UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation into the Feasibility of Producing and Using Biodiesel from Waste Grease at UBC

Alicia Figueira

Nathan Boldt

Ethan Dorion

Gautam Bellary

University of British Columbia

APSC 262

March 29, 2012

An Investigation into the Feasibility of Producing and Using Biodiesel from Waste Grease at UBC

Applied Science 262 – Technology and Society II

Written for:
Dr. Paul Winkelman

Written by:
Alicia Figueira
Nathan Boldt
Ethan Dorion
Gautam Bellary

Date of Submission:
March 29, 2012

ABSTRACT

In alignment with the goals of sustainability at UBC, outlined by Alberto Cayuela's presentation on March 6, 2012, an evaluation is being conducted on the potential of manufacturing and use of an alternative fuel called biodiesel. Presently, UBC is using petroleum diesel, B5 blend (5% biodiesel and 95% petroleum diesel mixture) and regular gasoline to fuel the campus maintenance and operations vehicles. Additionally, there is a significant amount of waste grease that UBC is producing through various food outlets on campus. The proposed project that is being evaluated will address these two issues and ultimately head in the direction of sustainability and reduced environmental impact. The focus of this evaluation is the feasibility of producing biodiesel fuel from the waste grease produced by UBC, based on a triple bottom line assessment.

The triple bottom line assessment is a criterion for evaluating the environmental, social and economic impacts of a product. A thorough qualitative and quantitative analysis is conducted at each step of the product's life. The environmental impacts, economic feasibility and social acceptance are evaluated and compared to conclude the concept's practicability.

The result of the triple bottom line assessment concludes that biodiesel is a superior alternative fuel to diesel petroleum. Environmentally, biodiesel produces less amounts of harmful emissions compared to petroleum diesel. In its 30 year life cycle, biodiesel produces 86% less emissions compared to those of petroleum diesel. In addition, it produces less cancerous compounds, which reduces the health risks of burning fuel. Economically, despite high capital costs, manufacturing and using biodiesels at UBC is feasible, if creative measures are taken. Finally on a social scale biodiesel is looked upon positively by the majority of people and a learning opportunity is created through student involvement. For UBC, an alternative fuel that reduces harmful emissions is the next step toward total sustainability. When the standards of the ASTM are met, biodiesel can be used in UBC's campus vehicles with a seamless transition. For these reasons, it is recommended that UBC implement the manufacturing and use of biodiesel made from waste grease for campus vehicles.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

GLOSSARY

Biodiesel – A compression ignited fuel used in a similar way to petroleum diesel in vehicles.

Break Even – The time that is required for the money saved as a result of an investment to equal the money invested.

Ecological Footprint – The net impact something has on the environment, including emissions and use of non – renewable resources.

Grease – The waste oil produced by restaurants that can be used to produce biodiesel.

Lifecycle Emissions – The total emissions produced in the lifecycle of a product, covering production, transportation, consumption, disposal and storage.

Lower Heating Value – The amount of energy released when a fuel is burned completely.

Carbon Monoxide – A toxic gas that combines with oxygen in the atmosphere to produce carbon dioxide and ozone (both of which are pollutants to the atmosphere).

Scales of Economy – Increased efficiency of producing a product due to expansion, which reduces costs of production.

Soot – Carbon particles resulting from incomplete combustion.

Tar Sands – Sand or clay mixed with water and bitumen (a higher viscous form of crude oil) OilPrice.com. (2012).

Total Hydrocarbon – Compound consisting of hydrogen and oxygen.

Yellow Grease – The waste grease produced by restaurants.

LIST OF ABBREVIATIONS

ASTM – American Society for Testing and Materials

CO – Carbon Monoxide

L – Litre

mg – Milligrams

MJ/L – Mega Joules per Litre

kg – Kilograms

lbs – Pounds

NO_x – Mono-Nitrogen Oxides

THC – Total Hydrocarbon

UBC- University of British Columbia

1.0 INTRODUCTION

At the University of British Columbia, environmental awareness is a growing subject of interest. UBC is continually broadening its horizons in the areas of reducing, reusing and recycling. All of the efforts in each of these areas are leading UBC towards a completely sustainable university campus. To add to the list of projects UBC is exploring and executing, is the idea of fuelling the many vehicles owned and operated by UBC with an alternative fuel. This fuel, called biodiesel, is one that could be created from waste grease that the UBC campus restaurants produce. The sustainability model behind this project is that in using waste grease from UBC's own campus to fuel its own vehicles results in direct recycling of resources. Biodiesel, more importantly, reduces greenhouse gas emission significantly when burned, compared to petroleum diesel. In addition, on a large economic scale, since grease is a by-product that already exists, there would be no increased demand for commodities and thus, using biodiesels created with waste grease has no unintended effect on the economy (it would not influence the price of any commodities).

