UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Examining Waste Cooking Oil Supply for Campus Biodiesel Production and Implementation

Cheryl Gomes, Danielle Salvatore, David Chan, Fraser Howatson, Jan Laesecke, Jesse Hudkins

University of British Columbia

April 30, 2014

Examining Waste Cooking Oil Supply for Campus Biodiesel Production and Implementation

David Chan
Cheryl Gomes
Fraser Howatson
Jesse Hudkins
Jan Laesecke
Danielle Salvatore

Introduction

This study investigates the feasibility of already-existing supply and demand of biodiesel at the University of British Columbia. A student-led project operating under an *Engineers for a Sustainable World* chapter manages a batch biodiesel processing operation in conjunction with the department of Chemical and Biological Engineering. Currently, the group produces 60 Liter batches for distribution to housing and dining and services. The fuel is currently dispensed through a blend-on-demand station, which mixes petroleum diesel and biodiesel in concentrations set by the user. While current fuel demand is being met, there exists the potential to produce more fuel for the AMS.

The project background derives from an introductory meeting of two managers from the AMS seeking a new catering vehicle for on campus use. As sustainability is a primary concern for the University, alternative energy vehicles were primarily considered. Through mutual contacts at the University, the biodiesel group was contacted for further information for a potential collaboration.

This investigation covered three primary sections, the implications of biodiesel on vehicle systems and in particular on the vehicle of choice, the economic feasibility of the production and sale of the biodiesel that would be sold to the AMS, and the environmental benefits associated with using biodiesel for a catering vehicle on campus.

The implications of biodiesel on vehicle systems

Biodiesel is manufactured from plant oils, animal fats, and in this case, recycled cooking oils. It is renewable, energy-efficient and can displace petroleum-derived diesel fuel. Furthermore, it is nontoxic, biodegradable and suitable for sensitive environments and can reduce the effects of greenhouse gas emissions and therefore climate change as a whole. Biodiesel has a higher cetane number (a measure of the ignition value of diesel fuel) and lubricity (capability of reducing friction) than petroleum diesel. One drawback of biodiesel is that not all diesel engine manufacturers cover biodiesel use in their warranties and there are slight maintenance modifications required (further details will be described below). Biodiesel is most commonly used as a blend with petroleum diesel in B20 (20% biodiesel, 80% petroleum diesel). However biodiesel in its pure form, known as B100, still demonstrates capability of usage as a fuel if proper precautions are taken.

B20 has gained prevalence due to its favored balance of cost, emissions and ability to act as a solvent (and therefore clean the fuel system). Furthermore, B20 avoids many cold-weather performance and materials compatibility concerns associated with B100.

Implementing B20 as a fuel source does not demand engine outfitting due to similar fuel consumption, horsepower, and torque as petroleum diesel.

While B100 would have a fivefold positive impact on greenhouse gas emission reduction in comparison to B20, it is less often used due to its higher cost and cold weather issues. Low temperature gelling of higher biodiesel blends occur during cold seasons, due to molecular aggregation and crystallization. Since biodiesel has a solvent effect proportionate to the amount of biodiesel in the fuel, the solvent effect of B100 is much more significant than B20. While it can clean a vehicle's fuel system, B100 would also release the deposits accumulated from previous petroleum diesel use that may initially clog filters and require filter replacement in the first few tanks of B100 usage. Also, B100 contains approximately 8% less energy per gallon than petroleum diesel. B20 results in 1% to 2% reduction in energy per gallon, which is typically unnoticed in terms of performance or fuel economy. Lastly, B100 requires special handling and storage, since it freezes at higher temperatures, and is incompatible with some hoses, gaskets, metals and plastics due to degradation effects.

The proposed vehicle, the 2014 Mercedes-Benz Sprinter Cargo Van, would not need any modifications in order to run on biodiesel fuels up to B20. If it were to run on fuels greater than B20, the fuel line should be changed to an SAE J30R9 fluoroelastomer lined 3/8" hose due to the solvent properties of blends above B20. The UBC Student Housing and Hospitality Services at UBC currently runs B20 biodiesel provided by the sustainability club. The only adjustments they have made to their truck is they change their fuel filters on a yearly basis, as opposed to a three year change cycle, for petroleum diesel. The Sprinter would also require yearly fuel filter changes. It is also recommended to check for contamination. Post 2007 diesels typically use an in-cylinder post combustion squirt of fuel as part of their emissions system. This post-combustion squirt vaporizes but does not combust, allowing the biodiesel to make its way past the piston rings and migrates into the crankcase, where it dilutes engine oil and can polymerize on the insides of the crankcase. This contamination can cause high wear on the engine, and oil sampling and monitoring would be recommended.

