ECOLOGY NORTH

Feasibility of Biodiesel Production and Direct Use of Used Vegetable Oil for Heating in the City of Yellowknife

FINAL REPORT

Submitted to:

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Government of the Northwest Territories - Environment and Natural Resources

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Feasibility of Biodiesel Production and Direct Use of Used Vegetable Oil for Heating in Yellowknife

For more information, please contact Ecology North. Copies of this document can be downloaded on our website at www.ecologynorth.ca.

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Ecology North is a non-profit environmental and community organization that was established in 1971. Ecology North strives to bring people and knowledge together for a healthy northern environment. Ecology North's current areas of focus include climate change, sustainable living, environmental education, waste reduction and local food production.

Ecology North received funding from the Canadian Northern Economic Development Agency (CanNor) and Government of the Northwest Territories - Environment and Natural Resources to carry out this project from October 2010- March 2011.

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Thank you and we look forward to collaborating on future phases of this project!

Contents

Executive Summary

In 2009, Yellowknife resident Daniel Gillis began experiments to create biodiesel and use it in his diesel truck and oil stove. Dan surveyed Yellowknife restaurants in early 2010 to determine that about 84,000 litres of used vegetable oil were being produced and landfilled each year.

In September of 2010, the Canadian Northern Economic Development Agency (CanNor) and Government of the Northwest Territories - Environment and Natural Resources (GNWT-ENR) agreed to fund an expanded biodiesel project that would include renting an appropriate facility and producing biodiesel as a pilot project with the intent of the project eventually becoming a self-sustaining business. This funded project officially began in October 2010.

The goals of the project were to create an alternative home heating fuel, divert used vegetable oil (UVO) from the landfill, create a feasible business model, and pass knowledge of the project on to others.

A facility at 13 Coronation Drive was rented by Daniel Gillis to complete the biodiesel project. Unfortunately, this facility was found to be inappropriate for biodiesel production by the Fire Marshall. Extensive renovations would be required, so collection of UVO was terminated and the processing of biodiesel was delayed until a new building or other solution could be found.

In February 2011, Ecology North contracted Dwayne Wohlgemuth of Ko Energy to investigate the requirements of the Fire Code in relation to biodiesel production and to determine the feasibility of any required renovations to the facility at 13 Coronation Drive. Dwayne determined that the required renovations would be extensive and not practical for the building. An alternative, that of using UVO directly in boilers, was also explored and was determined to be more economical than creating biodiesel due primarily to reduced operating costs. This alternative was further explored and defined including the selection of suitable buildings and selection of boilers.

Ecology North will further pursue this preferred option of using used vegetable oil in a boiler installed to provide space heating to a building in Yellowknife.

Introduction

A survey of Yellowknife restaurants, completed in April of 2010, determined that the volume of used vegetable oil (UVO) produced in Yellowknife each year is about 84,000 litres. Vegetable oil has an energy content of 90% of that of diesel or about 34.8 MJ/litre (33,000 Btu per litre). This oil could be used by converting it to biodiesel or by using it directly. The use of this oil would reduce landfilled waste, reduce fossil fuel consumption, and contribute to a lower cost of living in Yellowknife by turning this current waste product into a resource.

The original objective of this project was to determine the feasibility of biodiesel production from used vegetable oil in Yellowknife. The initial contractor who had been retained to work on this project, Mr. Dan Gillis, had previously produced some small-scale batches of biodiesel in a shop that was part of a multi-unit building used for storage by a number of individuals and businesses. When the contractor investigated the building upgrades that would be required to satisfy fire and building code requirements for a biodiesel production facility, and the costs of insurance associated with operating the facility, it seemed that biodiesel production as initially proposed was not economically feasible at the current time. As a result, the biodiesel facility was not constructed, and no biodiesel was produced.

At this point in the project (February 2011), Ecology North secured a second contractor, Dwayne Wohlgemuth, to explore the alternative of burning used vegetable oil directly as a fuel source instead of converting it into biodiesel, and to conduct a more-detailed financial and technical analysis of biodiesel production. As outlined in this report, our investigation into the financial and technical aspects of directly burning used vegetable oil suggests that there is a good business-case for collecting and using the used vegetable oil as a fuel source.

Given the events described above, it was not possible to meet the biodiesel production goals initially outlined for this project. Although the project did not unfold as initially planned, the process of conducting a detailed financial and technical analysis of direct waste vegetable oil use in comparison with biodiesel production has been productive, and has made it possible to develop clear next steps to continue progressing towards the ultimate goal of diverting Yellowknife's used vegetable oil resource from the landfill, and using it as a local fuel source.

Potential Savings and Benefits

Diversion of UVO in Yellowknife would reduce disposal costs for restaurants and institutions, reduce diesel consumption and GHG emissions, and create local economic opportunities. Landfill tipping fees in Yellowknife are $25/tonne for cooking grease,[1] which at 0.92 kg/litre costs restaurants about $1,900 per year[2]. The real disposal cost in Yellowknife is estimated at $75/tonne[3], so the City is subsidizing used vegetable oil disposal at a rate of $50/tonne. Thus, the City would save about $3,900 per year if this used oil were diverted. The resulting empty containers could also be recycled. The 84,000 litres of UVO is equivalent to about 76,000 litres of diesel fuel, so using the oil would reduce GHG emissions by 210 tonnes per year. The savings are summarized below:

- $1,900 per year for restaurants in landfill costs
- $3,900 per year for the City in reduced landfill subsidization
- $76,000 per year in imported fuel at a diesel cost of $1.00/litre[4]
- 210 tonnes per year of GHG emissions

Quantifying the Used Vegetable Oil Resource in Yellowknife

A survey was completed in April 2010 of most Yellowknife restaurants. The results of that survey are given in the table to the right.

Most of the restaurants and institutions surveyed put their used vegetable oil back into the 15L (4 gallon) pails or buckets in which they were purchased. Oil in the original containers is straightforward to collect as it can be picked up individually and placed in the back of a truck or van. The three exceptions are noted in the table with an asterisk. McDonald's pours their UVO into larger cardboard boxes lined with plastic, which they then freeze until time for disposal. The other two put their UVO in a bulk tank. Given the option of free pick-up of oil in original containers, these three restaurants could likely be convinced to change their used oil storage methods.

Restaurant / Institution	15L pails / week	L/year
A Taste of Saigon	3	2,340
A&W	4	3,120
Boston Pizza	6	4,680
Bruno's Pizza	8	6,240
Bullock's Bistro	4	3,120
Corner Mart Pizza	6	4,680
Coyote's Bar & Grill	4	3,120
Diamante	6	4,680
Fuego	2	1,560
Gold Range Bistro *	6	4,680
KFC	10	7,800
Larga Kitikmeot	1	780
Le Frolic / Bush Pilot Cafe	4	3,120
Mark's / Red Apple	7	5,460
McDonald's *	12	9,360
Papa Jim's	3	2,340
Pizza Hut	6	4,680
Salvation Army	0	0
Surly Bob's	3	2,340
The Black Knight	4	3,120
The Diner *	6	4,680
Thornton's	3	2,340
	Total:	**84,240**

1 City of Yellowknife (2011) *Tipping Fees.* http://www.yellowknife.ca/Assets/Public+Works+$!26+Engineering/RevisedSWFTippingFees-Jan1$!2c2011.pdf [accessed March 15, 2011]
2 Piedmont Biofuels (2011) http://www.biofuels.coop/pdfs/3_quality.pdf
3 Gartner Lee Ltd. (2007) *Final Report: City of Yellowknife Solid Waste Composition Study and Waste Reduction Recommendations.* Yellowknife, NT.
4 Natural Resources Canada (2011) *Fuel Focus.* http://nrcan.gc.ca/eneene/focinf-eng.php The average Canadian price for fuel oil on March 29, 2011 was $1.21 per litre.

Biodiesel Production

An Example: A Small Biodiesel Production Facility

The EverPure Biodiesel Cooperative in Erin, Ontario, began in 2008 by supplying biodiesel to farmers and other community members. Biodiesel was originally purchased from a large supplier, but in 2010 the Co-op struck a deal with a local business, Zuraw Tech, to process UVO and sell the biodiesel to the Co-op. The Collective began a full-circle operation by supplying fresh vegetable oil to restaurants and collecting the restaurants' UVO.

Pure biodiesel is sold in the summer from self-serve stations, and limited quantities of mixed diesel are sold in the winter. As of March, 2011, the Co-op had about 40 restaurants each contributing an average of about 1,000 litres per year (40,000 litres per year total).[5] The Co-op eventually hopes to produce 5,000 litres/week (260,000 litres/year).

