



Biofuel Feasibility Report for Dalhousie University:
An Assessment of Options for Transportation and Space Heating



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Glossary

CHP – combined heat and power

DI – direct injection engine

FAME – fatty acid methyl esters

FFA – free fatty acid

GHG – greenhouse gas

HP – horsepower (≈ 0.746 kW)

HRM – Halifax Regional Municipality

IDI – indirect injection engine

RPP – refined petroleum products

VO – vegetable oil

SVO – straight vegetable oil

WVO – waste vegetable oil

Note: all '\$' figures are in Canadian dollars unless otherwise specified.

1. Introduction

Dalhousie University, the largest post-secondary institution in Atlantic Canada, has a long-standing reputation as a leader in innovation and research. Also, it is a signatory to a number of declarations bolstering its commitment to pollution reduction, waste recycling, and ecological conservation.

These include the Halifax Declaration, which stipulates Dalhousie's commitment to "cooperate with one another and with all segments of society in the pursuit of practical capacity-building ... to achieve the effective revision and reversal of those current practices which contribute to environmental degradation" (IISD-a 1996); the Talloires Declaration which requires Dalhousie to "set an example of environmental responsibility by establishing programs of resource conservation, recycling, and waste reduction at the universities" (IISD-b 1996); and the UNEP International Declaration on Cleaner Production which mandates the University to "create innovative solutions by supporting the development of products and services which are environmentally efficient and meet consumer needs" as well as to "encourage new and additional finance and investment in preventive technology options, and promote environmentally sound technology" (UNEP 2007), among other directives.


Further to this, Dalhousie is situated in Halifax, Nova Scotia –a municipality with a "world-class waste resource management program" that is highlighted by their "Harbour Solutions Project, pesticide use reduction program, [and] composting and recycling systems" (HRM 2008). Among its waste recycling programs, HRM's municipal bus fleet, Metro Transit, switched to using a B20 blend of waste oil-derived biodiesel starting in the Fall of 2004.

In the 2007 Federal budget, the Canadian government allotted \$500 million for private sector investments in jumpstarting large-scale demonstration facilities for the production of biofuels. In 2008, the Canadian Senate passed the Biofuels Bill, an amendment to the *Canadian Environmental Protection Act* (Bill C-33), opening the way for the development of specific regulations; the federal government has already proposed mandating a renewable fuel content of 5% in gasoline by 2010 and 2% in diesel fuel and heating oil by 2012 (BFuel 2007). They have also mandated a seven year renewable fuels operating incentive program that subsidizes \$0.20 cents per litre of biodiesel produced in Canada for three years with a decline rate of \$0.02/year.

The Government has earmarked an estimated \$2.2 billion over 9 years towards "renewable fuels" with the majority of this directed towards research and development of biodiesel. In terms of development, Canada was producing about 15.5 million litres of biodiesel per year in 2004 (S&T Consultants 2004). The marriage of research and development for biofuel utilization has long had a foothold in universities throughout North America.

Innumerable post-secondary institutions are embarking on campus or city-wide biofuel projects, from research to implementation. One such example is the National Biodiesel Education program of the College of Agricultural and Life Sciences at the University of Idaho, which has run numerous diesel engines on various forms of biofuels; research and fuel-switching has been directly applied to university equipment such as farm machinery, stationary engines, Cummins Diesel engines in Dodge Pickups, Navistar engines in Ford Pickups, and Caterpillar engines in trucks involving biofuels derived from a number of oils including mustard seed, canola, rapeseed, and soybean (NBEP 2008).

More proximate examples include the University of British Columbia's biodiesel project, which has established a biodiesel processing facility and research space supplying all University diesel landscaping vehicles with a B20 blend of biodiesel (UBC 2008). Waste cooking oil is collected from restaurants, cafeterias and residences on campus and brought to the project's facility; with a production capacity of up to 1000 litres each day, the biodiesel processor normally churns out approximately 500 litres of biodiesel per week during the Fall and Winter semesters.



Luther College produces more than 10,000 litres of biodiesel each year – that's 35% of their use and \$8,300 in savings.

Biox, a company initiated by a former University of Toronto (UofT) professor in the Chemical Engineering Department and supported by the UofT Innovations Foundation, has snowballed to become the largest producers of biodiesel in Canada (Biox 2008). The Biox facility in southern Ontario generates more than 60 million litres of commercially available biodiesel per year, from mostly inedible tallow.

Luther College in Regina, Saskatchewan, has a small-scale biodiesel processing facility producing more than 10,000 litres per year, representing 35% of usage and saving the institution a high-end estimate of \$8,300 per fiscal year. They have reported carbon emission to have been reduced by 50,000 pounds (Tenneson 2008).

Dalhousie has the potential to capitalize on a burgeoning industry, minimize its waste output, and reduce its energy consumption. Any small-to-medium scale waste-to-fuel processing facilities at Dalhousie can help to showcase sustainable models of energy production in a way that demonstrates the University's commitment to exploring ecologically-sound technology. As the illusory glamour of large-scale agricultural biofuel operations begins to fade, leaving in its wake problems of land mismanagement and increased emissions, more moderately-sized systems for conversion of recycled oil present an attractive counterpoint.

This report focuses on recycling of waste vegetable oil (WVO) feedstocks on campus. While the supply of this feedstock is minute relative to energy demand, there is the

potential for future quantities of yellow grease to come “on-stream” as campus food operations expand and Dalhousie forges relationships with potential suppliers within HRM.

Yellow grease refers to the used cooking oil, either vegetable-derived or animal-based (i.e. tallow), from restaurants or other food service operation prior to being filtered, de-watered, and either converted to biodiesel or used straight in an engine. For the purposes of this report, ‘biofuel’ refers to either biodiesel or WVO.

Although the vast majority of yellow grease supply is processed for animal feed or consumed by rendering plants for glycerin applications, much of it is disposed in landfills or through private waste service companies. Accounting for exports and typical diversion streams, it has been estimated that Nova Scotia has approximately 1,542 tonnes of yellow grease than can be directed towards biofuel production as a potential feedstock (S&T Consultants 2004).

2. Background: Energy Needs at Dalhousie

The following examines options for diverting fossil fuel use, and primarily RPP’s, at Dalhousie with waste oil feedstocks. Central heating fuel, residential heating, diesel vehicle consumption, and decentralized power production at the University will come under review.

Dalhousie University consumes a range of different distilled fuels, including bunker C (heavy fuel oil no. 6) for steam generation towards meeting campus heating and cooling needs and light fuel oil (diesel no. 2) for residential space heating and transport vehicles. The University uses about 130,000 MWh of thermal energy per year, the vast majority of which is directed to space heating needs.

In the 2007-2008 academic year, Dalhousie used approximately 13.8 million litres of bunker C, 923,000 litres of residential heating fuel oil, and 4000 litres of diesel fuel for vehicles operated by Facilities Management and Aramark (Bourgeois 2008, Hines 2008), the campus food service provider.

Table 1 illustrates the amount of consumption for diesel-fuelled vehicles and equipment at Dalhousie. This does not include departmental fleets, student union services and faculty, staff, or student transportation modes.

