Crop Diversification
Division

Alberta
AGRICULTURE, FOOD AND
RURAL DEVELOPMENT

Non-Food/Non-Feed Industrial Uses of Agricultural Products for Alberta

A Review of Research and Development

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METHODOLOGY

The Crop Diversification Division of Alberta Agriculture Food and Rural Development compiled this report. The report is based entirely on the review of the literature. The rights of others to the original material are acknowledged:

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Annual report of the Government-Industry Forum on Non-Food Uses of Crops Department for Environment, Food & Rural Affairs August 2002, UK

SUMMARY

This report reviews the literature on the market, research and development opportunities in Canada in the use of bio-based renewable resources (agricultural inputs) in the manufacture of basic chemical intermediates, and products.

Earlier research has rated these industries as having high market success factors in Canada:
- Adhesives and sealant, inks,
- Surfactants, fibreboard, and environmental products,
- Acetic acid/fatty acids,
- Resins/plastics, pharmaceuticals, nutraceuticals,
- Paints /woven cloths,
- Pigments/dyes and paper,
- Lubricating greases and oils,
- Fuel

Independent studies in Alberta have recognised additional key areas of focus as:
- Bio-Chemicals (Ethanol, Bio-Diesel)
- Bio-Lubricants
- Bio-Materials, Ag-Fibres e.g. strawboard, Ag-fibre composites, e.g. moulded building products, special papers, automotive parts
- Bio-polymers/plastics
- Bio-Medical
- Bio-Degradable Packaging

Alberta's agri-industrial processing sector is in its early stages of commercialization and expansion. Currently only a handful of companies have been identified within this sector. Products manufactured and exported include fuel alcohol as gasoline oxygenates gluten, animal blood based meat binder, strawboard and biodegradable lubricants.

Agriculture and Agri-Food Canada study concluded that bio-based programs should be carefully crafted to facilitate cluster-based regional development; co-ordinated science and technology investments; commercialisation centres; pilot plants and research parks; and close networking among public, private and non-governmental organisations stakeholders from the core of these clusters.

Canada's key advantage is its large landmass and associated biomass, which can support a major chemicals industry, based on renewable feedstock. Also, there is already an emerging industry in Canada based on novel uses of agricultural and forest biomass to produce fine chemicals, cosmetics, dietary supplements, nutraceuticals, animal feeds, durable composite materials and other value added products.

In Canada there is considerable research on production of fuel ethanol and other chemicals from biomass at a number of Canadian universities (as well as at a number

of government research centres (the National Research Council, Alberta Research Council, Saskatchewan Research Council). A research network has recently been proposed in biomass production and biomass utilisation for fuels and chemical feedstock.

There is a strong research capacity in fine chemicals at a number of Canadian universities as indicated by the number of university spin-off companies specialising in this field

Over the longer term, adoption of biofuels and biobased aromatic and alkane chemicals could grow significantly, given investment in the necessary research and development and perhaps carefully chosen incentives.

Agriculture and Agri-Food Canada is developing an action plan to facilitate the development of industrial and other non-food products derived from agricultural materials in consultation with federal, provincial and private sector partners.

Introduction

Recent advances in information technology, biochemistry and engineering are creating a new range of environment-friendly replacement products that can be made from agricultural and other renewable feedstocks, also called biomass. The term bioproducts is used to describe a commercial or industrial product (other than food and feed) that is generated from biomass. These products include biopower (heat and electricity), biofuels (ethanol and biodiesel), industrial biochemicals and a broad range of other bioproducts like agri-fibre panels, textiles made from flax and hemp, and bioplastics made from cornstarch. Many of these bio-based products are substitutes for similar products derived from non-renewable petrochemical feedstock that is known to cause significant health and environmental damage

At the turn of the 20th century most nonfuel industrial products including dyes, inks, paints, medicines, chemicals, clothing, synthetic fibers, and plastics were made from trees, vegetables, or crops. The first commercial plastic, introduced in the 1880s, was actually made from cotton. The first film plastic cellophane is still available. The first synthetic fibre was cotton-based rayon. Rayon is still a significant commercial fibre[1]. After World War II, petrochemicals began to dominate the synthetics market. By 1990, for every industrial product except paper, petroleum had replaced starch, vegetable oil, and cellulose, the three primary components of plant matter that served as the feedstock for the early industrial era.

However, recent developments are raising the prospects that many petrochemically derived products can be replaced with industrial materials processed from renewable resources. Scientists and engineers continue to make progress in research and development of technologies that bring down the real cost of processing plant matter into value-added products. Simultaneously, environmental concerns and legislation are intensifying the interest in agricultural and forestry resources as alternative feedstocks. Sustained growth of this burgeoning industry will depend on developing new markets and cost-competitive biobased industrial products.

Most biobased raw materials are produced in agriculture, silviculture, and microbial systems. Silviculture crops are an important source of material for the pulp, paper, construction, and chemical industries. Agricultural crops are chemical feedstocks that can be converted to fuels, chemicals, and biobased materials. Waste biomass should be considered as another major currently unused source of raw materials for Alberta and Canada. In many cases a plant matter derived product enters the market by displacing a portion of the petroleum-derived product and then gradually increases its proportion. For example, in the late 1980s plastic manufacturers introduced products containing 6 percent starch. In 1993 some plastics contain over 85 percent starch. In

[1] Morris and Ahmed (1992) The Carbohydrate Economy: Making Chemicals and Industrial Materials from Plant Matter

the paint market, vegetable oils began by replacing the mineral oils and, more recently, biopigments have been added.

Strengths/ Opportunities for Investment in Canada

Canada's key advantage is its large landmass and associated biomass, which can support a major chemicals industry, based on renewable feedstocks. Also, there is already an emerging industry in Canada based on novel uses of agricultural and forest biomass to produce fine chemicals, cosmetics, dietary supplements, nutraceuticals, animal feeds, durable composite materials and other value added products. When these factors are combined with the availability of renewable hydroelectric energy, the presence of other resource industries which are major consumers of chemicals and generous incentives for industrial R&D, the case can be made that Canada is an ideal location to develop the next generation of chemical industries which will be based on renewable feedstock.

Lack of in-house R&D expertise in biotechnology is another barrier, especially in the industrial chemicals segment of the industry. Canadian companies, many of which are subsidiaries of multinational corporations, may have difficulty justifying significant investments for in-house R&D in biotechnology.

AAFC is developing an action plan to facilitate the development of industrial and other non-food products derived from agricultural materials in consultation with federal, provincial and private sector partners. In August 2000, Agriculture and Agri-Food Canada completed a background paper entitled "Discussion Framework: Developing Bio-based Industries in Canada". This discussion document summarises recent European and US research trends in bioenergy, biofuels and biochemical, and identifies promising market opportunities for biomass feedstocks from soybean, corn, wheat, canola and lignocellulosic materials. The paper concluded that bio-based programs should be carefully crafted to facilitate cluster-based regional development; co-ordinated science and technology investments; commercialisation centres; pilot plants and research parks; and close networking among public, private and non-governmental organisations stakeholders from the core of these clusters.

Factors driving change towards bio-based industries

In the last decade a combination of technological advances and environmental regulation has opened up new markets for industrial products derived from plant matter.

Technological advances

- Molecular sieves have dramatically lowered the cost of separating liquids.
- Advanced pyrolysis processes, that is, burning with low or zero levels of oxygen, have lowered the cost of generating and separating out gases and liquids from solids like wood.
- One of the most dramatic and far-reaching advances has been in our ability to produce enzymes.

