

**An Investigation into Sustainable Transport Options**

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**University of British Columbia**

**APSC 261**

**November 22, 2012**

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# **An Investigation into Sustainable Transport Options**

**APSC 261: Technology and Society**

**Tutorial Instructor: Dr. Grace**

**November 22, 2012**

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## **ABSTRACT**

The University of British Columbia (UBC) prides itself in being a national leader of sustainable development and studies. The UBC Farm is a center for sustainable learning and teachings. Therefore, it is critical that thorough investigations into sustainable options are completed before the farm makes major purchases. The UBC Farm has asked teams of the APSC 261 course to look into a triple bottom line assessment of sustainable transport options.

UBC Farm needs to replace its aging gasoline operated farm and delivery vehicle. The UBC Farm is looking for a new vehicle to use to transport produce to the market, relocate machinery, and transport employees around Vancouver. Requirements given include: must reliably run for at least 3 years, is highly fuel efficient, able to be maintained by the university, by plant-ops garage staff specifically, and is either a small truck or a 10 passenger van. Due to personnel and time constraints three options were investigated: using a car co-op's services, purchasing a diesel engine vehicle, and purchasing a diesel vehicle and using bio-diesel.

The investigation has found that purchasing a diesel vehicle and fueling it with bio-diesel is the recommended choice of action. While Modo has offered discounts on their services, the inconvenience of traveling off campus to find and retrieve a vehicle outweighs the potential cost savings and the ability to spread the knowledge of car sharing. Diesel engines are more efficient than conventional gasoline engines, and used vehicles are relatively inexpensive; emissions are a concern with older models. Bio-diesel is available on campus, at the same price as conventional diesel, and has less emission problems as conventional diesel. Furthermore, the bio-diesel is partially renewable and a diesel engine truck will not need to be converted if the model year is after 1994. Investigating all the options, bio-diesel is ultimately the best choice economically, environmentally, and socially.

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## **GLOSSARY**

Run lean - combustion uses excess air rather than the stoichiometric value

## **LIST OF ABBREVIATIONS**

B20: A type of bio-diesel sold commercially where there is 20% bio-diesel and 80% regular petrol diesel blended together.

B100: Pure bio-diesel without any addition of regular petrol diesel

CHBE: Chemical and Biological Engineering

CO: Carbon Monoxide

DOC: Diesel Oxidation Catalysts

DPF: Diesel Particulate Filters

EPA: Environmental Protection Agency

HC: Hydrocarbon

NO<sub>x</sub>: Nitrogen Oxide

PM: Particulate Matter

ppm: Parts per million

SO<sub>2</sub>: Sulphur Dioxide

UBC: University of British Columbia

VOCs: Volatile Organic Compounds



## **1.0 INTRODUCTION**

The University of British Columbia (UBC) prides itself in being a leader in sustainability and green design. It was one of the first universities in Canada to open a Sustainability Office in 1998. The UBC Farm is a key area for UBC sustainability research and development. It is, therefore, important for all facets of the Farm to be considered sustainable. In order for this to be possible, awareness of the negative and positive aspects of consumer choices is important. The choices of the Farm must be economically, environmentally, and socially sensitive in order for it to excel as an area of sustainable learning and cultural sensitivity. This process is what is known as a “triple bottom line assessment” to analyse the impact of a new product, material, or technology.

This report summarizes the findings of a triple bottom line assessment of sustainable transportation options for the UBC Farm to assist the Farm in the decision making process for a new vehicle. The UBC Farm is looking for a new vehicle, either a small truck or large van, to transport produce to the UBC market, relocate machinery, and transport employees around Vancouver. The vehicle must reliably run for at least three years and can be maintained by the plant-ops garage staff to reduce maintenance costs. It must also be highly fuel efficient, as the funding for the vehicle is relatively low, and to be as environmentally friendly as possible. Therefore, many factors are taken into account for this assessment.

Due to time and personnel constraints three possible transportation options are considered for this assessment. After a thorough examination of possible options the use of a car co-op company’s services, a diesel engine truck, and a bio-diesel engine truck were chosen for this project. To assess all three options the economic, environmental, and social aspects of each are explored. The indicators for each of these aspects are defined by the stakeholder from the UBC Farm, Véronik Campbell. These indicators are defined in the sections to follow.

