Development. 1998.

In 1999-2000, the EU produced about 60,000 to 70,000 tonnes of flax and 25,000 to 30,000 tonnes of hemp. In countries like France, Belgium, and the Netherlands, the long bast fibres are used for apparel and home furnishings markets, while the short fibres (called "tow") are a by-product of the process and are used mostly in the apparel and pulp markets.[122] In other countries where flax and hemp processing is new — like Germany, the United Kingdom, and Scandinavia — the long and short fibres are processed together in "total fibre" lines to produce short fibres that are targeted for technical applications. The processing of long hemp fibres requires either traditional water retting or one of the new biological or physio-chemical retting technologies. The former is not economically or ecologically viable, while the latter has not yet been commercialized. As a result, long hemp fibres are imported from Eastern Europe and China.[123]

The most important markets for EU flax short fibres are specialty pulps (45%), apparel and home textiles (20%), and export markets (25%).[124] Hemp markets are dominated by specialty pulp (87%), a small niche area that includes cigarette paper, bank notes, technical filters, and hygiene products.[125]

Pulp and paper experts see the markets for flax and hemp specialty pulp as stagnant and possibly decreasing because the paper industry is increasingly substituting flax and hemp with less expensive wood fibres (combined with additives).[126] The addition of new hemp mills in the EU is not expected to result in market expansion but rather in displacement competition.

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[122]Normally, 50% of the tow goes into the pulp industry, and 25% goes into apparel and home furnishings. When linen is in vogue and prices for good quality tow increase, about 50% of the tow goes into the higher priced apparel and home textiles market, and 25% goes into pulp.

[123]Ibid.

[124]More than 50% of the flax long fibres produced in the EU are actually exported for spinning, mainly to China and Brazil, and are returned to Europe as yarns or fabric. See Study on Markets and Price Situation of Natural Fibres (Germany and EU). Nova Institute. March 2000.

[125]Hemp pulp mills are found in France and Spain. In France, 95% of hemp is used in the specialty pulp industry. Over time, the percentage of hemp used for pulp will decline as the new hemp processing countries come on-stream and target the technical fibres for use in the automotive and insulation industries.

[126]Flax and hemp also face competition from other fibres for the specialty pulp market. In Germany, for example, cotton linters and rags that are used in bank notes dominate the market, followed by imported abaca, which is used in tea filters and vacuum bags. Other fibres, such as esparto and bamboo, compete for the production of coffee filters. Of the 38,500 tonnes of specialty pulp used in Germany in 1999, only 200 tonnes came from flax and hemp, down from 700 tonnes in 1995. Flax and hemp pulp cost significantly more than other natural fibres: about $US 1,900/tonne (bleached) vs $US 1,300/tonne for esparto; $US 1,100 - $1,300/tonne for cotton; $US 900 - 1,200/tonne for kenaf; and $US 700/tonne for bamboo.

The main market for hemp hurds is animal bedding (mostly horse bedding),[127] and for flax shives, it is the construction sector. The importance of the construction market, which has a lower profit margin than animal bedding, is expected to expand as the animal bedding market becomes saturated. Finding high-value markets for shives and hurds is crucial for keeping flax and hemp fibre prices competitive.[128]

Both crops require new markets if they are to expand. Two new market areas are emerging: nonwovens in the automotive sector[129] and building insulation.[130] Both (in total) now account for about 10% of the flax and hemp markets, but this could grow to 30-40% by 2005. These technical markets are less subject to price fluctuations caused by fashion swings and provide more stable, growth-oriented markets.[131]

Hemp and flax compete in the same US markets for apparel and home furnishings. Several well-known designers like Calvin Klein, Giorgio Armani, and Ralph Lauren have used hemp in their clothing lines. Hemp also is being considered in home furnishings such as upholstery, drapery, and floor coverings.

The USDA has tried to estimate the low-end demand for hemp textiles by converting imports to the equivalent domestic production and acreage required to displace hemp imports. Assuming a yield of 0.7 tonnes of fibre per acre and using linen yarn and fabric conversion factors, the USDA estimated that total hemp imports could be produced on less than 2,000 acres of land.

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[127]The emphasis on horse bedding has also been pursued in Canada, perhaps to the detriment of seeking other more value-added industrial markets. The markets for hemp hurds do not necessarily translate directly to the Canadian context. There is no domestic forestry industry in the UK that is comparable to Canada. As a result, the UK horse bedding market does not have access to large supplies of wood shavings like we do in Canada. As a result, the animal bedding market in Canada is likely to be smaller and less significant.

[128]Ibid.

[129]Geotextiles is another potential market. However, stiff competition is expected from coir, which is priced lower and does not biodegrade as quickly as either flax or hemp fibres (which have a much lower lignin content) and jute, which is also priced lower.

[130]In the EU, the market for insulation materials made from flax is expected to be several 10,000 tonnes by 2005, provided costs can be lowered and comprehensive marketing schemes can be implemented.

> At present, natural fibres cost two to four times as much as conventional materials. Although the raw materials account for only 10-25% of the costs of the finished product, there are strong pressures to keep raw material costs down. Flax and hemp fibres must compete against low-cost recycled cellulose, agricultural residues, and low-grade wool, all of which also have a good ecological profile and widespread availability.
>
> Flax and hemp processors are hoping to reduce costs by integrating fibre production with insulation mat manufacturing and by using less-costly and novel technologies.
>
> Optimism about future insulation markets, particularly in Scandinavia, seem to be driven by potential health risks associated with the use of glass fibres.

