UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An investigation into the comparative performance of biodiesel against petroleum-derived diesel by analyzing their environmental, economic and social impacts

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APSC 262

March 29, 2012

APSC 262 Sustainability Project:

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ABSTRACT

Through University of British Columbia's (UBC) SEEDS program, the initiative of replacing the majority of UBC vehicle fleets is investigated. Most of UBC vehicle fleets currently run on petroleum-based diesel with biodiesel produced from waste grease disposed by AMS Food and Beverage Operations as well as the UBC Food Service Operations. The objective of this report is to prepare a comparative investigation of the performance of biodiesel against petroleum-derived diesel by examining their environmental, economic and social impacts. The scope of the report includes qualitative and quantitative data related to the environmental, economic and social performance of two popular blends of biodiesel which are B20 (20% biodiesel 80% diesel) in comparison to B100 (100% biodiesel) and petroleum-derived diesel. Although a large number of UBC vehicles are using B5 blend and diesel, it is assumed in this report that all UBC vehicles are utilizing diesel as fuel due to the lack of data available for B5 blend. The environmental implications of petroleum-derived diesel, B20 and B100 are evaluated based on the greenhouse gas emissions and smog-forming pollutants. The economic viability of replacing diesel fuel in campus vehicles with biodiesel is assessed based on its fuel cost, energy efficiency and the incentives from non-governmental organization (NGO) and the government. The social impacts of diesel and biodiesel are assessed based on their physical and chemical properties, human health effects and the social benefits they bring to the community. From the findings of this report, GHG emissions are reduced by 15.9% on average using B20 and 78.6% on average using B100 with respect to diesel. The analysis also shows that B100 and B20 reduce smog pollutants by 40.0% and 8.3% respectively compared to diesel. In terms of price per unit energy of fuel, B100 ($0.414/kWh) has the highest fuel cost, followed by B20 ($0.348/kWh) and finally, diesel fuel ($0.341/kWh). However, 80% of the fuel cost of biodiesel production is associated with the feedstock used. By using waste grease produced in UBC as feedstock, the cost of biodiesel can be reduced. Through various government incentives, the capital cost to build a biodiesel plant in UBC will be partially subsidized, making it a very appealing option. In terms of health risks, B20 emits 13% less polycyclic aromatic hydrocarbons (PAH) and 10% less particulate matters as opposed to diesel. The reduction of hazardous pollutants is even more significant for B100, which emits 80% less PAH and 47% less particulate matters than diesel. Based on the analysis of the report, it is recommended that UBC vehicles' fuel should be replaced with B20, since it has less environmental impact and more positive social impact compared to diesel. Although the fuel cost of B20 is slightly higher than diesel, it can be offset by using waste grease from UBC and incentives from government. Despite the fact that B100 has the highest positive environmental and social impact with respect to B20 and diesel, the fuel cost is the most expensive. However, the cost of biodiesel production is predicted to decrease, positioning B100 to be a competitive option in the future.

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GLOSSARY

Aldehydes	An organic compound containing a formyl group
Benzene	A natural constituent of crude oil
Carbon Monoxide	A product from the partial oxidation of carbon- containing compounds
Carcinogen	Any substance that causes cancer
Flashpoint	Lowest temperature at which a material can vaporize to form an ignitable mixture in air
Glycerine	A sweet colorless liquid obtained in the production of biodiesel. Commonly used as a solvent, antifreeze, plasticizer and sweetener
Greenhouse Gas	A gas in atmosphere that absorbs and emits radiation within the thermal infrared range
Industrial smog	An air pollutant that is produced when sulfur dioxide, particulates, and other pollutants released by industrial and household burning of fossil fuels is trapped by a thermal inversion.
Methyl Ester	Molecules created from a reaction between fats and methanol
Nitrogen Oxides	A binary compound of oxygen and nitrogen
Ozone	An air pollutant that deteriorates the respiratory systems of human
Photochemical smog	An air pollutant that is derived from vehicular emission produced from internal combustion engines and industrial fumes
Polycyclic Aromatic Hydrocarbons	An atmosphere pollutant that is produced as byproducts of fuel burning
Sodium Hydroxide	A commonly used catalyst for the transesterification process in the manufacture of biodiesel

Transesterification	A process which reacts an alcohol with an ester to form a new alcohol and a new ester
Troposphere	Lowest portion of Earth’s atmosphere that prevents damaging ultraviolet light from reaching the Earth’s surface

LIST OF ABBREVIATIONS

AMS – Alma Mater Society

B2 - 2% biodiesel and 98% diesel

B5 - 5% biodiesel and 95%diesel

B20 - 20% biodiesel and 80% diesel

B100 - 100% biodiesel or neat biodiesel

CH_4 – Methane

CO - Carbon monoxide

CO_2 –Carbon Dioxide

CSIRO - Commonwealth Scientific and Industrial Research Organization

CSTR – Continuous Stirred Tank Reactor

GHG- Greenhouse gas

km – Kilometer, unit of length in the metric system ($\times 10^3$ meter)

kWh- Kilowatt hour, unit of energy ($\times 10^3$ watt hours)