## **2.0 ECONOMIC ASSESSMENT**

Funding at the UBC Farm is a major concern when considering options for a new vehicle. Optimally, no money should be spent to obtain the vehicle, but, there are limitations regarding availability. Maintenance and fuel costs are also a concern as the Farm will be responsible for having the vehicle operational at all times. Therefore, the vehicle will have to be reliable, easy to maintain, and as fuel efficient as possible for the given price range. These strict guidelines pose some challenges for finding a suitable vehicle.

### **2.1 CAR CO-OP: ECONOMICAL ASSESSMENT**

The use of a car co-op company's services has been investigated as a possibility. Car2Go is unable to offer their services as they are only able to give discounts on using their SmartCars. This is considered unsuitable for the Farm's needs. They are also unwilling to donate funds as discussed with a contact who wishes to remain anonymous (personal communication, September 26, 2012). Zipcar has been unwilling to continue communication after initial contact was made and contact wishes to remain anonymous (personal communication, September 24, 2012). Regardless, the Marketing Director at Modo is more than willing to offer assistance with the project. The Farm will be eligible to apply as a business member for their services (Hilary Henegar, September – November, 2012). Fees for this membership include:

- \$500 deposit for the up to five driver registered
- \$20 to register each driver
- \$1 per year to renew each membership
- \$6 per hour during weekdays
- \$8 per hour during weekends
- \$6 for use between 11pm and 6am

This price will include: the cost of gas, insurance, maintenance, roadside assistance, and permit parking (Modo, 2011). However, the Farm is responsible for any and all cleaning costs as UBC Farm will be transporting potentially dirty produce and equipment. The Marketing Director, Hilary Henegar, has stated that Modo will offer the UBC Farm credits to go towards driving costs. She has warned that a vehicle may not always be available when the Farm requires it and, while the vehicle is able to be booked for a specific time, the driver will have to go and retrieve

the vehicle adding to the cost (Hilary Henegar, September – November, 2012). While vehicle reliability is not a concern when using Modo’s services, there are several unknown costs regarding cleanliness and availability.

## 2.2 DIESEL ENGINE: ECONOMICAL ASSESSMENT

When looking at the economics of owning and operating a diesel truck, there are number of factors that allow it to rank ahead of the alternatives. These factors are efficiency, economy, and reliability (Chevron Corporation, 2007). While a new diesel engine vehicle is out of the price range, used vehicles are available on Craigslist and Autotrader.ca for an appropriate price. A donation from UBC Plant Operations can also be looked into.

Diesel vehicles are generally more fuel efficient when compared to the readily available gasoline counterparts. This is due to the high efficiencies of the diesel cycle, shown in Figure 1 and numerically in Figure 2, and the fact that diesel fuel contains 10% more energy per volume than gasoline. The diesel cycle allows the diesel engine to operate at higher compression ratios and temperatures, thus increasing the fuel efficiency of new diesel vehicles by 50% when compared to gasoline vehicles (HybridCars, 2012).

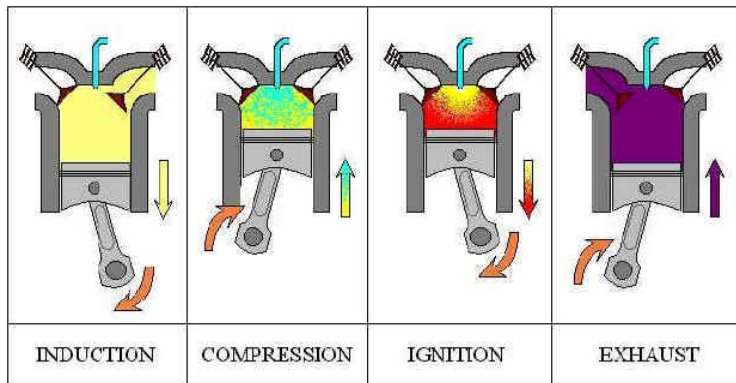


Figure 1 – Graphic Diesel Engine Cycle (<http://www.myrc toys.com/faqs/engine-diagrams-and-animations>)