- Regulation

Potential Benefits of Bio-based Industrial Products

Significant benefits could accrue to the Alberta by switching some production currently dependent on fossil resources to biological sources.
Use of currently unexploited productivity in agriculture and forestry;

Environmental Quality: The development of bio-industries will contribute significantly to reduce emissions of greenhouse gases and meet the world's commitments under the Kyoto Protocol.

Rural Employment: Farmers and rural communities could benefit from the employment and business opportunities that would result from production of biobased industrial products, by either growing new raw materials or providing locations for processing plants.

Development of novel materials not available from petroleum sources;

Revitalization of rural economies by production and processing of renewable resources in smaller communities;

Increase opportunities for exports of biobased products Canada, with its abundant biomass resources has the opportunity to lead the world in many non-food products.

Significant market opportunities for industrial uses of agricultural commodities replace petroleum products and reduce our dependance on the petrochemical industry.

There is a growing demand for environmental-friendly consumer products around the world.

Barriers to progress

Capital Investments

A substantial investment of capital will be required to commercialise biobased products.

- **Research and Technology** Certain industrial opportunities are limited by the current state of the technology or the technology is already pulling the product into the market. If a limitation the requirement for further researches will increase the cost and time of development.
- **Price Competitiveness**: The costs of many agricultural materials are not competitive with materials currently used. Price competitiveness is an issue

for some industrial products. The cost of large-scale production of biobased products depends on two primary factors: the cost of the raw material and the cost of the conversion process. The industries for producing chemicals and fuels from petroleum are characterised by high raw material costs relative to processing costs, while in the analogous biobased industries processing costs dominate..

- **Legal and Regulatory Issues** Regulatory issues can often impede the development of an industry. For example in the nutraceutical industry health claims are not currently allowed in Canada.
- **Environmental Demand and Impact**: A major issue with respect to agricultural industrial products is the extent to which environmental regulations are forcing target industries to modify their manufacturing processes or account for the disposal of their products after use. This issue can become a major driver for agricultural industrial product development.
- **Financing and Product/Process Scale-up.** Depending on the state of the technology and the requirements of the market early stage financing and the resource requirements to demonstrate the viability of the product or process on a market scale are usually constraints.
- **Market Demand and Market Structure** The degree of market demand and the relative ease of entry into the market are critical to success. For example. a traditional industry with well-established major players will impose significant barriers to new products or entrants
- **Raw Materials and Inputs:** The long-term availability of the essential agricultural raw materials (cereals, oils, fibre, animal by-products, starches, cellulose etc) is fundamental success factors. Other inputs such as skilled labour and supporting industries are either assets or deterrents to industrial development.

RANGE OF BIOBASED PRODUCTS

Royal Dutch Shell[2] has predicted that in the first half of the 21st century, biomass will come to supply 30% of worldwide needs for chemicals and fuels, accounting for a market of approximately US $ 150 billion. Major opportunities and potential applications of bioproducts fall into 5 main areas - chemicals, speciality chemicals, industrial fibres and industrial oils energy crops:

- **Commodity Chemicals and Fuels:** Polymers and Plastics, Dyes, Paints & Pigments, Pharmaceuticals
- **Specialty Chemicals:** Adhesives, Agrochemical, Personal Care Products, Soaps & Detergents, Specialized Organics
- **Industrial Fibers:** Paper & Board, Composites, Textile Fibers, Bulk Fibers
- **Industrial Oils:** Two Cycle Oils, Transmission Fluids, Lubricants

Commodity Chemicals and Fuels

Industrial chemicals include both inorganic and organic chemicals (petrochemicals and resins) and they account for about 43% of the overall chemical sector in Canada. In 1995, this segment of the industry had about 300 establishments employed 23,000 people and had shipments of $14.4 billion (1.7% of the global market) of which 63% was exported (3% of world exports). Most of the firms in this segment of the industry are Canadian subsidiaries of US and European multinational firms.

Other bulk chemicals are also produced at commercial scale from biomass. In the USA, for example these include cellulose esters and ethers (0.5 billion kg/y), sorbitol (0.19 billion kg/y) and citric acid (0.16 billion kg/y). Succinic acid is a precursor to compounds such as 1,4-butanediol and tetrahydrofuran which have combined sales of over US$ 1 billion in the US market.

Biobased industries of the future will include plant-derived commodity chemicals (those selling for under $1.00 per pound) to provide transportation fuels and intermediate chemicals for industrial processing.

Biodiesel

Vegetable-based diesel fuels are appealing in part because these biobased fuels confer some potential environmental benefits. One advantage of biodiesel over petroleum-derived diesel is the virtual absence of sulphur and aromatic compounds (Abbe, 1994). Disadvantages include the overall competitiveness of biodiesel because of its low energy output-to-input ratio (2:1 - ETSU), the high cost of producing biodiesel (the British Association for Biofuels and Oils provided a figure of 2 or 3 times that of

[2] OECD, Biotechnology for Clean Industrial Products and Processes, p. 32 (1998).

fossil diesel). Biodiesel is made by transesterifying plant oil(s) with methanol in the presence of a catalyst to produce fatty acid methyl esters. Methanol for the reaction is readily available from biomass, natural gas, or coal. It is also technically possible to produce synthetic gasoline or diesel fuel from woody biomass. This involves gasification followed by further processing. Oils that can be processed into biodiesel include soybean, canola, and industrial rapeseed (Harsch, 1992). An increased focus on biodiesel largely results from its success in Europe. Biodiesel is better developed in France and Germany.

Bioethanol

Ethanol can serve as a transportation fuel and also is a precursor to many other industrial chemicals. In the long term, large-scale production of fuel ethanol from lignocellulose materials could become technically feasible and economically favourable. Ethanol produced by fermentation of sugar can be used as a fuel in internal combustion engines. In certain countries e.g. Brazil bioethanol has been produced as a substitute for petrol (or to mix with petrol) to provide a renewable source of fuel for automotive transport, and as a source of hydrogen for fuel cells. Now there is a new bacterial process that can be used in place of the traditional yeast-based fermentation. The bacterial process makes use of a wider range of sugars and breaks down cellulose as well as smaller carbohydrates. This means that the ethanol yield can be up to twice that obtained from the same biomass through fermentation with yeast. . The bacterial process may make bioethanol a more competitive fuel.

In Canada, ethanol derived from grain requires tax concessions in order to be cost competitive as a replacement for gasoline. Iogen is a Canadian company that is a leader in developing bioprocessing methods for producing ethanol from waste cellulosic material rather than grain or corn. A demonstration project involving Iogen and Petro Canada is currently under way to evaluate the commercial viability of producing ethanol from cellulosic feedstock.

There is considerable research on production of fuel ethanol and other chemicals from biomass at a number of Canadian universities (University of British Columbia, University of Saskatchewan, Waterloo University, University of Toronto, Ryerson Polytechnical Université, Queen's University, McGill, Ecole Polytechnique, Université Laval) as well as at a number of government research centres (the National Research Council, Alberta Research Council, Saskatchewan Research Council). A research network has recently been proposed in biomass production and biomass utilisation for fuels and chemical feedstock (BIOCAP).

Bioplastics

Renewable resources such as industrial starches, fatty acids, and vegetable oils can serve as sources for bioplastics. Biodegradable thermoplastics such as starch esters, cellulose acetate blends, polylactide, thermoplastic proteins (e.g., zein), and poly(hydroxybutyric acid) (PHB) show great promise for replacing the plastics derived from petrochemicals that generally are not biodegradable. Bioplastics comprise about 5 percent of the total polymer, plastics, and resin market (Ahmed and Morris, 1994). The bioplastics industry has generated new markets for industrial starches. Starch can be directly manufactured into products such as biodegradable loose-fill packaging to replace nondegradable polystyrene-based packaging peanuts. Fermenting starch into lactic acid or PHB yields other starch-derived thermoplastics. The Cargill Company has introduced polylactide-based thermoplastics for single-use disposable products such as utensils, plates, and cups. ICI Corporation has commercialised biodegradable PHB plastics for shampoo bottles and other higher-cost disposable. Plant matter also provides a new material for direct processing into plastic and polymeric resins.