[131]Ibid.

The USDA also tried to calculate a high-end estimate of the market potential for hemp textiles by converting both imported flax and hemp imports to equivalent domestic acreage. Using the same methodology as discussed above, they came up with 250,000 acres.

Since flax and hemp fibres are targeting similar markets and flax produces a finer grade of textile fibre, it is unlikely that high-end apparel and home furnishings markets would provide significant opportunities for hemp fibres. This would argue against any significant market potential for woven hemp textiles beyond the lower end of the 2,000 to 250,000 acre range.[132]

Another recent development in the US seems to be working against both flax and hemp textiles in the apparel and home furnishings markets — Cargill Dow Polymers' announcement of construction of a USD$300 million polylactic acid (PLA) plant in Blair, Nebraska. PLA is made from the fermentation of corn. In addition to packaging applications, PLA will be targeted to high-end sports wear and home furnishings, including consumer products like carpets. Interface Carpets, for example, is now working as a product development ally with Cargill Dow Polymers to produce a PLA-based carpet. Until the launch of PLA, Interface had toyed with the idea using flax, hemp, and other natural fibres. PLA and other biochemicals, which will be addressed in a separate section, will ultimately compete against both flax and hemp for potential fibre markets.

Our analysis of world markets for textile fibres indicates that hemp will likely meet the same daunting market challenges as other natural fibres like flax and wool, which have not been able to increase market share even though they are legal. It will also have to compete against cotton, another natural fibre, whose qualities the marketplace clearly prefers to other natural fibres. PLA and other biochemicals will be used to create new biobased fibres that will compete against both natural fibres and petrochemical fibres.

Hemp production is legal in Asia, yet even in low-wage countries like China, it has not been able to successfully compete against other bast fibres like flax. Hemp has also been grown in Russia and Eastern Europe with state support, but the industry collapsed with the fall of the Soviet Union and the move to a more market-based economy. The production of hemp textiles has also been all but abandoned in Europe, despite legalization of hemp production and generous EU and state subsidies for R&D supporting crop production and fibre processing.

The high-end apparel and home furnishings market is being met by long flax fibres grown in France, Belgium, and the Netherlands. When linen is not in fashion in Europe, there is more than sufficient supply, and processors have to export fibres or use the tow in lower value-added pulp markets. The 18-year world production trend for flax does not show any growth.

The current focus of new flax and hemp processors in Europe is on industrial or technical fibres for nonwoven textile markets in the automotive and building insulation industries. The nonwoven automotive market in Europe seems to be the most promising and could reach a demand for 40,000 to 70,000 tonnes in the next five to ten years.

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[132]Industrial Hemp in the United States: Status and Market Potential. January 2000.

This analysis will now focus on the markets for nonwoven textiles and other composite materials.[133] This is not to say that there are no markets for flax and hemp fibres in the apparel and home furnishings sectors. In the case of flax, these markets are mature and show no signs of growth. For hemp, they are small "boutique" markets catering to novelty and fashion. The high cost of hemp fibres and their coarse fibre quality will restrict market growth.

3.15.2 Market analysis — nonwovens

The Association of the Nonwovens Fabric Industry (INDA) defines nonwovens as "*a sheet, web, or batt of natural and/or man-made fibers or filaments, excluding paper, that have not been converted into yarns, and that are bonded to each other by any of several means*."[134]

The various methods for bonding are:

- adding an adhesive
- thermally fusing the fibres or filaments to each other or to the other meltable fibres or powders
- fusing fibres by first dissolving and then resolidifying their surfaces
- creating physical tangles or tuft among the fibres
- stitching the fibres or filaments in place.

Nonwovens comprise about 20% of the total textile market, and the USD$2.8 billion North American nonwoven industry, the largest in the world, accounts for approximately one-third of worldwide sales.[135] Compared to conventional textiles, the growth rates for nonwovens are very high and have averaged 10% per year over the last 20 years. This is expected to persist for the next 10 years. The rapid commercial acceptance of nonwovens is due to these fibres having special properties, low cost, and rapid adaptation compared to traditional weaving and knitting.[136]

Because of their flexibility, the sub-markets for nonwovens are very diverse and include geotextiles, insulation materials, hygienic and health care textiles, and automotive applications. Debate exists regarding which nonwoven markets have potential for plant fibres. Some industry

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[133] A similar focus on nonwovens has been advocated by Ken Domier, "The Potential for Agricultural Fibres" in Alberta Hemp Symposium Proceedings. Alberta Agriculture, Food and Rural Development. 1998; and Nancy Kerr, "Evaluating Textile Properties of Alberta Hemp" in Alberta Hemp Symposium Proceedings. Alberta Agriculture, Food and Rural Development. 1998.

[134] Arthur Drelich, "Nonwoven classification: A simple system." Nonwovens Industry. p. 54-55. October 1998.

[135] According to 1997 estimates by INDA

[136] Monika Kannadaguli, "Introduction to Nonwovens." Dr. Kermit Duckett's Textile Science 526 web site. Nonwovens Science and Technology II: http://trcs.he.utk.edu/textile/nonwovens/default.html

observers argue that nonwoven filters, growth media, building insulation, and geotextiles offer potential.[137] Others are more sceptical.[138]

However, one area in which there is widespread agreement is the use of nonwovens in the manufacture of interior automotive parts.[139] Natural fibres are used for reinforcement in side door panels, rear package trays, pillars, and boot linings. Current technology will allow the use of 5-10 kilogram per vehicle.[140]

Generally, natural fibre nonwovens can be used as both fillers and reinforcement for interior components. Current applications, with typical weights of natural fibre used, include:[141]

- front door liners 1.2-1.8 kg
- rear door liners 0.8-1.5 kg
- boot liners 1.5-2.5 kg
- parcel shelves up to 2.0 kg.