This project aims to reduce UBC's waste products by reusing them, ultimately recycling valuable resources and reducing the use of environmentally harmful resources. In this study, the proposed project will be investigated using a triple bottom line assessment, from an economic perspective, an environmental perspective and finally a social perspective. The final conclusions and recommendations pertaining to this project will be a careful combination of the results found in each of the triple bottom line sections.

1.1 WHAT IS BIODIESEL?

To understand what this project is attempting to implement, it is important to understand the context. What is biodiesel? Where does it come from? To answer these questions one needs to start at the source. Biodiesels can start in the form of animal fats, vegetable oils, and greases. These products are then taken through a chemical process called transesterification whereby the glycerin is separated from the fats, oils or greases. The product left behind as a result of this process is called methyl ester which is the chemical name for biodiesel (National Biodiesel Board, 2012). Biodiesel is better for the environment because it is made from renewable resources and has fewer emissions compared to petroleum diesel. It is less toxic than table salt and biodegrades as fast as sugar (National Biodiesel Board, 2011). Finally, since it is made from renewable resources that UBC produces, it limits the need for non-renewable resources.

1.2 WHAT IS DIESEL FUEL?

Diesel fuel is derived from crude oil. Crude oil is extracted from the Earth's surface by the process of mining. This crude oil contains hydrocarbon compounds which are hydrogen and carbon molecular bonds. These hydrocarbon bonds create hydrocarbon chains. Each chain has a specific number of bonds and therefore carries specific characteristics. After the crude oil is extracted it is sent to oil refineries to separate the different hydrocarbon chains based on their boiling points. To separate diesel from the crude oil, the oil is placed in a fractional distillation column and is then subjected to a specific temperature. Because the hydrocarbon chains have their own specific boiling points, similar ones are able to be collected together. To separate and collect greater quantities of diesel, catalysts are used. The final step in making diesel fuel is purification. The diesel fuel is reacted with a catalyst exposing it to hydrogen under controlled conditions. The diesel is collected in its final state and sold. (Sandhyarani, 2011)

2.0 ECONOMIC ANALYSIS

According to Justin Ritchie (personal communication, February 15, 2012), UBC produces a total of 30 450 lbs of grease per year. If this is used to produce biodiesel, it could potentially be completely converted to produce 30 450 lbs of biodiesel per year (15 695.3269 L/year, see Appendix A for calculation) (Canakci, 2005, Waste vegetable oils and animal fats, para. 5). In 2011, UBC spent $355,149. 24 on pure petroleum diesel and $128,979.43 on a B5 blend (5% biodiesel and 95% petroleum diesel mixture) with a total expenditure of $484,128.67 on diesel fuel (personal communication with Adam McCluskey).

One alternative for UBC is to sell its grease to a biodiesel manufacturer who may be able to reduce the cost of production by having larger scales of economy. Due to the increase in the price of petroleum and increased interest in biodiesel, the value of grease has increased and companies are now purchasing waste grease from restaurants whereas in the past, they have paid companies to dispose of their grease (Morrow, 2008). UBC could potentially obtain approximately $0.40/kg of grease ($0.18/lb) (Hunter, 2006), which would result in a revenue of $5,524.75 per year. This would reduce the expenditure for fuel by 1.14% annually.

Another alternative is to produce biodiesel using the waste grease. The average cost of producing biodiesel over the past 8 years has been approximately $0.38/L (Radich, 2004) (see Appendix A), which would result in a cost of $5,964.22 per year to produce. Since UBC would not be required to purchase the grease, this would reduce the costs by $5,524.75 per year. Therefore, the total cost of producing biodiesel for use at UBC would be $439.47 per year.