Table 1. Dalhousie University diesel vehicles and fuel consumption for 2007-2008.

Vehicle	Units	Model, Year and Specifications	Consumption (L)	Operator
Truck	1	2005 Dodge Sprinter	1,547	Aramark
Van	1	Ford E450 Van (2002)	2,240	Facilities Management
Bobcat	2	Kubota engine 4cyl (2003)	U	Facilities Management
Tractor	1	New Holland (Ford) Tractor;	U	Facilities

		3cyl S773 diesel 25 HP (1990)		Management
Tractor	1	John Deere 2320 series Yanmar 24HP 3 cylinder (1988)	U	Facilities Management
Mower	1	Mower; Yanmar 3cylinder	45	Facilities Management

U = data unavailable at time of printing.

With dwindling supplies of finite fossil fuels resulting in volatile oil prices, accelerated climate change due, in part, to the burning of hydrocarbon fuels, and a shaky economy, discussions around energy reductions and replacements are of society's utmost priority.

Herein this report, five strategies have been identified and reviewed for their feasibility in terms of, most influentially, cost, GHG emissions, and flexibility:

STRATEGIES

- 1 – WVO as fuel for diesel engines in fleet vehicles;
- 2 – WVO as fuel for residential space heating on campus;
- 3 – WVO as fuel for power generation (or micro-CHP);
- 4 – WVO for on-site Biodiesel production towards any of above applications;
- 5 – Use of off-site Biodiesel towards any of above applications.

3. WVO as a Feedstock

3.1 Fuel from Waste

In 1900, the Otto company of Germany ran a demonstration diesel engine on vegetable oil and ignited what would eventually become everything from a booming agricultural industry to every car-owning scavenger's obsession.

Waste cooking oil, or yellow grease, is similar enough in its chemical constituents and combustion characteristics to be used as an alternative to diesel fuel or light fuel oil applications. However, as outlined below, certain preliminary steps such as viscosity reduction, filtering, and dewatering of the oil should be undertaken to avoid mechanical failures.

3.2 Availability at Dalhousie

Food service operations at Dalhousie University are exclusively contracted out to Aramark Inc, which manages five large cafeterias and a number of retail operations. Serving over 2000 Dalhousie students, in the residential cafeterias alone, each of Aramark's kitchens has at least two deep fryers where fish, chicken, potatoes, and battered vegetables are fried. A corn-sunflower blended brand of cooking oil, free of trans fats, is ordered in bulk and filtered a number of times for reuse. After the oil

cycles through the fryers multiple times, the water and fats begin to separate, the consistency becomes more viscous, the color darkens, and the oil is discarded.

Two oil drums located behind the Risley Hall and Life Science Centre cafeteria can store 600 litres of WVO at any given time. These storage containers are emptied, free of cost, by a waste recycling company once they reach capacity every 1.5 months.

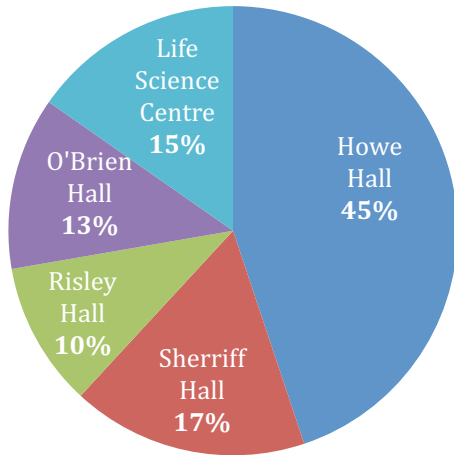


Figure 1. Distribution of WVO availability at Dalhousie University cafeterias.

In 2008, Aramark produced 5014 litres of WVO (Hines 2008), all of which was picked up and presumably used for rendering towards secondary product production (i.e. soaps, cosmetics). There is value-added potential to using this product for campus operations. The following explores the energy-reduction opportunities, GHG-mitigation potential, and cost feasibility of utilizing WVO directly or as biodiesel blends for University fleet vehicles, space heating, and small-scale power production on campus.

It should be noted that, notwithstanding direct energy impacts of WVO fuel-switching, adopting any of the aforementioned strategies can automatically reduce energy consumption in three ways; firstly, it limits the fuel used to transport heating oil or diesel onto the campus. Secondly, it avoids the transportation energy consumed in requiring the WVO to be carted off-site. Thirdly, by converting various waste streams to energy sources on-site they are diverted from landfills and the associated energy inputs required to break down the waste.

Each of these energy reductions has a corresponding decrease in GHG emissions, as described further into the report.

4. Use of WVO in Diesel Engines

As illustrated in Table 2, the WVO has between 9.6 and 10.1 kWh of thermal energy per litre available. Methyl esters, as will later be discussed, have slightly higher energy density on account of their alcohol content. Viscosity, or the fluid's resistance to flow –empirically observed by its relative thickness- is reduced in each fuels by increasing its temperature. The cetane number is a measure of the fuel's ignition delay and typically falls in the range between 38 and 55 for most fuels; a higher cetane number corresponds to shorter ignition delays and a more complete combustion of fuel injected into the combustion chamber.

Finally the flash point defines the lowest temperature the fuel must reach in order

to form an ignitable mixture in air. Therefore, when using WVO as the fuel, it must either be mixed with petroleum diesel or sufficiently preheated prior to use in the engine.

Table 2. Physical and chemical characteristics of diesel and vegetable oils (Altin 2001).

Fuel Type	Calorific value (BTU/kg)	Energy density (kWh/L)	Viscosity (mm ² /s)		Cetane number	Flash point (°C)	Chemical formula
			27°C	75°C			
Diesel fuel	41095.8	9.8	4.3	1.5	47.0	58.0	C ₁₆ H ₃₄
Raw sunflower oil	37469.7	10.1	58.0	15.0	37.1	220.0	C ₅₇ H ₁₀₃ O ₆
Corn oil	35858.1	9.6	46.0	10.5	37.6	270-295	C ₅₆ H ₁₀₃ O ₆
Raw soybean oil	37562.6	10.1	65.0	9.0	37.9	230.0	C ₅₇ H ₁₀₂ O ₆
Soybean methyl ester	37692.5	9.6	11.0	4.3	37.0	69.0	C ₅₃ H ₁₀₁ O ₆
Sunflower methyl ester	38468.9	9.9	10.0	7.5	45-52	85.0	C ₅₅ H ₁₀₅ O ₆

Though the combustion characteristics of WVO and diesel are close enough so as to burn the unconventional fuel in a diesel engine, two physical properties must be addressed to ensure proper operation. The viscosity and the surface tension of the WVO must be reduced.

Vegetable oils have higher viscosity levels than diesel at the same temperature, resulting in a reduced atomization in the fuel injection (Almeida 2002). Therefore, in a direct injection (DI) engine, for example, when straight vegetable oil or a partial blend with diesel is heated first, more fuel can be sprayed and therefore enter the combustion chamber. It is, thus, imperative to make this modification (Triandafyllis 2003) if deciding, for instance, to use WVO in the V6 turbo diesel engine of Aramark's Dodge Sprinter at Dalhousie University.