The above applications are now well established for natural fibres, but other end uses are now becoming a realistic possibility, including:[142]

- seat backs 1.6-2.0 kg
- sunroof sliders up to 0.4 kg
- NVH material minimum 0.5 kg
- headliners avg. 2.5 kg
- floorpan - not known.

Use of natural fibres in blended thermoplastic or resinated thermoset compression mouldings is now generally accepted for applications as door liners/panels, parcel shelves, and boot liners. The following producers and models are known to incorporate natural fibres for such components to a greater or lesser extent:[143]

- DaimlerChrysler: A-Series, C-Series, E-Series, S-Series (door panels, windshield/dashboard, business table, pillar cover panel)
- Audi: A3, A4, A6, A8, A4 Avant, Roadster, Coupe (seat back, side and back door panel, boot lining, spare tire lining)
- BMW: 3, 5, and 7 series (door panels, headliner, boot lining, seat back)

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[137] Dr. Per Ole Olesen. Perspectives on the Performance of Natural Fibres. IENICA 1999.

[138] For example, see Study on Markets and Price Situation of Natural Fibres (Germany and EU). Nova Institute. March 2000.

[139] Dr. Thomas Schuh, Renewable Materials for Automotive Applications. IENICA 1999.

[140] Ibid.

[141] The Use of Natural Fibres in Nonwoven Structures for Applications as Automotive Component Substrates. The Textile Consultancy Limited. 1999.

[142] Ibid.

[143] Study on Markets and Price Situation of Natural Fibres (Germany and EU). Nova Institute. March 2000.

- Volkswagen: Golf, Passat, Bora (door panel, seat back, boot lid finish panel, boot liner)
- Opel GM: Vectra, Astra (headliner panel, door panels, pillar cover panel, instrument panel)
- Ford: Mondeo, Focus, Zafira (door panels, B-pillar, boot liner)
- Fiat: Punto, Brava, Marea, Alfa Romeo 146, 156
- Romeo 146, 156
- Renault: Clio
- Peugeot: new 406
- Volvo: C70, V70
- Saab (door panels)
- Rover: Rover 2000 and other (insulation, rear storage shelf).

Using supplementary calender bonding, the market is beginning to open for lightweight natural fibre reinforced substrate for structural headliners, as a replacement for glass fibre. There are increasing possibilities for customized blends of natural fibres to optimize binder saturation and resultant performance — such as flax/sisal or possibly flax/jute. The penetration of the automotive industry may be followed by similar success in the bus, railway, and aircraft industries.

In 1996, the EU used 3,900 tonnes of natural fibres.[144] By 1999, usage had grown to 21,300 tonnes and involved jute, sisal, and kenaf as well as flax and hemp. About 70% of the fibres were imported from Eastern Europe and Asia. However, all of the hemp fibres (1,700 tonnes) were produced in the EU.[145]

The markets are expected to increase to 40,000 to 70,000 tonnes in the medium term (5-10 years) and could double with the development of new technology. At DEM1.00 per kilogram, this results in a DEM40 million to DEM70 million annual market. The use of natural fibres in the automotive sector is well advanced in Germany and is spreading to other countries like Italy, France, and Sweden.[146]

3.15.3 Market analysis — biocomposites

Recent studies have shown that it is technically feasible to replace glass fibres with both flax and hemp fibres in injection molding for both interior and exterior parts. Natural fibres cost less; however, production costs are higher because existing processes are geared to the use of glass fibres. Once the production issues are resolved, as many believe they will be, natural fibres could begin to replace glass fibres, and their potential market could double from an average of 5-10

[144]By natural fibres we mean flax, hemp, sisal, jute, and kenaf. In Germany, for example, 50,000 to 60,000 tonnes/year of recovered cotton fibres and 50,000 to 70,000 tonnes/year of wood chips are also used. However, their market share is declining because of inferior mechanical properties and release of formaldehyde and phenol-based resins used to bond the fibres.

[145]Ibid.

[146]Ibid.

kilogram to 10-20 kilogram per car. The market potential could double from the current 80,000 to 160,000 tonnes per year.

On July 17, 2000, DaimlerChrysler Corporation announced that it will equip the new Mercedes-Benz Travego travel coach with a natural fibre-reinforced engine and transmission cover as standard equipment. This would be the first natural fibre-reinforced exterior component to go into series production. Until now, DaimlerChrysler's use of natural fibres like flax, sisal, coconut fibre, cotton, and hemp had been limited to interior parts like upholstery, door paneling, or the rear deck panel shelf.[147]

"*Use of natural fibres reduces weight by 10% and lowers the energy needed for production by 80%, while the cost of the component is 5% lower than the comparable fibreglass-reinforced component,*" according to Professor Heinrich Flegel, Director of Production Technology at the DaimlerChrysler Research Centre in Ulm, Germany.[148] The benefits of using natural fibres include:[149]

- no net CO_2 release
- 40% less weight compared to fibreglass
- production consumes one-fifth of the energy of fibreglass production.