2.1 CURRENT SPENDING

According to Adam McCluskey, UBC purchased a total of 412,850.97 [L] in 2011 for a total cost of $484,128.67. This equates to approximately $1.17/L. The cost, therefore, to purchase the amount of fuel that could be manufactured on campus would be $18,405.08 per year.

2.2 CAPAL COSTS

A full manufacturing system, including installation would cost $195,000 (Circle Biodiesel & Ethanol Corporation, 2012) (see Appendix A). Including 12% taxes, the capital costs for producing biodiesel would be approximately $218,400. With this capital cost, it would take UBC approximately 12.15 years to break even (obtained by dividing the capital cost by the difference in cost per year of purchasing the fuel).

Although the cost of production would eventually break even, it would be more economically feasible to sell the waste grease produced at UBC and purchase petroleum diesel, as opposed to using the grease to produce and use biodiesel. However, technology may advance to reduce costs of producing biodiesel which may change the outcome of this comparison. In addition, being a university, UBC has resources that may be able to reduce the capital costs. For example, engineering students could contribute to the design and building of the mechanisms. Once the capital costs have been paid off, UBC will be reducing its expenditure on diesel fuel by $17,965.61 per year (3.7%). This project should be revised economically once biodiesel production (including capital) has a reduced cost or the value of grease has increased.

3.0 ENVIRONMENTAL ANALYSIS

Biodiesel is made from renewable resources, which have less of an environmental impact compared to petroleum diesel, which is made from crude oil. In addition, biodiesel produces fewer emissions than petroleum (United States Department of Energy and the United States Environmental Protection Agency, 2012). This section investigates the emissions produced when each fuel is burned and the lifecycle emissions of each fuel.

3.1 UBC'S CURRENT CONSUMPTION

Currently, UBC uses a combination of pure petroleum diesel and B5 blends (5% biodiesel and 95% petroleum diesel mixture) purchased from Chevron (personal communication with Adam McCluskey on March 27, 2012). Table 1 summarizes the information given by Adam McCluskey pertaining to fuel requirements for 2011.

Table 1 - UBC Fuel Needs for 2011

Fuel Type	Quantity
Pure Petroleum Diesel	302, 410.31 [L]
B5 Biodiesel Blend (5% Biodiesel and 95% Petroleum Diesel)	110,440.66 [L]
Total Fuel Needs	**412,850.97 [L]** **(407,328.94 [L] Pure Petroleum Diesel)**

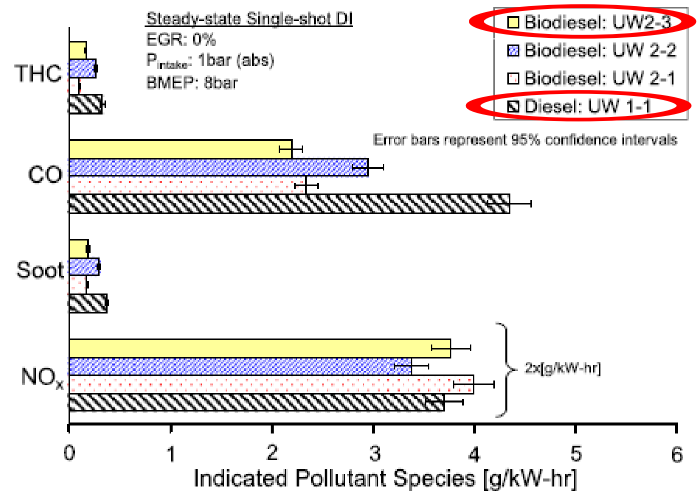
(Personal Communication with Adam McCluskey)

As mentioned above in the Economic Analysis section, 15,695.3269 [L/year] of biodiesel can be produced. This translates into a 3.9% reduction of UBC's dependence on diesel fuels. By increasing its scales of production by purchasing additional waste grease, this percentage reduction could increase significantly.

3.2 CONSUMPTION EMISSIONS

When fuel is burned, it releases harmful emissions into the atmosphere. These emissions contribute to the increasing global temperatures and are toxic. A study was done that compares the emissions of several types of biodiesels to petroleum diesel, which results can be seen in Figure 1. The type of fuel that is relevant to this report is called "UW No. 2-3" which is 100% biodiesel made from yellow grease.

