

Canadian Biodiesel Initiative:
Aligning Research Needs and Priorities
With the Emerging Industry

Final Report

Prepared for:



Natural Resources
Canada

Ressources naturelles
Canada

By:



Authors:

Bruce E. Holbein, Jamie D. Stephen, and David B. Layzell

BIOCAP Canada Foundation
156 Barrie Street,
Queen's University,
Kingston, Ontario K7L 3N6

Web: www.biocap.ca
Tel: 613 542 0025
Fax: 613 542 0045
Email: info@biocap.ca

August 23, 2004

Table of Contents

	Page
A. Executive Summary.....	3
B. Introduction.....	5
C. Biodiesel – The Opportunities and Challenges.....	7
1. Potential for Biodiesel	7
2. Biodiesel in Relation to Pending Changes to Petroleum Diesel.....	11
3. Present State of Biodiesel in Canada and Globally	11
D. Biodiesel Production Technologies and Research Needs	13
1. General Biodiesel Production Routes	13
2. Research Needs for Conventional Lipid Esterification Pathway	14
3. Research Needs for Non-Conventional Biodiesel Synthesis via Low- Lipid Biomass Gasification / Fischer-Tropsch Synthesis.....	16
4. Research Needs for Non-Conventional Biodiesel Synthesis by Lipid Hydrotreating (SuperCetane Pathway).....	17
5. Regulatory Challenges and Bottlenecks	18
6. Other Needs and Barriers	18
E. Key Elements in a National Biodiesel Research Initiative.....	19
1. Main Theme Areas for Research and Development.....	19
2. Potential Initial Research Objectives.....	20
3. Proposal for a Network of Research Networks to Deliver Biodiesel Research	21
4. Scope of Biodiesel Initiative Research Networks.....	24
F. Research Capacity in Canada	26
G. Conclusions / Next Steps.....	26
H. References	29
I. Appendix 1. Definitions.....	31
J. Appendix 2. Biodiesel and Related Researchers in Canada	32
K. Appendix 3. Canadian Biodiesel and Related Industries	34
L. Appendix 4. Advisory Steering Group.....	35

A. Executive Summary

This report explores the potential and challenges of the emerging biodiesel fuel industry in Canada, identifies the research gaps and priorities, and proposes an optimal strategy for coordinating an industry-supportive national biodiesel fuel research initiative.

Biodiesel is a liquid fuel produced chemically from renewable biomass resources that can partially or totally replace non-renewable fossil diesel fuel and therefore reduce greenhouse gas and other environmental emissions. In addition, it can reduce dependence on petroleum resources. Canada currently does not have a significant biodiesel production industry despite past successful test demonstration programs and several years of established and growing biodiesel utilization elsewhere in the world.

In order to identify current research gaps and priorities, industry needs, regulatory and social barriers for biodiesel in Canada, the BIOCAP Canada Foundation (BIOCAP) undertook a consultative process (using questionnaires, interviews direct meetings and a national workshop) and consulted with a multi-disciplinary advisory group to obtain input from relevant stakeholders (researchers, industry representatives, non-governmental organizations and governmental officials). These findings are reported and concluded in this discussion paper.

Biodiesel production utilizing conventional esterification of lipid materials (vegetable oils, waste fats and greases) is sufficiently developed technologically so as to permit the emergence of a Canadian production industry. Additionally, newly developed Canadian process improvements and innovations have helped increase the viability of biodiesel production in Canada.

However, competition exists with well-established food and other markets for fuel lipid feedstock supply, creating a high base production price. Lipid feedstock supply is likely to cause production and market constraints for the emerging industry, should demand for biodiesel be more than a few percent (e.g., >2%) of Canada's total transportation diesel use. Therefore, new research aimed at establishing higher lipid crop yields, increased lipid production, more efficient lipid recovery techniques for fuel-grade feedstock, and improved production cost efficiency is crucial to support the emerging industry. The establishment of new lipid crop production dedicated to fuel use, including non-food grade specifications, is seen as essential in overcoming supply, price, and societal constraints and barriers. This is considered a better option than diverting current food-grade oil to biodiesel production. Waste oil should also be considered as a primary feedstock and the full available supply should be utilized.

Additional research into value added co-products, such as glycerol, protein, and carbohydrate, along with the reduction of waste materials, will improve the overall process economics and assist in the realization of a competitive Canadian biodiesel industry.

A large potential for new alternate non-conventional biodiesel supply exists in low-lipid biomass feedstock, using primary gasification of biomass coupled with secondary Fischer-Tropsch (F-T) chemistry for production of biodiesel hydrocarbons. However, substantial research is needed to develop a technically and economically viable process for such an F-T biodiesel production route. A complete life cycle analysis of this alternate approach is required. This F-T avenue for biodiesel production is seen as complementary to conventional biodiesel production from lipids and has longer-term potential for increasing production volumes and improving sustainability.

Canada has significant biodiesel-related research interest and capacity at government and university research facilities, along with notable industrial innovation and leadership in relevant process technologies. Canada also has a large potential for increased production of lipid crops and utilization of abundant low lipid biomass resources as feedstock to support the emerging and developing biodiesel industry.

The crosscutting nature of biodiesel processing research places it as a theme within the biomass thermo-chemical processing sector (termed here 'Green Synthesis') and part of the broader technology research and development area of the bio-refinery. In addition, end user research is necessary to assess the impact of biodiesel on engine performance and emissions. Looking to the future, innovative biodiesel engine design could optimize performance for biodiesel blends or as neat fuel. It is essential to explore all variables in a feedstock to end-use thread.

New research funding can be effectively applied to both short and long term objectives, comprising both applied and basic research aspects, in order to assist the emergence and the continued development of the Canadian biodiesel industry. Much of the required research is multidisciplinary in nature and would be best serviced through strategic collaborations of university and industrial researchers.

An organized network structure would provide a means for establishing effective collaborations and maximizing value and return on research investment. Networking would also provide a vehicle for funding, leveraging research support and effective dissemination of results. This approach would build research capacity relevant to bioenergy in general and produce natural effective consortia and strategic alliances, encouraging commercialization and commercial integration of research results.

B. Introduction

Petroleum diesel continues to be a major fuel worldwide, especially for transportation (Table 1). Canada consumes approximately 23 million tonnes (approximately 26 billion litres) of diesel annually and 46% of this is utilized in the transportation sector, largely by heavy vehicles. The USA utilizes a higher (65%) proportion of its diesel consumption for transportation. Petroleum diesel consumption and

Table 1. World Petroleum Diesel Consumption and Proportion Used by Transportation Sector

Country / Region	Petroleum Diesel Consumption (MT/Yr) ^a	% Diesel Consumption for Transportation ^b	Transportation Petroleum Diesel Consumption (MT/Yr)
Canada	23.4	46	10.8
USA	178.4	65	116.0
EU	258.5	59	152.5
World	934.3	60	560.6

^a MT=10⁶ tonnes or ~1.14 X 10⁹ litres

^b IEA, 2004a data, balance of consumption utilized for industry, agriculture and public services

biodiesel potential are reported here on a mass basis (MT) for ready comparison to other IEA-reported regions (see IEA, 2004a for country to country comparative data) and because environmental benefits are ultimately reported on a specific mass basis (e.g. tonnes CO₂ reduction per tonne of biodiesel utilized etc).

Petroleum diesel usage is a substantial contributor to both greenhouse gas emissions and other atmospheric pollutants.

Transportation is the second leading Canadian GHG emissions-producing sector, contributing 190 Mt CO₂ in 2000 and accounting for over 31% of Canada's emissions growth from 1990 to 2000 (Environment Canada, 2002). Of the transportation sector emissions total, diesel vehicles accounted for 56Mt or 30% of all transportation GHG emissions. Therefore, petroleum diesel used in transportation currently contributes 8% of Canada's total GHG emissions.

Replacement of petroleum diesel with renewable diesel produced from biomass has the potential to provide significant reductions in GHG emissions because the carbon contained in biodiesel is biogenic, renewable and avoids fossil-fuel carbon emissions (USDA/ USDOE, 1998). The carbon utilized for biodiesel is in a closed carbon cycle and thus, does not result in a net release of greenhouse gas emissions. Biodiesel replacement of even 5 % of the currently used petroleum diesel could reduce GHG emissions by up to 2.5MT CO₂ /year (NRCan, 2002).

The transportation sector is an important initial target for use of biodiesel due to its high diesel consumption, established infrastructure for marketing and delivery and high fuel inventory turnover. As a biodegradable fuel, biodiesel may be more prone to longer-term storage problems. However, biodiesel use is otherwise appropriate for other stationary and off-road diesel applications, representing additional future potential approximately equal to that achievable in the transportation sector alone.

Petroleum diesel combustion is also a major source of other air contaminants (Environment Canada, 1999) including nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), particulate matter

(PM), and volatile organic compounds (VOC) (see Table 2). In particular, diesel fuel combustion is responsible for high levels of PM, SO_x, and NO_x, which are major contributors to smog in urban areas.

Biodiesel has been shown on a Life Cycle Analysis (LCA) basis to provide significant reductions in PM, SO_x, CO, and VOC as compared to petroleum diesel (USDA/USDOE, 1998). However, issues remain as to the actual improvements for some pollutant emissions (e.g. NO_x) and the benefits of using biodiesel under certain conditions (e.g. low temperature use and city vs. highway usage) (Beer *et al*, 2000). With its very low sulphur content, biodiesel permits utilization of specialized catalytic control devices that are not functional with traditional petroleum diesel (Walsh, 2000).

Supply, price and security issues with petroleum resources have also contributed to the developing interest in renewable energy, especially from biomass. The US Biomass Research and Development Technical Advisory Committee has set goals that biomass will supply 5% of the USA's power, 20% of its transportation fuels, and 25% of its chemicals by 2030 (USDOE, 2003). These combined goals are equivalent to a 30% reduction from the current USA petroleum consumption.

Table 2. Criteria Air Pollutants from Petroleum Use in Transportation

Sector	PM ₁₀	PM _{2.5}	SO _x	NO _x	VOC	CO
Diesel Transportation MT/Yr	0.051	0.047	0.051	0.595	0.074	0.279
Total Fuels Transportation MT/Yr	0.096	0.083	0.136	1.290	0.734	6.708
Diesel % Total	53	56	38	46	10	4

Biodiesel development is a prominent aspect of both the *USA Roadmap for Biomass Technologies* (DOE, 2002) and the *Canadian Innovation Roadmap on Biobased Feedstocks, Fuels and Industrial Products* (Industry Canada and Bio-products Canada, 2004).

Canada presently has no significant commercial scale biodiesel industry, even though the benefits of biodiesel usage have been confirmed for Canadian conditions in various test and demonstration programs.

The emerging nature of the Canadian biodiesel industry, together with the interest to identify research gaps/priorities and barriers to the emerging industry, has prompted this study. In order to identify current research gaps and priorities, industry needs, regulatory and social barriers for biodiesel in Canada, BIOCAP undertook a consultative process (using questionnaires, interviews and direct meetings) and consulted with a multi-disciplinary advisory group to obtain input from relevant stakeholders (researchers, industry representatives, non-governmental organizations and governmental officials). These findings are reported and concluded in this discussion paper.