The biodiesel is created in a large shop with concrete floors, vented storage tanks, an exhaust ventilation system, and spill containment for all liquids. Steel drums that are used for storing methanol are grounded to the building. Heavy vinyl collapsible berms are used for spill containment, which are available from S & G Diversified Products in California: http://www.sgenvironmental.com/

Michael Zuraw of Zuraw Tech states that their operation is currently not economically sustainable, and that they need to at least double their collection of UVO. Michael also stresses that restaurant oil requires lots of pre-treatment including dewatering, filtering, and acid esterification prior to conversion to biodiesel. When the free fatty acid (FFA) concentration exceeds 5%, as it does in most UVO, acid esterification is required in advance of the standard biodiesel reaction with alcohol. Restaurant oils can have FFA levels from 7% to 20% (Zuraw, 2011). Either sulphuric or phosphoric acid are used in the acid esterification.[6]

Other Biodiesel Co-ops

There are many biodiesel cooperatives operating in Canada. Many of them purchase biodiesel and sell it to their members, while a few produce their own biodiesel. A few notable cooperatives that have websites are given here:

- Vancouver Biodiesel Cooperative www.vancouverbiodiesel.org
  This cooperative purchases biodiesel and operates a card-lock pump for its members.
- Cowichan Biodiesel Cooperative www.smellbetter.org
  This cooperative gathers UVO and provides both biodiesel and UVO to its members.
- Island Biodiesel www.islandbiodiesel.ca
  This cooperative in BC supports individuals making biodiesel, assists with selling and trading of biodiesel between members, and has a vision to develop local infrastructure for biodiesel distribution and production.

[5] Zuraw Tech (2011) Michael Zuraw. Personal communication. March 15, 2011.
[6] Gerben, J. Van et al. (2004) *Biodiesel Production Technology*. National Renewable Energy Laboratory. p. 32. http://www.nrel.gov/docs/fy04osti/36244.pdf [accessed 21 March 2011]

Biodiesel Production in Yellowknife

Pre-Project Biodiesel Production

In December 2009, Yellowknife resident Daniel Gillis began to do independent research into the possibility of creating biodiesel for his own use. It soon became apparent to him that no such facility was in operation in Yellowknife, and this presented him with an opportunity of diverting used oil from the dump, and using it to save heating and transportation costs.

He began to build on his research by conducting small experiments at home. Gillis purchased an old diesel truck, and after ordering some materials and instructions from an internet resource, soon had created a form of biodiesel that he was able to successfully use in his truck for several weeks. This 'biodiesel' was simply a mixture of used vegetable oil (UVO), kerosene, a small amount of gasoline, and an even smaller amount of DSE (Diesel Secret Energy), a proprietary product that claims to reduce viscosity and increase the effective BTU of this form of biodiesel. See Appendix I for a description of the biodiesel production process followed by Gillis.

Although this fuel ran quite well in his old truck, complications ensued when the temperature dropped to below -25C. The fuel gelled significantly, and this made starting the vehicle problematic.

Later, Gillis experimented with this 'DSE biodiesel' by using it in his oil stove; a gravity-fed unit that is designed to operate on #2 Diesel, or heating oil. This was not very successful, as the fuel was too viscous to flow properly, and burned with a low-heat flame that was insufficient for heating in very cold temperatures. Additionally, it was very difficult to light and burned with a very black and sooty flame.

It became clear that only a clean-burning, high-BTU, low-viscosity fuel alternative could be considered. It is claimed that true biodiesel burns with virtually the same characteristics as diesel, so this was selected to be the fuel of choice.

A facility at 13 Coronation Drive was rented in order to produce biodiesel, and about 8 tonnes of used oil was collected prior to January 2011. At this point, the Fire Marshall was contacted and he responded with many issues that required a more in-depth analysis.

The Ecology North Biodiesel Project

In October 2010, the ENR and CanNor-funded biodiesel project began. A Fuel Meister biodiesel production system was purchased, and used oil was collected. By January 2011, about 8 tonnes of UVO was collected. When the Fire Marshall was contacted, a number of fire code issues became apparent. At this point, Ecology North hired a second contractor to investigate the fire code requirements and explore the options for using Yellowknife's used vegetable oil.

Biodiesel, UVO, Methanol, and the Fire Code

Buildings where flammable and combustible liquids are used have special requirements to reduce fire risk, and requirements relevant to the NWT are given in the 2010 National Fire Code of Canada (NFC). Liquids are divided into risk classes according to their flashpoints, where their flash point is the lowest temperature at which the liquid will vaporize to produce an ignitable mixture in air. Boiling points are also used to divide Class I liquids into

Class IA and IB. Flammable and combustible liquids are defined as follows, where definitions dividing classes have been omitted:

> ***Flammable liquid***: liquids with flashpoints below 37.8 °C (classes IA, IB, IC)
> ***Combustible liquid***: liquids with flashpoints between 37.8 °C and 93.3 °C (classes II, IIIA)

The flashpoints, boiling points, and NFC classifications of UVO, biodiesel, diesel, and methanol are given below.

Liquid	Boiling Point	Flashpoint	Fire Code Classification
Methanol	65 °C	12 °C	Class IB – flammable liquid
Diesel	>150 °C[7]	>40 °C	Class II – combustible liquid
Biodiesel	>200 °C	>130 °C[8]	NA
UVO	NA	320 °C	NA

Biodiesel and UVO both have flashpoints higher than 93.3 °C, while the NFC only regulates liquids with flashpoints lower than 93.3 °C. According to the NFC, liquids with flashpoints above 93.3 °C are not regulated "…because they are deemed to represent no greater fire hazard than other combustibles, such as wood or paper products."[9] Therefore, no special fire permits or regulations are required for the biodiesel or UVO itself. The use of methanol in the conversion process, however, does require the facility to meet the requirements of the NFC.

The requirements of a building or space where methanol is used are given in Division B, Part 4 of the NFC. Given the proposed facility space with area less than 100 m^2 and the proposed outdoor storage of methanol, the biodiesel facility could be located in a building of ***industrial occupancy*** **without an automatic fire suppression system and with a minimum 1-hour fire separation** if the following conditions are met:

- 4.2.9.1 – Maximum quantity of methanol stored is lessor of 1,500 litres or 100 litres/m^2 of floor area
- 4.1.1.4 – Electrical equipment and wiring conforms to CSA 22.1 *Canadian Electrical Code Part 1* for hazardous locations.
- 4.1.6.1 and 4.1.6.2 – Potential spills are contained by a non-combustible barrier or a non-combustible drainage system.
- 4.2.9.2 – Rooms must be liquid-tight where walls join the floors.
- 4.1.7.2 – Mechanical ventilation is provided that is interlocked with any process using the methanol, which means that the ventilation system must function simultaneously with the process. For example, the ventilation system could operate simultaneously with a methanol dispensing pump. Make-up or replacement air must be provided to compensate for exhausted air.

[7] Petro-Canada (2011) *MSDS.* http://www.online.petro-canada.ca/datasheets/en_CA/w104.pdf [accessed March 7, 2011]
[8] Biodiesel Association of Canada (2005) *MSDS for Biodiesel*. http://www.wbfuels.com/MaterialSafetyDataSheet.pdf [accessed March 7, 2011]
[9] National Fire Code of Canada (2010) Division B, Appendix A. Page A-14.

- 4.1.8.2 – Static electric charge is controlled by extending fill pipes to within 150 mm of the bottom of any tank being filled and by electrically connecting metallic storage and fill containers. Other methods must be used for non-metallic containers, such as limiting flow rates to less than 1 m/s, limiting the free fall of the liquid, extending fill hoses to the bottom of receiving containers, or by using anti-static additives.
- 4.2.9.5 – The room must be equipped with explosion venting, which is designed to prevent critical structural and mechanical damage from an internal explosion.

The YK Dairies building previously proposed for the biodiesel project does not meet these requirements. Spill containment is not possible due to the wood frame construction and the presence of adjacent storage suites. The wooden walls do not have a 1-hour fire rating and no mechanical ventilation is installed.

Potential Sites for the Biodiesel Project

For biodiesel production, an industrial building with concrete floors and concrete pony walls, existing ventilation systems, and potential spill containment would be required. The old Ron's Auto Shop located at 300 Woolgar Avenue, for example, would be an ideal location. The building was listed for sale in March 2011, however. Staff at Ron's Auto indicated that they would contact Ecology North if they did not sell the building and if they would therefore be interested in renting one bay in the building.

A small space within a vehicle garage would also be appropriate. Vehicle garages are equipped with exhaust fans to allow for operation of a motor vehicle indoors, and are already designed for storage of combustible and flammable liquids such as used motor oil and diesel. A vehicle garage could also benefit from the biodiesel produced, since the garage would most likely be heated with heating fuel.

Insurance

Liability insurance is required for a biodiesel operation, and Ecology North received notification in March 2011 that their existing liability insurance would not cover any aspects of a biodiesel operation. Norland Insurance Agencies of Yellowknife was therefore contacted to obtain a budget estimate of liability insurance costs for a Yellowknife-based biodiesel operation. The cost would be a minimum of $5,000 per year and could be higher depending on project location and other details.