Biopolymers

The great majority of all biomass consists of natural polymers, and the great majority of all biomass is carbohydrate in nature. This means that the majority of all biomass is in the form of carbohydrate polymers, called polysaccharides. These natural polymers (biopolymers) can be used both as nature provides them and as the skeletal framework of other derived polymers. By far the most abundant of these carbohydrate polymers is cellulose, the principal component of cell walls of all higher plants. Cellulosic plant materials are used as fuel, lumber, and textiles. Cellulose is currently used to make paper, cellophane, photographic film, membranes, explosives, textile fibers, water-soluble gums, and organic-solvent-soluble polymers used in lacquers and varnishes.

The principal cellulose derivative is cellulose acetate, which is used to make photographic film, acetate rayon, various thermoplastic products, and lacquers. The world's annual consumption of cellulose acetate is about 750,000 tons, 400,000 to 450,000 tons being produced in North America. Cellulose acetate products are biodegradable.

While use of biopolymers, largely polysaccharides, as is and in modified form is now considerable, only a infinitesimal amount of that available is now utilised commercially in applications also served by petroleum-based polymers; so the potential is enormous. Broader application of such preformed polymeric materials awaits research and development.

A graft copolymer of latex and starch is used to make coated papers. Certain starch-based plastics are also in commercial use, as are various graft polymers between starch and synthetics. One class of graft polymers absorb many times its weight in water and has many applications such as absorbent soft.

Paints and coatings

In 1998, the Canadian **paints and coatings** industry included 120 establishments that employed 6600 people and had shipments of $ 1.8 billion of which $251 million were exported. The binder (the base material forming the coating film) in paints used to be formulated using linseed or soybean oils. Now most paints and coatings are based on higher-performance synthetic resins such as alkyds, acrylics, vinyl, epoxies, urethanes, polyesters, phenolics and silicones. As a result of environmental pressures to reduce emissions of volatile organic compounds, there has been a shift to water based formulations where possible. No information was found on R&D or commercial applications involving biotechnology in producing ingredients for paints and coatings.

Adhesives and Sealants

The adhesives and sealants industry in 1998 included 42 establishments which employed 1790 people and had shipments of $450 million of which $186 million were exported. In this segment of the industry, low-to-medium performance products are often based on natural products such as starch, dextrin, natural rubber or protein; however, there is strong competition from synthetic polymers such as polyvinyl acetate, polyvinyl alcohol, polyesters, acrylics, neoprene, butyl rubber and phenolics. High performance adhesives and sealants have enhanced properties (bond strength, elongation capacity, durability and resistance to weathering or microbiological attack) and products in this segment of the market are exclusively synthetic polymers such as epoxy, polysulfide, cyanoacrylate and silicone.

One interesting use of biocatalysis in the adhesives field is the use of the enzyme peroxidase to replace the toxic chemical formaldehyde in the production of phenolic resins. Enzymol International[3] has developed a patented process that uses peroxidase extracted from soybean seed coat to generate the free radicals required to polymerize the phenolic chemicals. A similar process was developed by Forintec and is now used by CanFibre (Vancouver, British Columbia) to replace formaldehyde in the conventional urea-formaldehyde process for manufacturing medium density particleboard[4].

The paints and coatings as well as the sealants and adhesives industries are mature and grow on average at the same rate as the overall economy; although, in some speciality areas the growth rates are significantly higher. Most of the Canadian firms in these segments of the industry are subsidiaries of multinational companies and few perform any R&D on raw materials and or formulation but rather depend on their parent companies for R&D and technology. However, they also depend on raw material suppliers for introduction of new technologies. Many of these suppliers are

[3] **Enzymol International, Inc.,** 6927 Americana Parkway, Columbus, Ohio 43068, Phone: 614-856-3050, Fax: 614-856-3056, E-Mail: enzy@iwaynet.net
[4] Information from Industry Canada, Chemicals & Plastics Branch on STRATEGIS

Canadian SMEs and it is through these companies that bioprocesses and renewable biological source materials could enter into common use.

Examples include starch-derived plastics, biopolymers for secondary oil recovery, paper, and fabric coatings.

Intermediate Chemicals

Organic chemicals are synthesized primarily from petroleum for production of numerous nonfuel industrial products such as paints, solvents, clothing, synthetic fibers, and plastics. Thus, intermediate chemicals are an important market targeted by the biobased industry.

Ethylene is perhaps the most important petrochemical because of the value of its numerous derivatives such as polyethylene, ethylene dichloride, vinyl chloride, ethylene oxide, styrene, ethanol, vinyl acetate, and acetaldehyde. Today, biobased ethylene production based on ethanol derived from corn stover still is not cost competitive with petroethylene sources.

Acetic acid could be a large-volume chemical target for the biobased industry. It is used primarily as a raw material in the production of vinyl acetate, acetic anhydride, cellulose acetate, acetate solvents, terephthalic acid, and various dyes and pigments and as a solvent in the chemical processing industry. The food, textiles, and pharmaceuticals industries also use acetic acid in their manufacturing processes. Biobased acetic acid may be produced by fermenting corn starch or cheese whey waste or as a byproduct of the sulfite wood pulping process.

Fatty acids readily available from plant oils are used to make soaps, lubricants, chemical intermediates such as esters, ethoxylates, and amides. These three important classes of intermediates are used in the manufacture of surfactants, cosmetics, alkyd resins, nylon-6, plasticizers, lubricants and greases, paper, and pharmaceuticals (Ahmed and Morris, 1994).

Specialty Chemicals

The world-wide market for speciality chemicals (enzymes, biopesticide, thickening agents, and antioxidants) is $3 billion and growing by 10 to 20 percent per year. The market for detergent enzymes alone is about $500 million annually. As sales volume has increased, the cost of detergent enzymes has fallen 75 percent over the past decade. Many new applications for enzymes are being explored, including animal feeds, wood bleaching, and leather manufacture. In each, enzymes improve the industrial process and make it less polluting. Increasingly, niche markets will be sought for a wide array of plant chemicals (e.g. chiral compounds) not available from petrochemical markets.

Like industrial chemicals, fine and speculate chemicals can also be separated into inorganic and organic categories. The organic chemicals category includes pharmaceuticals, vitamins, flavours and fragrances, enzymes, chiral intermediates and other speciality chemicals. There are about 100 firms (including biopharmaceutical firms) in this segment of the Canadian chemical industry, most of that are small and Canadian owned. There are currently no official statistics available on the size and performance of the fine chemical industry in Canada.

The higher value of fine and speciality chemicals and the large global markets associated with some of them provides more latitude for use of biocatalysis and biological starting materials. It is estimated that the worldwide market for fine chemicals that go into pharmaceuticals is around US $24 billionn[5]
Decision Resources[6] reported that the global market for non-pharmaceutical fine chemicals produced by fermentation was more than US $ 6 billion in 1996:

- $2.4 billion for amino acids
- $2 billion for vitamins
- $1.2 billion for enzymes
- $0.5 billion for biopolymers.