C. Biodiesel – The Opportunities and Challenges

1. Potential for Biodiesel

Biodiesel is presently produced from the esterification of lipid materials (fats and oils), such as soy oil in the United States and rapeseed oil in Europe. Canada produces vast quantities of canola (rapeseed), along with, to a lesser extent, other oil crops such as soy, mustard and corn. Canada is a net exporter of canola oil and non-crushed canola seed, making canola the likely initial source for virgin oil esterification biodiesel feedstock domestically.

Biodiesel can also be produced conventionally from other natural fats and oils, such as tallow, grease, and used cooking oil. Canada is a net exporter of tallow and grease, providing another potential domestic feedstock for production. Current issues related to restrictions on rendered animal products for animal and human feed materials (i.e., from risks associated with Bovine Spongiform Encephalopathy (BSE) and other animal diseases) have resulted in a potential increased availability of these materials that could be utilized for biodiesel production.

The Canadian General Standards Board has now recognized ASTM D6751 (USA biodiesel specification – *Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels*; ASTM, 2003) as part of its new CGSB-3.520 specification: *Automotive low sulphur diesel fuel containing low levels of biodiesel esters (B1 – B5)*. This industry-accepted specification recognizes only alkyl esters of lipids as biodiesel, which are produced by esterification. Other bio-based diesel fuels, including SuperCetane and Fischer-Tropsch synthesis products are currently not included in biodiesel standards.

An inventory of the main Canadian lipid feedstocks provides a general assessment of the preliminary potential for conventional biodiesel production (Table 3).

The major cropped lipid source in Canada is canola oil extracted from canola seed. It is important to note that of the approximately 6 MT of canola seed that will be harvested in 2003-2004 (USDA, 2003 and Canadian Canola Council, 2004), 50% will be exported as raw seed while 2.5 MT seed will be crushed domestically to yield 1.05 MT canola oil (42% oil yield from seed). Therefore, exported seed represents an additional potential oil yield of 1.3MT.

Some 0.29 MT of animal tallow and grease are produced in Canada each year of which 85 % is typically exported. However, current restrictions on the use of these materials may increase availability of some animal lipids for biodiesel feedstock from reduced exportation.

Soy oil imports exceed exports and without significant increases in soy production, this is not presently regarded as a key potential biodiesel feedstock. Two additional oil crops that could be considered are mustard and flax, although currently, both have Canadian production volumes far below canola.

A preliminary case-study analysis for utilizing Canada's existing lipid feedstocks for biodiesel production to meet a B5 requirement, i.e., biodiesel production to 5% of Canada's current transportation petroleum diesel consumption (a requirement for 0.54 MT biodiesel or approximately 610 million litres/yr), was conducted (see Table 3). This scenario involves both increased production and diversion of currently exported lipid materials. To make such a significant market-driven contribution to diesel fuel supply, substantial production increases (e.g., 10% increase in canola production) and export diversion (e.g. 50% diversion of animal lipids and canola oil) would be required.

On a volume basis, canola oil and animal lipids show the greatest resource from which to base an emerging Canadian biodiesel industry. This is due to the underutilized capacity for additional canola oil production from domestic crushing of currently exported harvested seed and changing policy constraints of animal lipid use in their traditional markets. This is not to say that other oil crops will not play a significant role in the Canadian biodiesel industry in the future.

Established food markets and prices for canola and soy oil, as well as production costs, make their use as a biodiesel feedstock currently financially uncompetitive with petroleum-derived diesel. In addition, diversion of food-grade products to a fuel production stream raises ethical issues regarding human/animal consumption. On occasion, the use of crops for non-food products provides a secondary market that becomes valuable to producers if the primary food market is oversupplied. Additionally, approximately 5% of canola produced each year is substandard and not fit for food markets. These feedstocks could potentially be utilized for biodiesel production.

Biodiesel production could benefit significantly from newly-developed fuel grade specifications, potentially less stringent than food-grade, or employing fuel-compatible but not food-compatible, extraction solvents, as lipid feedstocks.

Table 3. Major Canadian Lipids Production and Export 2003^a
Including Case To Meet 5% of Transportation Diesel Demand

Commodity	Production or Export MT/year	Potential Biodiesel via 10% Production Increase MT/year ^b	Potential Biodiesel via Diverting 50% Exports MT/Yr ^c	% Current Transportation Petroleum Diesel Demand
Tallow and grease Produced ^d	0.29	N/A	N/A	Na
Tallow and grease Net exported ^d	0.25	N/A	0.11	1.0 %
Soy Oil Produced	0.32	0.032	N/A	0.3%
Soy Oil Net Exported	(0.08)	N/A	0	N/A
Canola (Rape) Oil Produced	1.05	0.10	N/A	0.9%
Canola (Rape) Oil Net Exported	0.60	N/A	0.30	2.7%

^a USDA 2003

^b biodiesel production from dedicated new production, assuming 0.9 tonne biodiesel/ tonne feedstock yield (Klass, 1998)

^c biodiesel production from diverted export, assuming 0.9 tonne biodiesel/ tonne feedstock yield (Klass, 1998)

^d most recent data available (USDA 1997 and IEA, 2004b)

This opens the possibility for utilizing new, more cost-effective and more efficient extraction technologies for application to fuel-production dedicated crops. In addition, the utilization of ‘off-spec’ oil product that now arises in food production (such as substandard oil aesthetics) is also a biodiesel feedstock opportunity. It is imperative that the technical and economic implications of such oil sourcing for fuel production are properly addressed through dedicated research. There are also important opportunities to improve the range of lipid crops, lipid crop yields and oil extraction efficiencies to supply this developing market.

Canada has a large biomass inventory from the agricultural, forestry and municipal sectors consisting of largely unused residual material that is high in energy content but low in lipid content (Woods and Layzell, 2003). Such low-lipid content biomass feedstock provides a potential for non-conventional biodiesel production through gasification and Fischer-Tropsch synthesis of biodiesel (see Table 4).

Biomass waste feedstocks, including forestry and agricultural residues, and municipal waste, are currently underutilized and have the potential to supply biodiesel product equivalent to 150% of the

current Canadian petroleum diesel transportation consumption. In addition, sustainable forestry for biodiesel production is an untapped resource that needs to be investigated and quantified.

This vast potential for biomass-derived biodiesel has important implications for the developing biodiesel industry and market pending the resolution of a variety of knowledge gaps and the development of economically viable process technology. Dedicated research is necessary to further develop this technology and to establish its overall sustainability.

A large portion of ‘available’ biomass feedstock is dispersed geographically or is in remote regions, impacting its overall industrial availability. Further research into transportation/distribution systems and technologies is essential to a sustainable and economically viable biomass-based biodiesel industry. One possibility for increased transportation efficiency is on-site pretreatment, (e.g. pyrolysis, which would enable the transportation of a higher-energy density feedstock).

The current biodiesel standards in Canada (CGSB-3.520, 2004 release) and the USA (ASTM D6751, 2003) do not include Fischer-Tropsch renewable diesel or SuperCetane hydrocarbons (catalytic hydrotreating of lipids) as biodiesel. However, these hydrocarbons, unlike conventional alkyl ester biodiesel, are pure hydrocarbon and the petroleum industry has experience with such synthetic fuels (eg. synthesis from ‘stranded’ natural gas reserves or following coal gasification). Therefore, it is unlikely that substantial research on performance of F-T or SuperCetane products would be necessary to permit amendment for their inclusion to the current Canadian and USA diesel standards. The petroleum industry is likely to regard F-T or SuperCetane biodiesels as conventional diesel from a usage perspective, regardless of their biological origins. Both can act as blending stock to enhance product quality and quantity, particularly for ultra low sulphur diesel.

The overall energy balance, conversion efficiency and economics for gasification of biomass feedstocks (as shown in Table 4) have not been extensively analyzed. While F-T ‘green’ diesel has been successfully made in mass volumes from natural gas feedstock in areas where access to crude oil has been restricted (Schubert *et al*, 2001), the approach of biomass gasification coupled to Fischer-Tropsch synthesis has not yet been developed or commercialized. New research is required to investigate this technology approach as applied to Canadian biomass resources.

Table 4. Low- lipid Biomass Available for Potential Gasification / F-T Biodiesel Synthesis

Biomass Feedstock	Biomass MT/Yr ^a	Energy Content GJ x 10⁹ ^b	Potential F-T Biodiesel Yield MT/Yr ^c
Wood residue non stem	91.5	1.43	12.0
Wood residue, wood product	5.38	0.08	0.7
Agricultural crop residues	12.9	0.20	1.7
Municipal wastes	23.0	0.36	3.1
Total	133	2.1	17.5

a oven dry mass, adapted from Wood and Layzell, 2003

b theoretical energy content; tonnes carbon contained (not shown) X 35.76 GJ/ tonne C

c assuming 150 litres (132 kg) / tonne biomass (from Boerrigter *et al*, 2003); not shown are other energy products including F-T waxes and any net electrical and thermal energy products of gasification / F-T.

For the purposes of this discussion paper, all renewable diesel fuels are termed biodiesel, while alkyl esters are termed conventional biodiesel and Fischer-Tropsch biodiesel is termed non-conventional biodiesel. The potential biodiesel production segments (conventional and non-conventional), as pertaining to both lipid and low-lipid content feedstocks, are summarized in Table 5 along with their key impacts or implications on market supply.

Canada would appear to have sufficient lipid feedstock supply to support an emerging biodiesel industry based on conventional biodiesel production and with demand of up to approximately 2% of the current transportation sector diesel consumption. Introduction of non-conventional biodiesel production technology and use of alternate low-lipid biomass resources has the potential to improve supply as the industry develops and demand grows.

Table 5. Potential Biodiesel Production Inventory, Segments and Market Implications
Including Case Meeting 5% of Transportation Diesel Demand and Beyond

Market / production segment	Biodiesel Yield (MT/Yr)	% Current Transportation Petroleum Diesel Demand	Qualifying Note
10 % increased soy oil production (via esterification)	0.03	0.3%	Unlikely option; soy oil now imported to meet domestic demand
10% increased canola (rape) oil production (via esterification)	0.10	0.9%	Reasonable increase; new production with dedicated 'fuel grade crop/ oil' or use of off-spec food oil
Tallow / grease 50% export diverted to production (via esterification)	0.11	1.0%	A portion possible due to established markets at competitive prices; Current restrictions on use of exports enhance
Canola (rape) 50% export diverted to production (via esterification)	0.30	2.7%	A portion likely, as food grade oil being diverted from established markets; enhanced by diversion of exported seed to domestic oil production
10% waste biomass (via non-conventional gasification/ Fischer-Tropsch)	1.80	16.7 %	Reasonable; only 10% available biomass utilized (large growth potential)
Total	2.76	21.6%	>2% difficult to reach with conventional technology and current lipid feedstocks 5 % near term supply reasonable through segment mix

2. Biodiesel in Relation to Pending Changes to Petroleum Diesel

Biodiesel, in addition to being a renewable fuel, has the potential to substantially reduce environmental emissions now attributable to petroleum diesel use (NRCAN, 2002 and IEA, 2004).

Petroleum diesel is recognized to be problematic for emissions of SO_x, particulates, NO_x and VOC's, and anticipated regulatory changes will mandate introduction by 2006 of ultra low sulphur (S) petroleum diesel. The current excess sulphur content contributes to SO_x and other emissions (Table 2). The natural content of sulphur in petroleum diesel interferes with catalytic converters and other emission control devices, presently precluding their usage.