Diesel fuel up to B5 Biodiesel content according to ULSD specification ASTM D6751 meets Mercedes-Benz approved fuel standards and will not void coverage under the Mercedes-Benz Limited Warranty. All diesel fuels containing greater than B5 biodiesel (B6 to B100) are not approved by Mercedes-Benz as the risk for engine damage is increased. The MB sprinter warranty is as follows:

> *Requires the use of ultra low sulfur diesel fuel. Mercedes-Benz Sprinters are approved to use B5 biodiesel (approved diesel fuel with a maximum 5% biodiesel*

content) in all BlueTEC engines. The only approved biodiesel content is one that both meets ASTM D6751 specifications and has the oxidation stability necessary to prevent deposit-/corrosion-related damages to the system (min. 6h, proven by EN14112 method). Please see your service station for further information. If the B5 biodiesel blend does not clearly indicate that it meets the above standards, please do not use it. The Mercedes-Benz Sprinter New Vehicle Limited Warranty does not cover damage caused by non-Mercedes-Benz approved fuel standards (SOURCE: Mercedes Benz Canada)

The sprinter has a fuel efficiency of approximate 9.7 L/100km. Since the truck drives approximately 10 km/day it will use 7 L/week of fuel. The Sprinter tank is 100 L in size and will therefore need to be refilled approximately every 3 months.

Economic Assessment

Assumptions

For this preliminary economic assessment, we have made the following assumptions regarding the operation and material inputs:

1. Methanol will continued to be supplied free of charge by the U.B.C. Solvent exchange even with an increase in methanol demand to cover the increased fuel production.
2. 90 batches of biodiesel will be produced annually. Each batch will produce approximately 60 L biodiesel resulting in roughly 5400 L of biodiesel produced per year.
3. ASTM testing will be conducted on the first three batches of biodiesel produced. Provided there are no discrepancies between the results and the fuel meets the ASTM quality standards for biodiesel, no further third party testing will be done for one year unless there is significant alteration to the process.
4. Diesel fuel for the purpose of blending will no bare and delivery cost as our order will be tacked on to the existing Clean Energy Research Centre (CERC) account. We assume diesel fuel price of $1.50 per litre of diesel.

Material Costs

Material costs are based producing 60 L of biodiesel in an existing batch reaction. A list of reagents can their respective usages is displayed in Table 1. Potassium Hydroxide is used as a catalyst in the transesterification reaction of the spent cooking oil and methanol. Currently, there is no procedure in place to recover the used catalyst for re-use. Ion resin is used at a rate of roughly 1 L per annum.

Table 1 Material Costs per 60 L Fuel Produced

Product	Price	=Usage per Batch	Cost per Batch
Methanol	-	14 L	$0.00
Cooking Oil	-	60 L	$0.00
Potassium hydroxide	$46.80 / kg	800 g	$37.44
Amazon	$30.00	$0.33	$0.33
		Total	**$37.77**

Labor Costs

The estimation of labor costs is based on a fair living wage of $18.75 per hour in Vancouver, British Columbia. The total number of man-hours necessary to deliver a single 60 L batch of fuel is approximately 20 which include in-house quality control testing as seen in Table 2. However, from experience it is noted that a bulk of those 20 hours require only the presence of an operator in the event of an emergency. With this in mind, the authors propose that the 20 hours per batch be divided in half into "operating" and "standby" wage categories. The standby hours would be billed at minimum wage, $10.25 per hour. This is a fair assessment given the position would be targeted at a CHBE student that would be presumably in the building anyways and could use the standby time for their own academic pursuits.

Table 2 Labour Costs per 60 L Batch

Procedure	Time
Waste oil Titration	1
Waste oil Filtration	1
Oil Transfer	1
Water Removal	2
Oil Transfer	2
Heating of R1	2
Transesterification	2
Methanol Removal	6
IX Column	1
Quality Control	2
Total	**20**
Labour Cost	**$290.00**

Testing Costs

Biodiesel produced will be sent to Intertek for independent third party testing. The biodiesel will be tested against ASTM BQ9000 standards. The tests will cost approximately $300 per testing event which will be carried out 3 times annually so long as test results are consistent with fuel quality standards and no significant process alterations take place. These 3 independent testing events, totalling $900 per year, work out to $10 per batch based on the production of 90 batches of biodiesel per year. Total material and operating costs as well as potential sale prices are shown below:

Table 3 Material and Operating Costs

	$/Batch	$/L
Materials	$37.77	$0.63
Labour	$290.00	$4.83
Third Party Testing	$10.00	$0.17

From the initial price breakdown, the fuel costs for pure and blended biodiesel are 375% and 150% the price of normal petroleum diesel, respectively. While the biodiesel fuel offers an incentive to reduce carbon emissions and using campus-sourced waste products, this is a significant price to pay. Another option in considering the biodiesel production would be to increase the reactor sizing.

