Biodiesel Vehicle Fuel: GHG Reductions, Air Emissions, Supply and Economic Overview

DISCUSSION PAPER C3 – 015

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EXECUTIVE SUMMARY

This discussion paper focuses on five major aspects of biodiesel vehicle fuel. Specifically these are: feedstock supply (Canada and Alberta), greenhouse gas (GHG) reductions, other emission reductions, economic viability and fuel property challenge issues. Additional elements discussed within the report include energy balance and efficiency, and notable biodiesel developments in Canada. The major findings are as follows:

Feedstock Supply:
Alberta has the potential to become a production center for biodiesel. The primary feedstocks for biodiesel are canola (or soybean), animal fats (tallow), and used cooking oils. Alberta is a major canola and tallow producer, with sufficient volumes to support substantial production, in excess of 100 million litres per year, accounting for the use of off-grade canola only.

GHG Reductions:
Consensus exists that biodiesel has a significant advantage over petroleum diesel in terms of lifecycle GHG reductions.

- For a B20 blend (20% biodiesel and 80% petroleum diesel), GHG lifecycle reductions over conventional petroleum diesel range between 10 and 20%, depending on the feedstock used.
- For a B100 blend (100% biodiesel), GHG lifecycle reductions over conventional petroleum diesel range between 40 and 90%, depending on the feedstock used.

Other Emissions:
Consensus also exists that biodiesel results in other air quality, health-related emission reductions (on a lifecycle and exhaust only basis) with respect to the following emissions: carbon monoxide, particulate matter, oxides of sulphur and volatile organic compounds. These emission reductions range between 3 and 11% for a B20 blend. Biodiesel can result in an increase in nitrogen oxide emissions.

Economic Viability:
Research shows that biodiesel is not currently cost competitive with petroleum diesel. However, at a B20 blend with some form of tax exemption on the biodiesel portion of the fuel, per litre costs range close to or slightly less than the retail cost of fully taxed petroleum diesel. Furthermore, assuming a trend toward higher costs for petroleum diesel and decreased costs of biodiesel production (increased technology efficiencies), economic viability of biodiesel as a niche fuel seems probable over the short term, relying on some for of modest tax exemption.

Challenges – Fuel Properties:
While 100% biodiesel (B100) is not stable in very cold temperatures, B20 vehicle demonstrations in cold weather conditions (-20 to -40 C) have revealed almost no operational problems. In terms of material compatibilities, biodiesel has presented problems for pre-1993 engine parts, however newer engine materials are largely biodiesel friendly. Diesel engine manufacturers warranties are beginning to make favourable allowance for biodiesel use, particularly in Europe and it is expected that this trend will continue as biodiesel gains more momentum.

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1. INTRODUCTION

> "The use of plant oil as fuel may seem insignificant today. But such products can in time become just as important as kerosene and the coal-tar-products of today "
>
> *Rudolf Diesel (inventor of the diesel engine), 1912*

Biodiesel has a lengthy history as a viable transportation fuel. Prior to World War II, biodiesel was used successfully and extensively in South Africa to power heavy-duty vehicles. Of late, biodiesel has received increased attention because of its potential to reduce emissions, particularly greenhouse gas (GHG) emissions. Since biodiesel is a renewable fuel that can be produced from plant and animal sources, an opportunity exists to reduce GHG emissions when compared to nonrenewable petroleum diesel. Biodiesel also has the potential to reduce North American dependence on off-shore oil.

Biodiesel can be used in any diesel engine with few or no modifications, and while it does have advantages over conventional diesel use on the environmental front, some challenges exist with respect to costs of production, cold weather properties and feedstock volumes. These factors will be examined in this paper along with a focus on emission reductions.

Definition:

Biodiesel is an alternative fuel that can be produced from any fat or vegetable oil. Biodiesel fuels are methyl or ethyl esters derived from a broad variety of renewable sources such as vegetable oil (soy, canola, rape seed), animal fat and cooking oil. Esters are oxygenated organic compounds that can be used in compression ignition engines because key properties are comparable to those of diesel fuel.

Biodiesel is produced in a pure form (100% biodiesel referred to as "B100" or "neat biodiesel") and may be blended with petroleum-based diesel fuel. Biodiesel blends are designated based on the percentage of pure biodiesel contained in the blend (e.g., B2 – 2% biodiesel; B20 – 20% biodiesel, etc.).

2. PRODUCTION

Biodiesel fuels are produced through a process called transesterification, in which various oils (triglycerides) are converted into methyl ester through a chemical reaction with methanol in the presence of a catalyst, such as sodium or potassium hydroxide. The by-products of this chemical reaction are glycerols and water. Biodiesel fuels naturally contain oxygen, and while not inherently contained in the feedstock, sulphur may be present because of contamination during the transesterification process and in storage.

Three basic routes to methyl ester production from oil and fats exist, and are well known. These are:

- Base catalyst transesterification of the oil with methanol.
- Directed acid catalyzed esterification of the oil with methanol.
- Conversion of the oil to fatty acids, and then to methyl esters with acidic catalysts.