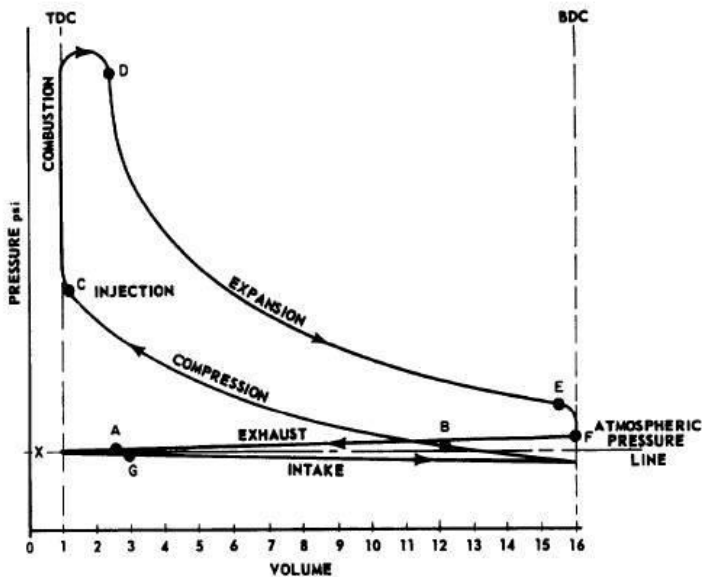


Figure 2 - Graphical Representation of the Diesel Cycle (<http://www.tpub.com/engine3/en3-15.htm>)

The cost of diesel fuel is comparable to that of gasoline and experiences less price fluctuations due to the constant demand from the transportation industry. With diesel fuel it is then easier to budget for the expected fuel costs throughout the year because of price stability.

Diesel engines are more reliable and generally require less maintenance compared to their gasoline counterparts due to a number of reasons. Diesel engines do not require an ignition system to ignite the fuel; therefore, it has one less system that requires maintenance. Diesel engines operate at low RPM's and the diesel fuel is a better lubricant than gasoline, ultimately reducing the internal wear of the engine. Thus decreasing the maintenance cost when comparing to a traditional gasoline engine vehicle.

### 2.3 BIO-DIESEL ENGINE: ECONOMICAL ASSESSMENT

When considering the bio-diesel vehicle, various cost factors needed to be investigated. These include the price of the fuel, availability, conversion costs and maintenance specific to bio-diesel engine vehicles. While a new diesel engine vehicle is out of the price range to be converted to bio-diesel, used vehicles are available on Craigslist and Autotrader.ca for an appropriate price. A donation from UBC Plant Operations can also be looked into.

Bio-diesel is available to be purchased at the Chemical and Biological Engineering Sustainability Club (CHBE, 2012). The fuel they supply is B20 bio-diesel. B20 is a mixture of 20% bio-diesel and 80% diesel (Sustainability, October 5, 2012). Since the bio-diesel is predominantly diesel, the Sustainability Club sells their fuel for the same cost of regular diesel. However, the B20 blend will produce 2.2% fewer miles per gallon when compared to petrol diesel (Anthony, 2012). This reduced performance is a by-product of the fact that bio-diesel has a slightly lower energy content compared to petrol diesel. The CHBE club's supply of B20 is conveniently located on campus, compared to the costly and inconvenient option of off campus diesel or bio-diesel refueling.

It is found that the use of B20 bio-diesel requires no modifications on operational diesel engines. However, if a higher grade of bio-diesel is used (B80 or higher) and the vehicle is older than 1994, then mechanical issues can be a problem (Fangrui Ma, 1999). The higher ratio fuels are more corrosive and the older seals are not as resilient. The seals in the fuel system of pre-1994 vehicles cannot withstand the corrosive properties of higher grade bio-diesel. If bio-diesel is obtained from an alternate source, it is possible that the mix of the bio-diesel will be greater than 20%. If this is the case, modifications would be necessary to older diesel engine models and can potentially increase the overall cost of the vehicle (Fangrui Ma, 1999).