L – Litre, unit of volume

lbs – Pounds, unit of weight

LCA – Life-cycle Assessment

NGO – Non-governmental organization

NPAH – Nitrated polycyclic aromatic hydrocarbons

N_2O – Nitrous Oxide

PAH - Polycyclic aromatic hydrocarbons

PM - Particulate matter

SEEDS – Social, Ecological, Economic, Development Studies

SO_x – Sulphur

UBC- University of British Columbia

1.0 INTRODUCTION

Biodiesel is an alternative fuel made from assorted lipids such as vegetable oil (soy, canola rape seed), cooking oil and animal fats. Biodiesel can be produced in a pure form (B100, 100% biodiesel or neat biodiesel) or blended with petroleum-derived diesel. The typical blends which are extensively used are B2 (2% biodiesel and 98% diesel), B5 (5% biodiesel and 95% diesel) and B20 (20% biodiesel and 80% diesel). Biodiesel is a renewable energy source where upon, combustion; fewer pollutants are emitted into the atmosphere, making it a cleaner alternative to regular diesel. Hence, biodiesel has received increased attention of late because it reduces global and local environmental impact by generating less GHG and air pollutants. Apart from that, biodiesel also provides economic savings because the production requires less amounts of energy than compared to diesel. Furthermore, government incentives such as tax reduction from using biodiesel and NGO support also lead to potential savings. In terms of social impact, biodiesel emits less harmful pollutants compared to petroleum-based diesel, which in turn reduces human health risks. The use and production of biodiesel is essential for raising public awareness for maintaining and achieving sustainability through the use of renewable energy in the form of biodiesel.

Biodiesel is produced via transesterification of oils into methyl ester (biodiesel) by chemically reacting with methanol. A base catalyst such as sodium hydroxide is normally used in this reaction. The only byproduct from this reaction is glycerine. Hence, the transesterification produces no environmentally harmful byproducts. The two major processes of production are carried out in a batch reactor and plug flow reactor. The batch reaction process involves stirring the reactants in a tank with an excess of alcohol and a base catalyst. The process operates at a temperature of about 65 degrees centigrade. The plug flow reaction system uses a system of continuously-stirred tank reactor (CSTR). Typically, the plug flow reaction system involves multiple CSTR with separators connected between them to remove any glycerine. Methanol is injected into each of the reactors to maintain an excess of alcohol, which drives the continuous production of the ester (biodiesel).

2.0 ENVIRONMENTAL IMPACT

The environmental impact of petroleum-derived diesel and biodiesel is assessed based on the GHG emissions and smog-forming pollutants. Two complete LCAs of diesel and biodiesel (B20 and B100) based on the Levelton/NRCan (LevNRCan) study and Commonwealth Scientific and Industrial Research Organization (CSIRO) are used to examine the emission of GHG. To evaluate smog-forming pollutants such as nitrogen oxides, particulate matter and carbon monoxide, the emission profiles of 155 Montreal city buses' tailpipe from the combustion of diesel and biodiesel blends (B20 and B100) are utilized to determine the air pollutants generated from the fuels.

2.1 GHG EMISSIONS

GHG is a gas in the atmosphere that absorbs and emits radiation within the thermal infrared range, causing global warming. Scientists predict global warming will "trigger increasingly frequent and violent storms, heat waves, flooding, tornadoes, and cyclones" (Boyd, Murray-Hill & Schaddelee, 2004 p. 113).The primary greenhouse gases in the Earth's atmosphere are carbon dioxide, methane, nitrous oxide, and ozone. The GHG emissions for diesel, B20 and B100 are examined over the entire life cycle which includes the downstream and upstream emissions. In other words, the LCA accounts for both the direct and indrect emissions from net vehicle operation and also indirect emissions. Since UBC's source of producing biodiesel is primarily grease waste, it is assumed that the biodiesel is produced from animal fat or tallow and waste cooking oil. Two LCA studies, the Levelton/NRCan (LevNRCan) and Commonwealth Scientific and Industrial Research Organization (CSIRO) are used to examine the emissions of GHG over the whole life cycle of biodiesel, B20 and B100.

The LevNRCan study examines the total upstream and downstream GHG emissions in the lifecycle of diesel, B20 and B100. The GHG emissions from the lifecycle work "incorporates the following elements: net vehicle operation; fuel dispensing/ storage/ distribution and production; feedstock transport; CH_4 and CO_2 leaks and flares; emissions displaced by co-products; transport" (Schmidt, 2004 p. 5). The types of GHG assessed in this study are CO_2, CH_4 and N_2O. The study assumes that animal fat-derived biodiesel is obtained from the "blend of waste grease and animal slaughterhouse residues" (Schmidt, 2004 p. 5). Based on table 1, animal fat-based B20 has 17.8% less GHG emissions compared to diesel fuel. This statistic demonstrates that by substituting diesel with B20 blend, the environmental impact can be further reduced.