The majority of the methyl esters produced today are done with the base catalyzed reaction because it is the most efficient for several reasons:

- Low temperature (up to 150F) and pressure (20 psi)
- High conversion (98%) with minimal side reactions and reaction time.
- Direct conversion to methyl ester with no intermediate steps.
- Exotic materials of construction are not necessary.[1]

In the United States, biodiesel is registered as a fuel and fuel additive with the Environmental Protection Agency (EPA) and meets clean diesel standards established by the California Air Resources Board (CARB). B100 or neat (100 percent) biodiesel has been designated as an alternative fuel by the Department of Energy (DOE) and the US Department of Transportation (DOT). In comparison, Canada has a relatively simple regulatory system for fuels. Information on the composition of fuels derived from crude oil, coal, or bitumous sands must be reported to government on a quarterly basis, and a Liquid Fuel Additive Report is required to be filed, initially, on a one-time basis. Considering the properties of biodiesel, production of biodiesel in Canada would require a Liquid Fuel Additives Report, but would not be subject to quarterly reporting. However, it is expected that in most cases Canadian production of biodiesel would voluntarily meet U.S. standards in order to open up export opportunities into the U.S.[2]

Lurgi Process:

Lurgi, a German company, is a leading developer of process technology. They offer a variety of process technologies for processing fatty acids including biodiesel production. In the Lurgi process, neutralized vegetable oil and methanol are reacted in a two-stage mixer/settler arrangement in the presence of catalysts. The glycerin produced in the reaction is dissolved in the surplus methanol and can be recovered. Most of the glycerin and methanol are removed from the methyl ester in a scrubber. Higher amounts of energy and materials are required if preprocessing is necessary to reduce the free fatty acid content or to produce pharmaceutical quality glycerin.[3]

BIOX Process:

The BIOX process, a relatively new biodiesel process developed by Professor David Boocock of the University of Toronto, has been successfully demonstrated in a laboratory setting. The traditional base-catalyzed method for producing fatty acid methyl esters from triglycerides and methanol has several disadvantages, including slow reaction at ambient temperature, and incomplete initial reaction requiring repeated stages. The BIOX process addresses these issues and is claimed to be the only biodiesel production process able to complete with petroleum diesel on a production basis, and the only process that can successfully exploit high fatty acids to produce biodiesel. This process is also able to deal effectively with animal fats and greases.[4]

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[1] Primary source for “Production” section: National Biodiesel Board. www.biodieselboard.org
[2] Primary Source for “Soybean” section: Draft – Levelton Engineering Ltd. in association with $(S\&T)^2$ Consultants Inc. for Natural Resources Canada – 2003, (LevNRCan – Draft
[3] See: www.lurgi-lifescience.com
[4] See: www.bioxcorp.com

3. FEEDSTOCK SUPPLY

Soybeans:

Soybeans are the world's largest oilseeds crop, with production accounting for 56% of the world's total oilseeds. The United States is the largest single producer of soybeans. The beans typically contain about 18-20% oil. Canadian production of soybeans is about 2.6 million tonnes per year, and is concentrated in Ontario. Due to growing conditions and agricultural industry infrastructure and traditions, soybeans are not considered a developing crop, or oil seed potential for biodiesel production in Alberta.[5]

Canola:

Canola oil and canola meal are produced from canola seed. The production is typically about 40% canola oil and 60% canola meal. Canadian production of canola is about 6 million tonnes per year, and Alberta production of canola is approximately 33% of Canadian output. The oil from this Alberta grown canola could produce in excess of 2 billion litres of biodiesel per year. However, high canola prices have deterred alternative uses for this oil seed crop. Frost or heat damaged canola is a lower priced alternative and represents a potential feedstock for biodiesel. In the case of frost-damaged canola, the price difference is only about 10% when compared to undamaged stock. However, heat damaged canola, resulting from storage problems, is of much lower value. Examining a 10-year average, off-grade canola makes up approximately 6% of total canola production in Western Canada.

The primary problem utilizing damaged or off-grade canola for biodiesel production is that volumes are relatively low and vary drastically from year to year. As an example in 1999/2000, approximately 645,000 tonnes of off-grade canola were available in Western Canada and in 2002/03 the total fell to 86,000 tonnes.[6] While the price of off-grade canola makes it an attractive option as a biodiesel feedstock, its volatile and unpredictable supply volumes make it an unreliable source. At best it could be considered as a feedstock supplement in years when large volumes are available.

Yellow Grease / Tallow:

Yellow grease is made up of restaurant greases (fats and oils from cooking) and animal fats from rendering plants. The rendering process recycles beef, pork and poultry by-products (bones, trim, fat, offal, feathers and waste cooking oils) into a broad range of commercial tallow and protein products. Tallows are used in the manufacture of products such as cosmetics, soaps, shampoos, candles, lubricants, paints, tires, perfumes, inks, cleaners, etc.

Canada is the world's third largest exporter of tallow after the U.S. and Australia. In 2001, approximately 240,000 tonnes were exported. In Western Canada, West Coast Reduction collects and processes the vast majority of yellow grease produced. Unfortunately, reliable estimates of Alberta production of yellow grease are not available at this time.

[5] Primary Source for "Soybean" section: LevNRCan – Draft
[6] Canada Grains Council

In addition to West Coast Reduction's contracts with the beef tallow market in Alberta, two other feedstock sources are Cargill Foods and Lakeside Packers. Both are large processing plants that generate, render and sell their own beef tallow. It is estimated that both companies combined produce about 90 million litres of tallow per year. The volatility of beef / cattle prices present challenges for using this source as a feedstock for biodiesel production. However, with the recent issues surrounding BSE, there is a new interest in markets for beef by-products, at potentially lower costs.

Alberta also has a large hog industry with slaughter activity concentrated at Olymel SEC in Red Deer and Maple Leaf Foods in Lethbridge. Together they process over 2.1 million head per year which represents approximately 11 millions litres of non-edible animal fat per year.

Feedstock Supply Overview:

Table 1 – Estimated Alberta Volumes

	Millions litres produced per year
Yellow grease (West Coast Reduction)	18
Beef tallow	90
Pork lard	11
Canola (off-grade)	3
Total	**122**

These estimates indicate that feedstock could be made available in Alberta to make well over 100 million litres of biodiesel annually. This total does not include provincial wide canola production, and uses off-grade canola only. If all canola were used, biodiesel production would rise dramatically to over 2 billion litres per year. However, dedicated canola production to biodiesel is not a probable scenario. To provide some context, total taxable (on-road) diesel sales in Alberta for 2003 was approximately 2.5 billion litres. Therefore, in order to have all diesel fuel blended to B20 (20% biodiesel), 500 million litres of biodiesel would be required.