Global automotive sales and potential market for natural fibres include:[150]

- 52.7 million cars and light trucks were sold in 1998.
- However, the strongest market growth is expected in developing countries.
- The estimated potential for natural fibre-based substrates is 15-30 kilogram per vehicle.
- The theoretical maximum usage has been calculated at 800,000 tonnes, assuming a 50:50 blend of natural fibre and synthetics.
- The Textile Consultancy estimates that natural fibre-based interior substrates account for about 40% of the market in Europe while moulded polypropylene or resinated wood composites account for the remaining 60%.

There is also a market for biocomposites in the construction industry. Construction materials in the wood-based composite industry are mainly flat (two-dimensional) sheet products such as glue-laminated beams, plywood veneers, oriented strandboard, flakeboard, particleboard, and medium-density fibreboard. During the last decade, many attempts have been made in North America to use crop residues, like wheat straw, to make similar two-dimensional composite

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[147] DaimerChrysler Corporation news release, July 17, 2000.

[148] Ibid.

[149] Ibid.

[150] The Use of Natural Fibres in Nonwoven Structures for Applications as Automotive Component Substrates. The Textile Consultancy Limited. 1999.

materials, particularly particleboard and medium-density fibreboard. Many of these attempts have failed for various reasons.[151]

Rather than imitate the forest products industry and try to compete in the same markets, plant fibres (particularly bast fibres like flax, hemp, and jute) could take advantage of their unique properties to make three-dimensional moulded products like furniture, curved walls, ceiling tiles, windows, and door frames.[152]

Bast plant fibres have a high strength-to-weight ratio (the strength of a good bast fibre is similar to Kelvar), good insulation properties (thermal, sound, electrical), and good reactivity (allows for chemical modification to achieve dimensional stability, durability, etc.), and cost less than glass fibres (a prominent fibre reinforcer).[153] Plant fibres can now be formed into fibre mats using physical entanglement (carding), nonwoven needling, or thermoplastic fibre melt matrix technologies. These mat technologies can be used to develop moulded products that have a uniform wall thickness and density.

Any of these mats can be formed into complex shapes using two types of **press-moulding** production technologies:

- **thermoplast method** — natural fibres are blended with polypropylene (PP) to form a mat and then pressed under heat to form the desired part

- **thermoset method** — natural fibres are soaked with synthetic binders (e.g., epoxy resin or polyurethane) and then moulded into the desired shape.

The benefits of this nonwoven process include:

- the ability to shape objects in three dimensions (opens up entirely new design opportunities)
- the ability to create wood grain patterns on the surface area of the mats
- high impact resistance
- 40% weight reduction (when plant fibres are used to replace glass fibres)
- low cost (compared to glass fibres)
- one-step manufacturing process (short manufacturing cycle times)
- occupational health and safety (potential for fewer problems of skin irritation and respiratory diseases using plant fibres vs glass fibres)
- combustible, recyclable, biodegradable, renewable resource
- carbon sequestration and good energy balance.

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[151]See, for example, Don Lengel, A Clarion Call for Common Sense and Realty in The Composite Panel Industry. A paper presented at the May 2001 meeting of the Eastern Canadian Section, Forest Products Society.

[152]Roger M. Rowell, The Limits of Design Potential in Plant Fiber Products. IENICA 1999.

[153]Dr. Per Ole Olesen, Perspectives on the Performance of Natural Fibres. IENICA 1999.

The markets can be extended further by using other composite technologies like injection moulding, extrusion moulding, liquid moulding, and pultrusion methods.[154] A more detailed discussion of these technologies is beyond the scope of this project.

3.15.4 Public policy

Fully exploiting these opportunities requires government policy support, at least until an industrial infrastructure can be developed to the point where it can perform economically.

According to Frank Riccio, "*the applicability of the EU business model is limited and certain factors must be carefully considered, to avoid the risk of assuming that opportunities for comparable market development exist in North America.*" A series of concurrent events occurred and coalesced to artificially influence the market dynamics:[155]

< The EU non-food agricultural subsidy scheme targeted both flax and hemp to support their development.

< Significant government funding was also made available for the research and development of both agricultural and industrial technologies to promote the industrial uses of these crops. After the fall of the Berlin Wall, the EU, especially West Germany, offered significant incentives to industry to invest in the construction of industrial facilities in the former East Germany in order to bring down unemployment. Between 1982-2002, the EU will have invested DEM100 million toward the development of flax and hemp harvesting, fibre processing, and market applications. EU state governments have spent additional sums. Germany alone has invested DEM175 million, with DEM88 million coming from the public sector.[156]

< The environmental movement in the EU, led by the German "Green Party," was making significant political inroads and helped to focus public attention on the automotive sector.

All of these factors came together and created markets for natural fibres, which may not have happened without the direct intervention of public policy at every step of the product supply chain.

3.15.5 Science and technology

Because of the particular structure of the automotive industry, much of the technology and industrial know-how developed for automotive nonwoven applications (using natural fibres) will be transferred, via the large Tier 1 suppliers, throughout the world. Already, applications developed first by German automotive manufacturers have quickly spread to manufacturers based in other countries.

[154] Ibid.
[155] Personal communication with Frank Riccio.
[156] Study on Markets and Price Situation of Natural Fibres (Germany and EU). Nova Institute. March 2000.