Analysers	Species	Measured unit
Non-dispersive infra-red (NDIR)	CO CO_2	ppm %
Paramagnetic	O_2	%
Chemiluminescence	NO	ppm
	NO_2	ppm
Heated flame ionisation detector (H-FID)	THC	ppm
Variable sampling smoke meter	Smoke/ dry soot	FSN (mg/m^3)



Zheng, M., Mulenga, M.C., Reader, G.T., Wang, M., Ting, D.S, & Tjong, J. (2008). Biodiesel engine performance and emissions in low temperature combustion. *Journal of Fuel (Guilford),*87, 714-722. doi:10.1016/j.fuel.2007.05.039

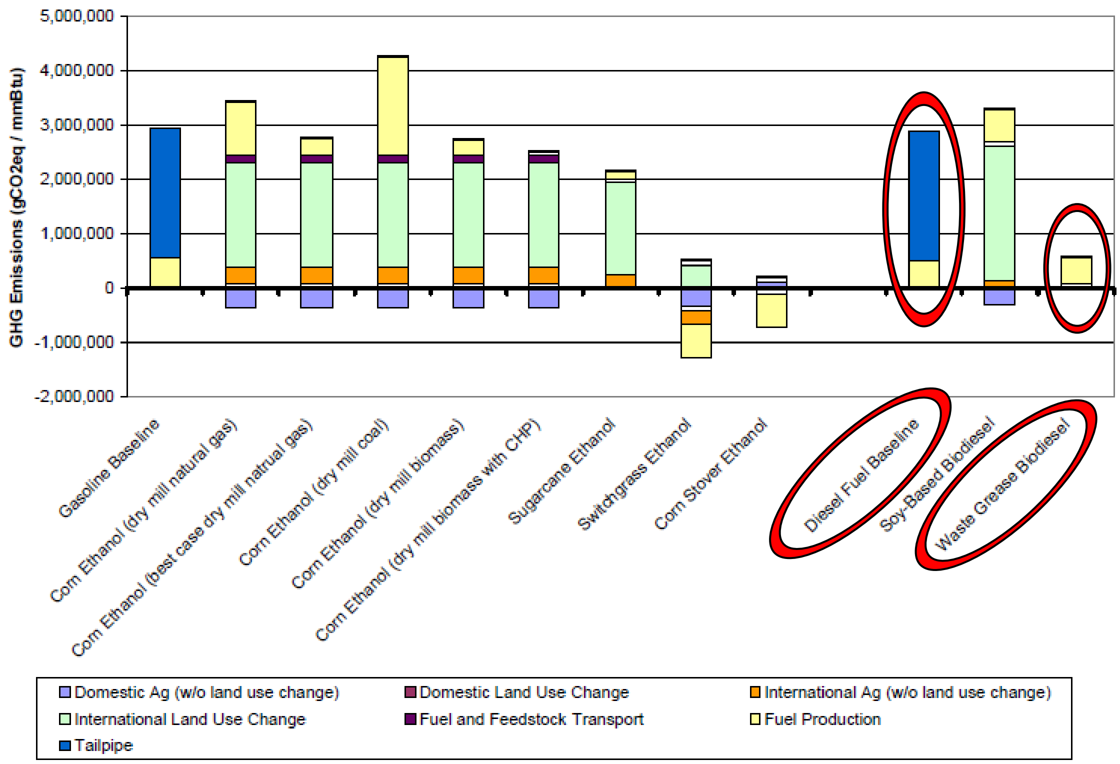
Figure 1 - Emission Production of Biodiesel and Petroleum Diesel

As can be seen in Figure 1, burning biodiesel produces significantly less soot, CO, THC and comparable NO_x emissions. Thus, overall, biodiesel releases less harmful pollutants into the atmosphere than petroleum diesel (Zheng et al., 2008).