It must be considered that the 122 million litres of feedstock produced, as outlined above, is already a viable commodity and currently has an established market. Due to these market demands, a major shift to biodiesel would require a breakdown in the existing market situation and /or an unprecedented high demand for biodiesel that could absorb higher costs. However, current questions around the beef industry, which represents a large feedstock source (as outlined above), presents potential opportunities for Alberta biodiesel production.[7]

4. GHG LIFECYCLES

Levelton / NRCan LevNRCan Study (2003):

The LevNRCan study is currently in a draft study phase, but represents the most detailed assessment and analysis of biodiesel on an emissions lifecycle basis in Canada. The study also references and incorporates lifecycle work from a wide range of credible international sources.

[7] Primary source for "Canola: and "Feedstock Supply Overview" sections: IAG-Enerquest

This study examines three different feedstocks, canola, soy and animal fats at three blends B2, B20 and B100. Both upstream and downstream emissions are calculated in the lifecycle incorporating the following elements:

- Net vehicle operation;
- Fuel dispensing / storage / distribution and production;
- Feedstock transport;
- Fertilizer and fertilizer production;
- Land use changes and cultivation;
- CH_4 and CO_2 leaks and flares;
- Emissions displaced by co-products;
- Vehicle assembly, materials and transport.

In the lifecycle case for canola and soybeans, the LevNRCan study assumes that the esterification of the canola oil occurs on the same site as the oil extraction process. It is also assumed that the canola is processed using the Lurgi system and crude glycerin will be produced.

In the lifecycle case for animal fat the LevNRCan study assumes that the esterification will take place at the same site as the rendering process. It is also assumed that the BIOX process, more suited to tallow and yellow grease, will be used. Crude glycerin is also produced as a by-product. The animal fat case is for the blend of waste grease and animal slaughterhouse residues.

The LevNRCan GHG lifecycle accounts for the following emissions: CO_2, CH_4 and N_20.

Biodiesel 2% Blend (B2):

The B2 blend is of interest primarily because of its engine lubricating properties, which are important in winter operating conditions and as a result of the lower sulphur content in petroleum diesel. Some refiners are using petroleum-based additives to overcome the lubricity problem of low sulphur diesel, and this is expected to continue as the 2006 refinery deadline of 15ppm for sulphur approaches.

Table 2 – LevNRCan B2 GHG Lifecycle

	Diesel Fuel	**Biodiesel**	**Biodiesel**	**Biodiesel**
		Canola	**Soyoil**	**Animal Fat**
	G/mile	G/mile	G/mile	G/mile
Total (full life cycle)	2,312.4	2,269.5	2,269.8	2,257.1
% changes from diesel	**--**	**-1.2**	**-1.2**	**-1.8**

Biodiesel 20% Blend (B20):

The B20 blend is the most popular for vehicle use and has been the test fuel from many demonstration projects and is being used on a regular basis in fleets throughout the U.S. and Europe.

Table 3 – LevNRCan B20 GHG Lifecycle

	Diesel Fuel	Biodiesel	Biodiesel	Biodiesel
		Canola	**Soyoil**	**Animal Fat**
	G/mile	G/mile	G/mile	G/mile
Total (full lifecycle)	2,312.4	2,025.1	2,028.0	1,900.5
% changes from diesel	**--**	**-12.4**	**-12.3**	**-17.8**

Biodiesel 100% Blend (B100):

The 100% biodiesel fuel can be used in engines directly, usually without modifications. This "neat" fuel use maximizes the environmental advantages but raises questions about engine manufactures acceptance (with respect to warranty) and cold weather properties.

Table 4 – LevNRCan B100 GHG Lifecycle

	Diesel Fuel	Biodiesel	Biodiesel	Biodiesel
		Canola	**Soyoil**	**Animal Fat**
	G/mile	G/mile	G/mile	G/mile
Total (full lifecycle)	*2,312.4*	838.4	853.3	191.4
% changes from diesel	**--**	**-63.7**	**-63.1**	**-91.7**

Commonwealth Scientific and Industrial Research Organization (CSIRO) GHG Lifecycles – Australia (2000):

The Australian CSIRO Study is an extensive, internationally recognized study focusing on lifecycle emissions analysis of several alternative fuels including biodiesel. This study conducted a major survey of other acclaimed studies and original research. The study adheres to the international framework for conducting lifecycles (ISO, 1998). The CSIRO full lifecycle analysis accounted for direct emissions from vehicles and also those associated with the fuels: extraction; production; transport; processing; conversion and distribution.

The CSIRO Study examined seven various biodiesel feedstock scenarios. Rape seed biodiesel has been removed for this report because it has been replaced in the Canadian context with canola that stands as a superior crop for conventional use and /or biodiesel production. An alternative allocation has been attributed to tallow and cooking oil. This designation assumes that additional tallow and cooking oil are required to be produced for biodiesel production, while the non-allocation for tallow and cooking oil assumes that no additional production is required and feedstock displaces alternate use.