In the area of automotive composites, Canada has already established a consortium of companies and research organizations to address some of the barriers to more widespread use, such as surface finish, slow cycle times, limited flexibility in choice and cost of materials, and issues pertaining to joining and assembly. The research project will be looking at hemp, flax, kenaf, and wood as cheaper and more environmentally friendly alternatives to current reinforcing agents.[157]

3.15.6 Conclusions

It seems clear from our analysis that there are interesting market opportunities for natural fibres in nonwoven applications in the automotive industry and potential market opportunities for three-dimensional composites in the construction sector. In each of these areas, the cost and unique performance characteristics of natural fibres offer a comparative advantage over wood fibres and fibreglass. In addition, these market opportunities do not require radical technological breakthroughs. Companies in Europe have taken existing technologies and processes and adapted them to the use of natural fibres. This technology and industrial know-how is making its way to North America.

Although interest within the industrial, academic, and agricultural sectors in North America has been high, an equivalent demand has only recently begun to emerge.

At present, there is no established bast fibre agricultural infrastructure in North America. The exception is oilseed flax residues, which may be considered for some applications but are still in their infancy.

The industrial technologies in North America still must be retooled to accept natural fibres. According to Frank Riccio, "*while there have been several undertakings, these are comparatively small-scale operations and until market demand reaches a critical mass, we may assume that large-scale investment and development will be limited*."[158]

Riccio goes on to say, "*interest is high, but until demand truly develops we are faced with a ‘chicken and egg' scenario.*"[159]

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[157]The consortium is led by Francois Trochu of the Ecole Polytechnique and includes researchers from Ecole Poly, Concordia, UBC, Ford, Sherbrooke, and UNB. Partners include: UNB, UQTR, U of T, RMC, Queens, and McGill, Atofina Canada Inc., CAMM, CRF-Nexwood, DuPont Canada, Ford Research Dearborn, Hempline Inc., LPM Technologies Inc., Rece-RPM, Siemens Automotive, and Weyerhauser. See Polymer Composites Project, The Automobile of the 21st Century. Networks of Excellence.

[158]Ibid.

[159]Ibid.

4.0 Potential in Canada's regions

This section of the report reviews the potential for non-food/non-feed uses of agricultural products across Canada.

4.1 Atlantic provinces

As is the case for all regions of the country, optimism for the future of bioprocessing and bioproducts is running high in Atlantic Canada. As stated in the recent road-mapping exercise for the region: "*The convergence of technologies (advanced and conventional) and the emerging social trends and concerns are leading to new business opportunities through the development of sustainable, value-added bio-based products.*" However, this optimism will be difficult to justify without a detailed strategy for exploiting the identified opportunities.

Fisheries and forestry, while obvious regional strengths and high priorities for economic development, fall outside the scope of this study. However, the Atlantic region is particularly well positioned to lever inter-sector collaboration and synergies in pursuit of economically viable opportunities for loggers, fishers, and farmers alike.

As the major agricultural crop in the region, potatoes are an obvious candidate for increased attention. Currently, most growers focus on growing potatoes for french fry use. Potato starch, as the primary ingredient and a product that is enjoying major success in a wide range of industrial markets, would appear to be an obvious choice for diversification and exploitation. However, the starch industry is dominated by multi-nationals that are in a position to seek out competitively priced raw materials, large quantities, and low-cost transportation to markets. Atlantic Canada is challenged on all three fronts. The fact that potatoes grown specifically for starch production are different from those grown for french fries further complicates the situation.

Increased recovery and processing of potato by-products from existing food operations is possible, but this opportunity would return little new income to production agriculture. Rotation requirements in most growing regions severely limit new potato acreage. While opportunities exist for local entrepreneurs to operate satellite businesses around the major food processing plant, this often means relatively modest profit potential (if there were high profits, the primary processor would enter the business). Dependency on a single purchaser can also lead to difficulties for the grower in the form of returns, and an alternative buyer for potatoes would be welcome.

As with other crops, the use of genetic modification for the purpose of concentrating end value carries significant potential for potatoes. The production of antibiotics and enzymes, for example, has the potential to drastically increase the net return to the region. However, this development should not outrun public and farmer acceptance.

A known priority is the ongoing search for profitable field crops that complement potatoes in rotation while returning higher profit to the farmer. Success in this endeavour will require the coordinated efforts of farmers, business investors, and the research community. The region's relatively consistent growing climate should help attract processors looking for a reliable supply of high-value raw commodities.

Agriculture-based bioresource development strategies in the Atlantic provinces, by necessity, are considerably different from those of either central Canada or the Prairies. The restrictive land base all but rules out a cost-competitive extensive farming approach. Interest in this region has rightfully focused on intensive farming, special crops, and niche opportunities where unique growing conditions can be used to advantage.

One example of this is the custom production of genetically modified (GM) canola seed in New Brunswick, in which isolation from commercial canola production assures both the purity of the strain and the prevention of cross contamination of the commercial crop. In a similar vein, growing GM crops (including potatoes) in isolated areas for processors in other regions may hold considerable promise. Care must be exercised in selecting crops that are of sufficiently high value to overcome the region's logistical disadvantages.

For the pharmaceutical, cosmetic, and other high-end product value sectors, the primary development hurdle is attracting processors with the right combination of market access and in-house technical expertise. In this sector in particular, market share is based on an uncompromising commitment to product quality. The road to competitive advantage is long and paved with many layers of investment.