### **3.0 ENVIRONMENTAL ASSESSMENT**

The sustainability of the vehicle used at the UBC Farms is an important factor as the Farm prides itself in being an environment of sustainable studies (The UBC Farm, 2012). A new vehicle can be used to further the education process, as it can explore the uses of diesel or bio-diesel fuels or the convenience of a car co-op's services. The fuel efficiency and emissions of the choice have a large impact on the environmental assessment of the option. Furthermore, the environmental sensitivity of each option strongly influences the final decision for the vehicle.

#### **3.1 CAR CO-OP: ENVIRONMENTAL ASSESSMENT**

Car co-op companies pride themselves on being a sustainable and environmentally friendly solution for transportation. As the number of cars on the road increases, the demand for more lanes and parking will also increase, which threatens green spaces. Sharing a fleet of vehicles, rather than owning a personal vehicle, ultimately leads to fewer cars on the road. This has the potential to reduce the public's dependence on a personal vehicle, reduce the amount of traveling via a personal vehicle, and decrease the amount of vehicles being manufactured (Zipcar, 2012). Modo states that "fewer cars on the road mean fewer greenhouse gas emissions, less stress on our green spaces, and less traffic in our city" (Modo, 2011). Appendix A shows research findings on vehicle trip reduction with the use of car co-ops rather than the use of a personal car. However, the Marketing Director at Modo has stated that the Farm is limited to only using the trucks within their fleet (Hilary Henegar, October, 2012). The problem is, the vehicles available for the Farm to use include Ford Rangers or trucks from the Mazda B-series, all of which are not particularly noted for being environmentally friendly or fuel efficient (Modo, 2011). The average mileage of these models is around 22 highway miles per gallon and gasoline emissions consist of carbon dioxide, carbon monoxide, hydrocarbons, and nitrogen oxides. However, couple this with the ability to teach the public about car co-ops at the Farm, it has potential to decrease the amount of trucks being personally owned in the Lower Mainland.

#### **3.2 DIESEL ENGINE: ENVIRONMENTAL ASSESSMENT**

Diesel engines have several environmental pros and cons when compared to a gasoline engine. Due to the high efficiency of the diesel cycle and the fact that diesel engines are designed

to run lean, they emit very little CO and unburned hydrocarbons compared to gasoline engines. With regards to the PM and NOx emissions, diesel engines emit more than their gasoline counterparts. Emission standards have been increasing over the years, concentrating on reducing PM and NOx emissions. This trend can be seen in Table 1 below, produced by the US Environmental Protection Agency (EPA) (Rakopoulos & Giakoumis, 2009).

**Table 1 - EPA Emission Standards for Heavy-duty Diesel Engines (Rakopoulos & Giakoumis)**

Year	HC (g/bhp-h)	CO (g/bhp-h)	NOx (g/bhp-h)	PM (g/bhp-h)
1988	1.3	15.5	10.7	0.6
1990	1.3	15.5	6	0.6
1991	1.3	15.5	5	0.25
1994	1.3	15.5	5	0.1
1998	1.3	15.5	4	0.1
2004	0.50*	15.5	2.5	0.1
2007	0.14*	15.5	0.2	0.01

\* Non-methane hydrocarbons

The emissions standards for 2007 and later model year diesel vehicles must comply with much more stringent emission standards, set by the EPA. These emission standards are met with the addition of Diesel Oxidation Catalysts (DOCs) and Diesel Particulate Filters (DPFs). Due to the high cost of newer diesel vehicles (2007 and later model year), it can be cost effective to retrofit older diesel vehicles with aftermarket DOCs or DPFs to reduce to PM emissions. DPFs can reduce PM emissions by 80% to 95%, while significantly reducing hydrocarbon and carbon monoxide emissions. The two types of DPFs are the actively regenerating filter and the catalysed filter. Both DPFs have their drawbacks. The drawback of the catalysed filter is it requires ultra-low sulfur fuel, 30 ppm sulfur or less, to operate effectively. The drawback of the actively regenerating filter is that it increases fuel consumption, as it uses a fuel burner to burn off the PM.

A less costly method of reducing PM emissions is to use a DOC, which can reduce PM emissions by 20% to 50%. DOCs are a well established technology, which is easy to retrofit and maintain (Stevens, Wilson, & Hammitt, 2005).