However, biodiesel is slightly less efficient than petroleum diesel. The lower heating value of petroleum diesel is 35.9MJ/L and 32.7 MJ/L for the yellow grease biodiesel (Zheng et al., 2008). In addition, the fuelling requirement for diesel is 44 mg/cycle while biodiesel requires 52mg/cycle of fuel. This means that more biofuel is required to be consumed during operation (Zheng et al., 2008). However, a blend of 20% biodiesel and 80% petroleum diesel has 15% fewer carbon dioxide emissions, reduces particulate matter emissions by 10%, decreases CO emissions by 11% and reduces unburned hydrocarbon emissions by 21% (Unites States Department of Energy, 2011). Despite requiring more fuel, biodiesel still has reduced emissions compared to petroleum diesel (Zheng et al., 2008).

3.3 LIFECYCLE EMISSIONS

Lifecycle emissions encompasses all emissions produced in the existence of a product, including production, transportation, consumption, disposal, and storage. Based on a 30 year lifecycle, the greenhouse gas emissions produced by using biodiesel are approximately 86% less than those produced from the use of petroleum diesel (Barnett, 2010). There are several stages in the production of both fuels that release greenhouse gasses. For petroleum diesel, each step in the process, described in the Introduction Section, is energy intensive and polluting (as can be seen in Figure 2 below). Furthermore, petroleum diesel would be required to be transported to UBC as opposed to being produced on campus. This adds to the total emissions created by using petroleum diesel. Biodiesel, on the other hand, produces much less emissions during combustion compared to diesel as can be seen in Figure 2.   The majority of its emissions come from producing the fuel (U.S. Environmental Protection Agency, 2009).



U.S. Environmental Protection Agency. (2009). *EPA lifecycle analysis of greenhouse gas emissions from renewable fuels.* (EPA-420-F-09-024). Retrieved from http://www.epa.gov/otaq/renewablefuels/420f09024.pdf

Figure 2 –Net Lifecycle Greenhouse Gas Emissions

As shown in Figure 2, biodiesel and petroleum diesel have comparable emissions produced during their respective manufacturing processes.

3.4 HEALTH EFFECTS

Using biodiesel has been shown to reduce health risks as well. Polycyclic aromatic hydrocarbons are found to be reduced by 75% to 85% and nitrated polycyclic aromatic hydrocarbons are found to be reduced by approximately 50% when using biodiesel instead of petroleum diesel (National Biodiesel Board, 2007). These substances are cancer causing compounds (National Biodiesel Board, 2007).

Generally, biodiesel, compared to petroleum diesel, has less environmental impact, reduced health risks and is more sustainable. Even if a leak were to occur, biodiesel biodegrades and would not harm the environment, whereas petroleum diesel would cause detrimental environmental effects (National Biodiesel Board, 2011). In addition, despite having less energy content, biodiesel produces fewer emissions than petroleum diesel during combustion. If UBC expanded its scales of production by purchasing waste grease, and also reduced the emissions produced during the manufacturing of the biodiesel, it could reduce its dependence on harmful resources even further. In every environmental aspect, biodiesel is either comparable to or much less harmful than petroleum diesel.

4.0 SOCIAL ANALYSIS

Understanding the social impact of transitioning from traditional diesel to biodiesel is a major factor to be considered when recommending this project. This transition may provide certain social challenges as the program is implemented. By trying to understand the social impact that this change might cause now, problems which may arise under the progression of the transition might be avoided.

In a survey conducted by the National Biodiesel Board in 2010 (Biodiesel Magazine, 2010), it was found that 52% of those surveyed had a positive impression of biodiesel, while 37% had no opinion (see Figure 3 below). 7% did not know whether biodiesel was positive or negative and just 4% of those aware of biodiesel thought negatively of it. This is all in light of the fact that only 76% of the population is aware of biodiesel.

Biodiesel Magazine. (2010). Annual survey shows public opinion of biodiesel positive, but soft. Retrieved from http://www.biodieselmagazine.com/articles/4551/annual-survey-shows-public-opinion-of-biodiesel-positive-but-soft

Figure 3 – Biodiesel Survey Results

While this survey was performed across the United States of America, given the environmentally-conscious culture of the Greater Vancouver area, it is reasonable to apply the same data to UBC. If anything, the results may be conservative when applied to the UBC community. This overall positive reaction is a great first step when analyzing the social impact that the transition to biodiesel might have on UBC's framework.