The Freedonia Group[7] estimated that the demand for fine and speciality chemicals derived from plant sources (flavours, fragrances, botanical extracts, nutraceuticals and pharmaceuticals) would grow at about 9% per year to reach US $ 2.9 billion in 2003. Chiral chemicals are a $ 6 billion business in the US and form a rapidly growing (10% per annum) segment of the fine chemicals market[8]. Chiral chemicals are isomers of asymmetric molecules, which have been separated and purified. They are used in synthesis of other chemicals (e.g. pharmaceuticals) which have special properties because they are asymmetric. Now over 40% of chiral chemicals are produced through the use of enzymes or microorganisms which selectively break down one of the isomers resulting in a mixture which can easily be separated to yield one isomer in higher purity than could be achieved by conventional processes.

Canada has a number of companies, which produce fine chemicals, or enzymes, by fermentation or extraction and purification from biological sources. Examples include:

- Iogen (Ottawa, Ontario) is a major producer of enzymes by fermentation for the energy, pulp & paper and textile industries;
- Canadian Invotech (Abbotsford British Columbia) extracts and purifies enzymes from eggs and animal tissues for use in the agrifood and pharmaceutical industries;

[5] Genetic Engineering News, Aug. 1999, p. 25.
[6] Decision Resources, Biotechnology's Impact on the Chemical Industry (1998).
[7] Freedonia Group, Plant Derived Chemicals - Market Evaluation (1998).
[8]Freedonia Group, Chiral Chemicals to 2003 (1999).

- Kemestrie (Sherbrooke, Québec) is a technology development company which focuses on biomass as a starting material for production of fine chemicals;
- Bioriginal (Saskatoon, Saskatchewan) is a producer and supplier of gamma linolenic acid, an unsaturated fatty acid which is extracted from plants and is used in cosmetics, skin care and nutriceutical products;
- Griffith Laboratories (Scarborough, Ontario) is a producer of enzymes and flavours for the food industry;
- SemBioSys (Calgary, Alberta) is a plant biotechnology company focused on using genetically engineered plants as 'factories' to produce high value proteins for the pharmaceutical industry;
- Nexia (Montréal, Québec) is a pioneer in the production of high value proteins in the milk of specially treated goats or cows who have genetically modified mammary cells implanted into their udder;
- Apotex Fermentation Inc. (Winnipeg, Manitoba) is Canada's largest facility for R&D and production of pharmaceuticals by fermentation and bioprocessing in compliance with certified Good Manufacturing Practise (cGMP);
- Diagnostic Chemicals (Charlottetown, Prince Edward Island) produces advanced pharmaceutical intermediates as well as catalytic enzymes and active compounds extracted from biological sources.

There are also a number of Canadian fine chemical companies specialising in direct organic chemical synthesis but which can also produce fine chemical derivatives of biological source material. Examples include:

- Dalton Chemical Laboratories (Toronto, Ontario)
- Raylo Chemicals (Edmonton, Alberta)
- Toronto Research Chemicals (Toronto, Ontario).

There is a strong research capacity in fine chemicals at a number of Canadian universities as indicated by the number of university spinoff companies specialising in this field (e.g.Toronto Research Chemicals, Dalton Chemicals, Kemestrie). The explosion of research in biopharmaceuticals has greatly contributed to this.

Examples of biobased speciality chemicals include bioherbicides, biopesticide; bulking and thickening agents for food and pharmaceutical products; flavours and fragrances; nutraceuticals (e.g., antioxidants, noncaloric fat replacements, cholesterol-lowering agents, and salt replacements); chiral chemicals; pharmaceuticals (e.g., Taxol); plant growth promoters; essential amino acids; vitamins; industrial biopolymers such as xanthan gum; and enzymes. Speciality chemicals can be made using fermentation and enzymatic processes or directly extracted from plants

Enzymes

Fermentation of biological materials will continue to be a primary source of most enzymes used today and new enzymes produced in the future. European companies dominate world enzyme production; the largest company, Novo Nordisk, currently supplies 40 to 50 percent of world sales (Thayer, 1994). Analysts predict enzyme sales will grow 10 percent annually over the next few years for traditional markets and new uses. The three largest markets for enzymes are the detergent, starch, and dairy industries. Amylases break down starch to glucose; then glucose isomerase is used to isomerize the glucose into fructose. The resulting mixture of glucose and fructose is used as a sweetener in soft drinks. Enzymes also have several uses in the dairy industry. The enzyme rennin coagulates milk protein and is used to make dairy products such as cheeses. A large-scale fermentation industry based on lignocellulosic materials will require huge volumes of cellulases, much larger amounts than for any other enzyme, at much lower enzyme prices than currently available.

Addition of beta-glucanases (enzymes that degrade beta-glucans) to animal feeds removes the beta-glucans and their associated problems. This technique makes it possible to produce efficient animal feeds from grains that are high in beta-glucans, such as barley and oats. It also decreases the amount of manure produced by animals consuming the feed.

Cosmetics and toiletries

The cosmetics and toiletries industry has traditionally been a major user of biological source materials and fine chemicals. Several small Canadian companies such as Bioriginal (Saskatoon, Saskatchewan), Canamino (Saskatoon, Saskatchewan), Fytochem (Saskatoon, Saskatchewan) and Natunola (Winchester, Ontario) are examples of companies which are suppliers of highly purified plant extracts (oils, starches) for this industry. Enzymes are also finding use in the cosmetics industry where, for example, laccase is being used in hair dyeing products[9].

Soaps and detergents

The soaps and detergents industry also uses biomass-derived feedstocks and enzymes. Most soap is produced from oils and fats derived from plants and animals. Most detergents contain enzymes that help remove stains (lipases for grease, proteases for proteins) or which help prevent pilling of cotton (cellulases). The enzymes are generally produced by fermentation using genetically modified microorganisms and may contribute to secondary energy savings in the use of these products because they enable the use of warm or cold water rather than hot water for washing.

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[9] Decision Resources, Biotechnology's Impact on the Chemical Industry, (1998

Agricultural Chemicals

Agricultural chemicals include pesticides and fertilisers. In 1996, ten Canadian establishments, mostly subsidiaries of multinational companies, were identified as producers of pesticide chemicals; although, most of the activity in Canada is in formulation and not the development of active ingredients. The 10 establishments employed almost 500 people and had shipments of $262 million of which 44% was exported

- Some biological pest control techniques use insect traps baited with pheromones (sex attractants) or insects which act as predators for pests - this reduces pesticide use, pesticide runoff and the energy use associated with transport and application of the pesticide; there are a number of small Canadian companies e.g BioControle Inc.(Ste Foy, Quebec), Coast Agri Inc.(Abbotsford, B.C.), Phero Tech Inc.(Delta, B.C.), Applied Bio-Nomics Ltd (Sidney, B.C.), which specialize in this area;
- Other biological pest control techniques involve the use of (i) bacteria e.g. *Bacillus thuringiensis* (B.t.), (ii) viruses which are toxic to only a very narrow range of insect pests and not to other species or (iii) nematodes which are effective against a wide range of grubs and weevils (Microkil, Bedford, N.S.).
- Some crops are now genetically engineered to have built-in pesticides which are toxic only to the insect pest and not to humans who eat the crop - this eliminates pesticide runoff and saves the energy associated with synthesis of a conventional chemical pesticide, transportation to the point of use and the fuel used by the farmer in applying the pesticide one or more times to the crop (major multinationals are active in Canada in this field);
- Other crops are genetically engineered to be resistant to a broad spectrum herbicide