### 3.3 BIO-DIESEL ENGINE: ENVIRONMENTAL ASSESSMENT

Bio-diesel engines have several environmental pros and cons when compared to a gasoline engine. Bio-diesel is bio-degradable and non-toxic since it is produced from vegetable oils or recycled cooking oil and animal fat. A diagram of the bio-diesel life cycle is shown below in Figure 3.

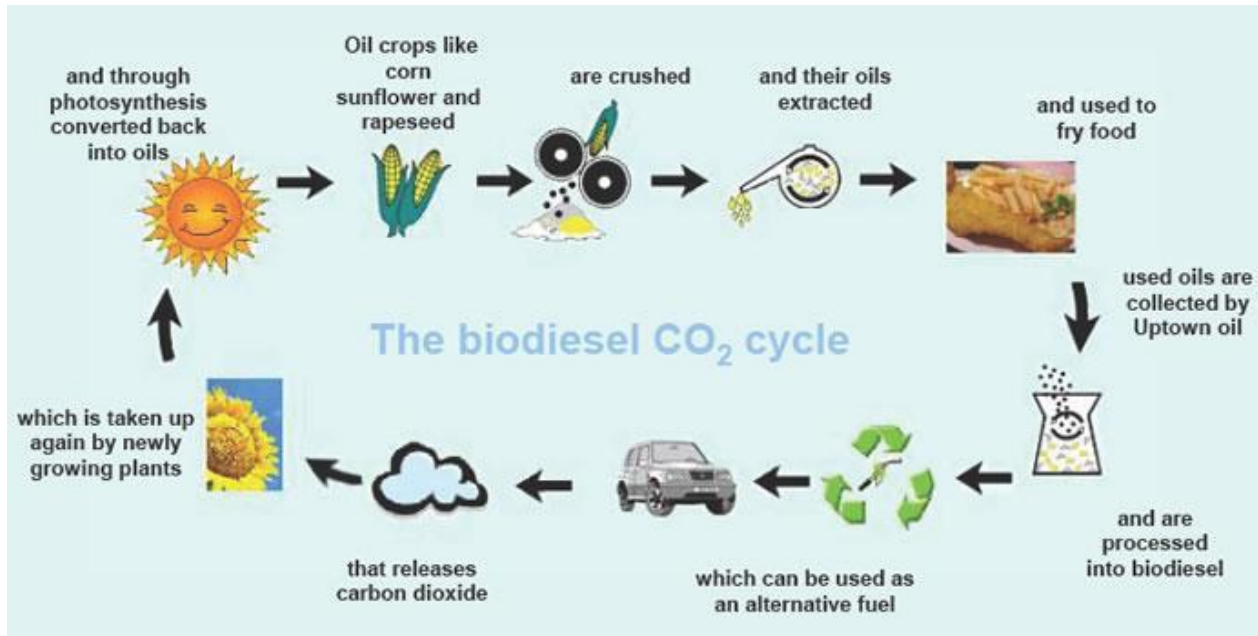


Figure 3 - Bio-Diesel Cycle (from: [http://www.uptownoil.co.uk/co2\\_biodiesel.html](http://www.uptownoil.co.uk/co2_biodiesel.html))

The major drawback of using bio-diesel rather than gasoline engine vehicles is fuel efficiency. As previously discussed the B20 blend will produce 2.2% fewer miles per gallon when compared to petrol diesel (Anthony, 2012). However, the effects of using more fuel are mitigated due to the fact that 20% of the fuel is derived from a reusable source.

One of the major environmental benefits of using bio-diesel is the reduction of emissions. About 11% of bio-diesels weight is made up of oxygen (Anthony, 2012). The presence of this oxygen in bio-diesel improves combustion in an engine which reduces carbon dioxide,



particulate matter, hydrocarbons, and carbon monoxide emissions. Typically, when compared to diesel, bio-diesel reduces emissions of particulate matter by 47%, unburnt hydrocarbons by 67%, and carbon monoxide by 48% (CHBE, 2012). While these are noteworthy reductions, there is also a negative effect that occurs with the increased oxygen content. The increase causes nitrogen oxide emissions to increase by 10% (Dincer, 2008). A more thorough breakdown of the emission when compared to diesel engines is included in Appendix B. There are methods of reducing this increased emission by blending in Kerosene or Fischer-Tropsch diesel (Anthony, 2012). At this point in time, the CHBE Sustainability Club was unable to specify if they were taking these actions to reduce the nitrogen oxide emissions.