Also, by using a heat exchanger, preheating the WVO with the vehicle's warm coolant return line, or a block heater can minimize poor atomization potential.

It should also be noted that there is a more substantial decrease in fuel consumption when the diesel-VO blends are used at low loads rather than high loads (Triandafyllis 2003).

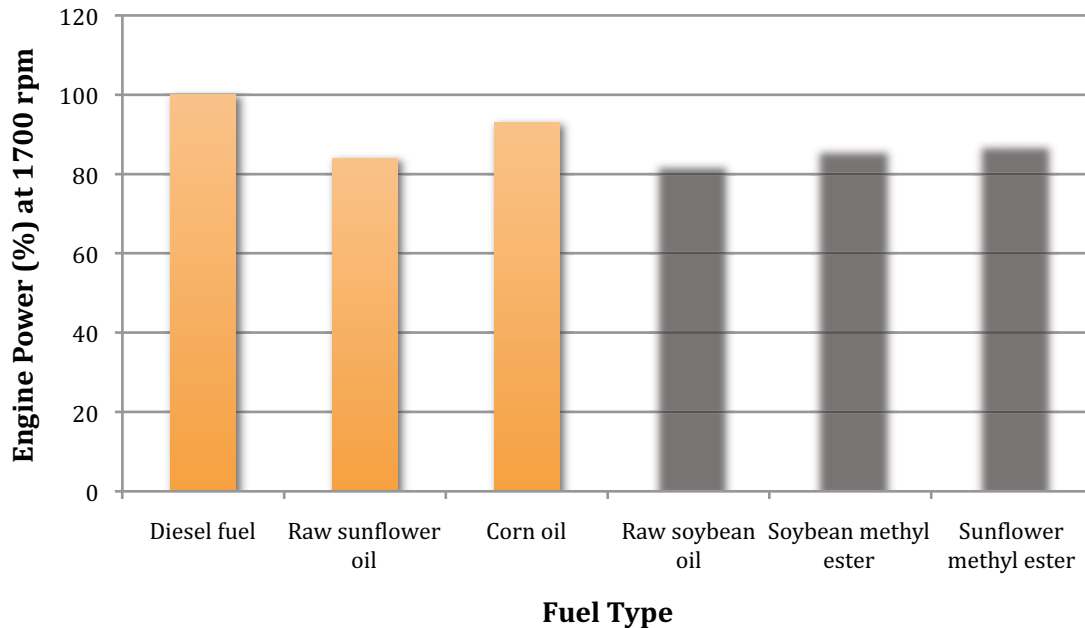


Figure 2. Maximum engine power for various fuel types using diesel as reference case, with peak output being 7.45 kW at 1700 rpm (Altin 2001).

Again, it is best to preheat VO to optimize performance in an indirect injection (IDI) engine with studies showing that, in so doing, cylinder gas and fuel line pressure for VO is very similar to diesel fuel; the IDI engine can “convert the fuel energy to mechanical energy equally for both fuels” (Ozsezena 2009).

4.1 Engine Modifications

Given the cold climates in Nova Scotia, vegetable oil must be pre-heated before reaching the vehicle engine.

The conversion of a diesel vehicle to run on vegetable oil (VO) fuel requires three essential modifications to the existing system: installation of a second tank, a heat exchanger, and a switch-valve. Figure 3 illustrates the typical arrangement of the system. The VO is pre-filtered and de-watered prior to its use in the system. Given the cold climates in Nova Scotia, however, the VO must be pre-heated to achieve a higher viscosity before running through the fuel lines and being injected to the engine.

A tank to store the VO can either be custom-made (using aluminum, polyethylene) or recycled; it should be sized in accordance with the rest of the system and installed in an accessible yet secure location underneath the hood of the vehicle or in the cargo compartment.

The system requires a heat exchanger, installed within the secondary (VO) tank and flushed with hot coolant from the engine to the radiator and/or a line-in-line heat

introduction foreign particles into fuel injectors can lead to eventual fouling and further complications such as stuck rings and cylinder scoring; a risk with use of either WVO or biodiesel in engines.

A number of operational and maintenance procedures are recommended to ensure proper operation of the diesel engine. These include:

- 1 Applying high-detergent (HD) lubricant oil, such as Castrol, to minimize any quality control issues that may arise from oil-sludge buildup, and to counteract any engine contamination that may accumulate after approximately 100 hours of operation;
- 2 Cleaning and testing fuel injectors, that may become clogged, after approximately 150 hours of service; this can be done either on or off-vehicle with strong solvents ensuring that the solution does not circulate into the fuel tank or come into contact with polymers of the fuel pump (Dorado 2002);
- 3 Starting the engine on diesel fuel, and allowing the temperature to rise; it is ideal to heat the WVO before the fuel pump and injectors to reduce its viscosity prior to combustion (Altin 2001);
- 4 WVO should be stored in a dark, dry, and temperature-regulated space to minimize excessive oxidative gum formation prior to use or processing;
- 5 If using biodiesel, its solvent quality typically cleans out fuel lines and may lead to clogging and fouling of the injectors; to avoid this problem, injectors should be manually cleaned with solvent (ex. the biodiesel itself); smaller blends should be used at first with incremental increases in biodiesel content, such as B5 followed by B20, B50, and finally B100.
- 6 Finally, with a double fuel tank set-up, the vehicle should typically be started and warmed up with petroleum diesel before switching to the biodiesel blend, and switched back to petroleum diesel before shutting down so no biodiesel remains in the fuel lines.

5. Use of WVO in Space Heating

Utilizing WVO in a furnace or boiler may require compressed air to ensure proper fuel atomization or preheaters to reduce the substance viscosity prior to combustion. Adjustments to residential fuel tanks and furnaces may be required including the installation of a preheater.

It is also recommended that the intake pipe and furnace strainer be situated between 3-6 inches above the base of the storage tank, with an oil filter added to the feed line between the tank and burner; finally, air supply to the burner may need to be adjusted, contingent on the it's output and size (Bartok 2007).

6. Use of WVO in Power (or CHP) Generation

WVO can be converted to electrical and thermal energy through the use of an internal or external combustion engine (ECE). Capital costs for such an engine are between 2500 and 6000 Canadian dollars per kilowatt (WADE 2006). Typically, by employing heat recovery, combined heat and power (CHP) units can convert 75-80% of the fuel source into useful energy with industrial plants reaching efficiencies of 90% or higher (IEA 2008).

Studies have shown that thermal efficiency is higher for SVO fuel than with biodiesel blends in a diesel engine intended for “micro CHP and its use in commercial and domestic applications”. With efficiencies at peak RPM and load capacity ranging between 40 and 50%, it was found that both fuels allowed for smooth engine operation with “low vibration and ... a significant reduction in noise levels and [carbon dioxide] emissions” (Alhakeem 2007).

One company which provides a micro-CHP system is the Owl Power Company and their *Vegawatt* system –a 5kW enclosed unit that can ostensibly handle over 150 litres of waste cooking oil per week. The unit costs about \$30,000 with an ROI of at least four years based on Dalhousie’s maximum output of approximately 140 litres per week during the winter term.