Economic Analysis

In March 2011, after site suitability and insurance became a challenge, a more in-depth analysis of the economics of biodiesel conversion was completed. The annual costs and revenue of a biodiesel business are presented below, with the following assumptions:

- Collection efficiency of 75% (84,000 litres x 75% = 63,000 litres/year of UVO)
- Sale price of biodiesel: $1.00/litre
- Percent by volume conversion of UVO to biodiesel: 90%
- Percent by volume left as glycerin: 10%
- Glycerin disposal cost: $75/tonne
- Required labour input of 20 hours/week for collection, conversion, and sales

Revenue	
Biodiesel sales	$56,700
Expenses	
UVO collection costs (automobile costs)	$3,000
Chemicals and supplies	$4,000
Quality testing	$8,000
Waste disposal of ~3,100 plastic pails/year	$200
Waste disposal of glycerin	$500
Equipment Maintenance	$500
Insurance	$7,000
Electricity	$2,400
Rent	$7,200
Salary (20 hrs/week @ $40/hour including benefits)	$41,600
Revenue less expenses	**-$17,700**

The economic analysis showed that the project would not be economically viable, and that other options would need to be investigated for diverting Yellowknife's used vegetable oil from the landfill.

Opportunities and Challenges for NWT Communities

Yellowknife, with a population of 20,000 people, produces 84,000 litres of used vegetable oil. The next two largest communities, Hay River and Inuvik, both have populations of fewer than 4,000. If they produce the same volume per capita, they would produce less than 17,000 litres of UVO per year.

A call was even received one day from the small community of Fort Providence stating that a restaurant had hundreds of gallons of WVO that could be picked up. Because the storage area in Yellowknife was already full, and since the quality of this WVO was unknown, it was not picked up. However, this goes to illustrate that even in the smallest communities there may be opportunities to collect and process UVO.

Producing biodiesel in Yellowknife appears to be financially challenging, and the cost of producing biodiesel outside of Yellowknife would be much greater for a variety of reasons. The use of straight UVO in boilers for space heating seems to be a much more feasible option. Liability insurance combined with the difficulty in obtaining pure methanol and the relatively small volumes of UVO available would make the cost of biodiesel production prohibitive. Used oil boilers are already installed in many communities to burn the oil from vehicles and other equipment, so many people are already familiar with burning used petroleum oils. The extra measures required to burn UVO could be completed by any heating contractor and would not require specialized equipment, chemicals, or technologies.

There are countless biodiesel operations throughout the world, however, that are very small and are designed to supply the needs of only a single household. These small operations are not subject to the rigours of government control, and are therefore very easy to build and operate, but are only feasible as a garage operation by a homeowner looking to save fuel costs.

Anyone with the ambition to save money on fuel while helping the environment can find plans on the internet to build their own biodiesel processing station. The best idea is to use found materials, such as a used water heater and second-hand plumbing. This will save considerably on the cost of the operation. The key is to take the time to follow directions and take small steps by making small experiments and test batches before attempting to create large batches of biodiesel.

In addition, individuals looking at biodiesel production need to ensure that they can get the requisite chemicals. Lye can be purchased online from businesses that deal with soap-making, and bulk methanol can be ordered through a general supply store. Methanol may be very expensive to get delivered, and it makes up 20% of the fuel, so if it costs $5/litre, the fuel will cost at least $1/litre to make.

An Alternative: Direct UVO Use

An alternative to converting UVO to biodiesel is to use UVO directly in water heaters, furnaces, or boilers specifically designed for heavier weight oils. There are many farms, restaurants, and greenhouses that have begun burning UVO and other products such as animal fats directly for heat.[10,11] The advantages and disadvantages to directly using UVO in boilers, compared to producing biodiesel, are listed below:

Advantages

- **No facility space required.** UVO would be delivered directly to the building where it is being used, and could be stored outdoors if not needed immediately.
- **Lower costs and less labour.** No chemical supplies, conversion equipment, or quality testing would be needed, thus reducing total operating costs. Insurance premiums would likely be lower, and there would be no utility bills. The labour required to convert the UVO to biodiesel would also be eliminated.
- **No retail sales.** No cash register, fuel pump, or staff time for retail sales would be required.
- **Minimal waste by-product.** The only waste by-product consists of water removed from the used oil along with solids that are filtered out. These solids can be composted.

Disadvantages

- **Application limited to large buildings and/or water heating loads.** UVO can only be used in equipment specifically designed for its use. Biodiesel, however, can be blended with regular fuel and used almost anywhere that regular fuel is used. Due to the cost of UVO boilers, the case only makes sense if one or a few large buildings can be identified that could use all of the UVO collected. A suitable building with an owner willing to install a new boiler or have a boiler installed outside the building is required.
- **Less public exposure.** Retail sales would likely result in more public exposure and greater awareness of the project when compared to using UVO in a few select buildings for water or space heating.

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[10] Grubinger, Vern (2006) *Case Study: Mike Collins, Old Athens Farm, Westminster, Vermont.* University of Vermont. http://www.mainerural.org/energy/fieldguide/casestudyoilheatgreenhouse.pdf [accessed 21 March 2011]
[11] Laughing Stock Farm http://laughingstockfarm.com/Renewable/Renewable.htm [accessed 21 March 2011]

Implementation Model

Used vegetable oil boilers are more expensive than standard oil boilers, so the approach to use UVO directly would only make sense for a few large buildings. It would be most logical for one business to collect the UVO, own a boiler, and sell heat to a building owner. This business (UVO Business) would ensure the boiler oil tank remains filled and ensure that the boiler is properly maintained. A meter would be installed on the boiler to determine the amount of heat sold and to properly bill the building owner. Thus, to obtain any revenue the UVO business would have to ensure the boiler was operating and delivering heat.

UVO would be collected throughout the year in 15-litre plastic pails from restaurants and stored outdoors until required. The oil would freeze solid in winter, but could be brought inside to thaw prior to use. The oil would thus present minimal fire hazard and could be stored in its original containers until required. The amount of stored oil would be greatest in the fall at about 21,000 litres, assuming the oil is only being used during the heating season and 63,000 litres (75% of 84,000 total available) was being collected annually.

Another option for the direct use of UVO in boilers would be for restaurants to install boilers so that they can use the oil directly in their own boilers. The replacement of an existing boiler with one capable of using both restaurant oil and heating oil would mean no secondary boiler building, no transportation of their oil, and lower engineering and installation costs compared to the installation of a separate boiler building to serve a large building. The restaurant, however, may have a challenge in retaining staff knowledgeable of the boiler and familiar with its operation. This option would only be feasible in larger restaurants that own their own building and which produce enough oil to operate a boiler.

Case Study: Laughing Stock Farm, Maine

This certified organic, 12 acre, four-season farm has been burning used vegetable oil and animal fats to heat winter greenhouses since 2003.[12] The farm is using a Clean Burn boiler, one that is also common in Yellowknife and elsewhere in the NWT. The boiler has a rated output of 372,000 Btu/hour and the burner (CB500) has a maximum oil flow rate of 13.5 litres per hour. Laughing Stock Farm burns about 34,000 litres (9,000 gallons) per year of vegetable oil and animal fats collected year-round from restaurants in their local region. The collected oils are about 70% vegetable oils and 30% animal fats.

The farm is able to burn all vegetable oils and animal fats, and doesn't have to be selective about what it collects. Ralph Turner, co-owner of Laughing Stock Farm, says that the bottom of the storage tanks often have 2 inches of crumbs and 6 inches of water, all of which is drained off and composted.

Ralph Turner is also a Professional Engineer and is Co-Chair of a working group at ASTM developing a *Standard Specification for Triglyceride Burner Fuels.* Triglyceride is an ester formed from glycerol and three fatty acids, and is the main component of vegetable oil and animals fats. The specification passed the subcommittee level of ASTM in December, 2010, and Ralph expects the standard to receive final approval by sometime in 2012. Once the fuel has a specification, testing and approval agencies such as the CSA and URL can test boilers and approve them for that fuel.

[12] Laughing Stock Farm (2011) Ralph Turner, owner. Personal communication. March 21, 2011.