The CSIRO Study GHG lifecycle work accounts for CO_2 only. Depending on the particular feedstock, CO_2 will represent 94–98% of total GHG emissions emitted on a lifecycle basis for biodiesel.[8]

[8] Commonwealth Scientific and Industrial Research Organization (CSIRO) in association with University of Melbourne for Australian Greenhouse Office – 2000, (CSIRO)

B20 (CSIRO) GHG Lifecycle:

Table 5

Full Lifecycle	Units (kg per MJ)	LS Diesel	Canola Biodiesel	Soybean Biodiesel	Tallow Biodiesel	Tallow Alt. Allocation	Cooking Oil Biodiesel	Cooking Oil Alt. allocation
GHG	CO_2	0.0858	0.0772	0.0751	0.0770	0.0785	0.0687	0.06875
% changes			**-10**	**-10**	**-10**	**-11**	**-20**	**-19**

B100 (CSIRO) GHG Lifecycle:

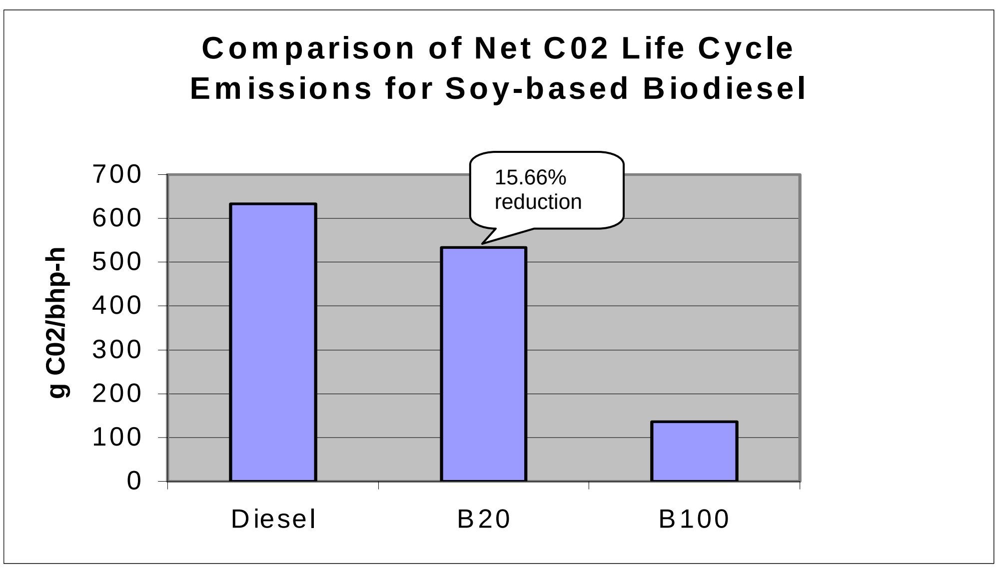
Table 6 Full Lifecycle	Units (kg per MJ)	LS Diesel	Canola Biodiesel	Soybean Biodiesel	Tallow Biodiesel	Tallow Alt. Allocation	Cooking Oil Biodiesel	Cooking Oil Alt. allocation
GHG	CO_2	0.0858	0.0433	0.0326	0.0420	0.0498	0.0062	0.0065
% changes			**-50**	**-60**	**-51**	**-42**	**-93**	**-92**

U.S. Biodiesel GHG Lifecycle, Departments of Energy and Agriculture (1998):

The following U.S. Government GHG lifecycle (CO_2) findings are for soybean-based biodiesel only. These findings show that for biodiesel, 84.4% of the CO2 emissions occur at the tailpipe. The remaining CO_2 comes almost equally from soybean agriculture, soybean crushing, and soy oil conversion to biodiesel.[9]

It can be assumed that the following results for soy would be very similar to canola, based on the results from LevNRCan and CSIRO, with a potential 10% margin of CO_2 lifecycle benefit to soy, at the B100 level.

Figure 1



[9] US Department of Energy and Agriculture, National Renewable Energy Laboratory -1998, (NREL)

GHG Lifecycle Summary:

From the results examined above, the following observations can be concluded:

- For B20 canola-based, GHG lifecycles range from 10 – 15% less than diesel.
- For B100 canola-based, GHG lifecycles range from 50 – 78% less than diesel.

- For B20 soy-based, GHG lifecycles range from 10 – 15% less than diesel.
- For B100 soy-based, GHG lifecycles range from 60 – 78% less than diesel.

- For B20 tallow-based, GHG lifecycles range from 11 –18% less than diesel.
- For B100 tallow-based, GHG lifecycles range from 42 – 92% less than diesel.

- For B20 cooking oil–based, GHG lifecycles range from 19 - 20% less than diesel.
- For B100 cooking oil-based, GHG lifecycles range from 92 -93% less than diesel.

The most divergent range (reduction from diesel) is found in the case of B100 tallow-based at 42-92%. This can likely be attributed to different accounting methods and allocations for methane generated from the cattle industry. As such, the GHG lifecycle showing the greatest advantage over petroleum diesel would not account for the majority of methane produced through livestock production, assuming that the livestock would be raised for additional / alternate commercial purposes. The more modest tallow-based GHG lifecycle improvement, over petroleum diesel, would likely attribute a greater portion of methane emissions to the upstream lifecycle (cattle production).

This summary indicates that significant GHG savings from biodiesel can be realized. GHG lifecycle reductions associated with canola and soy-based biodiesel are almost identical, while lifecycle reductions from biodiesel made from a feedstock of tallow and used cooking oil are potentially superior.

5. OTHER EMISSIONS

In addition to reducing GHG emissions biodiesel has the potential to reduce other emissions associated with air quality (smog) and health risks. LevNRCan and CSIRO have conducted extensive lifecycle analysis on the emissions outlined below, taking into account all upstream and downstream factors.