Unlike WVO or WVO-derived biofuels for residential heating or transport vehicles, however, the oil’s application in power generation technology limits its flexibility. Decentralized combined heat and power (micro-CHP) systems, for example, are stationary and limited supplies of WVO can only be used in these single applications to justify the capital expenses.

7. Use of WVO for Onsite Biodiesel Production

WVO can be used to produce a substance called biodiesel which can also reduce GHG emissions. Any such cooking oil-based fuel, either used on its own or as a diesel blend, can result in engine damage if a number of its constituents, namely particulates, free fatty acids and water content, are not eliminated prior to use.

A critical property of the WVO is the free fatty acid (FFA) content, which is typically higher than SVO feedstock due to its frequent heating; cooking oil consists of triglycerides surrounded by fatty acids freely adhering to basic substances. In the presence of hydrogen and heat, FFA’s undergo an addition reaction of hydrogenation where the gelling temperature of the oil increases.

Assuming a two-step acid-base catalyzed process is employed, a conversion factor of 97% can be achieved of WVO into biodiesel this was under extremely controlled conditions including a reaction time of 4 hours, a mole ratio of methanol to triacylglycerols of 10:1, and a sustained reaction temperature of 95°C (Wang 2007).

7.1 Transesterification Process

The production process involves a system that converts any vegetable-based oil into a combustible fuel equivalent in much of its properties and performance to petroleum diesel. In order to have an understanding of the individual system components, it is important to know the whole system function. The chemistry behind the oil-to-biodiesel conversion is quite simple. All vegetable oils, whether based in soy, corn, or canola, are comprised of triacylglycerols. These are chemically comprised of three long fatty acid chains attached to a glycerol backbone. The process is simply a conversion system, which removes the glycerol trunk, in the

A conversion process for biodiesel from WVO should begin by settling out the solids and filtering feedstock.



form of glycerin, from the oil and replaces it with an alcohol backbone, taking the form of either ethanol or methanol. In this way, the oil esters are converted through a process called 'transesterification' to fatty acid methyl/ethanol esters (FAME), a substance otherwise known by its household name, 'biodiesel'.

A conversion process for biodiesel production from WVO first begins by settling out the solid matter and filtering the organic particulates in the oil. Next the oil should be heated to evaporate the water off.

Catalysts and an alcohol are then added to the prepared feedstock to convert the WVO into biodiesel and a glycerin byproduct. The catalyst effectively severs the triglycerides from the esters so that they may combine with the alcohol. The alcohol can either be methyl alcohol, methanol, or ethyl alcohol, ethanol. Methanol must be added to the WVO feedstock at 6:1 ratio (mol/mol) while ethanol is added at a higher ratio of 30%. The benefit of ethanol, however, are that ethanol can be produced from organic wastes (ex. fermenting sugars) whereas methanol is largely synthetically produced from fossil fuels.

Conversion processes fall into three general categories of catalysts. These are alkaline-catalyzed, acid-base catalyzed, or enzyme-catalyzed.

Acidity from FFA in the WVO can be neutralized using an alkali catalyst such as sodium hydroxide (NaOH) or potassium hydroxide (KOH). NaOH is relatively low cost by virtue of its broad applicability and is commonly known as household lye. This catalyst must be added at a minimum of 0.35% in relation to the volume of WVO whereas KOH requires a minimum of 0.90% (Drown 1995). KOH, however, has comparable or higher rates of conversion and produces a potassium-enriched glycerin byproduct that can be regarded as a value-added agricultural fertilizer. Alkali-catalysis can, however, give rise to problems like glycerol recovery and the elimination of organic salts, among other things (Liu 2003).

Enzyme catalysis uses recombinant lipase enzymes, with or without immobilization,

which act under aqueous conditions on the carboxyl ester bonds present between the glycerol and fatty acid chains to achieve conversion of the oil feedstock into biodiesel (Liu 2003); conversion rates as high as 97.3% have been reported (Wang 2007). While the reaction typically takes longer than chemically driven conversions (Nelson 1996), the reaction takes place under mild conditions and is insensitive to high concentrations of free fatty acids – a major concern in applications where the feedstock is WVO. Furthermore, the enzymatic catalyst can be recycled towards future conversions and actually results in higher conversions of oil to methyl esters (Shimada 1999). The downside, however, is the higher cost of the catalyst –despite the lower costs of the reaction tank- coupled with the high degree of lipase sensitivity to methanol, unless the alcohol is kept in very low concentrations (Wang 2007).

To achieve high rates of conversion, in the absence of enzymatic catalysts, a two stage acid-base catalyzed conversion process is typically used. The first stage of the process involves esterification, a chemical reaction resulting in the formation of an ester product. A compound is formed between alcohol and acid – methanol and sulfuric acid, to be exact. Next, the compound goes through transesterification, a reaction in which one ester is converted into another by interchange of ester groups with an alcohol in the presence of a base. In this stage, the alcohol is still methanol, but the base is sodium hydroxide (lye).

It should be noted that ferric sulfate can serve as the heterogeneous acid catalyst towards the methanolysis of free fatty acids in WVO (Wang 2007). It is less ecologically deleterious than sulfuric acid, results in higher efficiencies of conversion, can be reused, and does not require specialized, and therefore more costly, anti-corrosion equipment for processing.

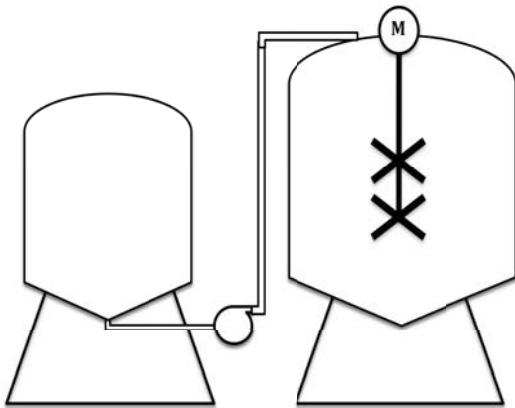


Figure 4. Schematic of a two-stage batch process for biodiesel production.

Finally, the glycerin is separated from the biodiesel (i.e. drained off from the bottom of the reaction chamber) and the final fuel product is washed, typically using aeration pumps and a water-washing column; methanol recovery can also be integrated at this point using, for example, hexane as an extraction solvent.

It should be noted that pretreatment and washing is critical in order to ensure optimal performance of the system and full conversion of the fuel. Since the feedstock being converted cannot be sourced by a consistent supply, quality control and

frequent regulatory testing are obligatory during and subsequent to the production stages.

7.2 Design Options

Although large-scale biodiesel producers typically use complex turn-key operations, feasible given relative economies of scale, Dalhousie's present limited supply of feedstock constrains the size of any potential facility. As such, batch processes are more cost-efficient (as opposed to continuous process technology) in smaller quantities; batch systems are less capital-intensive than continuous systems (Zeman 2006). Conversely, they are dependant on some manual operation and supervision.

Continuous systems, however, are not as flexible and degrade in reliability with periodic shutdowns which can lead to 'unsteady state' conditions resulting in off-spec product (i.e. not meeting ASTM standards); ideally, operating conditions including temperatures, pressures, and flow rates into the reactor(s) should remain as close to constant to ensure product consistency.