Ultra low S diesel will be introduced over the next few years (by 2006) to lower SO_x emissions and allow the utilization of other pollution control devices. These devices have had limited usage to date due to high fuel S content (Walsh, 2000).

Ultra low sulphur petroleum diesel (from process treatments) also requires adjustment to regain its former lubricity and because biodiesel is high in lubricity, it can potentially provide this benefit. Thus, an initial biodiesel market could develop on the basis of strictly supplying biodiesel additive for lubricity to ultra low sulphur petroleum diesel (e.g. 2-5% addition). This potential market segment is not directly driven by the other environmental (e.g. GHG emissions) benefits of biodiesel usage.

Additionally, a mandated use of ultra low sulphur diesel will add to production costs due to additional treatment steps necessary to remove sulphur from most petroleum feedstocks (USDOE, 2004). These higher production costs should drive an increase in petroleum diesel prices and therefore improve the cost competitiveness and market potential for biodiesel.

Engine manufacturers currently accept biodiesel additions at up to 5% generally without issues as to their manufacturer's warranty, but have yet to accept higher ratios in North America. Thus, engine warranty issues are not seen as a major factor for fuels containing up to 5% conventional biodiesel. Established biodiesel standards and a track record of performance should facilitate the move to accepted higher ratios of biodiesel. Development of mid-level blends of conventional biodiesel, such as B6-B20, will likely require increased data quantity and consistency to demonstrate satisfactory performance in both light and heavy-duty diesel engines under Canadian climatic conditions. The involvement of diesel engine Original Equipment Manufacturers (OEMs) in this research process would be highly desirable.

3. Present State of Biodiesel in Canada and Globally

There is virtually no commercial production of biodiesel in Canada at the present time. Test and demonstration programs have used either pilot production sources or imported biodiesel from the USA. Small quantities of biodiesel fuel, for use as a lubricity additive, are being produced domestically and biodiesel is being imported from the USA to meet existing demand. Canada's delayed emergence of a biodiesel industry is in contrast to the growing US market and the more established European market (see Table 6). Biodiesel production in the USA and Europe currently supplies 0.03 % and 0.6% of the transportation sector diesel demand in these markets, respectively (Bockey, 2003).

This data indicates that while biodiesel has a foothold in the USA and European markets, other barriers would appear to be restricting significant usage of biodiesel (i.e. to 5% or more of diesel demand) in Canada. It is likely that issues of relative cost are principal in this regard. Overall biodiesel production costs would decrease in-line with a drop in feedstock supply and process costs, as well as an increased use of co-products. Research related to these issues has been identified and solutions to these issues would assist the emerging Canadian industry.

Table 6. Current Biodiesel Production in North America and Europe

Country / Region	Biodiesel production tonnes/year ^a	% of Transportation Petroleum Diesel ^d
Canada	~0 ^b	0%
USA	54,000	0.03%
EU-8 ^c	1,109,000	0.6%

a from Bockey, 2003

b excluding test and demonstration quantities produced

c including GER, FRA, ITA, CZ, DK, AU, SWE and UK

d data from IEA, 2004

Based on present findings, Canada does have industrial process technology innovation through the proprietary BIOX Corp. (BIOX, 2004) process and the emerging Enerkem Inc. gasification / Fischer-Tropsch technology (Enerkem, 2004). Rothsay has also developed a proprietary esterification process for tallow, grease and other lipid feedstocks (Rothsay, 2004). Milligan Bio-Tech supplies lubricity additives for petroleum diesel (Milligan, 2004). NRCan has also developed the SuperCetane technology. The SuperCetane technology is a non-conventional approach to biodiesel, catalytically hydrotreating lipid feedstocks, that has been piloted and is ready for commercial scale-up (NRCan, 2003).

This initial industrial leadership (summarized in Appendix 3) lays a foundation for an emerging industry, which can build production capacity. This industrial base also provides the basis for effective industry-university collaborations that can close the research gaps of sustainable biodiesel use in Canada. The emerging market would presumably stimulate additional capacity development with new industrial players. It is also important to consider the Canadian biodiesel industry within an international production context, and consider the import/export implications and possibilities.

Canada possesses considerable biodiesel-relevant research capacity with researchers in government, university and industry and spanning the themes and topics relevant to biodiesel production from both high and low lipid feedstock. In addition, there exists a great capacity for lifecycle analysis and social science impacts analysis in the Canadian research community (see Appendix 2).

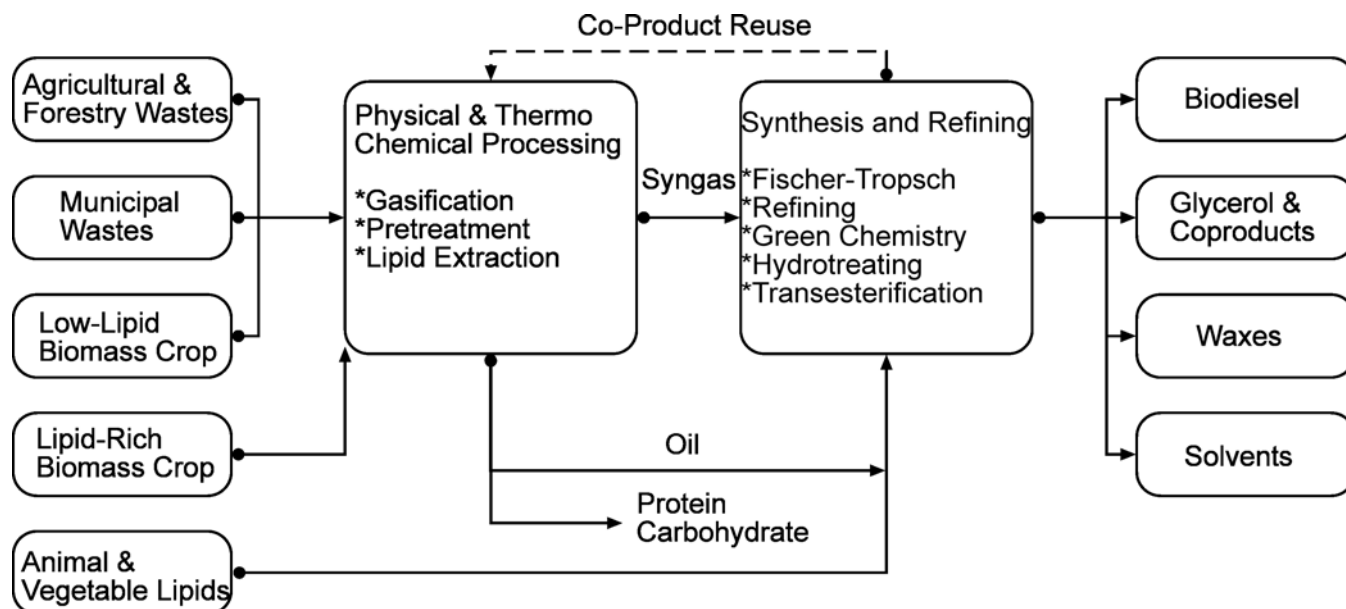
Canada's documented biomass advantage (Woods and Layzell, 2003) is also of interest in relation to the potential for the low-lipid biomass to biodiesel synthesis route. The development of Canadian technology appropriate for biomass gasification coupled to Fischer-Tropsch synthesis of biodiesel is important for establishing substantial and sustainable biodiesel capacity without heavy reliance on lipid food materials.

D. Biodiesel Production Technologies and Research Needs

1. General Biodiesel Production Routes

The general routes for conventional and non-conventional biodiesel production can be appreciated as integrated multi-step process pathways in the simplified feedstocks to products flow diagram (Figure 1).

Figure 1. Biodiesel Synthesis Pathways



Biodiesel production pathways can be classified into conventional (lipid esterification products) and non-conventional (potential new products from SuperCetane, lipid catalytic hydrotreating synthesis and Fischer-Tropsch synthesis from low-lipid biomass-derived synthesis gas). Appendix 1 contains additional definitions pertaining to these technologies and for the major process steps as diagrammed.

The three chemical pathways relate to two distinct types of feedstock; those rich in lipids, such as canola oil and animal rendering fats, and those low in lipid content, such as agricultural waste residues or municipal wastes. The two distinct feedstock types require fundamentally different processing and chemical synthesis to obtain biodiesel and related products.

With regard to conventional biodiesel production, lipid-rich biomass crops are initially processed to obtain oils, meal and fibre (protein and carbohydrate) products. The recovered oil can then be processed by transesterification synthesis to obtain alkyl esters (Tyson, 2003 and Klass, 1998). Animal fats and greases can also be converted to biodiesel via transesterification.

Alternatively, the SuperCetane process utilizes catalytic hydrotreating of the lipid feedstocks to obtain a high cetane hydrocarbon (NRCAN, 2003). While the recovered alkyl-esters and SuperCetane hydrocarbons are chemically distinct, both have diesel-like characteristics. The SuperCetane product has the higher cetane value of the two (~100) and can act as a blending stock to significantly increase overall fuel cetane.

Transesterification produces stoichiometric amounts of by-product glycerol. Glycerol is an established product that can be utilized as secondary feedstock for synthesis of other value-added products, via processes such as gasification. Transesterification also produces by-product soaps, depending on the specific process utilized and inorganic residues that require reuse or disposal.

Low-lipid biomass feedstocks, including agricultural and/or municipal wastes, can be potentially processed for biodiesel production by thermal gasification coupled to Fischer-Tropsch synthesis of hydrocarbons (Boerrigter *et al*, 2003, Schubert *et al*, 2001 and Klass, 1998). In this non-conventional approach, biomass is heated in a low oxygen environment to produce a synthesis gas (syngas) that contains both hydrogen and carbon monoxide. The syngas can then be reacted using an iron or cobalt catalyst in Fischer-Tropsch synthesis hydrogenation of carbon monoxide to produce hydrocarbons. With the appropriate catalyst and process conditions, a diesel-like hydrocarbon is produced.

The potential for a broad range of co-products exists for low-lipid biomass feedstocks given the range of potential product fractions capable through F-T synthesis (determined by the metallic catalyst chosen and process conditions employed).

F-T biodiesel would be a pure hydrocarbon product, chemically distinct from conventional alkyl-ester biodiesel and chemically more similar to petroleum diesel (Boerrigter *et al*, 2003). Secondary F-T products, including lighter (lower boiling point) and heavier (higher boiling point) hydrocarbons, are also produced and these could be utilized for other value-added products.