A video of Clean Burn boilers and the installation at Laughing Stock Farm is available online on Clean Burn's website: http://www.cleanburn.com/advantage/environment.html

More info about the burning of used oil at Laughing Stock Farm is available on the farm's website: http://www.laughingstockfarm.com

Technical Issues with Burning Used Vegetable Oil

Used vegetable oil and animal fats, when used in boilers, are referred to as Triglyceride Burner Fuel (TBF). Burning TBF in boilers is most similar to burning used petroleum oils since the viscosity of the two fuels is similar and burners designed for one fuel can handle the other. There are a few important differences, however:

- **Higher viscosity:** TBF has a higher viscosity than used petroleum oils and thus has to be heated for ease of pumping and for proper combustion. Both the holding tank and the line leading to the boiler need to be heat-traced and kept at a temperature of 50-60°C (120-140°F). The required temperature depends on fuel, since animal fats are more viscous and thus require a higher temperature than vegetable oils.
- **Variable viscosity:** The viscosity of TBF varies with temperature and specific type of fuel, so burners should use positive displacement pumps. These types of pumps move a specific quantity of liquid with every stroke or turn so that the pumping rate is independent of fluid properties.
- **Less Ash:** TBF produces very minimal amounts of ash, so boiler cleaning is required less often than for used petroleum oils. Ralph Turner of Laughing Stock Farm reports that he let his boiler run on TBF for 10,000 hours, or about 4 years, before cleaning, and there was minimal ash in the boiler. Boilers burning used petroleum oil need to be cleaned about every 1,000 hours.[13]
- **Lower Emissions:** TBF has lower sulphur contents than even No. 2 fuel oil.
- **Sticky:** Dripping oil can clog the nozzle where vegetable oil is injected into boilers. There are several methods used to prevent this:
    - Dual fuel boilers that burn propane, natural gas, or regular heating fuel on a rotational basis will burn off any residual vegetable oil with the higher fossil fuel combustion temperatures.
    - INOV8 has developed a burner with a pin that injects into the fuel nozzle to prevent the nozzle from plugging. However, one past user of INOV8 products stated that this pin itself occasionally becomes stuck in the nozzle.[14]

Boiler Sizing

A single boiler sized at 100% or more of a building's peak heating load does not operate at peak efficiency for most of the year due to frequent on/off cycling. Two or more boilers are typically installed in large buildings for this reason and to provide redundancy in case of a boiler failure. Public Works and Services of the GWNT typically installs two boilers each sized at around 60% of the building's peak load. One of the two boilers is always serving as a peaking boiler, which will only fire when the heating load is high such as when outdoor temperature drops below -20 °C.

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[13] Clean Burn (2011) *Used-Oil Coil Tube Boilers.* http://www.cleanburn.com/products/manuals/CB-200_350_500%20CTB%20BOOK.pdf [accessed March 21, 2011]
[14] Turner, Ralph (2011) Laughing Stock Farm. Personal communication. March 21, 2011.

A base boiler sized for only 50% of a building's peak space heating load will provide about 90% of the building's annual space heating. The GNWT sizes wood pellet boilers as base boilers at 50% of design heat load to offset fuel use in large buildings. The boiler cost is much less than a boiler sized for 100% of the building's load, but offsets almost as much fuel. A UVO boiler should also be installed as a base boiler sized at less than 60% of the building's peak heat load. The boiler will be less expensive, would have better combustion[15], and would operate more efficiently due to less on/off cycles. UVO use would be more evenly distributed throughout the year, resulting in less UVO storage requirements.

Boiler Selection

Three companies located in the United States were identified whose boilers are designed for UVO or which have been extensively tested with UVO:

- Inov8 International Inc., located in Wisconsin: http://www.inov8-intl.com/
- AgSolutions, located in Kentucky: http://www.agsolutionsllc.com
- Clean Burn, located in Pennsylvania: http://www.cleanburn.com/

Potential Building Criteria

The estimated UVO production in Yellowknife is 84,000 litres per year, so a building should be chosen with a fuel consumption of more than 84,000 litres per year so that vegetable oil heat provides less than 90% of total space heating requirements. It would be prudent to choose a building with even higher consumption, perhaps greater than 100,000 litres per year. This would ensure that all UVO can be used even if energy efficiency measures are taken in the building in the future or if used vegetable oil production increases. To determine a suitable building the following information would be required:

- fuel consumption data including specific delivery dates and quantities or monthly totals,
- electrical and mechanical drawings for the boiler room, and
- assurance that the building will remain in use for at least another 10 years.

Economic Analysis

The financial feasibility of using UVO directly was analyzed. As with the analysis of biodiesel production, this analysis assumes collection of 75% of Yellowknife UVO production, or about 63,000 litres per year. The analysis uses the following assumptions:

- Boiler efficiency: 80%
- UVO energy content of 34.8 MJ/litre or about 90% of that of No 2 heating fuel[16]
- Price of heat sold: $27.50 per gigajoule (equivalent to about $0.85/litre fuel oil at 80% efficiency)
- Required labour input of 10 hours/week for collection and boiler maintenance
- UVO would be collected year-round and would be stored outdoors. No storage costs have been included.

[15] INOV8 states that longer burn times will keep the combustion chamber hotter during firing and will result in less deposits and less cleaning. If more than one boiler is installed, they recommend a first-on, last-off control sequence.
[16] Inov8 http://www.inov8-intl.com/pdf/2010-hw210brochure.pdf

Revenue	
Sale of heat to building owners	$48,200
Expenses	
WVO collection costs (automobile costs)	$3,000
Waste disposal of ~3,100 plastic pails/year	$200
Equipment Maintenance	$5,000
Electricity	$1,500
Insurance	$5,000
Salary (10 hrs/week @ $40/hour including benefits)	$20,800
Revenue less expenses	**$12,700**

This option appears to be economically viable. The following budget was therefore developed for the installation of a UVO boiler, based on quotes from INOV8 for their boilers and a quote from FSC Architects & Engineers for engineering services. This budget results in a simple payback of approximately 10 years for the UVO business based on annual income of $12,700 after all costs including labour.

Budget for UVO Boiler Install

One boiler at one YK building

Project Management		$20,000
Engineering		$40,000
UVO Tanks		$5,000
Boiler		$25,000
Boiler building		$20,000
Boiler installation		$15,000
	Total	**$125,000**

Potential Sites

The ideal building for a UVO boiler would have the following characteristics:

- Be outside of the downtown core to avoid competition from a potential future district heating system, and to ensure sufficient space around the building for a new boiler building.
- Have a long heating season without other base loads that reduce the spring and fall heating loads.
- Be owned by a secure long-term customer such as the City of Yellowknife, a school district, or the GNWT.
- Be in good condition to ensure the building will still be used for a minimum of another 10 years.

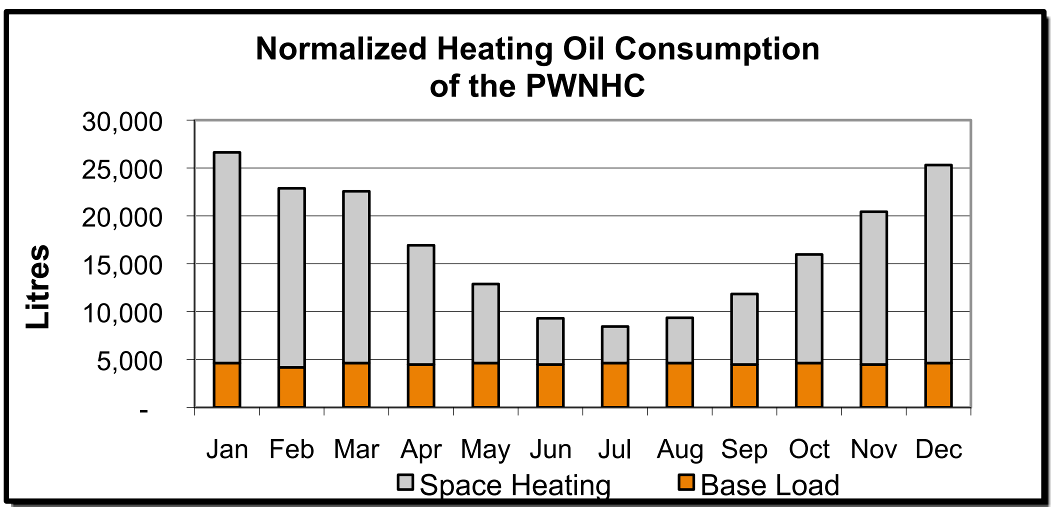
There are two approaches to determining the ideal size of building. One approach would be to offset the majority of the chosen building's fuel consumption, which would be advantageous to the building owner and would reduce the chances of future competition from other fuel sources. A second approach would be to select a building with a summer heat load and a full year heating season to reduce or eliminate the requirement for UVO storage and allow for a smaller boiler since the boiler would be operating for more months of the year. The two approaches are outlined below:

1. Select a building with a fuel consumption of 100,000 to 140,000 litres per year to ensure ability to use all UVO but also to allow UVO to provide the majority of the heating needs.
2. Select a building that requires fuel year-round. Ideally a building with consumption of approximately 6,000 litres per month in the summer could be selected, which would completely eliminate any UVO storage requirements.

Suitable Buildings

Potential buildings that have already been identified are listed below:

- **Prince of Whales Northern Heritage Centre (PWNHC)** – this building is owned by the GNWT and was built in 1979. Fuel consumption was 215, 258, and 250 thousand litres of fuel in 2006/07, 2007/08, and 2008/09, respectively. Recent fuel data for April – November 2010 was normalized to estimate current consumption at about 190,000 litres per year. There is some space around the building for an additional boiler and for UVO storage, though the mechanical room is located on the north corner, where space is limited and where walking paths and parking are located. As a public building, it would accommodate educational events and displays regarding the use of UVO for heating the building. This building would not likely be connected to a district heating system in the future due to its distance from other buildings. It has a high fuel requirement because of humidification for the preservation of artifacts, and requires fuel for most months of the year. The longer heating requirement for this building would allow for the installation of a smaller boiler and would mean less UVO storage requirements. A staff committee at PWNHC have also recently organised to investigate options for reducing energy consumption and costs. This is an extrapolation of data based on 8 months excluding the coldest ones, so this is only an approximate snapshot of monthly consumption, and this chart shows somewhat lower consumption than for the years of 2006-2008. Regardless of the approximation, the data is sufficient to say that the building uses between 180,000 and 250,000 litres per year.