Waste oil, in the quantities available at Dalhousie, can be processed in small volumes or stored for larger batches.



Waste oil in the quantities made available at Dalhousie can either be processed in small volumes as it becomes available, or stockpiled for larger batches. From an operational-cost perspective, it is more economically feasible to perform batch processes in larger amounts. Figure 2, for example, illustrates a two-stage 300 litre unit. Should Dalhousie secure alternate sources of yellow grease, resulting in a higher level of feedstock, a continuous process production can be considered.

8. Use of Biodiesel in Diesel Engines or Space Heating

Biodiesel burned in space heating equipment has shown similar performance results as fuel oil. Dependant on the feedstock source, it has been shown to be very thermally stable and close in performance as compared to light fuel oil (NBB 2003). This is as a result of having comparable BTU content and combustion characteristics; biodiesel has a heating value of approximately 123,000 BTU/gallon (~10 kWh/L) compared to approximately 140,000 BTU/gallon (~11 kWh/L) of light fuel oil used for residential heating (Krishna 2001).

There have been a number of successful cases of use of biodiesel in space heating equipment; the largest of which includes the United States Department of Agriculture's (USDA) Agricultural Research Service (ARS), which after running B20 in their machinery and 150 diesel vehicles of their fleet, began using a B5 blend for their heating equipment in 2000 (Krishna 2001). Moreover, utilities in North America have already begun providing biodiesel blends to residential customers; these include Clickable Enterprises in New York and Wilson's Fuel in Nova Scotia.

Should Dalhousie pursue this option, however, it is recommended that laboratory testing be conducted to address the biodiesel blend's impact on specific heating equipment parts including nonmetallic materials (elastomers) used in pump seals, gaskets, label adhesives, valve seats. Modifications should then be made to the

system as deemed appropriate.

Also, as with biodiesel use in vehicle applications, mixed blends –starting with B20- “should first be tested over several heating seasons in the field to establish practical use and identify any potential problems” and “research should be carried out to find the mechanisms for the reduction in NO_x in boilers and establish scale up rules” (Krishna 2001).

9. Use of off-site (i.e. Wilson Fuels) Biodiesel

Wilson’s Fuel, a Nova Scotia-based company operating a home heating fuel service and numerous gasoline retail outlets, began offering a commercially available biofuel blend in the early 2000’s. The biofuel is produced with fish oil residues from the production of nutraceutical products using omega-3 fatty acids. Ocean Nutrition Canada (ONC), the local biotechnology company producing the biofuel, uses this secondary product for process energy and sells the excess amount to Wilson’s who markets it as blends with its fuel for space heating and diesel vehicle consumption.

Their biofuel is produced under BQ-9000 standards and largely funneled to the residential heating market. Retail price of their diesel is available at rack price plus \$0.05/L making the either marginally cheaper or more expensive than regular retail diesel (ex. ~5¢/L less in 2007 and ~2¢/L more in 2009, based on average retail price). They also carry an “off-spec” (non-ASTM-certified) biofuel product, cost competitive with Bunker C oil, available for use in industrial boilers.

Pricing details may be subject to negotiation with interested clients. As supplies of off-site biodiesel are not as constrained, there is the potential for burning straight biodiesel or blends in the main boiler plant for hot steam production.

10. Comparative Assessment of Fuel-Switching Options for Dalhousie

10.1 Environmental Benefits and GHG Analysis

Using biofuels to replace the full or partial use of fossil-fuel based energy products carries certain environmental benefits. These include its classification as non-toxic, its biodegradability and the accelerated biodegradability of diesel when blended with biofuels (NBEP 2008), its facilitation of a more thorough combustion in blends, as well as its low sulphur content.

Using petroleum diesel as a baseline, there is a marked reduction of GHG emissions from the combustion of biofuels for use in fleet vehicles, heating, or power production. Burning pure biodiesel results in reductions of between 60 and 98 percent fewer greenhouse gas emissions compared with petroleum diesel. A fuel mixture with a 1:5 ratio of biodiesel to petroleum diesel (i.e. B20 blend) results in GHG emission reductions of 12 to 18 percent; a 2 percent blend produces between 1 to 2 percent fewer emissions.

Table 3. Emission reductions of blends using petroleum diesel as baseline (EERE 2004).

Emissions	Percent reduction (%)	
	B100	B20
Carbon Monoxide (CO)	43.2	12.6
Carbon Dioxide (CO ₂)	78.3	15.7
Hydrocarbons (HCs)	56.3	11.0
Nitrogen Oxide (NO _x)	+5.8	+1.2
Particulates	55.4	18.0
Air Toxics	60 - 90	12 - 20
Mutagenicity	80 - 90	20.0

The precise GHG reduction for the biodiesel is contingent on the feedstock. Examining the GHG pollutants specifically, combustion of a pure biodiesel blend made with soy-based oil results in a 36% reduction in carbon monoxide, a 47% reduction in particulate matter (less than 10 µm) and a 60% decrease in total hydrocarbons, when compared to burning low-sulfur diesel (Graboski 1998). Figure 5 shows the associated reductions in specific air pollutants associated with biodiesel use in an engine. Generally speaking, the combustion of biodiesel and WVO result in similar reductions of particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO₂), and hydrocarbons (HC).

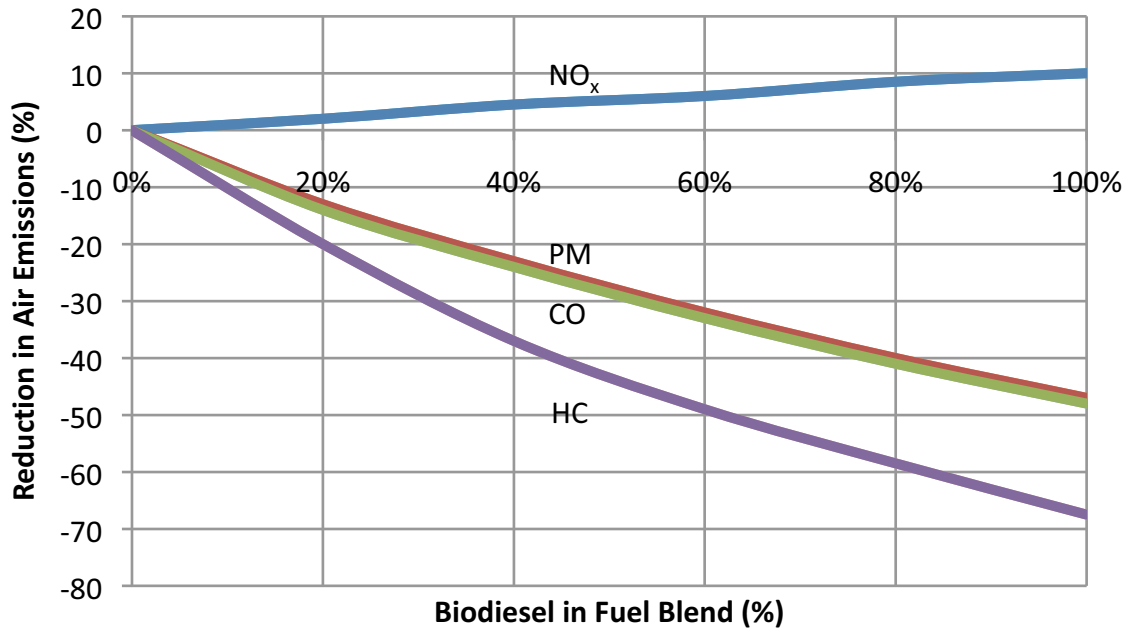


Figure 5. Air emissions of biodiesel blends compared to diesel (EPA 2002).