Only esterification products are currently recognized as biodiesel under industry specifications. However, the petroleum industry has experience in utilizing Fischer-Tropsch hydrocarbons and they can act as blending stocks for current petroleum derived fuels

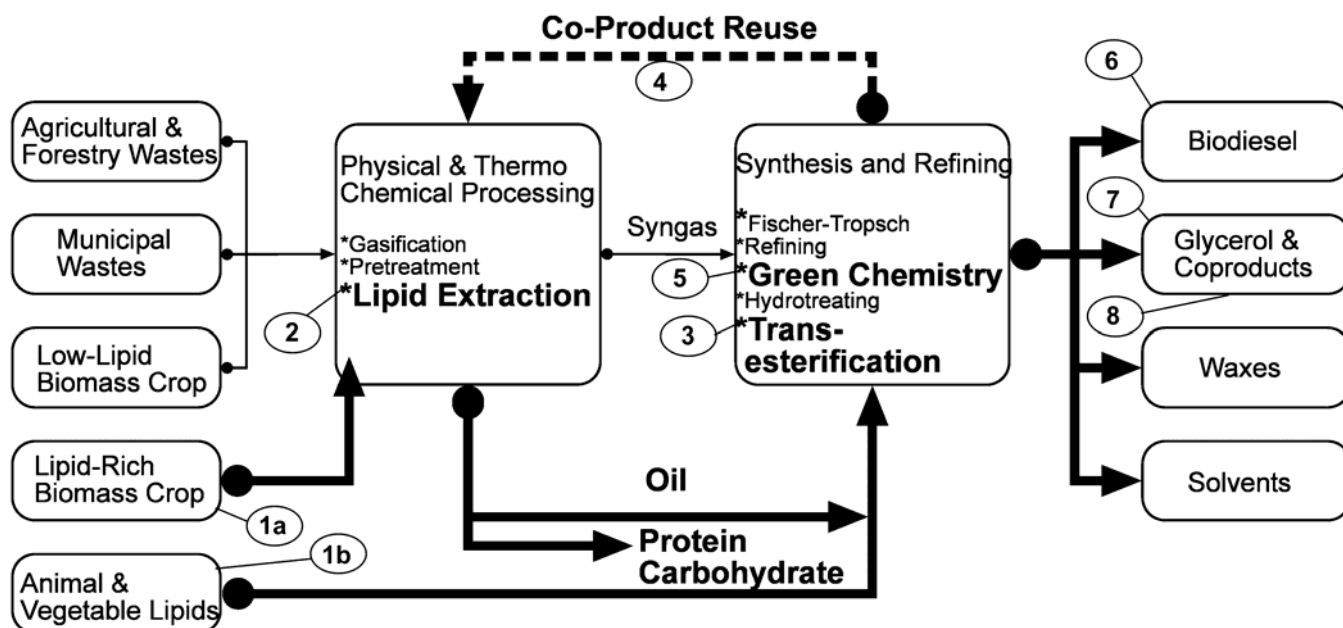
The process steps of hydrocracking and refining that are common to both the SuperCetane and Fischer-Tropsch synthesis routes utilize conventional petroleum industry unit processes and hardware. This technology transfer advantage and potential use of existing petroleum refining infrastructure is important to the development of biomass-specific processes.

Input from researchers at universities and government, industry representatives, NGO's and government representatives during the preparation of this report as well as the steering advisory group (see Appendix 4) allowed the identification of industry needs, research knowledge gaps and various barriers to an emerging biodiesel industry and market. These findings are summarized below using definable process pathway segments for both conventional lipid esterification synthesis (Figure 2 and Table 7) and non-conventional biomass gasification/ F-T synthesis (Figure 3 and Table 8).

2. Research Needs for Conventional Lipid Esterification Pathway

This pathway is illustrated in Figure 2 showing discrete pathway segments. Lipid feedstocks as either direct co-products of the food industry (1b) or from lipid rich crops (1a) after lipid extraction by pretreatment (2) are treated chemically to produce alkyl esters of the lipids (3) that form a biodiesel product (6). The main co-product glycerol is refined to provide a glycerol product (7) or is processed along with more dilute glycerol and other waste streams (alcohols, soaps, inorganic materials) to recover energy or alternate products (4). Glycerol can also be subjected to microbial or green chemistry processing (5) to produce value added products such as 1,3-propanediol for use in the chemical industry (8).

Figure 2. Feedstock to Products Pathways for Transesterification of Lipids



BOLD = Pathway

Table 7. Research Needs for Conventional Esterification Synthesis of Biodiesel

Segment #	Theme Area	Knowledge Gap / Need
1a	Oil producing Biomass Crops	<ul style="list-style-type: none"> o Fuel-specific cropping systems with improved efficiency over food-specific o Non-canola oil crop in rotation with wheat o Reduced feedstock cost o Potential role of perennial crops and novel oil crops o Regional differences in oil crop production and identification of optimal lands
1b	Recovered Oils/ Fats	<ul style="list-style-type: none"> o Improved extraction / recovery techniques o Risk of disease transmission o Fish oil as feedstock o Used cooking oil quantification and collection methods
2	Lipid Extraction	<ul style="list-style-type: none"> o Higher efficiency extraction techniques o Fuel vs. food grade oil specifications o Pure Plant vs. Straight Vegetable oils o Co-solvent for extraction compatible with esterification o Contaminant removal techniques o Waste treatment o Meal and residues as biomass feedstock o Uses for protein and carbohydrate products o Uses for lignin and phytate products o Novel oil extraction processes for potential novel oil crops/sources
3	Ester Synthesis Technology	<ul style="list-style-type: none"> o Renewable alkyl sources (ethanol or methanol) o Ethanol process technology o Free Fatty acid removal techniques o Improved synthesis from mixed oils/grease/fats
4	Co-product waste Utilization	<ul style="list-style-type: none"> o Wastewater treatment; anaerobic digestion o Salts and soaps reuse o Low-strength contaminated glycerol use
5	Green Chemistry Synthesis	<ul style="list-style-type: none"> o Glycerol conversions to value added chemicals (e.g., 1,3-propanediol) o Efficiency / benefits over microbial / enzyme process o Specific value-added methyl ester products o Potential for fatty acid ether products
6	Biodiesel Product	<ul style="list-style-type: none"> o Potential as gasoline additive o Impurities and impacts

7	Glycerol Product	<ul style="list-style-type: none"> o Efficient recovery of high purity product o Alternate uses of lower grades (energy feedstock) o Glycerol as energy source or gasification feedstock o Methanol production from glycerol o H2 or CH4 from glycerol via microbial anaerobic digestion
8	Value Added Chemicals	<ul style="list-style-type: none"> o Discrete esters or ethers for chemical uses o 1,3-propanediol feed for plastics o Novel chemicals from various feedstocks (eg. pesticides from mustard) o Uses for protein, carbohydrate, lignin, phytate
1-8 overall	Feedstock- Products	<ul style="list-style-type: none"> o Energy and emission balance on integrated feedstock to products basis; process economics o Marginal land opportunity for increased oil crop production o LCA including emissions of various feedstocks

3. Research Needs for Non-Conventional Biodiesel Synthesis via Low-Lipid Biomass Gasification / Fischer-Tropsch Synthesis

This non-conventional potential pathway for biodiesel is illustrated in Figure 3. Biomass such as municipal waste, lignocellulosic agricultural residues or a dedicated energy crop such as switchgrass (Bransby, 2004) with insufficient lipid content to warrant extraction of lipids for conventional synthesis of biodiesel (1) is pretreated for example by milling (2) or pyrolysis to provide a feedstock for gasification (3). Synthesis gas from gasification, rich in hydrogen and carbon monoxide is processed by Fischer-Tropsch synthesis (4) to produce hydrocarbons. Refining and fractionation of the hydrocarbons produces an alternative non-conventional biodiesel as well as potential product chemical intermediates such as alcohols (6), solvents and waxes (7). Green chemical synthesis (5) is employed to produce value-added chemicals from the non-diesel products.

Figure 3. Feedstock to Products Pathways for Gasification / Fischer-Tropsch Synthesis

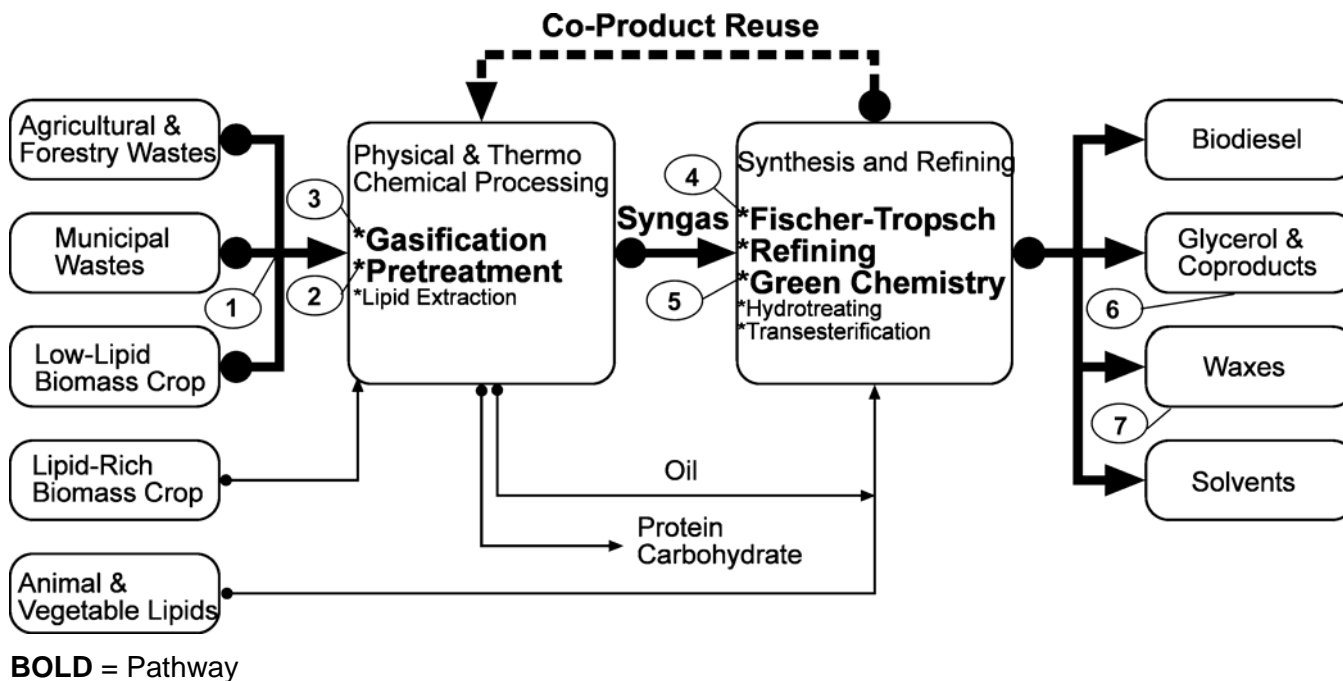


Table 8. Research Needs for Non-Conventional Biodiesel Synthesis via Low- Lipid Biomass Gasification / Fischer-Tropsch Synthesis

Segment #	Theme Area	Knowledge Gap / Need
1	Biomass Feed	<ul style="list-style-type: none"> o Energy crop possibilities o Contaminants in municipal wastes o Energy balance/yield vs. alternatives (e.g. microbial bioenergy process) o Supply and transportation logistics o Softwood vs. crop residues
2	Pretreatment Technologies	<ul style="list-style-type: none"> o Pyrolysis for energy- densified bio-oil product o Off-gas energy recovery o Removal of contaminants
3	Gasification Technology	<ul style="list-style-type: none"> o CO: H₂ process and control o Suppression of gas contaminants o Removal of contaminants (S etc) o Pyrolysis bio-oil as feedstock o Tail-gas energy recovery o Conversion/utilization of char co-product o Syngas conversion to alcohols
4	Fischer-Tropsch Synthesis	<ul style="list-style-type: none"> o Catalyst and process to yield maximal biodiesel o Tail gas energy use/recycling o Removal of impurities
5	Green Chemistry Synthesis	<ul style="list-style-type: none"> o Conversion of low bp F-T hydrocarbons (alcohols, etc) to chemical synthesis feedstocks o Syngas conversion to alcohols o Bio-oil component chemical conversions o Oxidation of F-T biodiesel
6	Value-added Chemicals	<ul style="list-style-type: none"> o Renewable source methanol production (F-T) o Bio-oil derived chemical feedstocks o Lubricants
7	Waxes/Oils	<ul style="list-style-type: none"> o Uses and value-added products from high bp F-T fractions
1-7 overall	Feedstock-products	<ul style="list-style-type: none"> o Overall energy and mass balance yield/gain o LCA of integrated process thread for GHG emissions and sustainability analysis o Process economics at varying scales of operation

4. Research Needs for Non-Conventional Biodiesel Synthesis by Lipid Hydrotreating (SuperCetane Pathway)

The SuperCetane pathway (not diagrammed) utilizes the same lipid feedstocks as for conventional biodiesel synthesis but employs catalytic hydrotreating to yield an alternate non-conventional biodiesel product. This pathway thus shares elements common to both the conventional lipid esterification and non-conventional gasification/ Fisher-Tropsch pathways. Research needs related to feedstocks for lipid esterification (Table 7) have similar significance for this pathway. Additionally, segments 5-7 for the gasification/F-T pathway (Table 8) also relate to this production route.