- **City of Yellowknife Multiplex** – this building has a significant amount of exterior space and could use all of Yellowknife's UVO. Fuel consumption was 230,000 litres in 2009/10 but should be slightly lower now with the installation of heat recovery from the ice rink.[17] The existing boilers are on the second floor, which adds a minor complication and some cost to potential piping connections. The use of heat recovery also shortens the potential heating season for a UVO boiler since the recovered heat would provide the necessary heating during mild weather.

[17] City of Yellowknife (2011) Mark Henry, Energy Coordinator. *Personal communication.* March 16, 2011.

- **City of Yellowknife Field House –** this new building (2010) is expected to have a fuel consumption over 100,000 litres per year.[18] Because the building is very new, much of the space around the building has not been landscaped or otherwise allocated to other uses. The building accepts recovered heat from the Multiplex ice rink, however, which would result in a more complex control of three different heating sources. The heating season for a UVO boiler would again be shorter than for other buildings.
- **Yellowknife Schools –** there are several schools situated outside of the downtown core that don't already have wood pellet heat and that have sufficient fuel consumption to satisfy the requirements of this project. There is some interest in installing a pellet boiler to heat both St Patrick & Weledeh schools, so these schools may be less suitable. A total of five schools have suitable fuel requirements:
    - **William McDonald –** 95,000 litres in 2006/07
    - **Range Lake North –** 125,000 litres in 2006/07
    - **Sissons School –** 101,000 litres in 2006/07
    - **Mildred Hall –** 166,000 litres in 2006/07
    - **St Patrick & Weledeh** - 198,000 litres in 2006/07
- **Rockhill Apartments (YWCA)** – this apartment building at 4910-54 Ave is owned by the GNWT but is leased to the YWCA and is used as transitional housing for families. It uses approximately 107,000 litres per year based on heating costs from 2008/09.[19] This is not an energy-efficient building, and an energy audit completed by PWS on the building in 2010 proposed measures that would reduce fuel consumption to less than 70,000 litres per year. The building is old, and the building could be either retrofitted or replaced in the next 10-15 years. If retrofitted, the building may not be able to consume all of Yellowknife's UVO. Politically, however, there would likely be strong support for a cheaper fuel source for this building as the YWCA has been struggling to pay for the increasing cost of heating fuel. As a non-governmental organization, the YWCA could more easily access funding to install a boiler, and could also undertake fundraising to pay for the boiler. The collection of UVO and the maintenance of the boiler would best be contracted out to a local business with payment based on heat produced to provide direct incentive to keep the boiler operating. A heat meter would thus be installed, and the cost to provide UVO and maintain the boiler would be somewhat lower than the cost of heating fuel. Based on the budget presented earlier in this document, the cost would be equivalent to about $0.60/litre for diesel.

Other Buildings that May be Considered

The following building planned for construction could be considered if it proceeds quickly or if the UVO project experiences delays in implementation. It would be ideal if a UVO boiler could be planned during the design stages of a new building.

- **New Women's Transitional Housing –** a new transitional housing facility is planned for 54th street. The size of the building is still unknown, however, and likely won't be defined until the summer of 2011.[20]

[18] *Ibid.*
[19] Public Works and Services (2010) *Heating Energy Analysis YWCA Rockhill Apartments*. Government of the NWT.
[20] Yellowknife Homelessness Coalition (2011) Amanda Mallon, Co-Chair. *Email communication.* March 16, 2011.

Buildings Considered but Rejected

It is worthwhile noting which other buildings were considered and rejected.

- **City of Yellowknife Baling Facility** – a boiler at this location could be owned and operated by the City of Yellowknife since restaurants already take their cooking grease to the landfill. The City could amend its tipping fee for cooking grease and make the disposal of cooking grease free. The City recently invested in a wood pellet boiler for the baling facility, however. The value of the UVO heat would thus be lower, equivalent to that produced by wood pellets. Annual fuel consumption at the facility was only 55,000 litres prior to the installation of the wood pellet boiler.[21]
- **City Hall** – this building uses about 61,000 litres per year of fuel oil.[22] Space around the building is limited, and the consumption is slightly lower than desired. The building is also within the downtown zone that could be served by a district heating system.
- **City of Yellowknife Main Pumphouse** – a significant amount of heat is required for water heating at this facility, but this heat is used over a relatively short period from mid-December to April. Thus, a UVO boiler would have to be sized larger than for a typical space heating application and UVO storage requirements would be higher. Fuel consumption was 285,000 litres in 2007/08, 214,000 in 2008/09, and 137,000 in 2009/10.[23]
- **City of Yellowknife Garage/Shop** – this building only uses about 42,000 litres per year of heating fuel.[24]

Boilers for Consideration

A boiler operating for 80% of the time during an 8-month heating season would need a flow rate of 19 litres/hour to use all of the available oil in Yellowknife. For an assumed used oil collection efficiency of 75%, the boiler would require a flow rate of 14 litres/hour. This equates to 5 and 3.7 US gallons per hour, respectively. A boiler with a lower flow rate would require a longer heating season or would have to be kept running more than 80% of the time to be able to use all of the available oil.

Inov8 International HW610 Boiler

The HW610 is the largest boiler manufactured by Inov8 and has a flow rate of 17.4 litres per hour (4.6 US gallons per hour). Of the three boilers listed in this report, the INOV8 boiler is the one most specifically targeted at used vegetable oil. The company is focused on providing boilers to the restaurant market and has extensively tested their boilers with UVO. There is at least one older model of INOV8 boiler being used in Yellowknife to burn used petroleum oil.[25]

This boiler uses a needle inserted into the burner nozzle to prevent oil blockage. This method, however, is reported by Laughing Stock Farm to cause problems. The needle occasionally becomes stuck itself, thus solving one problem but causing another. Discussion with users of recent INOV8 boilers is needed to determine if the sticking needle is still a problem in newer burners. The INOV8 burner has an ultraviolet flame sensor that INOV8

[21] City of Yellowknife (2011) Mark Henry, Energy Coordinator. *Personal communication.* March 16, 2011.
[22] *Ibid.*
[23] *Ibid.*
[24] *Ibid.*
[25] Faus, Rebecca (2011) INOV8 International Inc. Personal communication. March 14, 2011.

claims is superior to more common sensors because of the very light coloured flame of vegetable oils and biodiesel.

The University of Guelph has an INOV8 boiler that was purchased in 2008 and which has operated since 2009, mostly on biodiesel but also for a short time on vegetable oil. Mark Uher, a technician at the University, reports that INOV8 has good service.[26] However, the oil pump on the burner had to be rebuilt in 2010 after only 1,000 hours of use, and the University experienced a few problems with burning used vegetable oil. Mark reported that some settings were incorrect at the beginning for used vegetable oil. The University is now burning pure biodiesel and says that the boiler and burner are working well.

Ralph Turner of Laughing Stock Farm previously used an older model INOV8 boiler, which he replaced with a Clean Burn boiler due to a variety of issues. The needle was sticking in the nozzle, the air pressure was not adjustable and could not be increased high enough for vegetable oils, and the oil pump flow rates would vary with oil viscosity due to the use of a diaphragm pump rather than a positive displacement pump. In newer INOV8 burners, the pump appears to be the same, but the air pressure can now be controlled.

AgSolutions LLC B500 Boiler

The biggest boiler manufactured by AgSolutions is the B500 with a fuel flow rate of 14.19 litres per hour (3.75 US gallons per hour).

The AgSolutions boilers are advertised for restaurants as well as biodiesel facilities where they can burn vegetable oil and fuel with a certain percentage mix of the glycerin by-product from biodiesel production. These boilers use a Kagi burner, which in contrast to the INOV8 boiler, purges oil out of the system to prevent nozzle plugging. The company reports the boilers being widely used with vegetable oil, but the dealer for western Canada stated that he has no customers who are burning UVO in their boilers.[27] More investigation should be completed before considering this boiler for use with UVO.