Biodiesel itself is composed of 11 percent oxygen by mass and is almost sulphur-free, thus even low concentrations added to petroleum diesel make it burn better and may improve the performance of catalytic converters. Biodiesel generally results in a 78% reduction in total greenhouse gases.

Conversely, biodiesel combustion leads to an increase in nitrogen oxide (NOx) emissions, as shown in Figure 5. This is due to the high in-cylinder combustion temperatures reacting with the nitrogen present in the intake air; the variability between NOx emission output is largely contingent on feedstock; soybean-based biodiesel results in the highest levels. It should also be noted that plant-derived biofuels typically result in higher levels of CO depending on blend percentage; at B100, CO emissions can be about 15% higher with canola as compared to fuel from animal fats (EPA 2002).

Biodiesel generally results in a 78% reduction in total greenhouse gases when compared to petroleum diesel.

It should be noted, however, that NOx emissions actually decrease when biodiesel is burned in furnaces; a 20% blend, for example, results in reductions of 20% NOx (Krishna 2001). Similarly, sulfur dioxide (SO2) emissions are decreased, due to the biodiesel fuel's reduced sulfur content, by a comparable amount in relation to the blend (EERE 2004).

Life cycle assessment is an accounting methodology that adopts an inventory of the embedded costs, energy, or GHG's associated with a product from the mining or harvesting of its constituents through to its disposal (i.e. cradle to grave). From a life cycle perspective, GHG savings are further reduced with yellow grease feedstock, as illustrated in Figure 6, while reductions will vary with source. About 2.5 kg of CO2 is mitigated for every litre of biodiesel displacing petroleum diesel (STM 2003); soot is also further reduced.

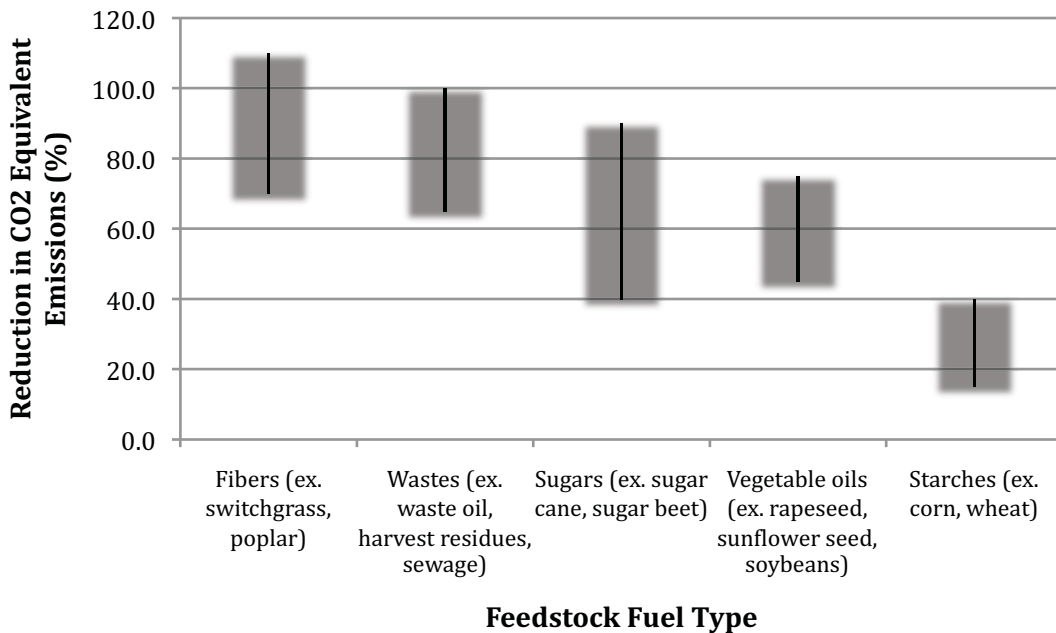


Figure 6. Percentages of GHG emission reductions by feedstock type per vehicle-kilometre driven (Hunt 2006).

10.2 Cost Analysis

When determining costs for the technologies under review, consideration must be taken to the relative scale of the technology given the limited size of feedstock supply. As mentioned in the introduction, Dalhousie is in an advantageous position of being able to pursue other supplementary source of feedstock supply. At the moment, however, the feedstock availability is more conducive to small-scale commercial applications. The cost comparison of all technologies includes pre-filtration and washing of the fuel (where applicable). Storage options have not been factored in, though the University will want to invest in storage tanks, with costs ranging in between \$1000 and \$4000 CDN, dependent on the number of protective walls.

The anticipated cost of an engine conversion for dual-fuel use is typically in the range of \$500 to 2500, depending on the complexity of the system components and their sourcing, not including the cost of labour for installation.

For on-site production of biodiesel, the major operating cost in biodiesel production is the cost of the feedstock – whereas the yellow grease, is (freely) available through Aramark as a WVO input, this is not a major cost concern. With more substantial biodiesel operations, the cost of yellow grease can cost the manufacturer between \$0.09 and 0.20 USD/lb, or \$0.29 USD/kg. In 2004, major waste oil rendering facilities in Nova Scotia such as Rothsay Laurenco of Truro, were paying about 112 \$/tonne for 150 t/week shipments of yellow grease.

As shown in Figure 7 and 8, the price of biodiesel is in large part a function of feedstock source, with operational costs diminishing as the supply moves further down the waste stream.

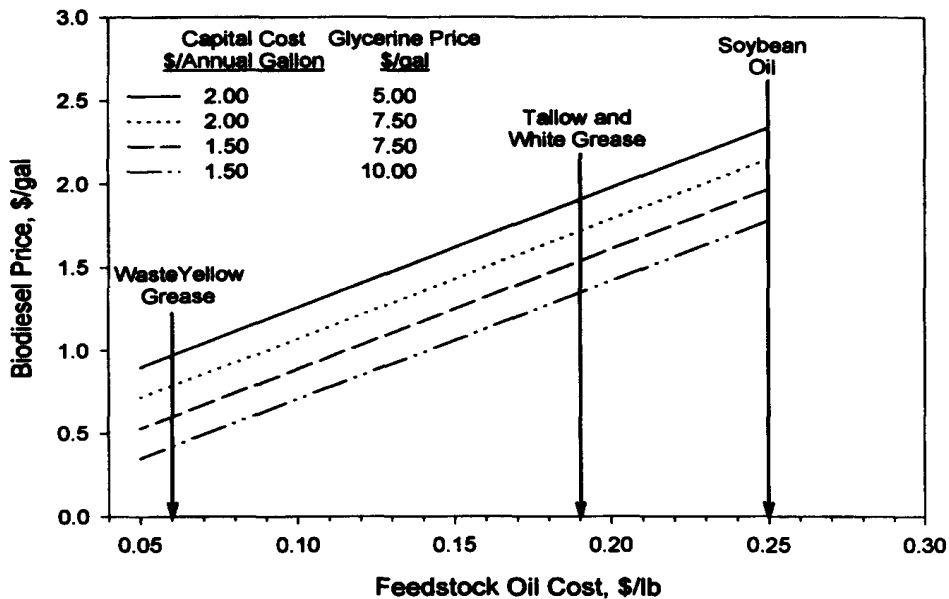


Figure 7. Sensitivity of biodiesel cost to feedstock cost, in USD/gal (Graboski 1998).