Both Fischer-Tropsch (hydrogenation of CO) and SuperCetane (hydrotreating) syntheses share some common process elements related to production, product fractionation, refining and recovery.

5. Regulatory Challenges and Bottlenecks

Various regulatory issues as identified by stakeholders represent potential barriers and serve to some extent as goals for an emerging Canadian biodiesel industry. These are summarized:

1. Need for a Canadian biodiesel fuel standard (standardization of fuel specifications)

- a. Standard agreed to by petroleum and biodiesel industry
- b. Canadian standard to be released in 2004 will cover only esterification products from lipid feedstocks
- c. Standard sets performance bar for new process technologies
- d. Standard may facilitate acceptance of use by engine manufacturers
- e. Standard will ensure against problems of inferior quality issues

2. Need for Subsidies/Incentives and Tax issues on biodiesel

- a. Excise tax on fuel relief to support emergence of industry through initial sales price benefit
- b. Value for carbon emission reductions in relation to market price benefit or incentive to producers

3. Potential biodiesel legislation/policy

- a. Defining role of government in relation to allowing/facilitating biodiesel industry and market emergence; leadership required at federal and provincial levels
- b. Mandating biodiesel addition to petroleum diesel to meet national or provincial environmental objectives
- c. Establish a biodiesel Value-Chain inclusive of feedstock production through to consumption

These challenges could be met and assisted through new research including integrative analyses of biodiesel sustainability combining LCA with economic/social impacts. This research would ideally be done in concert with research on technical needs and gaps. This would lead to vital policy-relevant information to enable governments to make informed choices on biodiesel.

6. Other Research Needs and Barriers

The health benefits of biodiesel use in Canada need to be better defined to provide additional support for its adoption, use, and public acceptance. Preliminary evidence elsewhere (USDOE-NREL, 2003) has projected that the average risk of premature death due to exposure to air toxics for B20 biodiesel used in heavy vehicles at 100% market penetration would be reduced by 5.9% from the standard petroleum diesel base case. However, the benefits and the health care impacts of B5 biodiesel introduction in Canada are largely unknown. Emission reductions, and therefore associated health benefits, may be tied to yet-to-be-determined threshold effects (possibly above B5) and it is unclear what benefits would be observed at low rates of biodiesel addition. B5 is likely to be the initial target for use in Canada (upper limit of new Canadian standard) and research should be undertaken to quantify the health benefits at this level of use in Canada.

Other stakeholder-identified societal, industrial and market place issues also represent potential barriers to an emerging Canadian biodiesel industry:

1. Supply assurances (varying sources, locales); transportation of biodiesel product to serve regional markets would be an important price determinant.

2. Response and support of Canadian petroleum industry to biodiesel and blends; utilization of existing petroleum industry infrastructure is essential to introduction of biodiesel.
3. Geographic differences and regionalization; some regions could have more stringent requirements than others due to climatic conditions, distance from production facilities, etc.
4. Utility of partnerships with Canadian Oil Processors Association (COPA) & Petroleum Technology Alliance of Canada (PTAC); partnering could enhance adoption and market development.
5. Redundancy and need to work cooperatively in a synergistic manner with other biodiesel and bioenergy related industry groups; common goals of various associations could improve progress of introduction and increased use. This comes with the challenges of intellectual property (IP).
6. Lack of complete economic analysis including return on investment for both industry and governments; this is an investment deterrent while better analysis could enhance investment possibilities.
7. Influence of process scale (and economies of scale), including differences between farm, regional and large industrial economic viability; large central production facilities would be more cost effective for production but necessitate product transportation while smaller regional facilities would ease transportation requirements

E. Key Elements in a National Biodiesel Research Initiative

1. Main Theme Areas for Research and Development

The main research themes, common to both conventional and non-conventional biodiesel synthesis pathways and emerging from the foregoing analysis of knowledge gaps, research and technology needs are summarized in Table 9. The wide range of supporting disciplines shown with these themes illustrates the broad multidisciplinary needs of the biodiesel initiative.

Table 9. Main Themes of Biodiesel Research and Their Supporting Disciplines

Theme Areas	Disciplines
A. Feedstock Production	Plant Science, Molecular Biology, Agriculture, Environmental science
B. Industrial Processing Technologies	Mechanical Engineering, Chemical Engineering, Process Engineering, Chemistry, Microbiology, Physics, Materials Science
1. Pre-treatment Technology Development	
2. Chemical Synthesis Technology Development	
3. Green Chemistry Synthesis of Value-Added Products	
C. Engine Design, Performance, Emissions and Fuel Standards	
D. Economic, Environmental Sustainability Assessment	Agricultural & Natural Resource Economics, Process Economics, Sociology, Life Cycle Analysis, Integrative Assessment Modeling, Ecology, Environmental Science, Law, Policy Studies

2. Potential Initial Research Objectives

Based on stakeholder input, broad research objectives have been identified in relation to the main theme areas as shown in Table 10.

Table 10. Initial Objectives For Main Themes of Biodiesel Research Initiative

Theme Areas	Research Objectives
A Feedstock Production	Develop improved lipid fuel crops and feedstocks Develop uses for carbohydrate and protein co-products Develop crop practices suited to feedstock production Investigate low-lipid biomass feedstock crops
B Industrial Processing Technologies	
1. Pre-treatment Technology Development	Develop fuel-specific lipid extraction technology Investigate potential of biooil as energy dense feedstock
2. Chemical Synthesis Technology Development	Improved overall esterification process Biomass gasification/ Fischer Tropsch development SuperCetane process development
3. Green Chemistry Synthesis of Value-Added Products	Value-added uses for glycerol, protein and co-products Investigate F-T light fraction for chemical feedstocks
C. Engine Design, Performance, Emissions and Fuel Standards	Quantify emissions at B5, B6-B20 and B100 Investigate performance on new generation engines Obtain data to support fuel adoption and standards
D. Economic, Environmental Sustainability Assessment	Complete LCA on biomass-F-T and SuperCetane Investigate agri-food policy issues of fuels and crops Complete integrated economic analysis of pathways

Some of the key research objectives can be further described:

- 1. Feedstock Development.** Develop oilseed or biomass crops that can provide a sustainable, cost-effective feedstock for the large-scale production of biodiesel fuels and related chemical products.
- 2. Improved Esterification Technology.** Provide technology innovation to improve overall process efficiencies, economics and sustainability of an emerging biodiesel industry based initially on conventional esterification of lipid feedstocks.
- 3. Gasification/Fischer Tropsch and SuperCetane Technology Development.** Investigate and develop non-conventional biodiesel and associated products synthesis technologies for lipids using catalytic hydrotreating and low-lipid biomass wastes and crops utilizing thermal gasification coupled to Fischer-Tropsch hydrocarbon synthesis.
- 4. Value-added Chemical Product Development.** Investigate and develop 'green chemical' synthesis pathways for esterification by-product glycerol and Fischer-Tropsch or SuperCetane light (solvents) and heavy (waxes) by-product fractions to produce value-added chemical products.

5. **Performance Analysis and Engine Design.** To assess the performance characteristics of biodiesel-petroleum diesel mixtures in a wide range of diesel engines and generators and develop standardization criteria or new technologies to overcome limitations
6. **Biodiesel Emissions Benefits.** To measure and assess emissions reductions at low blend ratios of up to B5 and B6-B20 as these are not likely linear.
7. **Socio-Economic and Policy Issues.** Assess the barriers and bottlenecks, as well as the opportunities and implementation strategies for the large-scale production and use of biodiesel fuels in Canada and internationally.

3. Proposal for a Network of Research Networks to Deliver Biodiesel Research

Following discussions and a national workshop with researchers and stakeholders, it became apparent that research was needed all along the biodiesel 'feedstock-to-end-user thread', from oilseed/biomass crops through industrial processing to the ultimate use of biodiesel in transportation vehicles, generators or other diesel engines.

Because of the diversity of expertise required for the 'feedstock-to-end-user thread', and because many of the technologies and products are linked to other aspects of agriculture, chemical refining, automobile design, or socio-economics, there was little support for the concept of a single 'stand-alone' Biodiesel Network that would cover all areas.

Rather, strong support was given to the idea of making research goals for biodiesel a key integrating element that would bring together a number of existing or emerging research networks. In particular:

- **Green Crop.** This BIOCAP supported Network centered at McGill University is currently preparing a full proposal for a \$1.3M per year (X 5 year) NSERC Network grant that will be submitted in Sept. 2004. A key component of this grant is the development of an oilseed crop optimized for biodiesel production. This network could effectively address the crop feedstock gaps identified in this discussion paper.
- **Afforestation and Biomass Crops.** This emerging BIOCAP network is being led out of the University of Saskatchewan. It will develop the tools and explore the potential, and assess the environmental and economic footprint associated with employing underused or abandoned farmlands for the large-scale production of lignocellulosic biomass for heat, power or fuel production. This network could examine the potential for growing lipid and biomass crops on underutilized or marginal lands and address the carbon reduction benefits, economics, rural impacts and sustainability of biodiesel production.
- **Green Energy Synthesis Network.** There is a need for a national research network that will assess and develop thermo-chemical processing technologies for biomass. A biodiesel research initiative could provide a core around which this network could grow.
- **Microbial Bio-processing Network.** Microbial and enzymatic conversions have a large role in bioenergy spanning from hydrogen, methane and alcohol production to energy recovery from non-microbial process wastes. There is a need for a national research network that would assess and develop microbial and enzymatic processing technologies for biomass conversion to fuels and industrial feedstocks including ethanol and methanol (alcohols for transesterification), methane, hydrogen and commodity chemicals.
- **Auto 21 NCE.** This is a Network of Centre of Excellence run out of the University of Windsor that could be an excellent forum for research to explore the performance of biodiesel in transportation vehicles and to develop new criteria and technologies for future biodiesel engines. Auto 21 and

the Biodiesel Initiative could both be enhanced through partnering and collaboration in the area of diesel engine performance and emissions investigations with biodiesel in new generation diesel engines. These areas of research would provide the basis for the necessary involvement by diesel engine OEMs.