Fertilisers

In 1994, there were 12 primary producers of fertilisers in Canada, with 22 operating facilities that employed 5800 people and exported $2.4 billion worth of product (73% of total shipments). Canada supplies almost 40% of world needs for potassium and sulphur fertilisers and the Canadian fertiliser industry has invested nearly $ 500 million in expanding capacity during 1995-97. Canada is home to some of the world's largest fertiliser companies. Current product research in the industry is focusing on:

The first generation of biological fertilisers was based on natural rhizobial bacteria found in the root nodules of legumes (peas, lentils, alfalfa, and sweet clover). These bacteria fix nitrogen from the air, providing a source of nitrogen for the plants without the use of chemical fertilisers. Canadian companies such as Premier Tech (Rivière du Loup, Québec), Agrium Biologicals (Saskatoon, Saskatchewan), Philom Bios (Saskatoon, Saskatchewan), MicroBio Rhizogen (Saskatoon, Saskatchewan) and Grow Tech Inc. (Nisku, Alberta) have isolated natural populations of these bacteria which are particularly good at fixing nitrogen and formulate them as biological fertilisers for legumes. Philom Bios also has a similar biological phosphate fertiliser which helps plants take up phosphate already in the soil, reducing the requirement for phosphate fertiliser. When these biological fertilisers are used to coat seeds before planting, the crop will have improved conditions for growth from the time of germination.

Specific fatty acids and essential oils are of value in cosmetics and "soft" healthcare (e.g. dietary supplements), as well as having possible uses as fine chemicals for research or small scale industrial processes. Borage and evening primrose both contain gamma linoleic acid, and there are many uses of hemp oil in cosmetics. Woad is a source of indigo dye; a new water extraction process has been developed and a potential market in plant derived printing inks for bubblejet printers has been identified

Starches

Starch molecules are polysaccharides, made up of repeating glucose units. The physical and chemical properties of different types of starch depend on the way the polysaccharide chains branch. The industrial uses of different starches are determined by their ability to form granules or cross-links. The main industrial uses for starch in the United Kingdom are in paper and cardboard manufacture, adhesives and surfactants. Areas of growing research interest include plastics and low-phosphate detergents. ICI have recently been investigating the potential of starch to replace petrochemical monomers as film-forming agents in paint. Other starches from crops such as Jerusalem artichoke and quinoa may have some specialist applications

Soy-based Inks

Soybean oil-based inks were introduced to U.S. markets in the 1970s in response to the oil shortages. Soybean oil is a carrier for a pigment in ink formulations. Soybased inks are more desirable because the lighter color of soybean oil enhances the true color of colored ink pigments compared to petroleum-based inks. Because soybean oil costs more than petroleum, black soybased inks are at a cost disadvantage. Some research indicates that soy inks can spread about 15 percent farther than petroleum-based inks, offsetting the differences in cost (EPA, 1994).

Industrial Fibers

Fibres are found in the stems and leaves of plants and sometimes in the seed casings (e.g. cotton fibres). The fibres can have particular characteristics (strength, lightness, softness, and water absorbency) that make them useful for industrial purposes. Flax and hemp are the two main types of plant fibre of interest to Alberta. The useful fibres of flax and hemp are found on the outside of the plant stems, and these need to be separated from the inner, woody material before use. The process of liberating the useful fibres (retting) relies on bacteria to break down partially the bonds between the fibres and the other stem material.

The most important market for flax short fibres is pulp. The speciality pulp sector is a stable, high-priced niche market. The most important product lines are cigarette paper, bank notes, technical filters, and hygiene products. The two main product lines are composites in the automotive industry and thermal insulation materials for the building sector.

The use of natural fibres in the automotive industry is particularly interesting. While the European automotive industry in 1996 used just 4,000-5,000 tons, in 1999, it was already more than 21,000 tons. Natural fibres are predominantly used for reinforcement of door panels, passenger rear decks, pillars and boot linings. The present state of technology allows the use of about 5-10 kg natural fibres per automobile.

Ecological thermal insulation materials

The second-most important market for flax and hemp short fibres is their use in ecological thermal insulation materials.

Woven textiles are one of the major markets for plant fibres. Linen from flax has traditionally been a high value product, but more recently flax has begun to be blended with other fibres; a market for hemp clothing has also developed. The fibres can also be used for making insulation materials and geotextile matting to reduce soil erosion on slopes. Many kinds of plant fibres can be used to make fibreboard and particleboard.

Papermaking is another area where plant fibres have applications. The strength of hemp and flax fibre means that using even small amounts can reduce the proportion of virgin fibre required to make good quality recycled paper.

Composite materials

Composite materials made from plant fibres mixed with resin are attracting great interest as replacements for glass fibres. The plant fibres offer a better strength-to-weight ratio than glass fibre (Robin Appel), do not cause skin irritation, and can biodegrade or be burnt to recover energy (Hemcore). Internal panels for cars (in particular, in the German automobile industry) look like an interesting market for these materials.

Industrial Oils: Two Cycle Oils, Transmission Fluids, Lubricants

The oils found in plant seeds consist of fatty acid molecules whose chemical properties are dictated by the carbon chain length and the number and location of unsaturated bonds. The seeds of different species and varieties have their own range of fatty acids, making them suitable for particular applications or processing techniques. Linseed oil has many long-standing uses, including the manufacture of linoleum, putty and paint. The three main applications of plant oils are lubricants, surfactants, and in paint formulation.

Lubricants

The **lubricants** industry is dominated by petroleum derived products. High euricic acid canola oils have found application as industrial lubricants and have the advantage of being more readily biodegradable and less toxic than their petrochemical counterparts. Work in this and related areas is ongoing at the NCR Plant Biotechnology Institute in Saskatoon. Certain plant oils can be used as lubricants without significant chemical processing.

In principle, all classes of surfactants could be made from renewable plant materials; products from these sources tend to offer biodegradability and low toxicity. The ability of unsaturated oils to oxidise and polymerise means that plant oils can be used as film-forming agents in paints. Linseed oil has been used as a drying oil in paint formulation. Calendula have been proposed as alternatives that have fewer drawbacks (especially less yellowing with age) than linseed.

Energy

The three main ways that crops can be used as energy sources are; biomass for combustion or gasification, for heat, electricity or combined heat and power; biomass for fermentation into bioethanol fuel; and plant oils for diesel fuel. All these methods provide renewable sources of energy and reduce net emissions of CO_2 compared with the use of fossil fuels

Biomass for electricity generation

The characteristics of an ideal energy crop for electricity generation include large dry matter yield in a short period of time. In the United Kingdom, the crops considered to be able to meet these requirements most effectively are willow and poplar short rotation coppices the perennial grass, miscanthus Waste straw and other by-products from arable crop production can also be used in this way. Other costs associated with growing miscanthus are storage, in particular to prevent rotting between harvest and use transporting the fuel from the farms. The electricity generating process include drying using waste heat, gasification, where the biomass thermally decompose to form a combustible gas, steam and solid carbon char, gas cleaning, where any tars and impurities are removed from the gas and electricity generation.

Forest Products

Forest products currently comprise the largest source of renewable resources for the biobased materials industry. Pre-existing uses of silviculture crops in the pulp and paper industry may provide predictable markets and sustain production of woody silviculture crops while new uses develop in the manufacture of high-value materials and chemicals.

The U.S. Forest Products Laboratory developed a "spaceboard," a lightweight structural composite made by molding pulp fiber slurries into waffle-shaped forms (Hunt and Scott, 1988) that is now commercialized. Scientists have also developed moldable plastic materials by combining pulp fibers with thermoplastics. These materials have many potential uses, for example, in car bodies and packaging materials. Courtaulds, a company from the United Kingdom, and Lenzing, an Austrian firm, each have begun large-scale production of lyocell, a cellulosic fiber made from a solvent spinning process and sold under the trade name of Tencel. Like rayon, Tencel is wood-pulp based; however, rayon requires dry cleaning and Tencel is washable. Tencel is the first new textile fiber to be introduced in 30 years and has been described as the "best thing since cotton."