The second aspect of the social impact is to investigate the impact that the grease collection might impose on the individuals involved in the process of producing the biodiesel (U.S. Department of Energy, 2004). The first initial benefit is that biodiesel does not contain any hazardous materials but should be treated with the same precautions as regular diesel. The food service workers are currently required to remove the waste grease from the trap, so this task will not be in addition to their current duties. The collection of the waste grease is also ongoing, so this too will not provide any change in current activities. The only additional duties will consist of those specifically employed to produce the biodiesel, reducing the direct impact on UBC's employees.

Finally, the end use must be assessed. The vehicles on campus that will convert to using biodiesel will have some alternative maintenance needs. This will introduce an additional task for the maintenance employees who keep UBC's vehicles running in good condition. Training will need to be provided on how to maintain the vehicles using biodiesel as there can be some different cleaning issues, such as sludge build up, that will need to be addressed on a regular basis. Biodiesel blends under 20% can be distributed in the same method as standard diesel, eliminating the need for specialized distribution systems (U.S. Department of Energy, 2004). Understanding these issues will be necessary in order to ensure the success of the biodiesel transition.

In addition to all this, it should be noted that there are standards involved in the production of biodiesel, the ASTM D 6751 standard will serve as a good guideline for the production at UBC (Canada Clean Fuels, 2005). This standard provides the minimum accepted values for the properties of the fuel to provide adequate satisfaction and protection. By following the laid out ASTM standard, proper trouble free operation can be assured. However, many engine warranties may be voided by the conversion to biodiesel. Given this fact, it may be advisable to only convert those vehicles which are no longer under warranty in order to reduce possible cost should a complication occur.

Biodiesel has gathered a great deal of attention in recent years, most of which is positive. The public's positive perception of biodiesel will only enhance the positive public perception of UBC should it choose to transition to this new fuel supply. Given that biodiesel can be used in the same vehicle systems as traditional diesel, many of the potential drawbacks are negated.

5.0 CONCLUSION

UBC is a place that honours its name by continuously challenging the norm and working for a better tomorrow. In this project, UBC is proposing to reduce the emissions produced by the many vehicles owned by the university. To extend this, UBC has proposed to use waste grease that the campus food services produce to convert to fuel for their vehicles, ultimately recycling a valuable resource that was once considered waste. After careful consideration of the three specific parameters of a triple bottom line assessment, this report has come to a conclusion and provides recommendations for the implementation of this potential project.

Based on the findings in the economic analysis, the data suggests that selling the waste grease that UBC produces and purchasing petroleum diesel is more economically beneficial. However, this is based on assumptions about the market for this type of material which may change in the future. One recommendation to enhance feasibility is to obtain donations and grants to reduce the capital cost. Another option for reducing cost might be to encourage biodiesel student-based projects in which the students get involved in building a biodiesel transesterfication plant at UBC. This would not only lower capital costs but would greatly increase the students' awareness in UBC's green agenda. Lowering the capital cost of a large project such as this would greatly improve the financial feasibility of creating and using biodiesel at UBC. UBC has many resources and sources of funding; the economic drawbacks of this project are therefore somewhat minimized from the larger perspective.

The environmental aspect of the triple bottom line assessment is a very important aspect of this report. UBC is a campus that is striving for 100% reduction in greenhouse gas emissions by 2050, according to Alberto Cayuela's presentation on March 6, 2012. This project is a step towards obtaining this goal. When comparing the life cycle emissions of biodiesel to those of petroleum diesel, there is an 86% reduction in harmful emissions (Barnett, 2010). This includes production, transportation, consumption, disposal, and storage. A recommendation would be to address the emissions produced by a transesterification plant. Lowering these emissions would significantly increase the reduction in emissions and would add further support for the use of biodiesel at UBC. Biodiesel reduces UBC's environmental impact, reduces health risks and is more sustainable compared to petroleum diesel.

Finally, the social aspect of the triple bottom line assessment also supports the project. The awareness of sustainability and the striving for a healthy future for our environment is not simply a UBC faculty agenda; it is also one that is widely supported and cherished by the UBC society, including students, residents and faculty members. The poll results from a survey conducted by The National Biodiesel in 2010 shows that biodiesel is thought of positively. UBC has already received wide recognition for its leadership in accelerating sustainable practices through the CIRS Building. It has become a point of pride for UBC students to be a part of a global movement for a healthy, sustainable school.