Table 1: 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**

Source: Schmidt, 2004 p. 6

Table 2 shows an even more significant reduction of GHG by using B100. B100 from animal fat displays a 91.7% reduction compared to diesel. Over the entire life cycle, B100 produces 73.9% less GHG emission than B20. Hence, neat biodiesel (B100) is preferable in terms of reducing GHG emissions. However, B100 has some disadvantages, including poor cold weather properties which will be further examined in the economic impact section.

Table 2: 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**

Source: Schmidt, 2004 p. 6

Similar to the LevNRCan study, the second study by CSIRO focuses on the lifecycle GHG emission analysis of diesel and biodiesel blends produced from different sources. However, the GHG lifecycle work includes only CO_2 unlike the first study which incorporates CO_2, CH_4 and N_2O. The study is more in-depth compared to the LevNRCan study because it examines the LCA of tallow and waste cooking oil-based biodiesel separately. Based on table 3, both the tallow and cooking-oil B20 blend show a 10% and 20% reduction of GHG emissions respectively compared to low sulphur diesel.

Table 3: CSIRO B20 GHG Lifecycle

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**

Source: Schmidt, 2004 p. 7

The B100 produced from tallow blend displays a 51% reduction from diesel while B100 produced from cooking oil exhibits a 93% reduction from diesel with reference to table 4. Similar to the LevNRCan study, using a higher blend of biodiesel will further reduce GHG emissions. Another observation that can be drawn from the CSIRO study is that, if the waste grease from UBC contains mostly waste cooking oil, the GHG emissions from the biodiesel production will be further reduced since cooking-oil based biodiesel emits less GHG on average compared to tallow-based cooking oil.

Table 4: CSIRO B100 GHG Lifecycle

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**

Source: Schmidt, 2004 p. 7

Based on the results of the two studies, it can be concluded that GHG emissions are reduced as the percentage of blended biodiesel increases. B100 has the least amount of GHG emissions throughout its lifecycle follow by B20 and diesel. Using a B100 blend for the vehicles can reduce the environmental impact significantly in the long run. However, due to the absence of data from the UBC waste grease, the proportion of animal fats and cooking oil in the waste are unknown. If the ratios are available, a more accurate GHG lifecycle analysis can be performed.

2.2 SMOG-FORMING POLLUTANTS

Smog is a type of air pollution. Smog is divided into two categories, industrial smog and photochemical smog. Industrial smog, is produced when sulfur dioxide, particulates, and other pollutants released by industrial and household burning of fossil fuels is trapped by a thermal inversion. Thermal inversion is an atmospheric condition where a layer of cold air is trapped by another layer of warm air above it. Photochemical smog is derived from vehicular emission produced by internal combustion engines and industrial fumes. The emissions which contain gases such as nitrogen oxides and carbon monoxides convert light energy into its internal energy, leading to the formation of excited monoatomic oxygen. Through photochemical reaction due to the excited monoatomic oxygen, ozone and smog will be formed in the troposphere. Photochemical smog has a similar appearance and produces similar effects to industrial smog. The combination of the two types of smog causes air pollution in cities. Apart from reducing air quality, smog can inflame breathing passages, reduce the lungs' working capacity and cause shortness of breath. To compare the smog-forming pollutants in petroleum-derived diesel and biodiesel blends (B20 and B100), tailpipe emissions from 155 Montreal city buses are examined for a one year period.

In the study of the Montreal city buses, smog-forming pollutants such as carbon monoxide, particulate matter and nitrogen oxides are measured from buses using either diesel, B20 and B100 as the fuel. The emissions are the results from the combustion of diesel and biodiesel blend only without considering the indirect emissions such as emissions from the production of the fuel.

Table 5: Exhaust Emissions

	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

Source: Schmidt, 2004 p. 10

From table 5, tallow-based B20 blend shows a 10% and 15% reduction of carbon monoxide and particulate matter emissions respectively compared to diesel. For tallow-based B100 blend, carbon monoxide and particulate matter emissions are reduced by 50% and 70% relative to diesel engine's emissions. However, nitrogen oxides emissions from B20 and B100 are indifferent from diesel. Hence, B100 displays the best potential for the fuel in the UBC vehicles to reduce smog formation although the nitrogen oxides emissions are the same for diesel, B20 and B100.

3.0 Economic Impact

Although the environmental performance of biodiesel surpasses that of diesel, the economic impact of biodiesel must also be analyzed to determine its financial viability. To evaluate the economic feasibility of replacing current fuels in campus vehicles with biodiesel, the fuel cost price of B20, B100 and diesel in terms of price per unit energy is investigated. Other aspects of economic evaluation include the energy balance, which is the amount of energy consumed per unit energy delivered, into useable biodiesel fuel, and the performance of conventional diesel engine when substituted with biodiesel fuel. Similarly, technical and financial supports from NGO for biodiesel projects are also examined. Government incentives to subsidize new biodiesel plants through various policies and programs such as exercise tax exemption, volumetric producer payment, funding for capital infrastructure as well as support for research and development of alternative fuel are further evaluated since they can make biodiesel a competitive option.

3.1 PRICE PER UNIT ENERGY

Each type of fuel has its own unique energy content. Diesel has a higher fuel energy content compared to biodiesel. From table 6, B100 has the lowest energy content, followed by B20 and lastly diesel.