Currently the batches are limited to 60L of produced biodiesel due to the volume limitation of the heating tank in the laboratory. By replacing the heater to the next most feasible system size, the reactor would be able to produce 100L per batch without significant changes to the net process time. Such an investment would require $350 for the entire system upgrade, however the result would bring down production costs of biodiesel to $3.38 per Liter. This would effectively pay for itself after the first 150 Litres of biodiesel sold, but a more thorough system analysis must be considered in order to ensure that the facilities can support larger heating vessels.

Other potential options for the UBC Biodiesel program would be to engage a work-learn position for biodiesel production through AMS sustainability funding. Positions such as this have been created for the biodiesel club in the past and would most likely be feasible in the future as well. This would effectively result in the AMS subsidizing their own fuel, however it would provide learning opportunities for students on campus and also mitigate existing waste streams currently generated by the University. This calculation assumed that half of the labour costs would be covered by Work Learn funding and

Combining the proposed reactor heater upgrading and also assuming a student wage subsidy from the AMS Work-Learn program, Biodiesel is priced somewhat competitively at $2.26 per liter. Further potential cost reductions would be most easily achieved through further funding student wages from an AMS Sustainability grant. Below table 4 summarizes the potential options of biodiesel cost reduction strategies with comparison to the initial "as-is" price estimates, and the current prices quoted from the Vancouver Biodiesel Co-Op.

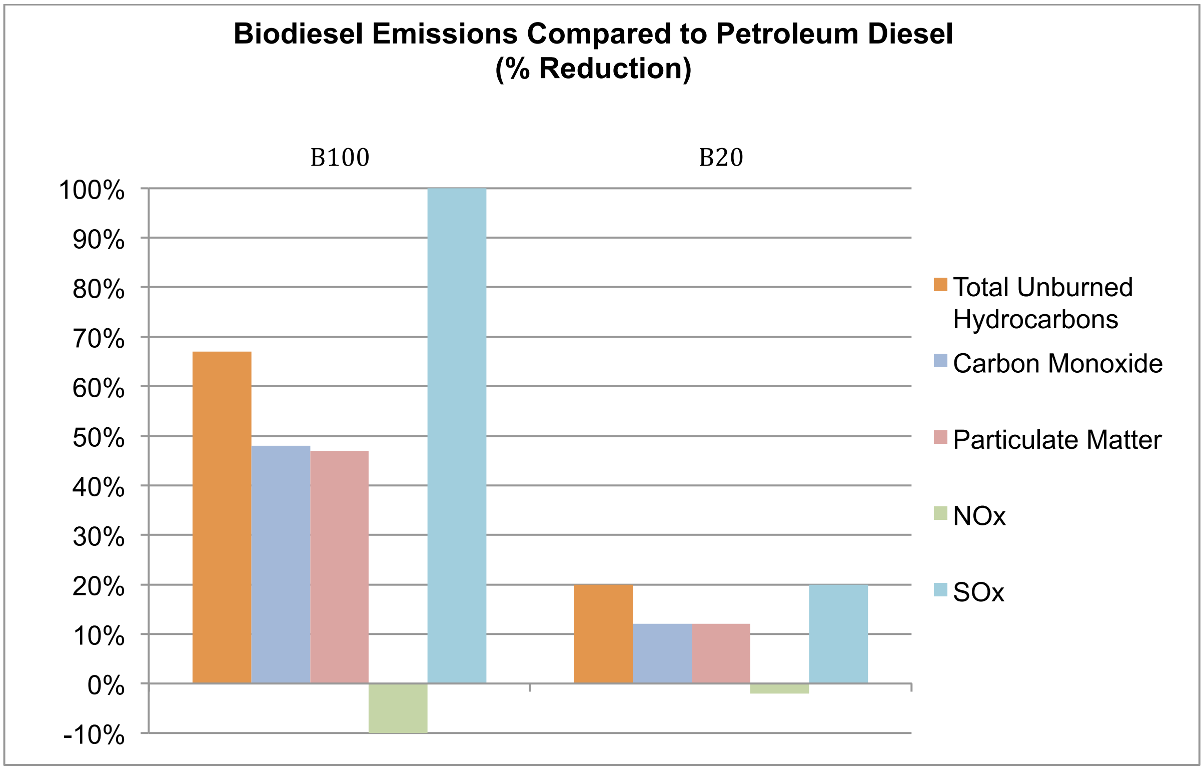
Table 4 Potential Price Reduction Strategies