The social aspect is most impacted by the decision to use and produce biodiesel. According to Adam McCluskey, UBC has 47 diesel vehicles which make up approximately 20% of its fleet. UBC can save 3.9% of its expenditure on this 20% of vehicles and reduce their petroleum diesel consumption by 3.7%. At this point in time, this translates to a small effect environmentally and economically, although still beneficial with the potential for increased benefits in the future.

One recommendation would be to exclude those vehicles still under warranty from the conversion process to avoid any irreversible costs if there are any complications. Another recommendation is to use a B20 blend (20% biodiesel, 95% petroleum diesel mixture). This will still have great environmental benefits, but it would also make implementation simpler and similar to petroleum diesel.

Biodiesel, as viewed by the three sections of the triple bottom line assessment, is the future for UBC. It is financially feasible with a little help and creativity, it is a step towards a completely emission-free campus, and it is a point of pride and great opportunity for UBC staff, students and the surrounding community. This project has been carefully evaluated and it is recommended that it proceeds.

REFERENCES

Barnett, M. O. (2010, June 16). Biofuels and Greenhouse Gas Emissions: Green or Red? *Environmental Science and Technology* , *44* (14), pp. 5330-5331.

Biodiesel basics-biodiesel.org. (2012). Retrieved from http://www.biodiesel.org/home

Biodiesel Magazine. (2010). Annual survey shows public opinion of biodiesel positive, but soft. Retrieved from http://www.biodieselmagazine.com/articles/4551/annual-survey-shows-public-opinion-of-biodiesel-positive-but-soft

Canada Clean Fuels. (2005). Standards and Warranties. Retrieved from http://www.canadacleanfuels.com/standardsandwarranties.html

Canakci, M. (2005). The potential of restaurant waste lipids as biodiesel feedstocks. *Bioresource Technology*. Retrieved from http://seniordesign.engr.uidaho.edu/2007_2008/frenchfryfuel/Biodiesel%20from%20WVO%20Mustafa%20Canakci.pdf

Circle Biodiesel & Ethanol Corporation. (2012). *Biodiesel Processors and Biodiesel Plants.* Retrieved from http://www.circlebio.com/biodiesel_processors_biodiesel_plants.htm?gclid=CKK297m-9K4CFasERQodeAIGHw

Hunter, L. (2006, April 1). Yellow Grease, Liquid Gold: Markets for recycled waste food oil. *Solid Waste and Recycling.* Retrieved from http://www.solidwastemag.com/news/yellow-grease-liquid-gold/1000203478/

Jarlett, B. (2002). *Cars Ok on Biodiesel.* Retrieved from http://www.biodieselfillingstations.co.uk/approvals.htm

Morrow, F. (2008, June 18). French-fry grease to liquid gold. *The Globe and Mail.* Retrieved from http://www.bcca.coop/news/french-fry-grease-liquid-gold

National Biodiesel Board. (2007). *Biodiesel Emissions*. Retrieved from http://www.biodiesel.org/docs/ffs-basics/emissions-fact-sheet.pdf?sfvrsn=4

National Biodiesel Board. (2011). *Environmental Benefits*. Retrieved from http://www.biodiesel.org/docs/ffs-health_environment/environmental-benefits.pdf?sfvrsn=4

National Biodiesel Board. (2012).*Biodiesel Basics*. Retrieved from http://www.biodiesel.org/what-is-biodiesel/biodiesel-basics

OilPrice.com. (2012). *What is Crude Oil?-A Detailed Explanation on this Essential Fossil Fuel.* Retrieved from http://oilprice.com/Energy/Crude-Oil/What-is-Crude-Oil-A-Detailed-Explanation-on-this-Essential-Fossil-Fuel.html

Radich, A. (2004). *Biodiesel Performance, Costs, and Use*. Retrieved from http://www.eia.gov/oiaf/analysispaper/biodiesel/

Sandhyarani, N. (2011). *How is diesel fuel made*. Retrieved from http://www.buzzle.com/articles/how-is-diesel-fuel-made.html