Raw Material Resource Base

Conversion of industrial production to the use of renewable resources will require abundant and inexpensive raw materials. The three potential sources of such materials are agricultural, forest crops and biological wastes (e.g., wood residue or corn stover).

Perennial grasses and legumes are being evaluated as potential energy crops (Hohenstein and Wright, 1994). These grasses include Bahia grass, Bermuda grass, eastern gama grass, reed canary grass, napiergrass, rye, Sudan grass, switchgrass, tall fescue, timothy, and weeping love grass. Legumes that have been tested include alfalfa, bird's-foot trefoil, crown vetch, flatpea, clover, and *Sericea lespedeza.*

Satisfying the raw material needs of expanding biobased industries will require crops with the following characteristics: contain biomolecules and biochemical systems with potential industrial applications; can be manipulated to produce desirable molecules; can sustain a high level of predictable raw material production; and are supported by an infrastructure for biomass harvesting, transfer, storage, and industrial processing.

Current Resources

Renewable resources have been used for a wide variety of industrial purposes. For example, siliviculture construction materials; wood can undergo additional processing to yield a variety of other products such as paper and textiles. Because agricultural and silvicultural crops are highly variable, plant parts become more valuable when they can be further separated into their biochemical components. In the long term, plant parts that can be converted to sugars for fermentation are likely to become a major feedstock for the production of biobased chemicals, fuels, and materials.

Woody Plant Parts (Lignocellulosics)

Woody plant parts are an abundant biological resource for the bio-based industry. Wood is a complex material composed of carbohydrate and lignin polymers that are chemically and physically intertwined. Considerable energy is required to separate the wood polymers from each other. Much of the harvested wood is used for lumber, and both wood and other woody materials are used for pulp production.

Separated Plant Components

Plant matter contains hundreds of components that are useful inputs for biobased production. Plants are primarily carbohydrates (cellulose, other polysaccharides such as starch, and sugars), lignins, proteins, and fats (oils). Starch and sugar polymers are end products of photosynthesis and dominate a plant's carbohydrate reserves. Accessing these vast carbohydrate reserves will be key to maintaining a renewable source of raw materials that can substitute for petrochemicals.

Cellulose

Cellulose is a carbohydrate polymer composed of glucose and constitutes about 45 percent of woody plant parts. Cellulose can be isolated by rops have been used for many years pulping processes and then further processed to yield such chemicals as ethanol and cellulose ethers; cellulose acetate, rayon, and cellulose nitrate; cellophane; and other cellulosics. Many of these derivatives have only specialty applications because their cost is high relative to that of petrochemical-derived polymers.

Hemicelluloses

Hemicelluloses are composed of carbohydrates based on pentose sugars (mainly xylose) as well as hexoses (mainly glucose and mannose). Hemicelluoses make up 25 to 35 percent of the dry weight of wood and agricultural residues; they are second only to cellulose in abundance among carbohydrates. While use of hemicellulose is currently limited, quantities of hemicelluloses, pectins, and various other plant polymers are abundant in residues and have great potential in the production of chemicals and materials.

Lignin

Lignin is a phenylpropane polymer that holds together cellulose and hemicellulose components of woody plant matter. Lignin constitutes about 15 to 25 percent of the weight of lignocellulose. Lignin has not yet been used as a raw material for industrial use in large quantities. Concerted attempts by pulp and paper research laboratories to develop new markets for byproduct lignins have had only limited success (Bozell and Landucci, 1993). Production of low-molecular-weight compounds from kraft lignin (phenols in particular) similarly has not yet proved commercially competitive. This reflects the chemical complexity of lignin and its resistance to depolymerization. Nevertheless, a recent DOE study concluded that pyrolysis of lignocellulosics (lignin, cellulose, and hemicellulose plant tissues) could make production of phenolics and anthraquinone from lignin competitive, and the potential also exists to produce benzene, toluene, and xylenes from lignin via pyrolysis (Bozell and Landucci, 1993). Lignocellulose pretreatment receives special attention in this report because it will be a key step for realizing the presently untapped potential of abundant lignocellulosic materials found in wood and other perennial crops.

Starch

Starch is the principal carbohydrate reserve of plants. Corn starch currently is a primary feedstock for starch-based ethanol, plastics, loose-fill packing material, adhesives, and other industrial products. Approximately 600 million bushels of corn went into production of industrial products during the marketing year 1995 to 1996; of that total, 395 million bushels were used to produce fuel ethanol (ERS, 1996b). While the supply of corn starch has been sufficient to meet current demands, primarily anhydrous motor fuel grade and industrial ethanol, other supplies of sugar feedstocks are being evaluated to meet anticipated increases in demand for oxygenated fuels and chemicals.

Proteins

Proteins are the primary means of expressing the genetic information coded in DNA. These polymers are based on building blocks of amino acid monomers whose sequence is predetermined by a genetic template. The sequence diversity of proteins is responsible for the wide array of functions performed by proteins in living organisms. A variety of plant proteins might one day be commercially exploited as materials, but current understanding of the structural properties of most plant proteins is limited.

One of the few well-understood plant proteins is zein, an abundant protein in corn seeds. Zein makes up 39 percent of the kernel protein, or about 4 percent of the kernel weight. The protein has several properties of industrial interest, such as the ability to form fibers and films that are tough, glossy, and grease and scuff resistant. Zein resists microbial attack and cures with formaldehyde to become essentially inert. In addition, it is water insoluble and thermoplastic.

Many crops can serve as sources of plant oils. Fatty acids derived from soybean oil are being converted into surfactants, emulsifiers, and alkyd resins for paints. Soybean oil can be chemically transesterified to produce biodiesel (methyl esters). In the future biodegradable lubricants may be produced from soybean oil; genetically modified soybean varieties hold the promise of yielding lubricant products that outperform petroleum-based lubricants (ERS, 1997b). Additional oilseed crops, some yielding oils with unusual properties, could be grown in the United States (e.g., petroselenic acid from coriander oil). Over the near term the volume of oil produced for such uses will remain small relative to petrochemical sources.

Fermentable Sugars

Fermentable sugars are by far the largest feedstock that might support a biobased chemicals industry in the United States. A wide range of fermentable sugars can be found in crops and wastes from agriculture and silviculture. Major feedstocks include corn, wheat, sorghum, potato, sugarbeet, and sugarcane; other sources include potato-processing residues, sugarbeet and cane molasses, and apple pomace (Polman, 1994). Sugars can be produced directly or derived from polysaccharides (such as cellulose and starch) and then, via microbial fermentation, used to produce a wide range of commodity and speciality chemicals. Existing commercial fermentation primarily utilise glucose (6-carbon sugar) to produce ethanol, acetic acid, amino acids, antibiotics, and other chemicals. Over the long term new sources of glucose will be required to meet the demands of a biobased industry. Growth of a biobased chemicals industry will depend on production of cellulose-rich crops, including those currently under production (e.g., corn and alfalfa) and others that presently are not grown commercially (e.g., switchgrass and hybrid poplar).