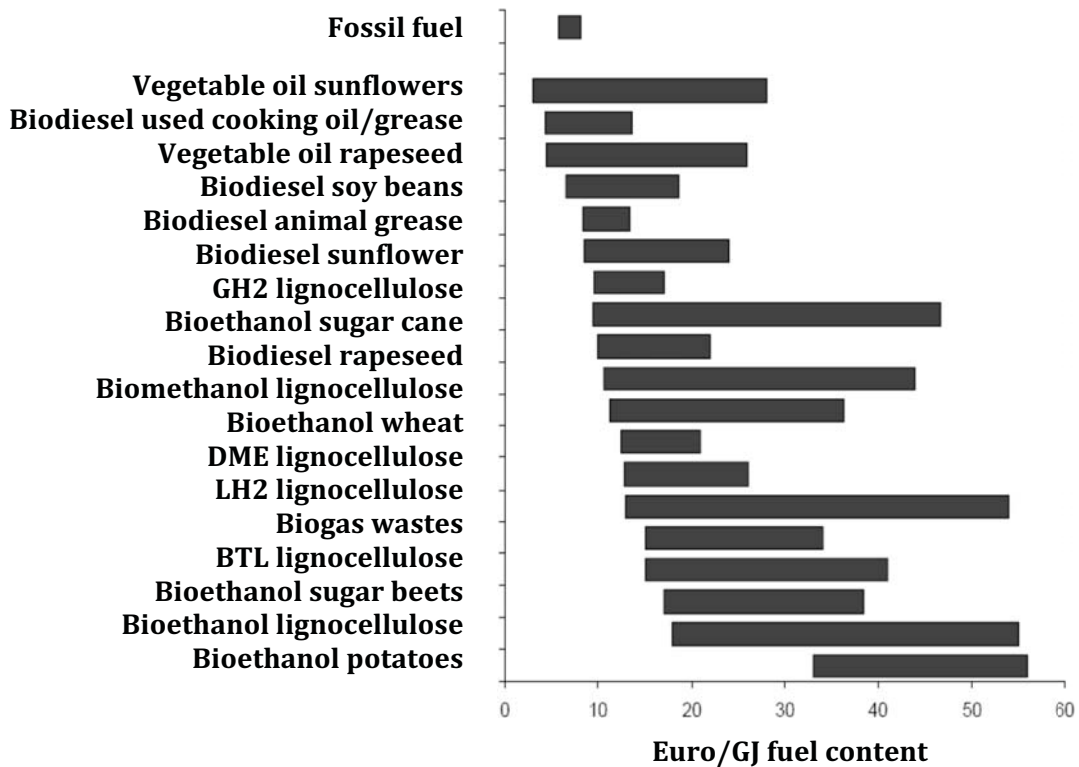


Figure 8. Production costs of biofuels as compared to fossil fuels in Euro/GJ (IFEU 2004).

Representing the full cost of biodiesel production requires performing a comprehensive life cycle assessment and examining the land use and transportation inputs of the Aramark vegetable oil and ONC fish oil.

Also of consideration, fuel consumption may increase slightly with the used of any biofuels – particularly in diesel engines. If Dalhousie University were to use biodiesel in a portion of its fleet vehicles, for instance, there would be a slight reduction in fuel economy of its vehicles as shown in Table 4. Testing of fuel economy between various blends used would be beneficial to determining losses.

Table 4. Fuel economy for biodiesel, vegetable oil methyl esters, and biodiesel/Number 2 diesel blends (Graboski 1998).

Biodiesel (%)	CO ₂ (MJ/kWh)	Fuel (MJ/kWh)
0.0	101.2	103.3
20.0	99.3	101.4
35.0	99.8	100.5
65.0	98.8	100.6
100.0	99.2	99.2

Given the presently reduced price of home heating and diesel fuel, certain technologies may look more attractive when RPP prices increase. Another ‘hidden cost’ of technology selection, as discussed in Appendix item A, is related to the

impact of WVO or biodiesel use on warranty and insurance policies of equipment.

Table 5 lists the payback period associated with each technology. Obviously the option of off-site biodiesel use carries with it no capital investments.

Table 5. Payback period for biofuel technologies at Dalhousie University.

No.	Fuel Type/Application	Payback Period			
		<1 year	1 - 2 years	2 - 3 years	>3 years
1	WVO in diesel fleet vehicles				
2	WVO in space heating				
3	WVO in micro-CHP				
4	On-site biodiesel for fleet			*	
5	On-site biodiesel for heating			*	
6	Off-site biodiesel for fleet				
7	Off-site biodiesel for heating				

* *Dependent on single-stage or dual-stage processing of fuel.*

11. Review and Recommendations

A review of Dalhousie University options for biofuel use reveals the following primary recommendations:

- 💧 Pursue intensive preliminary testing of pre-filtered WVO from Aramark food service locations in diesel engine combustion; further research is encouraged, to address biofuel information gaps, as outlined in Appendix B.
- 💧 Subsequent to quality control testing, install dual-tank system in either the Ford E-450 Van (Facilities Management) or the Dodge Sprinter (Aramark) towards use of pre-filtered WVO.
- 💧 Establish a storage facility and testing lab, the latter of which can be satellite (i.e. Chemistry building), proximate to WVO disposal points collect feedstock for large batch filtration.
- 💧 Enter into discussions with Wilson’s Fuel to phase in biodiesel blends into furnace use on campus, beginning with a B5 blend in the first trial season.
- 💧 Explore opportunities for partnership with surrounding WVO producers, including the IWK and businesses on the campus perimeter.

12. Financial Incentives

The following is a listing of provincial and federal programs that can support the research and development of biofuel use at Dalhousie University.

- **NextGen Biofuels Fund:** a program of Sustainable Development Technology Canada, which assists in a biofuel development project's capital expenditures while simultaneously "helping them to scale-up their technology solution to a large, demonstration-scale plant":

URL: http://www.sdtc.ca/en/funding/NextGen_Biofuels_Fund/index.htm

- **The Resource Recovery Fund Board (RRFB):** funds municipalities, businesses and community projects that reduce waste and divert materials from the landfill. Municipalities can receive funding for Municipal Approved Programs that assist in diverting materials from the landfill through waste reduction, reuse, recycling or composting initiatives.