#### **4.0 SOCIAL ASSESSMENT**

The UBC Farm is an area of sustainable learning and cultural sensitivity (The UBC Farm, 2012). It is, therefore, important to consider how the public and employees view the vehicle and how it reflects the Farm's teachings. The aesthetics and reliability of the vehicle will be continuously under scrutiny. The vehicle will be present for most of the Farm's public interactions. In terms of reliability, the vehicle is necessary to assist with the financial sustainability during market sales. Major factors that have been taken into account on this assessment include: how sustainable the public will view the option, the physical appearance of the vehicle, and if the Farm will be able to lead by example with its transportation choices.

#### **4.1 CAR CO-OP: SOCIAL ASSESSMENT**

The use of a car co-op company's services has several positive social aspects. The vehicle will be maintained by Modo rather than the Farm, therefore, the reliability and quality is assured (Modo, 2011). The fleet offers multiple newer model trucks, thus an aesthetically appealing vehicle that is in proper condition is readily available. Modo has also offered to complete an orientation with the Farm and potential drivers to ensure the transfer to their vehicles and services is as efficient as possible and to educate the drivers of their regulations (Hilary Henegar, September – November, 2012). Furthermore, as anyone, within reason, is able to register for Modo's services it is easy for the public to follow the Farm's example with its sustainable choice of transportation. Increasing the number of car share users can as much as “[halve] journey costs and the economy as a whole benefits greatly in reduced vehicle kilometres, increased average speeds and savings in fuel, accidents, and emissions” (Fellowsa N.T. and Pitfieldb D.E. 2000). However, the Farm is limited to only use the trucks within Modo's fleet, the sustainability of the choice may be questioned by the public. While sharing vehicles when they are not constantly in use is a sustainable choice when compared to owning a private vehicle. As stated in the previous section, using a regular gasoline pickup truck, when compared to a hybrid or bio-diesel, may be viewed as otherwise. It is important to remember that it is possible that the Farm is able to use the vehicle for educational purposes to teach the public about the sustainability of car co-op companies.

## **4.2 DIESEL ENGINE: SOCIAL ASSESSMENT**

Most people associate diesel vehicle with larger trucks that pour out black smoke from their smokestacks. This is no longer the case for new diesel vehicles, as diesel engines have made their way into smaller personal transportation vehicles and more stringent emissions requirements have greatly reduced this image. Older diesel vehicles are also known to have noisy engines. Over the years, technology in new diesel engines has greatly reduced engines noise. Diesel vehicles are very fuel efficient and reliable vehicles. As a result, diesel vehicles hold their value much better than their gasoline counterparts. Diesel vehicles can be converted to run on bio-diesel quite easily, this is very appealing to the environmentally conscientious consumer. The Farm can use a diesel vehicle as an opportunity to educate the public on the new environmental effects on using diesel as opposed to gasoline.

## **4.3 BIO-DIESEL ENGINE: SOCIAL ASSESSMENT**

Bio-diesel is seen socially as a more environmental fuel than gasoline and petrol diesel. This is partly because the main product that makes up bio-diesel is non-toxic and used for cooking on a daily basis. Bio-diesel has been proven to be a reliable fuel source in Europe with millions of car owners using it. This is particularly true in Germany, where it makes up 3% of the German diesel fuel market (CHBE, 2012).

Bio-diesel is seen as a cleaner fuel source by pedestrians. The reason for this is the exhaust of the vegetable oil that was used to make the fuel, does not smell like typical exhaust. When a group of pedestrians were surveyed about the smell of bio-diesel exhaust, it was described as faintly smelling of French fries (E. de Beaupre, September 20, 2012). This smell is more noticeable when there is a higher percentage bio-diesel such as B80 or B100.