Table 7 - Non-GHG Lifecycles - B100 / B20

% Changes From Diesel	Biodiesel Canola	Biodiesel Soyoil	Biodiesel Animal Fat	Biodiesel Cooking Oil
	B100 / B20	**B100 / B20**	**B100 / B20**	**B100 / B20**
Chlorofluorocarbons (CFCs)				
LevNRCan	0 / 0	0 / 0	0 / 0	0 /0
CSIRO	N/A	N/A	N/A	N/A
Carbon Monoxide (CO)				
LevNRCan	-50 / -10	-50 / -10	-50 / -10	N/A
CSIRO	-23 / -5	-14 / -3	- 13 / -3	-45 / -9

Particulate Matter (PM)				
LevNRCan	-12 / -4	-12 / -4	-40 / -9	N/A
CSIRO	-27 / -5	-28 / -6	-32 / -6	-33 / -7
Nitrogen Oxides (NO_x)				
LevNRCan	+53 / +10	+52 / +10	+3 / 0	N/A
CSIRO	+24 / + 5	+23 / +5	+24 / +5	+13 / +3
Oxides of Sulphur (SO_x)				
LevNRCan	-20 / -5	-21 / -5	-43 / -9	N/A
CSIRO	N/A	N/A	N/A	N/A
Volatile Organic Compounds (VOC)				
LevNRCan	-43 / -9	-42 / -9	-28 / -11	N/A
CSIRO	N/A	N/A	N/A	N/A

As shown above, reductions for all criteria emissions can be realized with both B100 and B20 blends, with the exception of NOx, that increased relative to diesel fuel. It also shows that the highly unsaturated fuels, canola and soy, produce the highest NOx.

Tailpipe (Exhaust) Emissions B100 / B20:

The following analysis examines non-GHG emissions, associated with air quality and health risks, from a tailpipe perspective. That is, the emissions profile of vehicle exhaust that is resulting from combustion of biodiesel or biodiesel blend only, without taking into account emissions generated from upstream activities (production, etc.).

The US EPA (2002) recently published a fact sheet on biodiesel exhaust emissions. They note that the actual emission impact of the use of biodiesel varies notably between various engine types. Their summary of exhaust emissions impact, relative to conventional diesel fuel for B100 and B20 for an engine that takes full advantage of the fuel's clean burning properties are shown in the following table. This summary analysis is a combination of findings utilizing various engine / vehicle types and feedstocks (soy, rape, animal fats).

Table 8 – Exhaust Emissions (A)

	B100	**B20**
% changes from diesel		
Carbon Monoxide	-50%	-10
Particulate Matter	-70	-15
Total Hydrocarbons	-40	-10
Sulfate Emissions	-100	-20
Nitrogen Oxides	+9	+2

Studies from Delucchi, University of California, Davis and results from GHGenius data (below) confirm the EPA results with similar values.

Table 9 – Exhaust Emissions (B)

	Canola and Soy Biodiesel	Tallow
% changes from diesel		
	B100 / B20	**B100 / B20**
Carbon Monoxide	-50 / -10	-50 / -10
Particulate Matter	-70 / -15	-70 / -15
Nitrogen Oxides	+10 / +2	0 / 0

The exhaust results above were met or in some cases exceeded with Montreal's BIOBUS demonstration project that tested various blends of biodiesel in 155 City of Montreal buses for a one-year period. As in the case with the life cycle analysis, significant reductions of all emissions are realized for the both B100 and B20, with the exception of nitrogen oxides.

6. ENERGY BALANCE / ENERGY EFFICIENCY

Energy balance refers to the amount of energy required to extract, refine, produce or transform a resource into a useable fuel. LevNRCan reports the following energy balances for biodiesel production considering these elements: fuel dispensing, distribution, storage, production, feedstock transmission, recovery and agricultural chemical manufacture.[10]

Table 10 – Energy Balance

Diesel Fuel	Biodiesel
Energy consumed per unit energy delivered	Energy consumed per unit energy delivered
0.24	0.070 (canola)
0.24	0.034 (soy)
0.24	0.226 (yellow grease)
0.24	-0.005 (animal)

According to the data outlined above (LevNRCan), biodiesel has a better energy balance than petroleum diesel. However, it must be noted that this particular energy balance analysis accounts for a co-product credit for the resulting by-product of glycerin from canola / soy biodiesel production, and bone meal by-product from animal (tallow) biodiesel production. No by-product credit is given in the case of yellow grease (waste cooking oil) biodiesel production.

Without this co-product allocation, it has been concluded by a major U.S. study that biodiesel (canola and soy) and petroleum diesel are almost equally efficient at converting raw energy resources into fuels, attributing biodiesel's advantage to the renewable nature of its feedstock.[11]

Efficiency:

Biodiesel contains some oxygen in the fuel (a small weight penalty) and as a result has a slightly lower energy content compared to petroleum diesel on a volumetric basis.

[10] LevNRCan
[11] NERL

Diesel contains about 129,500 Btu/gal while biodiesel contains on average 117,468 Btu.gal, depending on the feedstock, as shown below.[12]

Table 11 - Energy Content (B100)

Conventional Diesel	129,500 Btu/gal
Animal-fat Biodiesel	115,720 Btu/gal
% Change (B100) % Change (B20)	-10.6% -2.1%

Conventional Diesel	129,500 Btu/gal
Plant-based Biodiesel	119,216 Btu/gal
% Change (B100) % Change (B20)	-7.9% - 1.6%

Graboski tested various biodiesel types on the same engine and his test results showed no difference in engine energy efficiency (fuel economy).[13] The BIOBUS demonstration project in Montreal, using B20 from various feedstocks, could find no conclusive variation in fuel economy comparing biodiesel to conventional petroleum diesel.[14]

7. ENGINE MANUFACTURERS

Biodiesel can be used in diesel engines with few or no engine modifications. Many major engine companies have stated formally that the use of blends up to B20 will not void their parts and workmanship warranties, with some qualifications regarding fuel usage impacts, types of biodiesel and blend levels. The following table presents some of the key points form some major engine manufacturers.