One of the more promising options for the region might be the year-round controlled environment production of crops with high medicinal and/or cosmetic value. Such a facility might also include higher-valued specialty food crops such as leaf lettuce and herbs. Products might be marketed either as fresh or semi-processed ingredients via air freight to the eastern seaboard in the US, to central Canada, and ultimately to Europe. The economics of such ventures must be considered carefully since indoor production technologies have been generally understood for several years, and competition could come from many locations around the globe. In Atlantic Canada's case, the inclusion of conventionally produced blueberries, other high value fruit, and perhaps selected marine species in a comprehensive air delivery program may be worth considering.

On the other end of the scale, simple, local, low-tech biofuel approaches may work in some parts of the region, but the abundant supply of forest products in most areas sets a low base price. Straw and/or fruit and vegetable wastes might be compressed for use as heating fuel or compost, thereby expanding the distance over which profitable sales could be made. The potential to convert these materials into motile fuels, although not yet commercially feasible, may become possible if the current technological hurdles for this technology can be overcome.

4.2 Quebec

Canada's largest province is in a strong position to become a major player in the non-food/non-feed agricultural processing field. The combination of a large agricultural base, coupled with a government dedicated to supporting both the farming and research communities, has provided the basic building blocks upon which a world-competitive industry could develop. In addition, the Quebec research community enjoys strong linkages to Europe, where much of the cutting-edge work is being done in this field.

Quebec is currently home to many of Canada's leading biotechnology and pharmaceutical companies. It is reported that a total of 278 companies are active in the bioproducts industry within the province. Of these, about three-quarters are operating in the medical field; the remainder are operating in agricultural, food, and environmental fields. About two-thirds of the firms are located in the Montreal area with another 20% in Quebec.[160] Although the industry as it currently operates uses very low volumes of product from agriculture origin, important synergies could develop between the pharmaceutical world and the industrial chemical world.

The province can also claim some of the best public research programs and pilot production facilities in North America in both the medical and food technology fields. These combined strengths, if focused on the industrial uses sector, would provide the region with many of the tools needed to both attract investment and support companies that may have deficiencies in their in-house R&D capabilities. The fact that Quebec is strategically located from a domestic and international trade perspective adds to the region’s considerable strengths.

The proposed construction of a 120 million litre ethanol plant to be built in Varennes by Commercial Alcohols adds an important component to the mix. ADM's presence in Candiac represents another potential cornerstone that might underpin a biobased industrial products industry. Additionally, the very significant volume of animal production offers another avenue for researchers and companies to pursue in finding new products and new uses for agricultural materials.

The large forest products industry in Quebec may be viewed as distracting from agriculture, but in fact, there may be ways for the two industries to work collaboratively in the development of new industrial products — ways that draw on the strengths of both industries.

4.3 Ontario

The opportunities for industrial uses of agricultural resources are numerous and seemingly very attractive in Ontario. In addition to the favourable growing climate in most of the agricultural areas, the province enjoys both significant home markets for industrial products and close access to the US industrial heartland.

[160] Paul Beaulieu, et al., Profile of bio-industry in Quebec. profil2001BioIndustrieQuebecen.pdf

A "carbohydrate corridor" is forming in Ontario that runs from Sarnia through to Ottawa and Montreal. This corridor includes the existing strengths in ethanol production in Chatham, starch and citric acid production in Port Colbourne, vegetable ink manufacturing in Weston (Toronto), a cellulose to ethanol pilot plant in Ottawa, and biopharmaceutical activity in the Ottawa/Stormont, Dundas, Glengarry area. Also being proposed as part of the "corridor" is a potential PLA plant in Sarnia, an expansion of the Chatham ethanol plant, a potential biodiesel plant in Oakville, and a new ethanol plant in Cornwall.

The fact that southern Ontario is the hub of the auto industry and others that consume large quantities of industrial chemicals further enhances the potential in this region. The pressing questions regarding the future development of this industry will be those relating to technical know-how and financing in the case of homegrown businesses, and the competitiveness of the economic/political climate in the case of the MNE investor.

An important second node in the Ontario bioproducts field is represented by a strong pharmaceutical research and development capability in the Ottawa area. Though much smaller than industrial chemicals, this sector holds significant economic potential.

The fact that the Ontario biobased industries have been evolving around corn and soy, the two crops that have benefitted from major investments in research in the biobased field in the US, further adds to the strength of the region. Products are compatible with US norms, and the numerous branch plants of US companies operating in southern Ontario are familiar with these starting materials.

Although there is potential for production of the full range of products, such as pharmaceuticals, ingredients for cosmetics, niche market fragrances, etc., the production of so-called "platform chemicals," including a range of industrial alcohols, organic acids, sugars, aldehydes, etc., would appear to hold the greatest promise for this region. From platform chemicals, a full range of conversion chemicals and manufactured end products can flow. In addition to the direct economic benefit that would occur from the successful placing of one or more world-class biorefineries in the province, many spin-off enterprises would surely emerge.

Agricultural locations in Ontario lying outside the normal reach of a biorefinery would still not be excluded from the industrial options. They would only be limited to more of the niche product opportunities. Again, as elsewhere, many of the "possibilities" for new industrial uses that are being touted will no doubt prove unattainable due to pure economics or to the lack of sufficient capital to capture and grow the technology needed to sustain a viable business in a competitive marketplace.