Significant increases in glucose reserves are available from lignocellulosic substances found in most plants, crop residues, and waste paper. Cellulose can be hydrolyzed by acid to glucose, although much of the glucose is destroyed during this process. The second most abundant sugar, found in hardwood and agricultural residues, is xylose derived from xylan hemicelluloses. Xylose is relatively easily recovered by acid or enzymatic hydrolysis but can be fermented to ethanol only by a few naturally occurring organisms or recombinant microbes. The practical sugar yield from lignocellulosics would increase significantly if commercial fermentation could utilise xylose (a 5-carbon sugar or pentose) as well as glucose (a 6-carbon sugar or hexose).

Evaluating Alternative Crop Sources of Petroselenic Acid Coriander is grown primarily for its use as a spice, but it may have potential industrial uses. The plant's seeds are 17 to 20 percent triglyceride, 80 to 90 percent of which is (esterfied) petroselenic acid (an 18-carbon fatty acid with a single unsaturated bond at C-6), Oxidative cleavage of the petroseienic acid's double bond yields adipic acid, a 6-carbon dicarboxylic acid used in the synthetic polymers or nylon industry

Assessment and Ranking of Industrial Products

Canada

Based on secondary research findings and subjective interview information and comments the industrial market development criteria (or success factors) have been evaluated and ranked according to the major industries and product markets considered within the scope of this study. The market opportunities rated in descending order of potential for Canada are as follows[10]:

1. Adhesives and Sealants
2. Inks, Surfactants, Fibreboard, and Environmental Products
3. Detergents/Cleaners
4. Acetic Acid/Fatty Acids
5. Leather Products and Resins/Plastics
6. Pulp
7. Pharmaceuticals, Nutraceuticals, Paints and Wool/Woven Cloths
8. Pigments/Dyes and Paper
9. Lubricating Greases and Oils
10. Toiletries and Fuel

The key drivers or market development criteria ranging from the most positive to the least positive influence in terms of future industrial opportunity development are summarised below.

Raw Materials and Inputs
2. Environmental Demands and Impacts
3. Market Demand and Market Access
4. Legal and Regulatory Issues
5. Price Competitiveness
6. Research and Technology
7. Financing and Scale-up

Alberta Strategy

Alberta's agri-industrial processing sector is in its early stages of commercialization and expansion. Currently only a handful of companies have been identified within this sector. Products manufactured and exported include fuel alcohol as gasoline oxygenate, gluten, animal blood based meat binder, strawboard and biodegradable lubricants. Some of the potential growth areas being assessed include:

Bio-Chemicals

Bio-Fuels

- Ethanol (expansion & 4-6 new plants)

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[10] *Ashmead Economic Research & Serecon Management Consulting, Non-Food/Non-Feed Industrial Uses of Agricultural Products in Canada, Agriculture and Agri-Food Canada, October, 1997.*

- Bio-Diesel (3-6 plants)
- Co-Generation
- Bio-Lubricants (expansion & 1 new plant)

Bio-Materials

- Ag-Fibres eg. Strawboard (3 new plants)
- Ag-Fibre Composites
  eg. Molded Building Products
  Special Papers
  Automotive Parts

Personal Care/Health (Ingredients only)

- Cosmetics
- Essential Oils
- Pharma/Vet Products
- Cosmeceuticals
- Molecular Farming/Biotech

Bio-Polymers/Plastics

- Bio-Medical
- Bio-Degradable Packaging

Industrial opportunity cluster

The process of the development of opportunities in industrial markets focuses on the concept of industrial opportunity clusters. These opportunity clusters contain interdependent key industries and/or firms with the potential to share the technology and economic infrastructure. There are similarities in labour force characteristics, common inputs and suppliers the ability to form strategic alliances with suppliers as well as potential competitors and the ability to form strong ties with local institutions universities research institutions and government bodies[11]. Thus within each opportunity cluster exists excellent potential for synergistic collaboration in overcoming commercialisation barriers. The study identified five potential opportunity clusters based upon the integration of the agricultural sectors and the target market clusters for industrial products. These five industrial opportunity clusters are as follows.

1. Biochemical
2. Energy
3. Biomass
4. Environmental
5. Health

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[11] KPMG. *Building Technology Bridges: Cluster Based Economic Development for Western Canada*. DRI/McGraw-Hill. Impax Policy Services. August 1996.

In the midterm, biobased products will be primarily oxygenated chemicals and materials; petroleum will remain a more competitive feedstock for hydrocarbon-based liquid fuels and aromatic and alkane chemicals. Over the longer term, adoption of biofuels and biobased aromatic and alkane chemicals could grow significantly, given investment in the necessary research and development and perhaps carefully chosen incentives. Biomass processing (fermentation of starch or cellulose accompanied by additional chemical, thermal, and physical processing steps) can produce a number of oxygenated intermediate chemicals. These include ethylene glycol, adipic acid, ethanol, acetic acid, isopropanol, acetone, butanol, citric acid, 1,4-butanediol, methyl ethyl ketone, N-butanol, succinic acid, itaconic acid, lactic acid, fumaric acid, and propionic acid. These intermediate chemicals have uses in the manufacture of such polymers as nylon, polyesters, and urethanes; of various plastics and high-strength composites; and of solvents, coatings, and antifreeze. Numerous chemical markets may be filled by agricultural feedstocks.

Significant opportunities exist to increase markets for biobased materials. Because most industrial materials can be produced from agricultural and forestry feedstocks, markets for biomaterials and biopolymers likely will increase.

Research Activities

In general, research on the underlying production processes should focus on the science and engineering necessary to reduce the most significant cost barriers to commercialisation. Economic and market studies could help clearly identify these barriers, determine the costs of alternative plant feedstocks, and understand the effects of fluctuating industrial demand and agricultural production on the risks and returns for bio- processing investments. There are also storage and transportation problems unique to biobased products. Most biomass crop production takes place during a portion of the year, but biomass raw materials should be available on a continuous basis for industrial processing. Thus, there is a need to do research in these areas.

Based on the review of the pertinent literature and other on-going projects in USA, EU specific recommended research priorities for biology that have been identified include:

- Biomass production can be improved by development of new cultivars and crops with enhanced agronomic traits. Researchers will need to use both traditional plant breeding and genetic engineering techniques to improve yield and pest resistance of traditional crops and new crops.

- Significant screening efforts are needed to identify carbohydrates, lipids, and proteins with industrial potential.

- Biobased research should support improvement of plant productivity. High-level plant productivity on a consistent basis will be essential for supplying biomaterials for industrial production.

- Introduction of new crops that have the potential to produce desired biochemical.

- the physiology and biochemistry of plants and micro-organisms directed toward modification of plant metabolism and improved bioconversion processes;

Recommended research priorities for engineering include:

- equipment and methods to harvest, store, and fractionate biomass for subsequent conversion processes;

- methods to increase the efficiency and significantly reduce the costs of conversion of biomass to liquid fuel and organic chemicals, including pretreatment of lignocellulosics, as well as other alternative processes so as to make biobased feedstocks economically competitive;

- principles and processing equipment to handle solid feedstocks;

- fermentation technologies to improve the rate of fermentation, yield, and concentration of biobased products; and

- Downstream technologies to separate and purify products in dilute aqueous streams.