Clean Burn CB-500

This boiler is the biggest manufactured by Clean Burn, and has a maximum fuel consumption of 13.5 litres per hour (3.57 US gallons per hour). There are several Clean Burn boilers in use in Yellowknife, and this manufacturer was recommended by an engineer at FSC Architects and Engineers in Yellowknife due to the reliability and ease of maintenance of their products.[28]

The Clean Burn CB-500 boiler is being used by Laughing Stock Farm, and the boiler and burner are reported to work very well, be easy to clean, and be easy to maintain and operate.[29] The dripping and plugging nozzle is a problem, but nozzles on this burner are easy to remove for cleaning. Ralph, co-owner, says that he removes the nozzle for cleaning about once per week. He keeps numerous nozzles on hand so that he can simply exchange the nozzle with a clean one. He then only has to clean nozzles every few months, which he does by soaking the nozzles in a pH 13 solution to remove any sticky oil. Ralph has to change the nozzle more than once/week in the

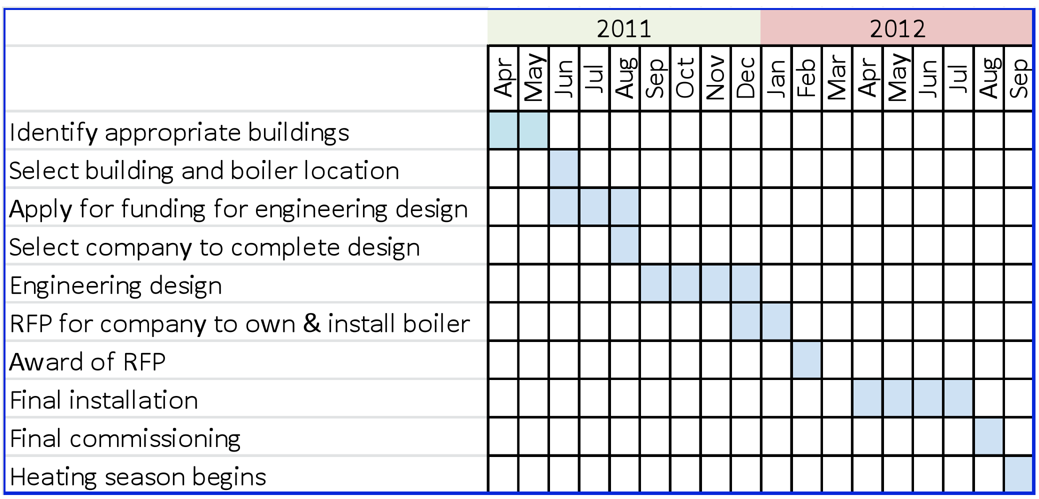
[26] Uher, Mark (2011) University of Guelph. Personal communication. March 16, 2011.
[27] Akawashi (2011) Katana Systems. Personal communication. March 21, 2011.
[28] Peer, Mark (2011) FSC Architects and Engineers. Personal communication. March 11, 2011.
[29] Turner, Mark (2011) Laughing Stock Farm. Personal communication. March 21, 2011.

spring and fall when the boiler is operating with more frequent on/off cycles, but this partial load scenario would be minimized in a situation with a large building and a boiler sized for about half of the design heating load.

A major benefit of the Clean Burn burner is the positive displacement pump. This pump ensures a constant flow of oil regardless of fluid temperature and viscosity. In situations where the oil temperature varies or where fluid viscosity varies, the positive displacement pump ensures constant flow to the burner. Burners on the other two boilers use pressure pumps which will pump less fluid if viscosity increases.

Next Steps

Using UVO directly would mean significantly lower operating costs compared to a biodiesel conversion operation. Using UVO directly appears to be the only option with annual positive cash flow. Thus, finding a suitable building would be the next logical step to determine if this approach can be taken. Finding an owner willing to purchase heat from a UVO boiler would facilitate further steps such as acquiring funding. The following GANTT chart shows a suggested timeline for project implementation.



Conclusions

Following fire code and insurance issues, no biodiesel was produced during this project. However, facility requirements for a biodiesel facility were determined, and a more in-depth analysis of the economics of biodiesel conversion was completed. An alternative, that of using UVO directly for space heating, was researched and an implementation model was developed. This alternative method of using UVO appears to be more financially feasible and thus a better long-term way of diverting Yellowknife’s used vegetable oil from the landfill and making it into a valuable resource.

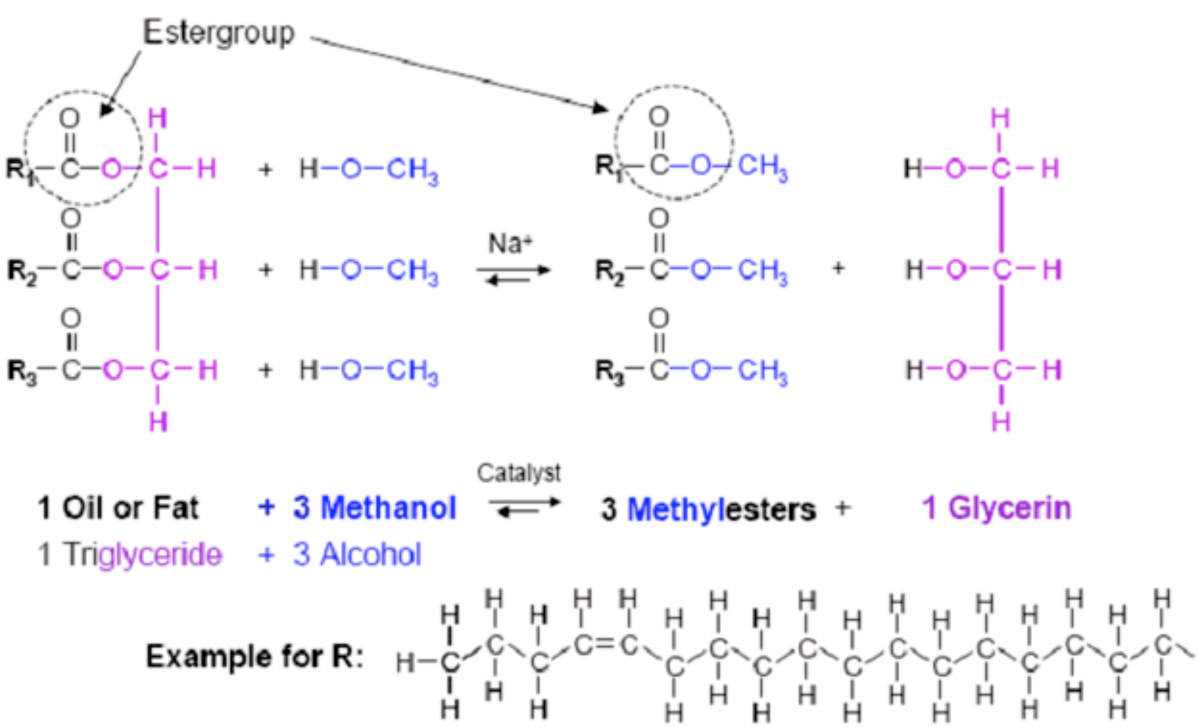
Appendix I: Description of the Biodiesel Production Process

Description of the physical and chemical process of biodiesel production

Biodiesel is made from vegetable and animal oils and fats, or **triglycerides**. Biodiesel cannot be made from any other kinds of oil (such as used engine oil).

Chemically, triglycerides consist of three long-chain fatty acid molecules joined by a glycerine molecule. The biodiesel process uses a catalyst (lye) to break off the glycerine molecule and combine each of the three fatty-acid chains with a molecule of methanol, creating mono-alkyl esters, or Fatty Acid Methyl Esters (FAME) -- biodiesel. The glycerine sinks to the bottom and is removed.

This process is called **transesterification**. A transesterification is the conversion (switching) of one ester into another -- a glyceride ester into an alkyl ester in the case of biodiesel, where methanol replaces the glycerine. The diagram below shows a simplification of the chemical process, where R represents different alkyl groups.



The factors affecting the transesterification process are

1. Oil temperature
2. Reaction temperature
3. Ratio of alcohol to oil
4. Catalyst type & concentration
5. Intensity of mixing
6. Purity of reactants

Chemicals Needed

Methanol

Methanol is also called methyl alcohol, wood alcohol, wood naphtha, wood spirits, methyl hydrate (or "stove fuel"), carbinol, colonial spirits, Columbian spirits, Manhattan spirits, methylol, methyl hydroxide, hydroxymethane, monohydroxymethane, pyroxylic spirit, or MeOH (CH_3OH or CH_4O). It must be 99+% pure.

For a complete reaction, 20% to 22% methanol by volume must be used, or 200-220 ml methanol to 1 litre of UVO. This usually gives good results. Difficulties with washing and the quality checks are more often due to errors with titration and inaccurate measurements or to poor processing than to not enough methanol.

Lye

The catalyst can be either potassium hydroxide (KOH) or sodium hydroxide (caustic soda, NaOH). Potassium hydroxide reacts much quicker, and tends to produce a more complete reaction with less agitation and heat. Sodium hydroxide is more readily available, costs less, and is the standard catalyst for titration.

NaOH is used as a drain-cleaner and you can also get it from hardware or soap-making stores. It has to be pure NaOH. With used oil, titration with NaOH to check the acid content has become the de-facto comparative measure of different oils; whether they use NaOH or KOH in their processing, when describing oils most biodiesel brewers refer to however many millilitres of NaOH solution it needed to titrate the oil.

Titration

For processing used oil, it's essential to titrate the oil to determine the Free Fatty Acid (FFA) content and calculate how much extra lye will be required to neutralize it. The higher the titration level, the more water, impurities and suspensions the oil is likely to contain and the longer it will take to settle.