United States Department of Energy. (2011, October 20). *Alternative Fuels and Advanced Vehicle Data Center: Biodiesel Benefits.* Retrieved from http://www.afdc.energy.gov/afdc/fuels/biodiesel_benefits.html

United States Department of Energy and the United States Environmental Protection Agency. (2012, February 14). *Biodiesel.* Retrieved from FuelEconomy.gov: http://www.fueleconomy.gov/feg/biodiesel.shtml

U.S. Department of Energy. (2004). BIODIESEL Handling and Use Guidelines. (Report #:DOE/GO-102004-1999) Retrieved from: http://www.canadacleanfuels.com/pdfs/tp36182.pdf

U.S. Environmental Protection Agency. (2009). *EPA lifecycle analysis of greenhouse gas emissions from renewable fuels.* (EPA-420-F-09-024). Retrieved from http://www.epa.gov/otaq/renewablefuels/420f09024.pdf

Zheng, M., Mulenga, M.C., Reader, G.T., Wang, M., Ting, D.S, & Tjong, J. (2008). Biodiesel engine performance and emissions in low temperature combustion. *Journal of Fuel (Guilford),*87, 714-722. doi:10.1016/j.fuel.2007.05.039

APPENDIX A - ECONOMIC DATA

This section provides the information used to assess the biodiesel project's economic feasibility. It includes the calculations used to obtain the amount of fuel UBC could produce on campus, information pertaining to costs of producing biodiesel and has a description of the capital investments.

A.1 CALCULATION OF BIODIESEL PRODUCTION FOR UBC

The following is the process used to calculate the amount of biodiesel that UBC could produce per year:

$$\text{Density of biodiesel} \approx 0.88 \left[\frac{\text{gram}}{\text{cm}^3}\right] \text{ (Jarlett, 2002)}$$

$$1 \text{ [lb]} = 453.59237 \text{ [gram]}$$

$$30\,450 \text{ [lb]} = 13\,811\,887.7 \text{ [gram]}$$

Therefore,

$$\frac{13\,811\,887.7 \text{ [gram]}}{0.88\left[\frac{\text{gram}}{\text{cm}^3}\right]} = 15\,695\,326.93 \text{ [cm}^3\text{]} = \boxed{15\,695.3269 \text{ [L]}}$$

A.2 THE COST OF PRODUCING BIODIESEL FROM 2004 TO 2012

Table 2 (Radich, 2004) shows the cost of producing biodiesel over the past 8 years.

Table 2 – Cost of Producing Biodiesel

Market Year	Cost of Production [$/Gal]	Cost of Production [$/L]
2004/05	1.41	0.37
2005/06	1.39	0.37
2006/07	1.38	0.36
2007/08	1.37	0.36
2008/09	1.40	0.37
2009/10	1.42	0.38
2010/11	1.47	0.39
2011/12	1.51	0.40
2012/13	1.55	0.41
Average	**1.43**	**0.38**

Adapted from (Radich, 2004)

The average cost is $0.38/L to produce biodiesel.

A.3 CAPITAL COSTS

One supplier whose pricing information was available was Circle Biodiesel & Ethanol Corporation. Their website claims that a system costs $195,000 and includes the following (Circle Biodiesel & Ethanol Corporation, 2012):

- Explosion proof wiring
- Transesterification unit
- Reactor pumps
- Premixing container for catalyst
- Thermocouples
- Metering valves
- Fluid pumps
- Control panel
- Centrifuge
- Methanol recovery system
- Wires and cables
- Oil heating units
- Filtration units
- Automatic locking ball valves
- Float switches
- Flow meters
- Skid mounted on 5' x 10' frame
- Installation and setup

According to their website, their processor produces biodiesel that meets the ASTM D-6751 specification and the biodiesel processors meet the MIL-STD-1472 requirements (Circle Biodiesel & Ethanol Corporation, 2012). In addition, its "capacity is 450 gallons of biodiesel fuel per batch with each batch taking three hours forty-five minutes" (Circle Biodiesel & Ethanol Corporation, 2012). According to the calculations above, 15,695.3269 litres (4,146.26672 gallons) can be produced per year. This will result in approximately 10 batches per year.