A possible partnership between the CHBE Sustainability Club and the UBC Farm could produce many opportunities to spread knowledge to the public about bio-diesel, as well as, the other projects that the UBC Farm works on. The CHBE Sustainability Club does presentations at different events to teach and promote sustainability. The UBC Farm could potentially team up with them to expand this impact. If the UBC Farm partners up with the CHBE Sustainability

Club this might allow for the opportunity for CHBE to conduct studies on effects of changing the production methods of bio-diesel has on the resulting emissions. Furthermore, the UBC Farm will be supporting UBC clubs and sustainable development within the UBC campus. As well as, pose as an opportunity for new projects at the UBC Farm.

## **5.0 CONCLUSION AND RECOMMENDATIONS**

In conclusion, it has been shown that both bio-diesel and car co-ops are seen to be a step in the right direction in promoting sustainability by society. Bio-diesel and car co-op vehicles both have the potential to reduced emissions when compared to the typical uses of vehicles today. Due to the fact that the availability of trucks in the MODO's fleet pose as a major unknown factor, along with the price of retrieving the vehicle, it has been decided to not use this option. A diesel or bio-diesel truck would be a more reliable option for the farm.

The recommendation for the UBC Farm is to acquire a diesel truck with the initial intention of using the CHBE Sustainability Club's bio-diesel. A partnership could be developed between the two, resulting in advancement in bio-diesel research. Furthermore, it is recommended to develop a new project at the UBC Farm, to work on developing and promoting bio-diesel for sustainable transportation. As a failsafe, if unseen circumstances prevent the use or manufacturing of bio-diesel on campus, the truck can be used as a conventional diesel truck. This would still be more convenient than using a car co-op service.

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Zipcar Contact (September 24, 2012) Telephone Call and Corresponding Email Messages

## APPENDIX A – Car Share User Model

Table 1 shows the reduction of trips for three different testing simulations. A weekday average 5.5 million trips is considered for all purposes in the study. The Do Minimum is the data will no car sharing services. Test 1 “supposes there are no extra incentives to car-sharers beyond what can be gained from savings in individual journey costs” (Fellowsa N.T. and Pitfieldb D.E. 2000). Test 2 assumes “supposes a greater degree of participation” without further incentive (Fellowsa N.T. and Pitfieldb D.E. 2000). Test 3 is a scenario where car sharing is “effectively promoted through the introduction of high-occupancy vehicle segregated lanes, reserved city centre parking and other such incentives” (Fellowsa N.T. and Pitfieldb D.E. 2000). It can be seen that there is a reduction of 127 619 trips in 24 hours if there is user incentive for using a car co-op.

**Table 2- Car-sharing operational analysis: trip information**

(<http://www.sciencedirect.com/science/article/pii/S1361920999000164>)

Test	Time period	Total number of trips	24 h flow	Reduction from “Do Minimum”
“Do Minimum”	AM peak	499 504		
	Off peak	315 003	5 664 577	N/A
	PM peak	497 776		
Test 1	AM peak	498 464		
	Off peak	314 884	5 659 101	5476
	PM peak	496 960		
Test 2	AM peak	497 268		
	Off peak	314 481	5 649 529	15 048
	PM peak	495 861		
Test 3	AM peak	483 554		
	Off peak	309 628	5 536 958	127 619
	PM peak	483 126		



## APPENDIX B – Bio-Diesel Emissions

Table 3 shows the average emissions comparative to regular petrol diesel. This information has been provided by the article “Lower emissions from bio-diesel combustion” (Dincer, 2008).

**Table 3 - Average Bio-Diesel Emissions Compared to Conventional Diesel (Journal of Energy sources. Part A, Recovery, utilization, and environmental effects)**

Emission type	Pure bio-diesel B100 (%)	20% Bio-diesel + 80% Petro diesel B20 (%)
Total unburned hydrocarbons (HC)	-67	-20
Carbon monoxide	-48	-12
Particulate matter	-47	-12
NO <sub>x</sub>	+10	+2
Sulfates	-100	-20
Polycyclic aromatic hydrocarbons	-80	-13
Ozone potential of speciated HC	-50	-10