Table 12 – Engine Warranty Policies

Caterpillar	Caterpillar neither approves nor prohibits the use of biodiesel fuels. Caterpillar is not in a position to evaluate the many variation of biodiesel fuels, and the long-term effects on performance, durability or emissions compliance of caterpillar products. The use of biodiesel fuel does not affect Caterpillar's materials and workmanship warranty. Failures resulting from the use of the fuel are not Caterpillar factor defects and therefore the cost of repair would not be covered by the Caterpillar warranty. (Some Caterpillar engines are limited to 5% biodiesel blends.)
Cummins	Almost identical to above (Caterpillar policy)
Detroit Diesel	Biodiesel fuels may be produced from a wide variety of sources and maybe used in all DDC engines provided they are derived from soy methyl ester and rape methyl ester (canola) and are blended to a maximum of 20% by volume in diesel fuel. The resulting blend must meet DDC specified fuel properties. These blends have not been fully evaluated relative to diesel fuel system durability or engine oil effects.
International	Almost identical to Caterpillar and Cummins.

These statements by the major heavy duty engine manufacturers, while accepting of biodiesel, are generally less supportive than the automobile manufacturers statements concerning low level ethanol blends at this time. However, the auto manufacturers statements regarding ethanol blends did change over time, and in the beginning were similar to the above statements regarding biodiesel. It is expected that as biodiesel continues to gain momentum, North American manufacturers will become more supportive of this fuel type. This trend has already been established in Europe with the following examples of large European (division) engine / vehicle manufacturers that have established specific, favourable warranty policy toward biodiesel: BMW, Renault, Peugeot, Volkswagen, Mercedes Benz, Volvo, Ford, John Deere, etc.[15]

[12] NREL
[13] Graboski, M., Effect of Biodiesel Composition on Nox and PM Emissions from a DDC Series 60 Engine, for National Renewable Energy Laboratory - 1999
[14] BioBus Final Report, Biodiesel Demonstration and Assessment with the Societe de transport de Montreal (STM), 2003 (BIOBUS Final Report)
[15] Primary source for "Engine Manufacturers" section: LevNRCan (Draft)

8. TEMPERATURE ISSUES

As with any diesel fuel, biodiesel can begin to gel at low temperatures. Some types of biodiesel freeze at higher temperatures than others, depending on the level of saturated components in the fuel.

- 100% biodiesel, or high range blends, should be stored at temperatures at least 10 degrees Celsius higher than the pour point of the fuel (0 C to 15 C). A storage temperature of 8 to 10 C is adequate for most B100 blends.
- Blends of biodiesel and diesel should be stored at temperatures of at least 10 degrees above the pour point of the blended fuel. The pour point or petroleum diesel ranges between –40 to –10 C.
- Pure biodiesel can be stored underground in most cold climates, but above ground fuel systems should be protected with insulation, agitation, heating systems, or other measures if freezing weather is common.

Biodiesel can be splash blended with no problems if the diesel fuel temperature is 10 C or higher. If biodiesel is blended with cold diesel fuel (fuel temperature is less than 8 C to 10 C), the saturated compounds in the biodiesel can crystallize and plug fuel filters and fuel lines.

Pure biodiesel is difficult to ship in cold weather. In the winter, most biodiesel is shipped one of three ways:

- hot in tank cars for immediate delivery,
- frozen in tank cars equipped with steam coils (the tank cars are melted at the final destination),
- in 20% blends with available winter diesel, or in a 50% blend with kerosene.[16]

User experience with cold weather varies. B20 blends have been used in some very cold climates such as northern Minnesota, Wyoming, Quebec, Ontario and Alberta where temperatures routinely fall below –40 C in the winter. It can be concluded that laboratory tests appear to be more conservative than field experience. This was confirmed with the Montreal BIOBUS demonstration project, that reported no specific complications or problems arising from use of B20 in buses running approximately 10,000 km. through the coldest period of winter (overnight temperatures dropping to between –20 and –30 C).[17]

9. MATERIALS COMPATIBILITY (ENGINES AND STORAGE)

Biodiesel is a mild solvent. The most commonly encountered problem with solvency is biodiesel's tendency to "clean out" storage tanks, including the vehicle fuel tanks and fuel systems. Some types of diesel (No. 2) form sediments that accumulate in storage systems, forming layers of sludge-like sediment. Biodiesel, particularly B100, will dissolve these sediments and carry the suspended solids into the fuel systems of vehicles. Fuel filters will successfully handle this issue in the majority of situations, but in severe cases, the dissolved sediments have caused fuel injector failure.

Few problems have been encountered with B20 in typical diesel storage situations. The solvency effect of the biodiesel in B20 is sufficiently diluted so that most problems

[16] Primary source for "Temperature Issues" section: LevNRCan Draft
[17] BIOBUS Final Report

encountered are minor. These problems include an occasional plugged fuel filter. When using B20, sediments are usually completed filtered out after the first few tanks of fuel.

Biodiesel also can affect some seals, gaskets, and adhesives, particularly those made before 1993 and those made from natural or nitrile rubber. Engines with these materials would need to be modified. However, most engines made after 1994 have been constructed with gaskets and seals that are generally biodiesel resistant.[18]

10. COSTS

LevNRCan Analysis – Canola / Soy:

The costs of canola oil and soyoil are well established and tracked commodities. Thirty cents per pound was used as the price of canola oil and soy oil for biodiesel production. The current price of canola is approximately 20 cents per pound.[19]

The production costs of a biodiesel system based on canola oil or soy oil will be similar. In the following table, the estimated production costs are presented for a 60 million litre per year plant.