- **Greenhouse Gas Management Canada.** This is a \$3.4M, 3-year, BIOCAP-SSHRC Human dimensions network that is exploring the socio-economic and policy issues surrounding the use of biological systems to reduce greenhouse gas emissions, enhance carbon sinks and provide a renewable supply of biomass energy. GHGMC could be a forum for additional research in the social science area relevant to biodiesel.

Figure 4 shows a visual representation of the feedstock to end-use biodiesel research theme areas, as identified in Table 9. Figure 5 shows how those theme areas could be met within a national biodiesel initiative that encompasses several established and emerging research networks.

Figure 4. Biodiesel Research Themes in a Feedstock to End-Use Thread

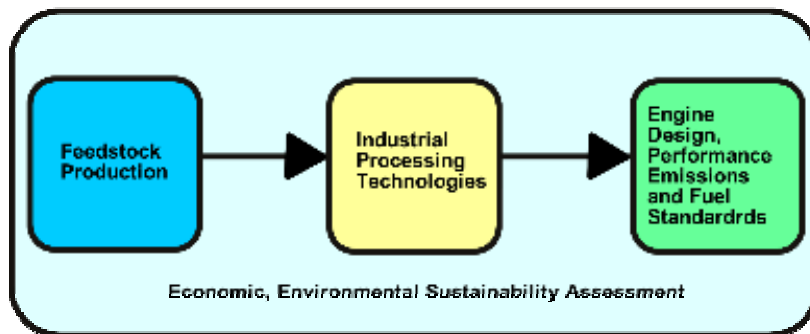


Figure 5. Biodiesel Research Delivery Mechanisms in a Feedstock to End-Use Thread

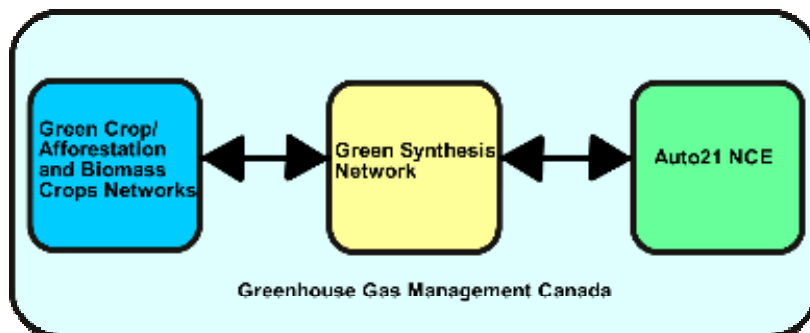
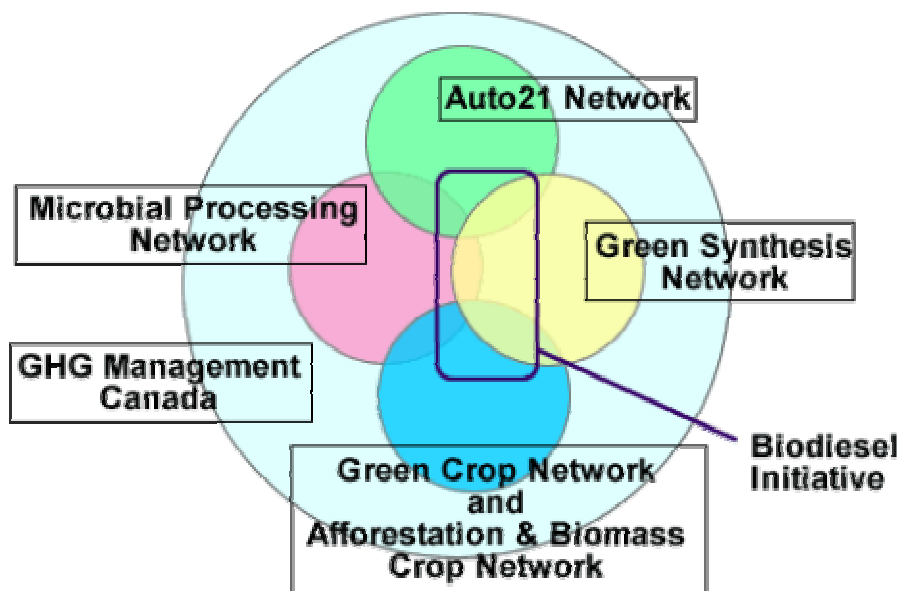


Figure 6 provides a diagram that shows how these various networks could be linked together, and the integrating ‘space’ occupied by the Biodiesel research initiative outlined in this report.

In this model, the majority of the resources for a national biodiesel research initiative would probably be focused on the Green Energy Synthesis Network, although it would also be important to support research initiatives in a number of other networks such as Auto 21, Green Crop, GHG Management Canada, etc. In addition, it would be important to have an organization with responsibility (e.g., as a secretariat) for ensuring that the results and insights from the various projects are integrated and communicated among groups and back to the stakeholders and users.

Figure 6. Location and Crosscutting Nature of the Biodiesel Initiative



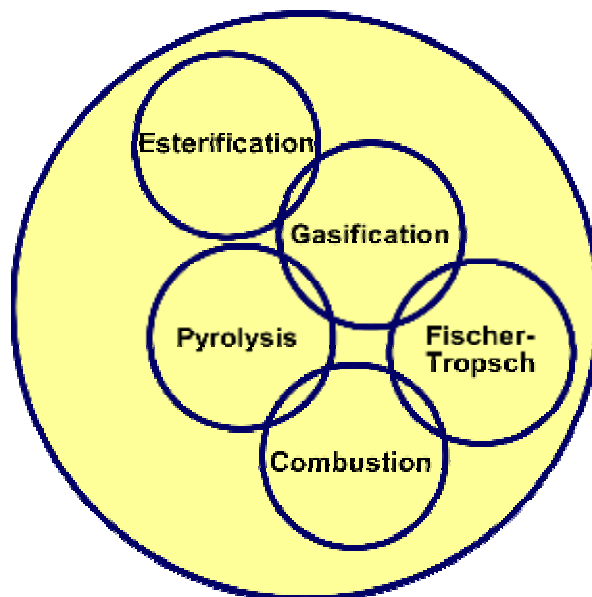
A national network needs a defined set of objectives and it needs researchers from various disciplines (or groups of disciplines) who will work cooperatively to address these objectives. The crosscutting and inter-disciplinary aspects of the biodiesel initiative can be appreciated from an analysis of the various types of research and disciplines called on in the broad main theme area of process development.

An organized network structure provides a means of establishing effective collaboration and maximizing value and return on research investment. Networks would provide a vehicle for funding, leveraging research support, and effective dissemination of results. This approach would also build research capacity relevant to bioenergy in general and natural effective synergies to move research findings to earlier commercial returns. These synergies should attract other avenues of support for the commercial demonstration phases from appropriate agencies such as SDTC and FCM.

The network approach would also facilitate important linkages to other domestic networks and to international agencies and networks (IEA, DOE etc).

To increase the chance of success of a sustainable biodiesel industry to have a significant impact on diesel use in Canada, it is essential that research is not done in isolation. Not only should researchers look internationally for collaborations and strategic research needs, but they must look at the broader picture of bioenergy and the biorefinery. Natural cross-over exists with many aspects of biomass processing, from gasification of glycerol derived from esterification, to the role pyrolysis biooil can play as a feedstock in gasification or combustion. These linkages are particularly pertinent when it comes to co-products and co-product utilization. Co-products can significantly change the economics of biodiesel production, and as such, any opportunity to maximize their impact should be taken. Figure 7 shows the structure of a potential Green Synthesis Network.

Figure 7. Suggested Green Synthesis Network Node Structure



4. Scope of Biodiesel Initiative Research Networks

As identified through research gap and priority assessment (questionnaire, interviews, workshop), the research objectives for each theme and network are outlined in tables 11 through 14. The feedstock to end-user thread and network integration of these research objectives is essential in the success of a national biodiesel initiative.

Table 11. Analyses of Research Objectives for Feedstock Production – Theme 1 (Scope of Green Crop / Afforestation and Biomass Crops Network Nodes)

High Lipid Crops	<ul style="list-style-type: none"> -Increased fuel-spec oil content in traditional oil crops (eg. canola, flax, mustard) -Enhancement of other traits to increase content of beneficial co-products -Utilization of perennial crops as potential oil sources -Selection of oil crops for production on marginal and non-ideal lands -Fuel specific cropping systems (including crop rotation) to maximize overall oil yield -Regional differences and ideal regional oil crops -Water impacts of enhanced oil crop production
Low Lipid Crops	<ul style="list-style-type: none"> -Increased growth for maximum biomass yield -Optimal nutrient management of biomass cropping -Quantifying the afforestation/biomass crop potential on marginal lands in Canada -Water impacts of biomass cropping -Biomass crops such as switchgrass in crop rotations -Enhanced carbon sequestration in soils via management practices and crop selection -Potential for agroforestry in providing biomass

Table 12. Analyses of Research Objectives and Sub-Themes for Industrial Processing Technologies – Theme 2 (Scope of a Green Energy Synthesis Network)

Production Route	Pretreatment Technologies	Chemical Synthesis	Green Chemistry
Esterification Production Route	<ul style="list-style-type: none"> -Fuel grade oil extraction technology -Extraction co-solvent utilization process compatibility -Fuel oil specifications vs. food grade -Contaminant removal techniques -value-added uses for protein and carbohydrate by-products 	<ul style="list-style-type: none"> - Renewable alkyl sources (ethanol or methanol) -Ethanol process technology -Free Fatty acid removal techniques -Improved synthesis for mixed oils 	<ul style="list-style-type: none"> - Glycerol conversions to value-added chemicals (e.g. 1,3-propanediol) -Specific value-added methyl ester products -Esterification as a Green Chemistry -Discrete esters for chemical uses -1,3-propanediol feed for plastics
Gasification / Fischer-Tropsch and SuperCetane Production Routes	<ul style="list-style-type: none"> - CO:H₂ process and control -Suppression of gas contaminants -Pyrolysis bio-oil as feedstock -Tail gas energy recovery 	<ul style="list-style-type: none"> -Catalyst and process to yield biodiesel -Tail gas energy use / recycling -Removal of impurities -F-T diesel yield vs. wax etc - energy balance; gasification with F-T 	<ul style="list-style-type: none"> - Conversion of low bp F-T hydrocarbons to chemical synthesis feedstocks - F-T as a Green Chemistry -SuperCetane as a Green Chemistry -conversion of high bp fractions from to value-added products/lubricants

Table 13. Analyses of Research Objectives and Sub-Themes for Engine Design, Performance, Emissions and Fuel Standards – Theme 3 (Scope of an Auto21 NCE Initiative)

Sub-Theme Area	
Engine Performance	Engine Design
<ul style="list-style-type: none"> -Ideal fuel blend with diesel/other fuels, as determined by Canadian conditions, engine impacts, and other criteria -Effects of different biodiesel blends with diesel/other fuels on engine deposits, GHG production, NO_x emission, atomization, combustion stability -Varying fuel properties (cetane, volatility, viscosity, thermal stability, corrosivity) and engine impacts -The effect of biodiesel feedstock source (eg. animal fat Vs. crop oil) and final engine performance -Impact of biodiesel on fuelling lines and injection systems -Impact of higher biodiesel acid number on engine wear -Engine performance of biomass/F-T biodiesel 	<ul style="list-style-type: none"> -Identification of engine design aspects for optimal biodiesel fuel performance -Biodiesel specific engine design – identifying the potential benefits -The potential of biodiesel in homogenous charge compression ignition (HCCI) engines -Optimization of biodiesel in hybrid automobiles