Table 6: Fuel Energy Content

	Gross Energy Content ASTM D 240 BTU/lb	Energy Density Calculated Value kWh/ℓ	Energy Content Variation per Unit Mass	Energy Content Variation per Unit Volume	Gross Energy Content ASTM D 4052 kg/m³
Fuels					
STM Reference Petrodiesel	**18,710**	**10.118**			**837.1**
#1 Petrodiesel	18,554	9.900	-0.8%	-2.1%	826.0
B5 – Animal Fat	18,634	10.101	-0.4%	0.2%	839.1
B5 – Used Cooking Oil	18,632	10.102	-0.4%	-0.2%	839.3
B5 – Vegetable Oil	18,630	10.141	-0.4%	-0.2%	842.6
B20 – Animal Fat	18,406	10.048	-1.6%	-0.7%	845.0
B20 – Used Cooking Oil	18,398	10.055	-1.7%	-0.6%	846.0
B20 – Vegetable Oil	18,392	10.087	-1.7%	-0.3%	849.0
B100 – Animal Fat	17,192	9.740	-8.1%	-3.7%	877.0
B100 – Used Cooking Oil	17,149	9.771	-8.3%	-3.4%	882.0
B100 – Vegetable Oil	17,119	9.831	-8.5%	-2.8%	889.0

Source: Hosatte & Lagacé, 2003, p.60

By integrating the fuel energy content factor into the fuel unit price, a better representation of the fuel cost is provided. The price per unit energy of the various fuels are analyzed and compared as shown in table 7.

Table 7: Price per unit energy of various fuels

Fuel Type	Unit Price ($/L)	Energy density (kWh/L)	Price per unit energy ($/kWh)
Diesel	3.45	10.118	0.341
B 20	3.50	10.055	0.348
B100	4.05	9.771	0.414

Source: Unit Price obtained from http://www.afdc.energy.gov/afdc/pdfs/afpr_jan_11.pdf

Energy density obtained from table_

As the table above shows, the price per unit energy of B100 is the highest followed by B20 and finally, diesel. It is important to note that the price of the biodiesel is largely associated with the price of feedstock. The price of feedstock contributes to 80% of the total cost (Demirbas, 2007, p.4666). However, UBC is able to generate 53492.67L of waste grease per year which can reduce the price of biodiesel.

3.2 ENERGY BALANCE/ ENERGY EFFICIENCY

Energy balance is a measure of the amount of energy consumed in fuel production as opposed to the energy generated from the fuel product. Energy balance is an important factor in economic evaluation, since it demonstrates the effectiveness of fuel production. Lower energy consumed per unit energy delivered implies a lower production fuel cost. Biodiesel is found to have a better energy balance compared to diesel as shown in table 8.

Table 8: Energy balance comparison

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)

Source: Schmidt, 2004, p. 10

The finding of Schmidt is also supported by supplementary research, which concludes that biodiesel has a higher amount of energy contained in the fuel per unit of fossil energy used in production (Ellis & Janaun, 2010, p.1316) as compared to diesel. Therefore, biodiesel is the more economical choice in terms of production cost.

The effects of replacing diesel with biodiesel in conventional diesel engine are also examined. This analysis is important because any deteriorating effects to the existing diesel engine caused by biodiesel blends may require an engine overhaul, which will increase the cost of the fuel. It is found that biodiesel blends, which have good lubricity characteristics, reduces wear on engine parts and minimizes the maintenance cost of the engine. When biodiesel is used to operate the diesel engine, wear scars are found to be reduced by 50 % compared to pure diesel.

B20 and B100 which are produced from used cooking oil have the same lubricity characteristics as shown in figure 1.

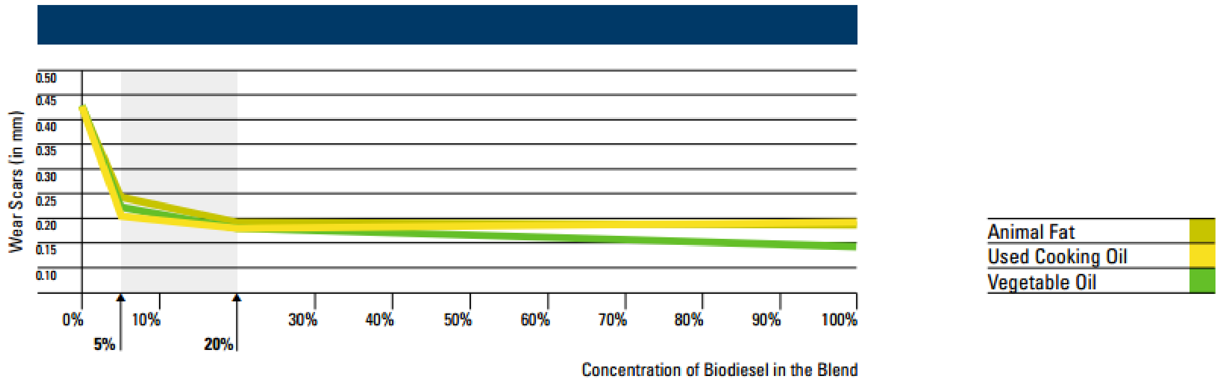

Figure 1: Lubricity of Various Fuels

Source: Hosatte & Lagacé, 2003, p.10

Biodiesel has low temperature properties, which causes it to gel at low temperatures. The gelling of biodiesel may affect the engine operation due to clogging of filters or coking of injectors. However, through experiments, "no specific complications or problems arise from the 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) in the Montreal BIOBUS demonstration project" (Schmidt, 2004, p. 12). Therefore, biodiesel is able to operate as fuel in a diesel engine without needing any major modifications to the engine or injection system. Hence, there will be no significant cost associated with an engine change when replaced with biodiesel.