4.4 Prairie provinces

Perhaps the greatest strength of this region lies in its ability to produce vast quantities of traditional crops (wheat, canola, barley, field peas, oats, rye, etc.) at very competitive prices. Wheat, in particular, with starch comprising close to 70% of the dry weight of the kernel, and a valuable protein co-product represents an important raw material for literally thousands of end products spanning the food, feed, and industrial markets. Few are aware of the pervasive role that starch and starch derivatives play in our economy. Over the past half century, we have come to learn what nature has learned through evolution — starch and oils/fats are the ideal storage depot for carbon chains that can be called upon to manufacture useful chemical substances (including biofuel) on a sustainable and as-needed basis.

In spite of the potential to produce competitively priced grain, prairie agriculture has suffered in recent times due to increased competition in traditional grain markets from other nations, many of whom were former customers. This has devastated many farm families and many regions. A means of reversing this difficult situation into an advantage would be widely welcomed. The use of starch and vegetable oil in industrial products is a potential win-win-win solution to this problem and therefore represents a tremendous opportunity. Farmers would win through access to more domestic markets where reduced freight costs would allow greater profit; processors would win through access to high quality and assured supply of their major ingredient(s); and taxpayers all across Canada would win through jobs, a better balance of trade in dozens of sectors, and a reduced need for transfer payments and farm support programs.

Like the other regions, the prairie provinces each have their own unique strengths and opportunities for both the production of special crops and the manufacture of valuable end products. Some of these opportunities are as follows:

- Manitoba is strategically located with regard to shipping east and south from the Prairies. Winnipeg is the terminus for much of the US citrus and other produce coming into Western Canada and has become a major transportation hub for the region. The significant back-haul south and east coupled with the competitive business climate allow Manitoba processors to be competitive throughout much of North America.

- The province enjoys some of the best growing conditions in the region. Many of the special crops that are grown at risk elsewhere on the prairies can be reliably produced in southern Manitoba. The diversified agricultural complex would also be conducive to the further processing of both plant and animal-based industrial products.

- Saskatchewan, through wise investment of time and resources, has become the "biotech valley" of Western Canada. Business and scientific leaders, particularly in the Saskatoon area, recognized early in the game the potential of biotechnology and how it would ultimately revolutionize agriculture worldwide. The cluster of people and research facilities on or near the University of Saskatchewan campus makes this location not only the hub of biobased research for the region, but also the home of a growing number of biotechnology-driven companies. This represents a very significant knowledge cluster from which other businesses will surely spring.

- Alberta, like Manitoba, has a strategic location advantage for shipping products grown and processed on the Prairies. In this case, target markets lie throughout the Pacific Rim. The buoyant economy and entrepreneurial approach bode well for the developing of a strong biobased industry. The significant land mass devoted to agriculture and the wide variance of weather and soil conditions has attracted investors of all types.

- The significant beef industry offers Alberta the opportunity to become a world leader not only in the wide range of food products that are produced, but also in industrial products that can be recovered through bioprocessing of animal-based by-products.

One important issue is that the prairie region will likely be the source of raw materials, but distance from markets will likely mean that processing will occur elsewhere. A possible exception is the growing industrial base in Alberta and the existing industrial activity in Manitoba.

4.5 British Columbia

Like Atlantic Canada, British Columbia focuses primarily on the substantial forestry and fishery opportunities they enjoy. Like their counterparts on the east coast, British Columbia has unique agricultural attributes and, therefore, has unique opportunities for entry into several biobased industrial markets.

The Penticton region, although limited in total acreage, is renown for the wide range of crops that can be grown. Strengths come not only from the favourable temperatures, but also from the assured annual rainfall. The greatly expanded wine industry since the NAFTA agreement was signed attests not only to the potential to grow grapes and produce wine, but also to do so competitively. Vancouver Island and the southern mainland also enjoy extensive greenhouse production where highly productive operations currently supply not only the full range of ornamental stock, but also significant production of specialty food crops. Other regions of the province provide unique conditions that allow for isolation production for seed multiplication or animal rearing. Even in the Peace River area in northern British Columbia, there are interesting possibilities of favourable production and processing opportunities.

In recent years, there has been considerable interest in pharmaceuticals, nutraceuticals, and functional foods, and the potential for gaining higher-valued end products from agriculture. It has been reported that there are about 25 companies currently producing or actively researching these types of products.[161] Some of these companies are taking advantage of the greenhouse growing environment and the local expertise in this method of production.

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[161]Personal communication with Joe Mazza, AAFC, Summerland Food Development Station.

5.0 Conclusions and recommendations: selecting the five priority sectors

The selection of the priority sectors for Phase 2 depends on two intersecting judgements. First, one needs to select criteria to use to make the selection, and second, one needs to judge how well a sector will perform within each criterion. The selection model uses four basic criteria:

- *Economic multiplier* refers to the inter-relationships a sector has with other parts of the economy and its potential for inducing increases in overall gross national product. In part, this is based on its current size and the potential it has for growth over the next 5 - 10 years.

- The *environmental benefit* reflects the sector's potential contribution to environmental quality, in the sense that it could replace current dirty production processes, and, more likely, in the sense that it displaces pollution at the end user level. This is a complex criterion to use since the outputs of a sector could have dramatic displacement capacity for GHG emissions, but for a small sector, it is unlikely to have much net effect.

- The *potential for farm income* measures the backward linkage to the farm gate, a very attractive feature of non-food/non-feed agricultural production.