The basic amount of lye required to process pure Canola oil is 3.5mL per litre of oil. There are various ways to titrate oil, from using test strips to phenolphthalein to electronic pH meters. The end result of all these methods is to come up with the exact ratio of lye to a particular batch of UVO.

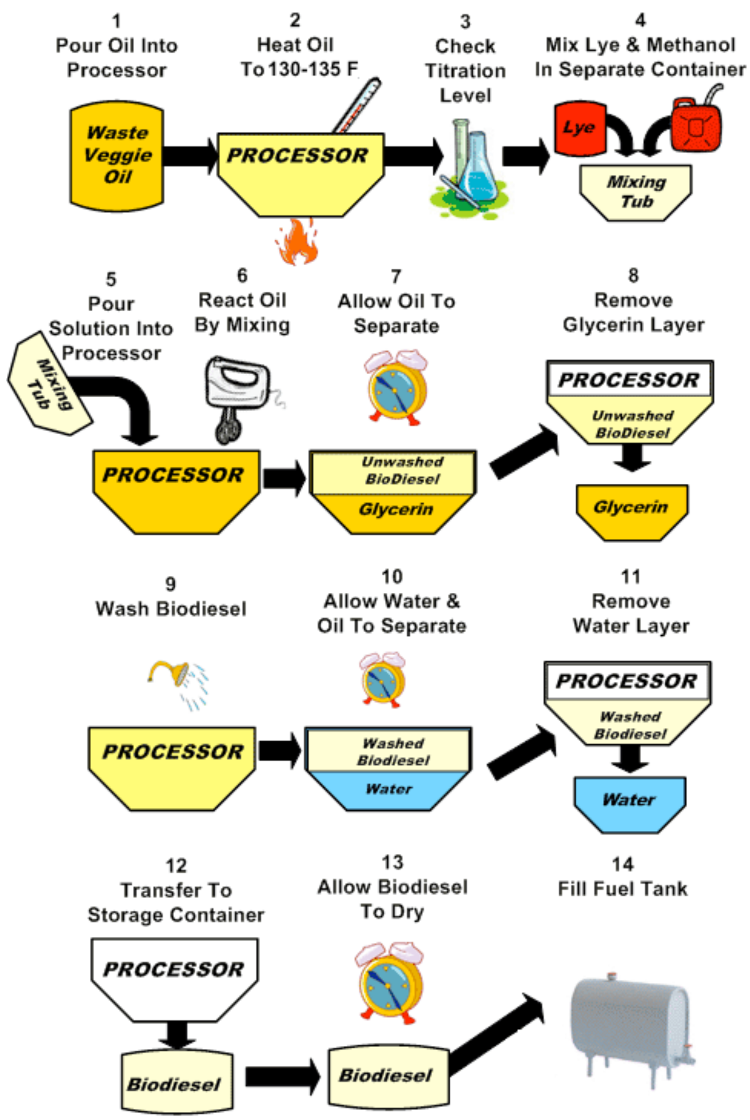
Too much lye, or using lye that has absorbed excessive moisture, will result in the creation of a batch of soap, entirely useless as fuel, but quite useful as an all-purpose cleaner. Too little lye will result in incomplete reaction, so the fuel will still contain glycerides, and may be harmful to the vehicle or heater it is used in. Therefore, using the precise amount of lye is critical.

Processing Biodiesel

Processing biodiesel is really quite straightforward; complexity is only added to further purify the fuel throughout the process. Basically, used oil is filtered for solid impurities, then passes into a processing station where it is heated to promote the chemical reaction about to take place. In a separate container, lye and methanol are mixed to create methanoxide. When the lye has fully dissolved, the methanoxide is ready to be introduced into the main reaction station with the used oil. Here, the combination is mixed and heated until a complete reaction takes place.

After waiting a prescribed amount of time, normally overnight, the glycerine will sink to the bottom of the processing station, and will be ready to be drained off by gravity. The remaining liquid in the processor is biodiesel. The only remaining step is to wash the fuel, either by water washing or a chemical wash. This is necessary to remove the water and any other impurities that remain in the fuel.

Once the biodiesel is fully washed and dried, it will be ready for use.



Washing Biodiesel

Biodiesel must be washed before use to remove soaps, excess methanol, residual lye, free glycerine and other contaminants. Quality biodiesel is well-washed biodiesel. This can be done by water-washing, or by a chemical process called Dry Washing. This uses chemicals such as Amberlite to pull out the suspended water.

Drying the fuel

When the fuel is clear - not colourless but translucent, - then it's dry. Actually it's never dry: despite what the standards say, it always absorbs some water from the atmosphere (1,200 ppm or more), but this is dissolved water, which is harmless, unlike suspended water, which must be removed.

This is usually accomplished by heating the resultant fuel and then allowing the water to settle out; or by using a bubble-drying technique.

Product Quality

Prior to use as a commercial fuel, the finished biodiesel must be analyzed to ensure it meets the required specifications. The most important aspects of biodiesel production to ensure trouble free operation in diesel engines and oil furnaces are:

- Complete Reaction
- Removal of Glycerin
- Removal of Catalyst
- Removal of Alcohol
- Absence of Free Fatty Acids

Processing UVO – Comparing Different Methods

There are many different variations for the various processes, chemicals and methods used to create biodiesel. This section will outline the pros and cons of many of these considerations, with a rationalization of each method that will be used for this project.

Biodiesel Types

There are three different types of fuel that could be considered biodiesel: Methyl ester biodiesel, hybrid biodiesel and SVO. Mixtures of biodiesel and petrodiesel can also be considered, where “B20” represents 20% biodiesel, 80% petrodiesel mix.

Shown below is a table of fuel properties for various types of biofuels, as compared with petrodiesel.

Fuel Properties Compared

	Density (Lbs/gal)	Heat of Combustion (BTU/gal)	Cetane Number	Viscosity (Centistokes)
#2 Diesel	7.05	140,000	48	3.0
Methyl Ester Biodiesel	7.3	130,000	52	5.7
B20 Mix	7.1	138,000	50	3.3
SVO	7.5	130,000	35 to 45	30 to 50

Generally, diesel engines run well with a cetane number (CN) from 40 to 55. Fuels with higher CN which have shorter ignition delays provide more time for the fuel combustion process to be completed. Hence, higher speed diesels operate more effectively with higher CN fuels.

Methyl Ester biodiesel, or 'true' biodiesel

Methyl ester biodiesel is created through the transesterification process. It involves the process mentioned above, where all the glycerine and other impurities are removed, to create pure methyl ester. Biodiesel is denser than petrodiesel – this may account for the fact that although the heat of combustion of biodiesel is slightly less than petrodiesel, the fuel mileage is virtually the same.

The major drawback for biodiesel is its increased viscosity – because most new diesel engines are designed to run on very low viscosity petrodiesel, it is often necessary to dilute biodiesel with petrodiesel to run this type of engine effectively.

Hybrid biodiesel

This 'DSE Biodiesel' consists of a mixture of filtered straight vegetable oil, 20% kerosene, 5% gasoline, cetane booster and a small amount of DSE (Diesel Secret Energy) that is a proprietary product that claims to produce a fuel that is entirely compatible with regular diesel engines. Although Gillis experienced some success with this product, it was not compatible with a very low-tech and simple gravity-fed oil stove, and caused major problems with a diesel engine in low-temperature conditions.

Hybrid biodiesel can describe any type of SVO and kerosene mix. Although kerosene effectively reduces the viscosity, it also reduces the lubricity. Since biodiesel has a very high level of lubricity, the reduction from mixing with kerosene balances out. However, no more than 20% kerosene by volume should be added.

Straight vegetable oil (SVO)

SVO can only be used in a diesel engine or furnace with modifications, due to its high viscosity. Conversion kits are advertised starting at $1000, but based on a report from Whitehorse, a conversion of a diesel engine in the north will cost closer to $5000. This approach might be practical if all the fuel was intended to be used in one converted vehicle, but is certainly not practical for use in multiple homes, as each homeowner would have to carry out expensive modifications. It makes much more sense to have a central fuel conversion facility and then distribute a compatible fuel.

Catalysts

There are a number of different types of catalysts that can be used in the transesterification process. The main types are

Base Catalysts

The most common and effective base catalysts are NaOH and KOH, although CaO has also been successfully employed.

- Sodium Hydroxide (NaOH)
  One reason for preferring NaOH solution is that it's usually the standard used in describing FFA content of different oils
  NaOH is more readily available than KOH, and is less expensive to purchase
- Potassium Hydroxide (KOH) is not as strong as NaOH, so you must use 1.4 times as much KOH
  KOH dissolves in methanol much faster and more easily than NaOH does, and doesn't "clump" together as NaOH can do. When you use KOH the glycerine by-product is liquid and won't solidify.
  KOH is generally easier to use than NaOH. It's more flexible and adaptable and it gives generally better results – for small facility use it may be a better catalyst than NaOH.
- Calcium Oxide (CaO) can be used repeatedly (up to 20 times) without losing its effectiveness. Its reaction temperature is quite high, however, at 65C.
  CaO use for transesterification is still in the testing stage and not enough information exists to consider it seriously at this time.