The impact of the fuel change on the performance of diesel engines is also critical in terms of end-use cost. Consequently, the energy efficiency and the specific fuel consumption also needs to be examined. The energy efficiency of biodiesel is found to be comparable with diesel. The use of biodiesel has no impact to the thermodynamic efficiency of the mechanical fuel injection system and the thermodynamic efficiency of electronic fuel injection system for biodiesel is only slightly lower than the diesel as shown in figure 2.

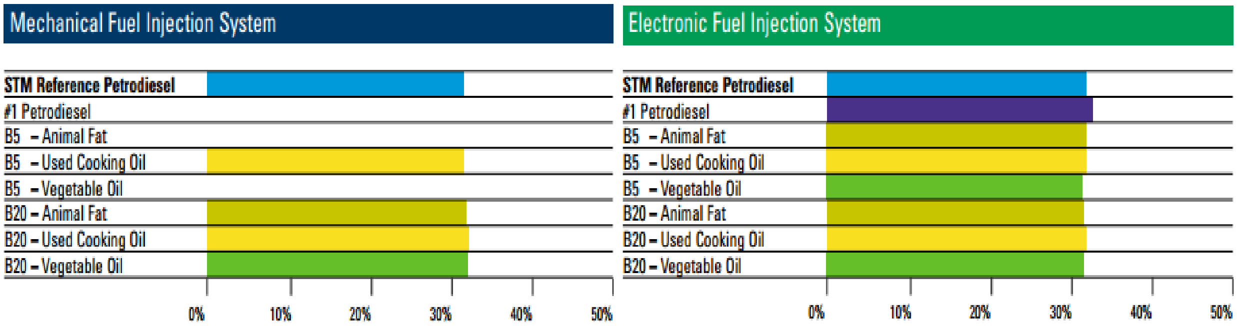

Figure 2: Thermodynamic efficiency of engines vs. fuel type

Source: Hosatte & Lagacé, 2003, p.61

However, the electronic fuel injection parameters can be adjusted to improve the thermodynamic efficiency (Hosatte & Lagacé, 2003, p.62). The effect on specific fuel consumption of a diesel engine driven on biodiesel is also found to be nearly equivalent to that of a diesel engine driven on diesel, even though the biodiesel blends have less fuel energy content. The variation of specific fuel consumption between B20 and diesel falls within the range of 1-2% for a diesel engine with both mechanical and electronic fuel injection system as shown in figure 3.

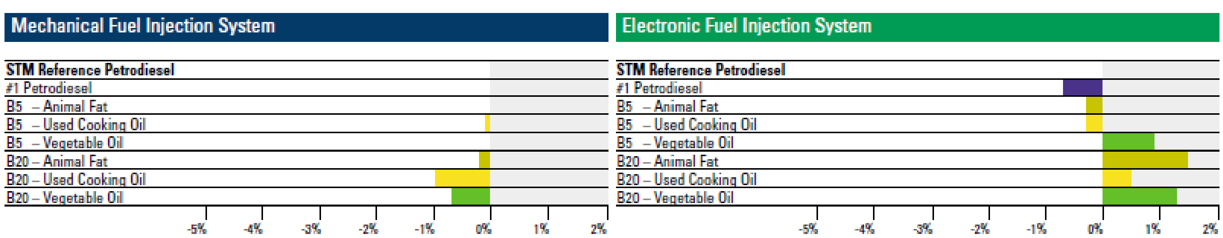

Figure 3: Percent variation of specific fuel consumption versus STM reference petrodiesel

Source: Hosatte & Lagacé, 2003, p.61

The fuel economy equivalence suggests that the biodiesel is economically feasible to be used in campus vehicles.

3.3 SUPPORTS FROM NGO

Non-governmental organization (NGO) refers to organizations that operate independently from the government. They also play an important role in determining the success of the biodiesel project. They are able to provide both technical as well as financial supports in implementing alternative fuel projects which requires new technologies, resources, and experts from different fields and areas. Engine manufacturers are the group directly associated with this sustainability project. Most of the major engine companies have formally assured that "the use of biodiesel blends up to B20 will not void their part and workmanship warranties, with some qualifications regarding fuel usage impacts, types of biodiesel and blend levels" (Schmidt, 2004, p. 11). However, concerns from automobile manufacturers regarding engine performance and have limited the amount of blends in diesel. It is expected that North American manufacturers will become more supportive in the use of biodiesel blends as it begins to gain traction. Currently, large European engine or vehicle manufacturers such as BMW, Renault, Peugeot, Volkswagen, Mercedes Benz, Volvo, Ford, John Deere, etc, have developed complimentary warranty policies in regards to biodiesel (Schmidt, 2004, p. 11). These continuing warranties not only ensure quality engine performance but they also protect stakeholders from costs associated with unwelcome breakdowns.