	B100	B20
Current	$5.63	$2.33
Upgrade Reactor	$3.38	$1.88
Work Learn	$3.77	$1.95
WL+ Upgrade	$2.26	$1.65
Vancouver Co-Op	$1.70	$1.54

Environmental Benefits

Emission Improvements

Running AMS delivery vehicles with biodiesel converted from AMS catering company's waste cooking oil provides a sustainable alternative for AMS delivery vehicles' fuel needs. Converting fleet vehicles to biodiesel will not only lower dependence on fossil fuels, but will additionally help reduce green house gas emissions and reduce air pollution and related public health risks. Biodiesel use has the potential to play an important role on reducing the levels of chief air pollutants afflicting urban areas targeted by the United States Environmental Protection Agency (USEPA): particulate matter (PM); carbon monoxide (CO); hydrocarbons (HC); sulfur oxides (SO_x); and nitrogen oxides (NO_x). Data compiled by the USEPA shows converting to biodiesel significantly decreases the most pertinent air pollutant emissions. NO_x is the only emission that sees a slight increase. Additional measures to reduced NO_x such as post-combustion NO_x removal technologies or pre-combustion additives in fuel.



(Source: USEPA)

Fuel Life-Cycle Analysis

To picture the full benefits of converting fleet vehicles to run off biodiesel, life cycle analysis is used to compare cradle-to-grave of fuel production compared to petroleum diesel. A life-cycle analysis of energy requirements and CO_2 can be performed using a robust and reliable method.

The benefit of using biodiesel during a vehicle's lifetime was determined to be proportionate to the blend level. Substituting B100 for petroleum diesel in vehicles reduces the lifetime consumption of petroleum by 95% whereas substituting for B20 will see a 19% reduction. This further reduces the emissions of CO_2 shows further environmental benefits. B100 use reduces net CO_2 emissions by 78.45% and B20 use reduces emissions by 15.66%.

Biodiesel's production process reveals further environmental benefits. Biodiesel and petroleum diesel production are essentially equal in efficiency for converting raw energy resources into fuels. Biodiesel's benefit its largest raw resource for production, soy oil, is renewable. For every unit of fossil fuel used in the life cycle, 0.83 units of petroleum diesel, 0.98 units of B20, or 3.2 units of B100 could be produced.

Based on the life-cycle analysis of petroleum diesel, B100 and B20, the environmental impacts are greatly reduced by using the biodiesel blends. Converting to biodiesel will reduce the dependence on fossil fuels, overall CO_2 emissions released and increase the energy output per units of fossil fuel consumed.

Conclusion

This report provides a preliminary investigation to the costs and environmental benefits associated with production of biodiesel from spent cooking oil for use in a proposed AMS food delivery truck. The use of biodiesel as a liquid transportation fuels provides significant environmental benefits in the forms of emission reductions and waste recycling as compared to conventional petro-diesel. However, biodiesel produced at such a small scale predictably falls short of being cost competitive with conventional diesel. This report makes some suggestions into future work pertaining to process scaling and labor subsidies that could reduce the price gap between the two fuels. There are also considerations to be made regarding the warranty of the proposed delivery vehicle. Blends over 5 % biodiesel would result in voiding the factory warranty, giving rise to additional economic concerns. However, given the University's aggressive stance on sustainability, it is seen that this project holds considerable potential to subsidize petro-fuel requirements, reduce emissions, promote sustainability at the university, and provide excellent work / learning student opportunities.

References

Mandal, B: *Environmental impact of using biodiesel as fuel in transportation: a review*. International Journal of Global Warming 3.3 (2011): 232-256.

Moser, B. R., Biofuels: Global Impact on Renewable Energy, Production Agriculture, and Technological Advancements. Springer: 2011.

Pillay, A. E. *Potential environmental effects linked to elemental toxicity of neem biodiesel and alternative fuels (B20/B100)*. Canadian Journal of Pure & Applied Sciences 7.2 (2013): 2397-2403.

Sheehan, J.; Camobreco, V.; Duffield, K.; Graboski, M.; Shapouri, H. *An Overview of Biodiesel and Petroleum Diesel Life Cycles*; TP-580-24772; NREL: Golden, CO, 1998.