Table 13 - Canola / Soy Biodiesel Production Costs –Oil (30 cents per lb.)

Expenses - Operating	**Dollars**	**Dollars per litre**
Feedstock	35,142,857	0.586
Glycerin	(5,873,016)	(0.098)
Methanol	1,944,000	0.032
Processing supplies	2,400,000	0.040
Direct labour	624,000	0.010
Direct labour - benefits	124,800	0.002
Maintenance and operating supplies	437,000	0.007
Natural gas	382,968	0.006
Electricity	31,746	0.001
	35,214,355	0.587
Expenses - Overhead		
General sales and administrative costs	187,200	0.003
Insurance and taxes	203,205	0.003
Su Total	390,405	0
Depreciation	1,092,500	0.018
Interest on long-term debt	1,093,046	0.018
Total Overhead	2,575,951	0.043
Total Costs	37,790,307	0.630

Based on the above LevNRCan cost production estimate of 63 cents per litre for canola / soy biodiesel, the following tax exemption scenarios are outlined for a B20 blend. A federal tax rate of 4 cents per litre, and a provincial tax rate of 15 cents per litre are assumed.

[18] Primary source for “Materials Compatibility” section: LevNRCan Draft
[19] Alberta Agriculture and Rural Development

Table 14 - Canola / Soy Biodiesel (B20) After Tax Cost

	Diesel Only	Fuel Taxes Included	Federal Tax Exempt	Both Taxes Exempt
Vegetable Biodiesel	Cents/litre	Cents/litre	Cents/litre	Cents/litre
Diesel Component	35	28.0	28.0	28.0
Biodiesel Component	0	12.6	12.6	12.6
Taxes	19	19	18.2	15.2
Total, pre GST	54	59.6	58.8	55.8

The soy canola oil biodiesel is still more costly than conventional diesel if both federal and provincial taxes are waived. Considering additional costs of blending, cold weather additives for the refiners and capital cost return for the producer, total retail pre-GST prices for biodiesel (B20) may be higher than those outlined above. However, some retailers may decide to absorb these extra costs, keeping B20 in the price range of conventional diesel, using biodiesel as a marketing product option among their conventional fuels. On a B20 basis, the retailer would still generate profit margin from the 80% portion of conventional fuel within the blend. LevNRcan estimates that tax incentives of about $0.40 cents per litre would be required to make canola / soy-based biodiesel (B100) economic to sell at the current feedstock costs and diesel fuel prices. However, it is not expected that B100 would be sold in a retail setting.

LevNRCan Analysis – Animal Fat:

The production economics for an animal fat plant using the BIOX technology is shown in the following table. It has been assumed that the cost of the tallow is 15 cents per pound. The production costs are 27 cents per litre lower than the vegetable oil systems due primarily to the lower feedstock costs and to the lower capital cost of the systems.

Table 15 - Biodiesel Production Costs – Animal Fats (15 cents per lb.)

Expenses - Operating	**Dollars**	**Dollars per litre**
Feedstock	17,571,429	0.293
Glycerin	(5,873,016)	(0.098)
Methanol	2,232,000	0.037
Processing supplies	3,000,000	0.050
Direct labour	624,000	0.010
Direct labour - benefits	124,800	0.002
Maintenance and operating supplies	345,000	0.006
Natural gas	1,380,700	0.023
Electricity	52,381	0.001
	19,457,294	0.324
Expenses - Overhead		
General sales and administrative costs	187,200	0.003
Insurance and taxes	160,425	0.003
Sub Total	347,625	0.006
Depreciation	862,500	0.014
Interest on long-term debt	862,931	0.014
	2,073,056	0.035
Total Costs	21,530,350	0.359

Based on the above cost production estimate of 35 cents per litre for animal fat (tallow) biodiesel, the following tax exemption scenarios are outlined for a B20 blend. As in the case above, a federal tax rate of 4 cents per litre and a provincial tax rate of 15 cents per litre are assumed.

Table 16 - Animal Fat Biodiesel (B20) After Tax Cost

	Diesel Only	Fuel Taxes Included	Federal Tax Exempt	Both Taxes Exempt
Animal Biodiesel	Cents/litre	Cents/litre	Cents/litre	Cents/litre
Diesel Component	35	28.0	28.0	28.0
Biodiesel Component	0	7.2	7.2	7.2
Taxes	19	19	18.2	15.2
Total, pre GST	54	54.2	53.4	50.4

The cost situation is more favourable for the tallow biodiesel due to the lower cost of the feedstock and the lower capital cost of the BIOX plant. The two scenarios that have some tax relief produce a blended cost that is less than diesel. These costs do not provide a return on capital for the owner of a plant, nor do they include any costs for cold flow additives or blending costs. The return is quite sensitive to diesel fuel price. It will also be sensitive to the capital cost of the plant. It must be noted that BIOX have not yet constructed a full-scale plant so there may be some uncertainty in the capital cost estimate.

Additional Cost Commentary:

It is noteworthy that IAG – Enerquest (2002) estimated Alberta biodiesel production based on canola, yellow grease and animal fat to range between 49 –53 cents per litre, compared to the 35 to 63 range from LevNRCan. These differences are due to different feedstock cost assumptions and production processes (e.g., IAG did not assume BIOX process and IAG used off-grade canola prices).

IAG concluded that the net result is that economic factors are not apparently favourable in today's market. However, it is noted that input costs have been steadily dropping over the past 5 years and diesel prices have shown steady if erratic increases over a similar period and if these trends continue, the margin situation may improve over the next few years.[20]

11. BIODIESEL DEVELOPMENTS IN CANADA

- In November 2002, the Government of Canada established a new target on biodiesel. Specifically, under the Climate Change Plan for Canada, the federal government has set a target for 500 million litres of biodiesel production by 2010.