According to Adam McCluskey, the Manager of UBC Inventory and Fleet Department, the use of biodiesel blends in campus service vehicles is restricted by the engine manufacturer. The maximum accepted level of biodiesel blends is merely 20% without voiding the part and workmanship warranties of the campus vehicles engine. Although the biodiesel pilot plant in UBC produces approximately 1000 litres of biodiesel a day, UBC vehicles are still running on B5 fuel supplied by external companies. Another way of solving this problem is to improve quality of the biodiesel produced through collaboration with biodiesel process technology manufacturers and consultants. Topia Energy Inc. is Canada's largest commercial producer of biodiesel fuel oil. It is also as a participant in the Certified Biodiesel Driven Program, which ensures that the fuel produced consistently meets the standards and specifications set by the engine manufacturers. The company owns the distribution rights of Modular Production Unit (MPU) in Canada, which is they are proven to run effectively on yellow grease (Boyd, Murray-

Hill & Schaddelee, 2004 p. 77). Therefore, UBC can take advantage of the available technical supports to improve the quality of biodiesel so that biodiesel produced can be certified and used in campus service vehicles.

3.4 GOVERNMENT INCENTIVES AND POLICIES

To confront the climate change as well as the diminishing fossil fuel resources, the Government of Canada demonstrates its continuous support for biodiesel by introducing various policies and incentives to stimulate its development. In 2003, the Government of Canada exempts the exercise tax for the biodiesel portion of diesel blends in Canada $0.04 is exempted for each litre of biodiesel (Laan, Litman & Steenblik, 2009, p.58). In 2008, the federal government introduced volumetric producer payments as high as $0.20 per litre for the production of renewable alternatives to diesel including biodiesel, which replaces the federal tax exemption on biodiesel (Laan, Litman & Steenblik, 2009, p.58).

In terms of the supports on the capital, infrastructure, incentive programs to support biodiesel production include the accelerated depreciation of capital. When depreciation is accelerated, the firm receives higher tax deductions in the early years of the investment, generating significant financial benefits on a present-value basis (Laan, Litman & Steenblik, 2009, p.60). The provincial government of British Columbia announced a funding of up to $10 million over 3 years, starting from 2009, to support the growth of the biodiesel production in the province. Another $10 million dollars in grants is also available for new liquid biofuels production from Innovative Clean Energy Fund (Laan, Litman & Steenblik, 2009, p.61).

Both the federal and provincial government also provides financial support for the research and development of biodiesel. The federal government allocates the funding through various programs such as the Agricultural Bioproducts Innovation Program, with a $145 million fund to support research networks, the SD Tech Fund by Sustainable Development Technology Canada with $550 million to support biodiesel-related projects, the Industrial Research Assistance Program and several other funding programs under the Canadian Biomass Innovation Network and Technology Early Action Measures (Laan, Litman & Steenblik, 2009, p.63-64).

British Columbia has also funded several research and development initiatives, such as the feasibility study of community-based production of biodiesel from waste cooking oil (Laan, Litman & Steenblik, 2009, p.64). With all the fundings available from both federal and provincial programs, it would be in UBC's best interest to take advantage of the financial support for the research and development of biodiesel production using waste grease.

4.0 SOCIAL IMPACT

The social impacts of diesel and biodiesel are assessed from the perspectives of their physical and chemical properties, human health effects and social benefits they bring to the community. The hazardous level of producing, handling and transporting the two fuels can be evaluated from their physical and chemical properties. In terms of human health effects, the chemical compounds produced from the emission of diesel exhaust will be investigated, as well as the effects of those compounds on human body. In the social benefits section, the potential changes biodiesel brings to the local community by the use of biodiesel will be examined.

4.1 PHYSICAL AND CHEMICAL PROPERTIES OF DIESEL AND BIODIESEL

The safety of the producing, handling and transporting diesel and biodiesel can be evaluated from their flashpoints, toxicities and the spill hazard. The comparison is shown in the following table:

Table 9 : Biodiesel/ diesel hazard comparison

Property	Biodiesel	Diesel
Flashpoint	150ºC	51.7ºC
Toxicity	Essentially non-toxic	Highly toxic
Spill hazard	Benign. Biodiesel is safe to handle with no dangerous fumes. No training required for handling.	Dangerous and toxic. Hazmat training required

Source: Boyd, Murray-Hill & Schaddelee, 2004, p.32

The flashpoint of biodiesel is relatively high compared to diesel, and can be considered as non-flammable under normal circumstances. From the perspective of spill hazard, biodiesel is relatively safe compared to diesel, which is dangerous and toxic. Handling diesel requires well-trained personnel unlike biodiesel. Biodiesel is also less toxic compared to diesel, which will be discussed in details in the following sections. Hence, the properties discussed make biodiesel a safer fuel to produce, transport and store, as well as being a cleaner and more environmentally friendly vehicle fuel.