Table 14. Analyses of Research Objectives and for Economic, Environmental Sustainability Assessment – Theme 4 (Scope of a Greenhouse Gas Management Canada / Auto21 Initiative)

- Complete LCA (including GHG) on Fischer-Tropsch biodiesel
- Complete integrated economic analysis of production pathways
- The potential and impacts of export/import of feedstocks and biodiesel
- Impact of enhanced biodiesel production on the rural economy, energy security, and northern communities
- Complete subsidy comparison between petroleum diesel and biodiesel
- Economic comparison between various oil crops for biodiesel use and traditional crops such as wheat
- The influence of economies of scale – ideal plant size, location to improve economic viability and feedstock availability
- Potential of small-scale plants and decentralization
- Regionalization – regional differences and identifying regions of opportunity
- Assessment of the response of the Canadian petroleum industry to biodiesel and biodiesel blends
- Quantifying high-lipid feedstock supply potential in Canada (including waste oils)
- Comparison of biomass and petroleum resources in Canada, including future sustainability
- Benefits/drawbacks of collaborations with other bioenergy technologies within the biorefinery
- Acceptance of biodiesel and high biodiesel blends by engine OEMs
- Optimal policy framework for biodiesel success in Canada, including taxing system, subsidies, incentives, regulation, standards

F. Research Capacity in Canada

Canada has a substantial number of research investigators that are either now working on some of the identified biodiesel research aspects, are interested in developing biodiesel related research programs or are working in related areas that are relevant to the biodiesel research needs determined in this report.

Appendix 2 provides a compendium of Canadian investigators who have expressed direct interest in this initiative or who could potentially contribute to research in this area.

Appendix 3 provides a listing of current Canadian industries that now provide the industrial capacity for the emerging biodiesel industry as well as having industrial research capacity in terms of researchers and facilities. Initial industrial capability spans the relevant areas of need including esterification, gasification/ Fischer-Tropsch synthesis and utilization of process co-products or their derivatives.

G. Conclusions / Next Steps

This investigation into the research and knowledge gaps of biodiesel production in Canada has identified numerous opportunities for technological and scientific innovation. In addition, societal, policy and regulatory barriers pertaining to the emergence of the Canadian biodiesel industry have been clearly highlighted.

Biodiesel production using conventional esterification of lipid materials (vegetable oils, waste fats and greases) is well developed technologically. This approach has benefited from recent Canadian process improvements and innovations in the hands of key industrial players and researchers. Utilization of this process in large-scale production facilities should prove sufficient for the emergence of the Canadian biodiesel industry. However, significant competition exists with established consumable oil markets, making the feedstock, and hence biodiesel, high in price.

Lipid feedstock supply and price are likely to remain as important determinants for the emerging industry and cause production and market constraints, should demand for biodiesel be more than a few percent of Canada's total transportation diesel demand.

Therefore, new research areas aimed at establishing higher lipid crop yields, increased lipid production, more efficient lipid recovery techniques for fuel-grade feedstock, more efficient process chemistries so as to lessen waste materials production and improve process costs, and new value-added uses for the major glycerol by-product have been identified as crucial to support this emerging industry.

The establishment of new lipid crop production dedicated to meeting fuel and not food specifications is seen as useful for overcoming supply, price, and societal constraints and barriers now associated with 'diverting' food materials to fuel usage. This is a better option than diverting oil destined for food markets to biodiesel production. In addition, waste oils represent an important opportunity for cheap and readily available feedstock.

Biodiesel production from low lipid content biomass resources (crop residues etc) utilizing primary gasification with secondary Fischer-Tropsch synthesis of hydrocarbons has a large potential for future biodiesel supply. However, substantial research is needed to establish an efficient and consistent conversion technology for Canada's biomass resources and to establish the overall process yields, energy balances, and economics. Performance results on this non-conventional biodiesel product are also needed to gain further petroleum industry acceptance.

The net environmental benefits from a life cycle analysis of this non-conventional approach also need to be researched and documented. This avenue for biodiesel production is complementary to the lipid synthesis routes and has long term importance to sustainable biodiesel and petroleum industry. Based on sheer feedstock supply, F-T biodiesel has considerable potential to increase Canadian renewable diesel volumes.

The SuperCetane technology appears technologically ready to proceed to commercial production, noting that it is also susceptible to lipid feedstock availability and price issues. This high cetane product may be a useful cetane-enhancing additive for fuel blends.

The technologies associated with biodiesel production are relatively broad-based and wide in potential scope, including thermal, synthetic chemical, catalytic, hydro treating and refining. Sufficiently developed through the new research identified here, these technologies could emerge as new green chemical synthetic routes for biodiesel with applications to other bio-fuels and broader aspects of bioenergy.

Canada has a sufficient industrial base to support the emergence of the biodiesel production industry using well-developed conventional technology, while additional industrial players would enter the market as it emerges and a demand for biodiesel volume has developed.

The Canadian research capacity in terms of university-, government- and industry-based investigators with established research interests directly or indirectly related to biodiesel production technologies is substantial and nation-wide.

The cross cutting nature of the relevant research themes for biodiesel are such that biodiesel production should effectively become a theme and part of a broader technology research and development initiative that has been termed 'Green Synthesis'.

Various aspects of research on new crops, microbial and enzymatic bioenergy technology, thermal technology and green chemical technologies can develop in a complementary manner within Green Synthesis. As such, biodiesel can be seen as a leading crosscutting theme where these various approaches together lead to early advances for biodiesel needs and enhanced outcomes applicable to bioenergy in general. Biodiesel production technologies could emerge as important first examples of green chemical syntheses.

End-user research is essential if biodiesel is to be accepted in ratios higher than B5 by petroleum companies and engine manufacturers. These two industries must be 'on-board' for a successful biodiesel industry in Canada to develop and expand. Both engine performance and design must be investigated with varying blends and neat biodiesel, with GHG and NOx emissions as a priority.

New research funding can be effectively applied to both shorter-term and longer-term needs, and to both applied and basic research, to assist the emergence and the continued development of the Canadian biodiesel industry. Much of this research requirement is seen as multi-disciplinary and would be serviced best through strategic collaborations of university and industrial researchers. Organized and integrated networks would provide a means of establishing effective collaboration and maximizing value and return on research investment.

H. References

- ASTM. 2003. <http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/D.htm?L+mystore+swmg5146+1086681795>
- Beer, T., T. Grant, R. Brown, J. Edwards, P. Nelson, H. Watson and D. Williams. 2000. Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles. CSIRO Atmospheric Research Report C/0411/1.1/F2 <http://www.greenhouse.gov.au/transport/publications/lifecycle.html>
- Bioenergy Conversion Factors. 2004. http://bioenergy.ornl.gov/papers/misc/energy_conv.html
- Biox. 2004. <http://www.bioxcorp.com/main.html>
- Bransby, D. 2004. Switchgrass profile. <http://bioenergy.ornl.gov/papers/misc/switchgrass-profile.html>
- Bockey, Dieter. 2003. Situation and Development Potential for the Production of Biodiesel – An International Study http://www.ufop.de/download/FAL_Bockey_english.pdf
- Boerrigter, H. H. den Uil and H.P. Calis. 2003. Green diesel from biomass by Fischer-Tropsch synthesis: new insights in gas cleaning and process design. <http://www.ecn.nl/docs/library/report/2003/rx03047.pdf>
- Canadian Canola Council. 2004. Market and Statistics. <http://www.canola-council.org/>
- Enerkem Inc. 2004. <http://www.enerkem.com/>
- Environment Canada. 1999. 1995 Criteria Air Contaminant Emissions for Canada December 99 http://www.ec.gc.ca/pdb/ape/ape_tables/canada95_e.cfm
- Environment Canada. 2002. Canada's Greenhouse Gas Inventory 1990-2000 Greenhouse Gas Division Environment Canada June 2002 http://www.ec.gc.ca/pdb/ghg/1990_00_report/sec2_e.cfm#top
- IEA. 2004a. Statistics-Oil. www.iea.org/Textbase/stats/oildata.asp?country=World
- IEA. 2004b. Biodiesel in North America: Implementation issues. IEA Bioenergy Task 39, final report. (S&T)² Consultants Inc. (available through NRCan prior to posting on IEA website, www.iea.org)
- Industry Canada and Bio-products Canada. 2004. Innovation Roadmap on biobased feedstocks, fuels and industrial products. http://www.bio-productscanada.org/pdf/en_roadmap_book.pdf
- Klass, D.L. 1998. Biomass for renewable energy, fuels and chemicals. AP USA.
- Milligan Bio-Tech. 2004. <http://www.milliganbiotech.com/index.html>
- Mullaney, H. and I.H. Farag. 2002. Technical, environmental and economic feasibility of bio-oil in New Hampshire's north country. UNH Project Numbers: 14B316 UDKEIF or ABAN-URI-BO43. <http://www.unh.edu/p2/biooil/bounhif.pdf>
- NRCan. 2002. Assessment of biodiesel and ethanol diesel blends, greenhouse gas emissions, exhaust emissions and policy issues. (Levelton and (S&T)²).
- NRCan. 2003. Super Cetane Technology. http://www.canren.gc.ca/tech_appl/index.asp?CaID=2&PgId=1083
- Rothsay Inc. 2004. <http://www.rothsay.ca/montreal.html#bio>

Schubert, P., S. LeViness, K. Arcuri and A. Stranges. 2001. Development of the modern Fischer-Tropsch process (1958-1999). http://www.fischer-tropsch.org/primary_documents/presentations/acs2001_chicago/chic_slide01.htm

Tyson, S.K. 2003. Biodiesel technology and feedstocks. <http://www.easternct.edu/depts/sustainenergy/calendar/biodiesel/Tyson%20-%20Biodiesel%20Technology%20and%20Feedstocks.pdf>

USDA/USDOE. 1998. Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus. NREL/SR-580-24089 UC Category 1503 http://www.ott.doe.gov/biofuels/lifecycle_pdf.html

USDA. 1997. Tallow and grease data. <http://www.fas.usda.gov/dlp2/circular/1997/97-03/tallow4.gif>

USDA. 2000. Tallow and grease summary for selected countries, 1996-2000. <http://www.fas.usda.gov/dlp2/circular/2000/00-03lp/t&qsum.pdf>

USDA. 2003. Canada Oilseeds and Products Annual 2003.GAIN Report #CA3030 <http://www.fas.usda.gov/gainfiles/200305/145885633.pdf>

USDOE. 2002. Roadmap for Biomass Technologies in the United States. Committee in the Vision for Bioenergy and Biobased Products in the United States. <http://www.bioproducts-bioenergy.gov/pdfs/FinalBiomassRoadmap.pdf>

USDOE. 2003a. Roadmap for Agriculture Biomass Feedstock Supply in the United States Office of Energy Efficiency and Renewable Energy, Biomass Program. http://www.bioproducts-bioenergy.gov/pdf/Ag_Roadmap.pdf

USDOE. 2003b. Impact of Biodiesel Fuels on Air Quality and Human Health. <http://www.eere.energy.gov/cleancities/afdc/pdfs/33793.pdf>

USDOE. 2004. The transition to ultra-low sulfur diesel fuel: effects on prices and supply. <http://www.eia.doe.gov/oiaf/servicerpt/ulsd/chapter3.html>

USDOE-NREL. 2003. Impact of Biodiesel Fuels on Air Quality and Human Health. <http://www.eere.energy.gov/cleancities/afdc/pdfs/33793.pdf>

Walsh, M.P. 2000. International Experience On Ultra Low Sulfur Diesel and Biodiesel http://www.cleanairnet.org/infopool/1411/articles-35672_international_experience.pdf

Wood, S. M. and D. B. Layzell. 2003. A Canadian Biomass Inventory: Feedstocks for a Bio-based economy, Final Report Prepared for Industry Canada Contract # 5006125 May 19, 2003. <http://biology.queensu.ca/~biol315s/Biomass%20Inventory.pdf>

I. Appendix 1. Definitions

Biodiesel. Biodiesel is functionally defined as a fuel product derived from renewable biomass that can be used in diesel engines and can replace petroleum diesel fuel at 100% or be blended with a conventional petroleum-derived diesel fuel in various proportions. Biodiesel by this definition includes fatty acid methyl esters derived from animal and vegetable lipids, alkyl esters of long chain fatty acids, the diesel- range hydrocarbons from Fischer- Tropsch synthesis using synthesis gas prepared from biomass and the diesel-like product of hydrogenation of lipids using the NRCan-developed SuperCetane synthesis technology.