Acid Catalyst

Sulphuric acid (H_2SO_4) has been found to be a very effective catalyst for a two-stage transesterification process. First, 8% methanol and 0.1% H_2SO_4 are combined with heated UVO, mixed and allowed to sit for at least 8 hours for a complete reaction. In the second stage, 12% methanol and 3.5 grams per litre of NaOH are combined (without titration!). This proceeds as normal, with glycerine settling out and completely reacted methyl ester biodiesel.

During the first stage, free fatty acids are esterified and some triglycerids are transesterified. The base-catalyzed second stage only does transesterification, but it's much quicker and more complete, and requires only about half the lye needed compared to a standard base reaction.

This process is not standard in small biodiesel operations, but may have the most consistent results. More research is warranted to find if this is the preferred method for biodiesel creation.

Washing Methods

Biodiesel must be washed before use to remove soaps, excess methanol, residual lye, free glycerine and other contaminants.

Mist washing

Mist-washing uses a fine spray above the wash-tank to send a mist of water droplets down onto the surface, creating zero agitation. It works, though it's slow and it uses a lot of water, and usually the water is not re-used. Unfortunately, mist washing is gentle and can mask an incomplete reaction, which agitation will reveal immediately.

Bubble washing

Bubble-washing uses a small air-pump, usually an aquarium aerator pump with a bubble-stone. Water is added to the biodiesel in the wash tank, and the water sinks to the bottom. Throw in the bubble-stone, which also sinks to the bottom, and switch on the pump. Air-bubbles (lots of little bubbles is best) rise through the water and into the biodiesel, carrying a film of water around them, which washes the biodiesel around the bubble. When it reaches the surface the bubble bursts, leaving the water to sink back down again, washing the fuel a second time.

Usually three or four washes are used, each of six to eight hours, often less for the first wash, with a settling period of at least 1 hour between washes. After it's settled the water is removed via a bottom-drain and replaced with fresh water.

Washing is completed when the water is clear after settling, with a pH of 7.

Advantages of bubble-washing:

> It's easy, it works, and it doesn't take much effort. For added convenience you could add a timer to switch off the air-pump after eight hours so you don't have to come back until a few hours later when it's settled and you can just change the water.

Disadvantages of bubble-washing:

> It might not take much effort but it takes a lot of time. Also, bubble-washing is gentle and can mask an incomplete reaction, which agitation will reveal immediately. The worst aspect of bubble-washing is that it fills the fuel with oxygen. This oxidation of the fuel makes it unsuitable for storage for any length of time.

Stir Washing

The most preferred method of water washing biodiesel is high-speed stir washing.

Advantages of stir-washing**:**

> Quick and effective, no masking of a poor reaction, and no oxidation.

Disadvantages:

> None, as long as the fuel is properly and completely processed.

Dry Washing

Dry-washing can be useful where water is scarce or expensive. This method is particularly useful in this facility, as there is no supply of running water.

There are two types of dry-washing compounds:

Magnesol was the first dry-wash product on the market, but users say it's messy, and removing it from the biodiesel takes careful filtering.

More recent products are **ion-exchange resins**, which remove all impurities (salts, soap, catalyst, glycerine and water) from raw biodiesel following separation of the glycerine by-product.

The resin is placed in a special exchange column with a drain at the bottom, and the biodiesel is fed into the top. Ion-exchange resins can be cleaned (with methanol) and re-used, up to a point.

Biodiesel Processing

Pre-Filtering

Each 15L container is poured through a t-shirt filter into one of two large plastic garbage cans fitted with a hose connection and valve. All large particulates are separated from the UVO here. Care is taken not to pour any water or emulsions that have settled to the bottom of the UVO containers; these emulsions simply clog up the filters, rendering them completely ineffective.

A transfer pump has been fitted in between these two receptacles, in order to pass the fuel through a 30 micron filter to a third larger garbage bin. The purpose of this arrangement is to have enough filtered oil ready to pump it over to the processor. Inside the third receptacle is fitted a sump pump, which delivers fuel to a second transfer pump. Two pumps in series were found to be necessary in order to pump the filtered oil across the room to the processor through a garden hose.

Titration

Each batch of UVO must be titrated carefully to determine the amount of lye required to carry out a complete reaction for a given volume of UVO.

1. Dissolve 1 gram of pure sodium hydroxide lye (NaOH) in 1 litre of distilled or de-ionized water (0.1% weight to volume NaOH solution).
2. In a smaller beaker, dissolve 1 ml of dewatered UVO in 10 ml of pure isopropyl alcohol (isopropanol).
3. Warm the beaker gently by standing it in some hot water, stir until all the oil dissolves in the alcohol and the mixture turns clear. If you're using phenolphthalein, add 2 drops of phenolphthalein solution.
4. Using a graduated syringe, add the 0.1% NaOH solution drop by drop to the oil-alcohol-phenolphthalein solution, stirring all the time. It might turn a bit cloudy, keep stirring. Keep on carefully adding the lye solution until the solution stays pink (actually magenta) for 15 seconds.
5. Take the number of millilitres of 0.1% lye solution you used and add 3.5 (the basic amount of lye needed for fresh oil). This is the number of grams of lye you'll need per litre of oil to process the WVO.

Mixing Methanoxide

Before mixing the methanoxide, it is very important to take an accurate measurement of the amount of UVO to be processed.

Carefully measure out and add the precise amount of lye (based on the titration completed above) into a half-litre HDPE container via a funnel.

Measure out the correct amount of methanol (20% of amount of UVO) and pour it in the HDPE container via a second funnel. Methanol also absorbs water from the atmosphere so do it quickly and replace the lid of the methanol container tightly.

Connect the tube to the top of the sealed mixing container, and carefully pour in the methanol and lye mixture. Stir the mixture at low speed with the drill and paint mixer. The mixture gets hot from the reaction. If you swirl it thoroughly for a minute or so five or six times over a period of time the lye will completely dissolve in the methanol, forming sodium methoxide or potassium methoxide. As soon as the liquid is clear with no undissolved particles you can begin the process.

The more you swirl the container the faster the lye will dissolve. With NaOH it can take from overnight to a few hours to as little as half-an-hour with lots of swirling. Mixing KOH is much faster; it dissolves in the methanol more easily than NaOH and can be ready for use in 10 minutes, with five or six shakes it takes about half an hour.

Processing Biodiesel

Heat the WVO in the processor to 55C. Carefully pour the prepared methoxide into the oil, then seal the processor top. Maintain the heat for at least an hour while mixing with an impeller blade (paint mixer) for the entire hour.

Turn off the heat and let the mixture settle overnight.

The glycerine should be completely separated from the biodiesel; it is heavier and will settle to the bottom of the processor. Drain off the glycerine and set it aside for further use. It is much preferable to drain a little of the biodiesel out rather than leaving glycerine in the processor. It is now time to wash the biodiesel.

At left is 55-gallon drum fitted with a drainage line. At right is pictured a FuelMeister processor, made of HDPE, with graduated measurements and extra hose fittings. Both processors should work, but the extra features of the FuelMeister make it much easier to manage and monitor the process.

Washing Biodiesel

Water Washing

Never try to wash an incomplete reaction; test-wash a sample first. If this not done, you risk mixing up a 50-gallon batch of mayonnaise-like soap.

1. Add 20% water to the unwashed biodiesel.
2. Use a motor-driven impeller (eg a paint-stirrer in an electric drill) to mix the water/fuel mixture for about 5 minutes, until it looks homogenous.
3. Let it settle for 1 hour.
4. Drain the water from the bottom
5. Repeat steps 1 to 4 until the water is clear. The first wash will most likely result in a milky-white water drain-off.

Let the fuel air-dry or heat it to 120F (48C) to dry.

Dry Washing

There should be no more than 1000 ppm of total impurities (glycerin, soap, unused catalyst and other trace impurities) in the Biodiesel to be dry washed. Therefore it is important to test the unwashed biodiesel for impurities before this method is used. In this facility, water washing will most likely act as a first-stage wash procedure.

Research shows that dry wash resins do an excellent job of dry washing biodiesel. Purolite and Amberlite are both based on a gel-type resin that is built around the same chemical ion exchange.

The resin beads are placed inside of a holding vessel and unwashed biodiesel is flowed through the resin beads. Typically the vessel is tubular and is referred to as an Ion Exchange Resin Column. The resin beads, when deposited in the column, form a "resin bed" at the base of the vessel.

1 lb of Purolite can be expected to treat approximately 100 gallons of biodiesel made from WVO, used according to manufacturer's recommendations.

Storage of Finished Biodiesel

The US DOE biodiesel handling and use guide says "... the least stable biodiesel could be stored for up to 8 months, while the most stable could be stored for a year or more." However, the recommended storage life is 6 months.

The biodiesel will be stored in a large HPDE container until it can be delivered to biodiesel users, such as the one shown in the photo below that holds about 1 tonne of fuel.