URL: <http://www.rrfb.com/pages/forms.html>

13. Appendices

13.1 Appendix A

Warranty and Insurance Issues at Dalhousie

The use of biofuels in any Dalhousie equipment should be communicated to the Office of Risk Management at Dalhousie University. For an engine modification to two trucks, for example, the Dalhousie insurance coverage would remain unaffected. Any potential engine issues as a result of using WVO, however, may present some insurance and warranty problems. John Deere, of which Dalhousie has a ground tractor and midmount mower for example, has stated that “raw pressed vegetable oils are not acceptable for use for fuel in any concentration”. Use of WVO, then, is up to the discretion of the operator.

Similarly, while certified biodiesel may be covered for use under most policies, the fuel’s solvent quality (i.e. fuel line cleansing properties) have led to clogged filters, resulting in skepticism surrounding its widespread use.

In the U.S., Federal law prohibits a warranty from being voided on the basis that biodiesel was used. Only if an engine experiences a failure caused directly by biodiesel use will the damage incurred be exempted from the original equipment manufacturer’s warranty (EERE 2004). On the other hand, most warranties by manufacturers of engines and vehicles provide warranties on their products covering “material and workmanship”; not necessarily damage caused by some external condition. Under most standard provincial automobile policies, the exclusion clause stipulates that the insurer shall not be liable for damage “caused by mechanical fracture or breakdown of any part of the automobile or by rusting, corrosion, wear and tear, freezing, or explosion within the combustion chamber, unless ... caused by fire, theft or malicious mischief...” (GoA 2004). This means that any filter clogging or engine failure associated with diesel fuel use (where biodiesel is used) may be excluded from the insurance policy where use of alternative fuel can be liable.

Off-spec biodiesel (that which is not certified in accordance with ASTM standards, such as PS121), however, typically nulls the warranty as the parts manufacturer cannot ensure its combustion quality. John Deere approves biodiesel use in blends of B5 in its PowerTech diesel engines; similarly Ford Motor company approves blends of 5% biodiesel or less in its vehicle engines.

13.2 Appendix B

Listing of field trials and research on biodiesel use in engines at private labs and Universities throughout North America.

An excerpt from (Schumacher 2001)

a) Urban Bus Data Collection

A total of ten buses have been monitored at Bi-State Development Agency in St. Louis, Missouri since April 14, 1994 (Schumacher, et. al., 1994c). All of the buses are powered by 1988 6V92TA Detroit Diesel engines. Five of the buses have been fueled with a 20% blend of biodiesel in 80% # 2 diesel fuel, and five of the buses are controls fueled with # 2 diesel fuel. Approximately 88,000 miles have been logged on each bus while fueling with a 20% biodiesel blend. The accumulation of wear metals in the engine lubricating oil, engine fuel system material compatibility, and engine durability have been monitored. Data related to fuel consumption, power, and exhaust emissions have been monitored and recorded (Schumacher, et. al, 1995c) (Schumacher & Madzura, 1996). New diesel fuel injectors were installed in each engine at the start of the project. Some fuel filter plugging was noted during the first weeks of fueling. Midway through the project, one injector was removed from each of the biodiesel buses and sent to Diesel Technology Company (DTC) for analysis.

DTC noted that cavitation had occurred on two of the five injectors that were analyzed. The biodiesel buses have experienced a higher level of cooling system maintenance than the diesel control buses. Radiators were removed, rodded, and/or replaced for nearly all of the biodiesel fueled buses. Large variations in fuel economy were noted in the project but these were attributed to fuel blending problems.

b) 5.9L Cummins Engines in Dodge Pickups at the University of Missouri

Starting in 1991, a 1991- 5.9L 6B Cummins engine and in 1992, a 1992- 5.9L 6B Cummins engine have been fueled with 100% neat biodiesel (Schumacher, et al., 1995a,d). The accumulation of wear metals has been noted in the engine lubricating oil, and the engine fuel system material compatibility, fuel economy, power, emissions, and engine durability have been monitored. Nitrile rubber fuel lines were replaced on the 1991 Dodge because they had deteriorated due to the solvent characteristics of the biodiesel. This was not necessary for the 1992 pickup as Dodge began using an elastomer that was resistant to biodiesel. At approximately 50,000 miles (1991-55,000 miles, 1992- 47,000 miles) a 30% power loss was noted during power testing. The fuel transfer pumps were subsequently replaced. Upon inspection, the diaphragm of each fuel transfer pump had deteriorated. This prevented the fuel transfer pump from delivering a full charge of fuel to the engine. After replacing the pumps, the pickups were retested for power, but were unable to match the performance of earlier power tests. The Bosch VE pump was removed from each pickup and examined by Capitol Diesel, a

diesel injection pump repair facility located near Jefferson City, Missouri. They found that the aneroid sensor of each injection pump had failed. The technician found a brown gelatin-like material in the aneroid sensor of each injection pump. The Bosch diesel fuel injectors of both engines were analyzed after approximately 50,000 miles of fueling by Bosch GmbH. Their report stated that no problems were noted and that Bosch approved of the use of 100% biodiesel in their fuel system. Approximately 100,000 miles had been logged on the 1992 pickup when the test was terminated on May 17, 1996. The engine was disassembled and examined by a team of Cummins Engine Company experts during the first week of June 1996. The draft report by Cummins indicated that the engine was wearing at a normal rate.

Fueling Farm Tractors with Biodiesel Blends

Quantitative data related to fuel consumption, power, and exhaust emissions were monitored and recorded while fueling Case-International 5120, 5130, & 5250 and Ford 4600 & 7740 tractors with blends ranging from 0 to 100% biodiesel. Material compatibility problems were noted when fueling with an experimental biodiesel fueling station. The 100% biodiesel dissolved the rubber fill hose after one month of use so that fuel leaked from the hose when refueling. John Deere tractors, models 6300, 7200, 7800 ran hotter when fueled with biodiesel (Schumacher, et al., 1994a). The tractors were tested for power while changing between blends of 0, 10, 20, 30, 40, 50, and 100% biodiesel / # 2 diesel fuel. Testing occurred on the same day, under similar temperature and humidity conditions, and within minutes of the previous test. When each engine fueled with 100% diesel fuel, the viscous fan that is designed to engage when cooling needs are the greatest, seldom engaged. The viscous fan almost always engaged when fueled with a biodiesel blend. The power that each engine was able to produce declined as the concentration of biodiesel increased. However, the decline in power seldom exceeded 1-3% except when the engine was converted to 100% biodiesel.

1000 Hour Durability testing

Two 1000 hour durability tests have been conducted by ORTECH International (Mississauga, Ontario, Canada) for the National Biodiesel Board (ORTECH, 1995 and Fosseen, 1995b). Both two-stroke (6V92-TA Detroit Diesel) and four-stroke (N14 Cummins) diesel engines were tested for power and long term durability. In both situations, the OEM selected the durability cycle that would be used when fueling the engine. Power and emissions were documented prior to initiating each 1000 hour durability test. The emissions produced by the engines paralleled data previously reported in the literature: NO_x increased while CO, HC, and PM declined. Injector cavitation problems were noted for the 6V92-TA at the end of the 1000 hour test. No injector problems were noted for the N14. Both engines experienced a loss in power during the testing.

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