- The Government of Canada continued to show its support for biodiesel by announcing in Budget 2003, that the biodiesel portion of diesel blends is exempt from the federal excise tax.

[20] Primary Source for "Additional Cost Commentary" section: IAG-Enerquest

- In August 2003, the Government of Canada announced $1 billion toward implementation of the Climate Change Plan for Canada. Of these funds, $11.9 million will support research and provide incentives for industrial-scale biodiesel pilot plants, and support demonstrations of its effectiveness to encourage broader use of this cleaner-burning alternative to conventional diesel. This program will help address the current technical and market barriers to commercial biodiesel production and use in Canada. This goal will be supported by the following: research & development (addressing cold flow properties, lubricity, emissions/co-benefits, life-cycle analysis, feedstock impacts, production and process, compatibility with new engine, fuel, and emission control technologies), and demonstrations and deployment.

- Ontario has implemented a provincial tax exemption of 14.3 cents per litre as of June 2002, the only province to do so.

- As announced in March 2002, BIOX Corporation was awarded funding to build a process demonstration unit. This project was funded through the Climate Change Action Fund.

- The Government of Canada, with other sponsors, supported the BIOBUS project conducted in Montreal. The Société de transport de Montréal (STM) tested B-5 and B-20 in 155 buses in downtown Montréal, as part of a demonstration project that ran for one year.

Producers of biodiesel in Canada:

- Topia Energy Inc. produces biodiesel from soy, canola and yellow grease in the Sudbury area. Topia is Canada's largest producer of biodiesel and produces approximately 75% of the production in Canada. Topia has opened Canada's first biodiesel fueling pump in the greater Toronto area, selling B20 at approximately 5-10% more than conventional diesel.[21]

- Milligan BioTech Inc. makes biodiesel from canola (and is supplying the biodiesel for the Saskatoon bus test) in their pilot plant at Foam Lake, SK as well as batch produced biodiesel in a fee for service facility in Saskatoon. Milligan sells their biodiesel as a diesel additive (B-1).

- Rothsay / Laurenco, supplied the biodiesel (from animal fat) for the Montreal bus demo. Rothsay is planning to expand its production of biodiesel into a stand alone plant. Rothsay has been running their own Montreal fleet on biodiesel since 2001 and continues to produce biodiesel within their rendering facility in Montreal.

Current biodiesel demonstrations and use in Canada:

- Saskatoon Transit Services is testing biodiesel by running two buses on B-5, along with two "control" buses running on conventional diesel. Over two years, each bus will be monitored and evaluated for emissions, fuel economy and engine wear.

[21] Phone call with Topia Corp. – www.topiaenergy.com

- City of Calgary Fire Department is testing B20 in one of their non-emergency response trucks, analyzing and collecting results regarding engine / maintenance performance and emission reductions.

- University of British Columbia (UBC) is undertaking small biodiesel batch production using waste vegetable and animal oils, to supply UBC Plant Operations with 80-90% of the fuel produced for the summer months, fueling lawnmowers, and potentially to UBC Plant Operations to fuel all diesel equipment (trucks, etc).

- The following Ontario municipalities have been using or demonstrating biodiesel use in their fleet: Brampton, Kingston, Guelph, Sudbury, Oshawa, Burlington, Oshawa, Markham, Toronto (Hydro).[22]

12. CONCLUSIONS

This paper has provided an overview of the some of the key environmental and economic factors concerning biodiesel. It can be concluded that due to issues surrounding costs, cold weather properties, engine warranty issues and materials compatibility, that high concentration blends such as B100 are not the recommended method by which to use biodiesel as a transportation fuel at this point in time. The B20 blend is a preferred option and has been used successfully and extensively in Europe and the U.S.

From the data collected and analysis considered, it appears that biodiesel can provide positive environmental impacts when replacing petroleum diesel fuel in terms of GHG emissions and other air-quality related emissions, with the exception of nitrogen oxides. On a life cycle basis B20 can provide a reduction of GHG emissions in the range of 10-20%, when compared to petroleum diesel. When considering other emissions that are associated with air quality and health risks, B20 shows reductions in the range of 10-20%, from both a lifecycle basis and tail-pipe (exhaust) perspective.

Alberta is has the potential to emerge as a biodiesel production center, considering the intensive canola and tallow industry located in the province. However, feedstock availability would depend largely on displacement of existing markets for these products and necessary market developments to warrant this shift. Without the use of market-grade canola, biodiesel feedstock is limited to just over 100 million litres. However, biodiesel could be used as a niche fuel with specific fleet application without requiring broad market-wide penetration. Additionally, an Alberta biodiesel producer could take advantage of export opportunities into other niche markets in the U.S. and B.C.

The primary hurdle facing a potential Canadian and Alberta biodiesel industry is the cost competitiveness issue. At this time petroleum diesel fuel is more cost competitive. In order for biodiesel to compete effectively diesel fuel prices would need to rise, or government action would be required (tax subsidies and/or blending mandates). Additionally, refiners would need to adopt this fuel as a blend product. Under current market conditions this would result in extra costs for refiners that would in be passed on to consumers. However, with some tax relief, it is realistic to conclude that biodiesel (B20) could sustain itself in the market as a niche fuel with a 5 –10% price premium over conventional diesel.

[22] NRCan, Office of Energy Efficiency, Vehicle Fuels

From an environmental and economic perspective, biodiesel from tallow (animal fat) and used cooking oils appears to be a superior option over biodiesel produce from vegetable oil. A combination of new process technology (BIOX) and potentially declining prices could position this particular fuel favourably.

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