Appendix

The Canadian Agricultural New Uses Council (CANUC)

The CANUC was established for the purpose of promoting the industrial and other. higher valued. uses of agricultural materials

Organization	Contact	Mission
Agriculture and Agri-Food Canada, Market and Industry Services Branch, Special	2200 Walkley Road, Floor 1Ottawa, ON K1A 0C5 **Phone:**(613) 759-6237	
Ag-West Biotech Inc	Ag-West Biotech 101 - 111 Research Drive Saskatoon, Saskatchewan Canada S7N 3R2 (306) 975-1939	agricultural biotechnology and promote the provincial industry around the world.
Centre for Agri-Industrial Technology Processing Alberta Agriculture, Food and Rural Development	6312 50th St. Edmonton, Alberta CANADA T6B 2N7 Phone 780) 427-8764 Fax (780) 427-4852	
BIOCAP Canada	22 Barrie Street Queen's University Kingston, ON K7L 3N6 **Phone:**(613) 533-2315 **Fax:** (613) 533-6645 **Email:**info@biocap.com **Web Site:** http://www.biocap.com/	The goal of the BIOCAP Canada Foundation is to build an understanding of how our forests and farm lands can be harnessed to support **Canada's Green Advantage** through:
Biotechnology Team, Southern Crop Protection and Food Research Centre, Agriculture and Agri-Food Canada	**Address:** 1391 Sandford St., London, ON N5V 4T3 **Phone:**(519) 457-1470 ext 268 **Fax:**(519) 457-3997 **Email:**brandleje@em.agr.ca	
Carbohydrate Research Group, Alberta	Carbohydrate Research Alberta Research Council	

Research Council	250 Karl Clark Road Edmonton, Alberta, Canada T6N 1E4 **Phone:**(780) 450-5321 **Fax:**(780) 988-9028 **Email:**srivastava@arc.ab.ca	
Crop Diversification Centre, Alberta Agriculture Food and Rural Development	CDC North 17505 Fort Road Edmonton Alberta Canada, T5B 4K3 **Phone:** 780-422-1789 **Fax:780**-6096 Email: stanford.blade@gov.ab.ca Web Site: http://www.agric.gov.ab.ca	Focus on biomass productivity research for agri-fibre, biofuels, biochemical, bioplastic
Crop Processing Development Centre, Prairie Agricultural Machinery Institute (PAMI)	Crop Processing Development Centre, Prairie Agricultural Box 1150, Highway 5 West Humboldt, Saskatchewan, Canada S0A 2A0e **Phone:** 800-567-PAMI (7264) **Fax:**306-682-5080 **Email:** humboldt@pami.ca **Web Site:** http://www.pami.ca/index.htm	The focus of the CPDC will be in maximizing the utilization of crop materials for feed, fibre, and fuel use.
Crop Utilization, Saskatoon Research Centre	Saskatoon Research Centre 107 Science Place SASKATOON, SK S7N 0X2 **Phone:**(306) 956-7655 **Fax:**(306) 956-7649 **Email:**brescianis@em.agr.ca **Web:**http://res2.agr.ca/saskatoon/	
Dow AgroScience	Customer Information Center Dow AgroSciences 9330 Zionsville Road Indianapolis, IN 46268-1054	
Fermentation Pilot	Saskatchewan Research Council	

Plant and Bioprocessing Lab,	15 Innovation Blvd. Saskatoon, SK Canada S7N 2X8 306) 933-8136 sosulski@src.sk.ca	
Forest Products Group, Alberta Research Council	Forest Products Alberta Research Council 250 Karl Clark Road Edmonton, Alberta, Canada T6N 1E4	The Forest Products group offers: a full-service research and testing facility for engineered composite panel products new processes and product testing
Guelph Centre for Functional Foods	P.O. Box 3650 95 Stone Rd West Guelph, ON N1H 8J7 **Phone:**(519) 767-6242 **Fax:**(519) 767-6255	Provides high quality, proprietary research and analytical services to the nutraceutical and functional food industry
Guelph Food Technology Centre	88 McGilvray Street, Guelph, Ontario, N1G 2W1 **Phone:** (519) 821-1246 ext. 5039 **Fax:**(519) 836-1281 **Email:** pozols@uoguelph.ca	
IEA – Bioenergy .	**Address:** IEA Bioenergy Secretary PO Box 6256 Whakarewarewa Rotorua New Zealand **Phone:**+64 7 348 2563 **Fax:**+64 7 348 7503 **Email:**jrtustin@xtra.co.nz **Web Site:** http://www.ieabioenergy.com/	IEA Bioenergy is an international collaborative agreement set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy RD&D programmes.
Medicinal Herb Research, Southern Crop Protection and Food Research Centre, Agriculture and Agri-Food Canada	1391 Sandford St., London, ON N5V 4T3 **Phone:** 519-457-1470 ext 240 **Fax:**519-457-3997 **Email:**chapmanr@em.agr.ca	

Ontario Agri-Food Technologies	Ontario Agri-Food Technologies 1 Stone Road West Guelph, Ontario N1G 4Y2 Canada **Phone:** (519) 826-4195 **Fax:** (519) 826-3389
Ontario Ministry of Agriculture and Rural Affairs (OMAFRA)	1 Stone Rd., 5th Fl. Guelph, Ontario N1G 4Y2 **Phone:**(519) 826-3281 **Fax:**519-826-4333
Plant Biotechnology Institute, National Research Council	110 Gymnasium Place Saskatoon, SK S7N 0W9 Canada **Phone:**(306) 975-5568 **Fax:**(306) 975-4008 **Email:**Royal.Hinther@nrc.ca
The BC Research Centre for Alternative Transportation Fuels	BC Research Inc. BC Research Complex 3650 Wesbrook Mall Vancouver, BC Canada V6S 2L2 Phone 604-224-4331 **Fax:**604-224-0540 http://catf.bcresearch.com
University of Alberta, Department of Chemistry, Glycobiology Group	Department of Chemistry University of Alberta Edmaonton, AB Canada T6G 2G2 **Phone:** (780) 492-9756 **Fax:**(780) 492-7705

Appendix 2 The Ethanol Industry in Canada

(http://www.ethanol-crfa.ca/industry.htm)

Ethanol is sold as a high-octane fuel that helps reduce air pollution while delivering improved vehicle performance. It is widely available in proportions of 5-10% ethanol blended with gasoline. Higher-level blends exist but are not commercially available in Canada at this time.

The Canadian ethanol industry is relatively new and growing, and is playing an increasing role in meeting the country's needs for renewable fuels. First blended with gas and sold in Manitoba twenty years ago, today ethanol is offered at approximately 1,000 locations in six provinces (the four Western provinces, Ontario and Quebec).

Canada's annual ethanol production is approximately 225 million litres per year, some of which is exported to the United States. Major initiatives underway will boost production significantly in the next few years. These include the development of new plants in Seaway Valley, Cornwall and Varennes, Quebec as well as a federal government commitment to increase ethanol production by 750 million litres per year.

While ethanol can be derived from a variety of sources, in Canada it has traditionally been made from starch contained in agricultural crops - corn, wheat and barley. The basic process involves the conversion of starch to sugars to ethanol via fermentation. New technology is providing opportunities to also produce ethanol from cellulosic feedstocks, such as agricultural residues (including straw and grass hay) and forestry products (wood chips).

The chart below shows the existing producers of ethanol suitable for blending with gasoline.

Firm	Location	Produce Ethanol From
API Grain Processors	Red Deer Alberta	Wheat feedstock
Commercial Alcohols Inc	Tiverton, Ontario, Chatham, Ontario, Varennes, Quebec* (plant under construction	Corn feedstock Corn feedstock
Mohawk Canada Inc	Minnedosa, Manitoba	Wheat feedstosk
Pound Maker Agventures Ltd	Lanigan, Saskatchewan	Wheat fedstock
Tembec	Temiscaming, Quebec	Wood waste

Gasoline quality in Canada is a provincial government responsibility. All ethanol-blended gasoline meets specifications enforced by the provincial governments, including specifications regarding volatility levels. National specifications have been produced by the Canadian General Standards Board (CGSB) of the Government of Canada, and many provinces require that all gasoline meet CGSB standards.

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