- Finally, *regional distribution* reflects the capacity for that sector to offer enhanced activity across the regions of Canada. A high score reflects wide distribution, and a low score indicates regional specialization.

In the model that appears in Table 12 (next page), we have also rated the criteria in terms of relative importance. A score of 3 reflects a high priority and a score of 1 indicates a low priority. A criterion can be dropped by changing the weight to 0.

Table 12: Selection of priority sectors					
Criteria $	Economic multiplier	Environmental benefit	Potential for farm income	Regional distribution	Total
Weight for criteria (High = 3, Moderate= 2, Low = 1, and None = 0) $	2	2	2	2	
Sector					
Adhesives	3	3	2	2	**20**
Biodiesel	1	2	2	2	**14**
Biopesticides	1	3	0	3	**14**
Bioplastics	3	3	2	1	**18**
Coatings and paints	1	2	3	1	**14**
Cosmetics	1	0	0	3	**8**
Ethanol	2	2	3	3	**20**
Fibreboard	1	0	2	2	**10**
Inks	1	2	1	1	**10**
Lubricants and hydraulic fluids	1	3	2	1	**14**
Platform chemicals	3	3	2	2	**20**
Pharmaceuticals	2	0	0	3	**10**
Pulp and paper	1	0	1	3	**10**
Surfactants	3	1	1	1	**12**
Textiles/nonwovens/biocomposites	1	1	1	3	**12**
Based on a three point scale in any cell, where High=3, Moderate=2; Low=1 and None=0					

In the first trial, all criteria are weighted equally at 2, and the result is that the top scores are:

- adhesives (20)
- ethanol (20)
- platform chemicals (20)
- bioplastics (18)
- biodiesel, biopesticides, paints and coatings, and lubricants (14).

If we adjust the weighting by increasing the weights for regional distribution and potential for farm income to 3 and reducing the weights for economic multiplier and environmental benefit to 1, the table revises as follows:

Table 13: Selection of priority sectors

Criteria $	Economic multiplier	Environmental benefit	Potential for farm income	Regional distribution	Total
Weight for criteria (High = 3, Moderate= 2, Low = 1, and None = 0) $	1	1	3	3	
Sector					
Adhesives	3	3	2	2	**18**
Biodiesel	1	2	2	2	**15**
Biopesticides	1	3	0	3	**13**
Bioplastics	3	3	2	1	**15**
Coatings and paints	1	2	3	1	**15**
Cosmetics	1	0	0	3	**10**
Ethanol	2	2	3	3	**22**
Fibreboard	1	0	2	2	**13**
Inks	1	2	1	1	**9**
Lubricants and hydraulic fluids	1	3	2	1	**13**
Platform chemicals	3	3	2	2	**18**
Pharmaceuticals	2	0	0	3	**11**
Pulp and paper	1	0	1	3	**13**
Surfactants	3	1	1	1	**10**
Textiles/nonwovens/biocomposites	1	1	1	3	**14**
Based on a three point scale in any cell, where High=3, Moderate=2; Low=1 and None=0					

The top five remain virtually the same:

< ethanol (22)
< platform chemicals (18)
< adhesives (18)
< biodiesel, paints and coatings, and bioplastics (15)

The final simulation (Table 14), drops regional distribution (sets the weight to 0), raises economic multiplier to 3, and places the other weights at 1.

Table 14: Selection of priority sectors

Criteria $	Economic multiplier	Environmental benefit	Potential for farm income	Regional distribution	Total
Weight for criteria (High = 3, Moderate= 2, Low = 1, and None = 0) $	3	1	1	0	
Sector					
Adhesives	3	3	2	2	**14**
Biodiesel	1	2	2	2	**7**
Biopesticides	1	3	0	3	**6**
Bioplastics	3	3	2	1	**14**
Coatings and paints	1	2	3	1	**8**
Cosmetics	1	0	0	3	**3**
Ethanol	2	2	3	3	**11**
Fibreboard	1	0	2	2	**5**
Inks	1	2	1	1	**6**
Lubricants and hydraulic fluids	1	3	2	1	**8**
Platform chemicals	3	3	2	2	**14**
Pharmaceuticals	2	0	0	3	**6**
Pulp and paper	1	0	1	3	**4**
Surfactants	3	1	1	1	**11**
Textiles/nonwovens/biocomposites	1	1	1	3	**5**
Based on a three point scale in any cell, where High=3, Moderate=2; Low=1 and None=0					

The top 5 sectors now become:

< adhesives (14)
< platform chemicals (14)
< bioplastics (14)
< ethanol (11)
< surfactants (11)

This analysis reveals some consistency in rankings. Adhesives, platform chemicals, ethanol, and bioplastics remain in the top five no matter the weighting on the criterion. Many sectors never rise in the rankings, such as pulp and paper, fiberboard, pharmaceuticals, etc., and these can be safely dropped from further consideration.

Based on the above, we recommend that Phase 2 concentrate on ethanol, platform chemicals, adhesives, bioplastics, and biodiesel. As a second tier, we suggest that AAFC consider investigating paints and coatings, biopesticides, and/or lubricants in Phase 2.

Note: Based on discussions at the June 25, 2002 in-person presentation to AAFC and members of the Interdepartmental Committee on Industrial Uses of Agricultural Materials, it was agreed to combine ethanol and biodiesel into one sector named biofuels and to focus Phase 2 research on biofuels co-products. It was further agreed to add biopesticides to the list of five sectors for further analysis in Phase 2.

APPENDIX A

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