4.2 CHEMICAL SUBSTANCES IN DIESEL EXHAUST EMMISIONS

Diesel exhaust contains hundreds of constituents in gas and particle forms. The gaseous components include carbon dioxide, oxygen, nitrogen, water vapor, carbon monoxide, nitrogen compounds, sulfur compounds, and numerous low-molecular-weight hydrocarbons. Some of the typical hydrocarbon components found in diesel exhaust are the aldehydes, benzene, polycyclic aromatic hydrocarbons (PAHs) and nitrated PAHs (NPAHs) (U.S. Environmental Protection Agency, 2002, p.1-1). According to studies, 92% of the particulates which contain the aforementioned toxic compounds are less than 1.0 microns by mass, making them fully respirable (Boyd, Murray-Hill & Schaddelee, 2004, p.33).

4.3 EFFECTS OF DIESEL EXHAUST EMMISIONS ON HUMAN HEALTH

According to the U.S. Environmental Protection Agency, more than 40 constituents of diesel exhaust are listed as hazardous air pollutants or toxic air contaminants. At least 21 of the substances are listed as carcinogens or reproductive toxicants (U.S. Environmental Protection Agency, 2002, p.1-6), and hydrocarbon components form majority of the list. The hydrocarbons are carcinogenic, meaning they are able to disrupt the metabolism process and genome of human body, ultimately leading to cancers and reproductive diseases.

Data indicates that 13,800 Canadians per year will develop critical cancer over their lifetimes due to frequent direct exposure to diesel fine particulate matter. New studies and preexisting research also predict that chronic exposure to fine particulate matter pollution will lead to the development of acute and chronic health problems and lower life expectancy (Boyd, Murray-Hill & Schaddelee, 2004, p.33). The following table below depicts the effects of carbon monoxide, sulphur, particulate matter and PAH on human health.

Table 10: Effects of diesel exhaust chemical substance on human health

Chemical substance	Effects on human health
Carbon monoxide(CO)	Inhibits the blood's capacity to carry oxygen, which will essentially cut off oxygen supply to vital organs such as the heart (which will cause chest pain, also known as angina) and brain. At an extreme level, CO will cause death.
Polycyclic aromatic hydrocarbon(PAH) / NPAH	Chronic exposure will lead to cataracts, liver and kidney damage as well as jaundice. Contact with skin may induce redness or skin inflammation. Increases the risk of skin, lung, bladder and gastrointestinal cancers. The elderly with declining organ function young children with immature and developing organs are more susceptible to the effects of PAHs.
Particulate matter(PM)	Leads to irritation of airways, coughing and difficulty in breathing. Aggravates asthma, decreases lung function and causes bronchitis. Also leads to irregular heartbeats, nonfatal heart attacks, as well as premature death in people with heart or lung disease. The elderly, children and people with lung or heart diseases are more susceptible to the effects of PM.
Sulphur(SO_x)	Leads to bronchoconstriction and aggravates asthma symptoms. Increases the risk of lung disease and bronchitis, as well as aggravates existing heart disease which leads to premature death.

Sources: U.S. Environmental Protection Agency (EPA), 2002

Department of Health, Government of South Australia, 2009, p.2

4.4 BIODIESEL EXHAUST EMMISIONS

Compared to diesel exhaust emissions, biodiesel exhaust emissions have significantly lower levels of hazardous chemical substances. B20 and B100 are used for comparison with diesel in terms of the chemical substances emitted. The reduction percentage in the table below is relative to the normal diesel fuel.

Table 11: Comparison of hazardous chemical substance contained in B100 and B20 to diesel

Chemical substances	B100	B20
Carbon monoxide(CO)	48% reduction	10% reduction
Polycyclic aromatic hydrocarbons(PAH)	80% reduction	13% reduction
Nitrated PAH(NPAH)	90% reduction	50% reduction
Particulate matter(PM)	47% reduction	10% reduction
Sulphur(SO_x)	100% reduction	20% reduction

Source: Boyd, Murray-Hill & Schaddelee, 2004, p.31

The reduced hazardous chemical substances in biodiesel exhaust emissions help reduce air pollution, particularly in urban areas, making biodiesel a cleaner fuel option. Using biodiesel will not only create a healthier environment for people to live in, especially for the elderly and young children, but lessen the chance of developing various respiratory diseases and cancers.

4.5 SOCIAL BENEFITS

From the previous sections, the advantage of using biodiesel over diesel is shown where biodiesel exhaust emits less hazardous substances compared to diesel. In addition, biodiesel has the potential to bring numerous benefits to the local community where biodiesel is commonly used and produced.

With the assumption that building a local biodiesel plant using wasted grease is economically viable, it will provide the community with an opportunity to be realistically involved in the effort to reduce GHG as well as the reliance on fossil fuel. The local biodiesel plant will provide the community with job opportunities, and develop personnel with the needed expertise to contribute to this up and coming field. Apart from that, using the local recycled wasted grease to produce biodiesel and distributing the fuel back into the community will help to fulfill the need of a sustainable and economic fuel.