Biodiesel from a current fuel standards perspective is defined as the product alkyl esters from inter-esterification of animal or plant derived lipids (oils or fats) using an alcohol such as ethanol or methanol as an alkyl group donor and a catalyst. This definition is utilized presently in industry accepted specifications and standards in Europe, the USA (ASTM D 6751) and Canada (CGSB-3.520, late 2004) and can be considered as conventional biodiesel for the purposes of this report.

Bio-oil. Bio-oil is not oil-like but rather is a poorly defined mixture of acids, alcohols, aldehydes, esters, ketones, sugars, phenols, guaiacols, syringols, furans, hydroxyacetic acid, hydroxyacetaldehyde, hydroxyacetone, 3-hydroxy-3-methoxy benzaldehyde and water. None of these components is lipid in nature and the term bio-oil is therefore utilized solely to suggest a contained energy content and value of the material. The organic acids cause bio-oil to be acidic, with a pH of less than 3. Because fast pyrolysis involves only the partial decomposition of biomass, the chemical composition of the resulting bio-oil is largely feedstock type dependent.

Fischer-Tropsch Synthesis Fischer-Tropsch (F-T) synthesis is hydrogenation of carbon monoxide in the presence of a catalyst to produce hydrocarbons. The carbon monoxide and hydrogen provided as a synthesis gas mixture can be obtained from coal, natural gas or biomass. A diesel product fraction obtained through specific catalyst production, process control and product cracking / refining would be a biodiesel provided the carbon and hydrogen substrates were biomass derived.

Gasification. Gasification is the breakdown of biomass in the presence of small controlled amounts of oxygen at high temperatures (e.g., 1000-1500 °C) and under pressure (e.g., 20-85 bar) to form CO, H₂ and CO₂ as a synthesis gas product. Additionally, synthesis gas contains lesser variable amounts of CH₄, NH₃, H₂S and HCN.

Green Synthesis Chemistry. Green Chemistry in general, refers to novel chemistries that employ less or non-toxic reagents for synthesis of value-added compounds and result in reduced overall environmental impacts relative to the chemical processes that they replace.

Pyrolysis. Pyrolysis is the breakdown of biomass in the absence of oxygen at temperatures above 250°C. The process produces a solid (char or charcoal), a liquid (bio-oil) and a mixture of gases. The ratio of the products varies with the chemical composition of the biomass and the process conditions. For example the pyrolysis of 1 tonne of hardwood typically yields about 350kg charcoal, 450kg bio-oil, 75kg tar and 60m³ gas. Fast pyrolysis is used to maximize bio-oil product formation.

SuperCetane Technology. A proprietary catalytic hydrotreating process for converting lipid feedstocks to low S, high cetane diesel blending stock and associated co-products as developed by the CANMET Energy Technology Centre, Natural Resources Canada.

J. Appendix 2. Biodiesel and Related Researchers in Canada

Name	Affiliation	Expertise
Abatzoglou, Nicolas	Université de Sherbrooke	Dry reforming and higher alcohols from synthesis gas
Ablett, Gary	University of Guelph	Soybean breeding, genetics, oil quality
Boocock, David	University of Toronto and BIOX Corp.	Solvent chemistry for esterification biodiesel production
Chornet, Esteban	Université de Sherbrooke and Enerkem Technologies	Gasification and Fischer-Tropsch for biodiesel production
Dalai, Ajay	University of Saskatchewan	Biodiesel production through both esterification and syngas conversion
Dube, Marc	University of Ottawa	Biodiesel production from waste cooking oils
Earl, Hugh	University of Guelph	Oilseed physiology and agronomy
Ellis, Naoko	University of British Columbia	Fluidized beds, bio-fuel upgrading and biodiesel production
Hertz, P. Barry	University of Saskatchewan	Biodiesel engine wear and lubrication
Hountin, Julien	Olds College	Biobased products and bioenergy
Hucq, Andre	University of Saskatchewan	Economic and social impacts and feasibility of biodiesel
Jääskeläinen, Hannu	University of Toronto	Engine combustion and emissions, including associated biodiesel impacts
Katepa-Mupondwa, Felicitas	Agriculture and Agri-Food Canada	Crop breeding and diversification
Kates, Morris	University of Ottawa	Biodiesel production from waste cooking oils
Keller, Wilf	National Research Council	Oilseed Biotechnology
Klein, Kurt	University of Lethbridge	Economics of bio-fuels and bio-products
Kott, Laima	University of Guelph	Canola breeding and biotechnology
Kunst, Ljerka	University of British Columbia	Molecular biology of <i>Brassica</i> and <i>Arabidopsis</i> genes for increased oil
Lydiate, Derek	University of Saskatchewan	Molecular mapping in <i>Brassicas</i>
MacLean, Heather	University of Toronto	Life Cycle Analysis
McLean, David	University of Ottawa	Biochemical kinetics and biodiesel production from waste cooking oil, statistic model building
McVetty, Peter	University of Manitoba	Hybrid and conventional cultivar canola breeding, agronomy and physiology of canola
Monnier, Jacques	Natural Resources Canada	SuperCetane production of biodiesel
Rajcan, Istvan	University of Guelph	Soybean breeding and genetics
Rakow, Gerhard	Agriculture and Agri-Food Canada	Oilseed (<i>Brassica</i>) breeding
Reader, Graham	University of Windsor	Engine performance and optimization of combustion
Reaney, Martin	Agriculture and Agri-Food Canada	Bio-products and processing
Rideout, Greg	Environment Canada	Emissions measurement

Scarth, Rachel	University of Manitoba	Breeding for oil quality in canola/rapeseed
Schlaf, Marcel	University of Guelph	Utilization of glycerol for 1,3-propane diol and value-added products
Sobiesiak, Andrzej	University of Windsor	Biodiesel and alternative fuels combustion, emissions, and engine performance
Sokhansanj, Shahab	University of British Columbia	Biomass supply, distribution, and transportation
Stumborg, Mark	Agriculture and Agri-Food Canada	Applied technology transfer for bio-products
Tabil, Lope	University of Saskatchewan	Value-added processing of biological materials, bio-processing
Taylor, David	National Research Council	Seed oil modification
Thomassin, Paul	McGill University	Agricultural and bio-product economics
Thomson, Murray	University of Toronto	Basis for biodiesel emissions and performance
Tremblay, Andre	University of Ottawa	Biodiesel production, synthetic membrane utilization, gas separation membranes
Wallace, James	University of Toronto	Combustion properties of alternative fuels
Watkinson, Paul	University of British Columbia	Transfer processes and gas-solid interactions at elevated temperatures, gasification
Watts, Chris	Dalhousie University	Biodiesel Properties and Impacts on Performance
Weselake, Randall	University of Lethbridge	Molecular biology of triacylglycerol and biosynthesis of rape
Zheng, Ming	University of Windsor	Engine performance and optimization

K. Appendix 3. Canadian Biodiesel and Related Industries

Biodiesel Producers

BIOX Corporation

125 Lakeshore Road East, Suite 200

Oakville, ON

L6J 1H3

Expertise: Esterification biodiesel production

Enerkem Technologies Inc.

615 Boulevard de René Levesque, Suite 1220

Montreal, QC

H3B 1P5

Expertise: Gasification and Fischer-Tropsch biodiesel production

Milligan Bio-Tech Inc.

Box 822

Foam Lake, SK

S0A 1A0

Expertise: Canola-based diesel fuel additives production

Ocean Nutrition Canada Ltd.

757 Bedford Highway

Bedford, NS

B4A 3Z7

Expertise: Esterification biodiesel production as a by-product of primary fish-sourced food supplements

Rothsay

880 Hwy 5 West

P.O. Box 8270

Dundas, ON

L9H 5G1

Expertise: Rendering products including esterification biodiesel production

Sungas Energy Corp.

820 Bonner Avenue,

Winnipeg, MB

R2G 2J7

Expertise: Gasification and Fischer-Tropsch biodiesel production

Topia Energy Inc.

Suite 900, 275 Slater Street

Ottawa, ON

K1P 5H9

Expertise: Esterification biodiesel production/distribution

Biodiesel Importers

Bio-Diesel Canada Inc.

922 The East Mall

Etobicoke, ON

M9B 6K1

Expertise: Biodiesel importers

Canada Clean Fuels

365 Evans Avenue, Suite 500

Etobicoke, ON

M8Z 1K2

Expertise: Biodiesel importers

L. Appendix 4. Advisory Steering Group

David Layzell (Chair),
CEO and Research Director
BIOCAP Canada Foundation

Esteban Chornet,
President, Enerkem Technologies; &
Professor, Department of Chemical
Engineering,
Université de Sherbrooke

Ajay Dalai,
Professor,
Department of Chemical Engineering,
University of Saskatchewan

Lori Heigh,
Economist,
Research Planning and Coordination,
Agriculture and Agri-Food Canada

Ed Hogan,
Manager,
Thermo-chemical Conversion,
Renewable Energy Technologies,
Natural Resources Canada

Bruce Holbein,
Consultant for BIOCAP Canada Foundation
Principal, Holbein & Associates

Heather MacLean,
Assistant Professor,
Department of Civil Engineering,
University of Toronto

Kevin Norton,
Chief Operating Officer,
BIOX Corporation

Christine Paquette,
Executive Director,
Biodiesel Association of Canada

Martin Reaney,
Research Scientist,
Bio-products and Processing,
Agriculture and Agri-Food Canada

Marcel Schlaf,
Assistant Professor,
Department of Chemistry and Biochemistry,
University of Guelph

Chris Watts,
Professor,
Department of Biological Engineering,
Dalhousie University

Jamie Stephen (Secretary),
Research and Communications Coordinator,
BIOCAP Canada Foundation