The use and production of biodiesel will raise the public awareness of the importance of maintaining and achieving sustainability through the use of renewable energy in the form of biodiesel. This approach will hopefully rekindle the interest and passion of the community, as well as convincing them – that achieving sustainability is possible with collective effort, and the community will change their lifestyle to contribute to this goal.

5.0 CONCLUSION

Through University of British Columbia's (UBC) SEEDS program, the initiative of replacing the majority of UBC vehicle fleets is investigated. Most of UBC vehicle fleets currently run on petroleum-based diesel with biodiesel produced from waste grease disposed by AMS Food and Beverage Operations as well as UBC Food Service Operation. The objective of this report is to prepare a comparative evaluation of the performance of biodiesel against petroleum-derived diesel by examining their environmental, economic and social impacts. Qualitative and quantitative data related to environmental, economic and social performance of two popular blends of biodiesel which are B20 (20% biodiesel 80% diesel) and B100 (100% biodiesel) and petroleum-derived diesel are used to determine the best fuel option for the UBC vehicle fleet.

The environmental impact of petroleum-derived diesel and biodiesel is assessed based on the GHG emissions and smog-forming pollutants. Since UBC's source of producing biodiesel is mainly grease waste, it is assumed that the biodiesel is produced from animal fat or tallow and waste cooking oil. Based on the two studies by LevNRCan and CSIRO, GHG emissions are reduced as percentage of blended biodiesel increases. By taking the average of the data from the two studies, it can be determined that using B100 reduces GHG emissions by 78.6% and using B20 reduces GHG emissions by 15.9% compared to diesel. Hence, B100 has the least amount of GHG emissions throughout its lifecycle followed by B20 and diesel. In the Montreal Biobus study, smog-forming pollutants such as carbon monoxide, particulate matter and nitrogen oxides are measured from buses which use either diesel, B20 and B100 as the fuel. On average, the findings indicate that B100 and B20 reduce smog pollutants by 40.0% and 8.3% respectively. Although the nitrogen oxides emissions are the same for diesel, B20 and B100, B100 displays the best potential to serve as fuel in the UBC vehicles. In short, utilizing a B100 blend for the vehicles can reduce the environmental impact significantly in the long run.

The economic feasibility of biodiesel is assessed based on the price per unit energy, energy balance, impact on the performance of diesel engine, supports from NGO as well as incentives from government. The price per unit energy of fuel is higher as the blend of biodiesel increases and thus, B100 ($0.414) has highest unit price, followed by B20 ($0.348), while diesel fuel ($0.341) is the cheapest among these three types of fuel. However, 80% of the cost is associated with the feedstock. By using waste grease produced in UBC as feedstock, it will reduce the production cost and lowers the fuel cost. Energy balance of biodiesel is also better compared to diesel, since biodiesel consumes 6% less energy than diesel fuel for every unit of energy produced. As demonstrated in the BIOBUS project, conventional diesel engine is proved to operate well with biodiesel even in the coldest weather despite its low temperature properties. The lubricity characteristic of biodiesel also helps reduce the direct contact between the mechanical parts and thus decreases the wear rate of the engine. The energy efficiency as well as the specific fuel consumption of biodiesel is also found to be comparable with diesel, with a slight variation of 1-2%. Furthermore, engine manufacturers are becoming more supportive of biodiesel by extending the warranties of engines operated by certain levels of biodiesel blends. Through various government incentives which subsidize the capital cost of new biodiesel plant, UBC's biodiesel pilot plant project can be a feasible option.

The social impacts of diesel and biodiesel are assessed based upon physical and chemical properties, human health effects and social benefits they bring to the community. Biodiesel has relatively low flashpoint and is non-toxic, which makes it cleaner and safer for producing, transporting and storage. The U.S. Environmental Protection Agency states that more than 40 constituents of diesel exhaust are listed as hazardous air pollutants or toxic air contaminants, which lead to various health risks. Estimation shows that 13,800 Canadians per year will develop critical cancer over their lifetimes due to frequent direct exposure to diesel fine particulate matter. Compared to diesel, B20 emits 13% less PAH and 10% less particulate matters, while the reduction of those hazardous emissions is even more significant for B100, which emits 80% less PAH and 47% less particulate matters. Having a biodiesel plant in UBC is able to promote the positive impacts of biodiesel to the public, and allows the community to directly involve in the campaign to reduce GHG. In short, biodiesel reduces the emission of hazardous air pollutants and reduces the health risks of the public.

Based on the analysis of the report, it is recommended for UBC vehicles' fuel to be replaced with B20 since it has less environmental impact and more positive social impact compared to diesel. Although the fuel cost of B20 is slightly higher than diesel, it can be offset by using waste grease from UBC and incentives from government. Despite the fact that B100 has the highest positive environment and social impact with respect to B20 and diesel, the fuel cost is the most expensive. However, the cost of biodiesel production is predicted to decrease, positioning B100 to be a competitive option in the future.

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