

Comparison of Biodiesel Feedstocks Common to Coastal Alaska

Burke Anderson

The Evergreen State College

Individual Learning Contract, Spring 2008

Abstract

Biodiesel is a non-petroleum fuel designed to run in a diesel engine. It can be made from a variety of different feedstocks, including virgin vegetable oil, waste cooking oil, and animal fats. The aim of this research was to compare and contrast biodiesel made from fish oil to other more traditional sources. In this paper I examined traditional biodiesel feedstocks available in coastal Alaska. These sources were: virgin olive oil, virgin corn oil, waste canola oil and mixed cooking oils. These samples were tested against biodiesel made from fish oil, to investigate if fish oil is a viable alternative feedstock. The findings indicate that herring oil is not a viable substitute feedstock mainly because the resulting biodiesel is solid at room temperature. A separate aim of the research was to investigate if fish oil could be turned into biodiesel using equipment that had been recycled. This portion of the research showed that indeed, a reactor can be built from recycled materials, however there was not an opportunity to test it specifically with fish oil.

Introduction

The state of Alaska has unique and challenging energy issues. Because of the state's vast distances, many remote communities, and extreme climates, Alaskans are especially dependent on fossil fuels for transportation, heating and electrical generation. Not only is this dependence environmentally damaging, it is extremely expensive. Fossil fuel prices are regularly over \$7 a gallon in bush Alaska.¹ One possible way to help reduce consumption of liquid fossil fuels is to substitute a biomass fuel, such as biodiesel.

Biodiesel is an organic fuel for diesel engines. It is made from organic oils, such as vegetable or animal oils, combined with an alcohol, and mixed with a catalyst, commonly sodium hydroxide. Biodiesel has similar characteristics to petroleum diesel fuel (petro-diesel), and therefore requires no modification to existing fuel storage, delivery and engine systems. It is non-toxic, biodegradable and less flammable than petroleum diesel (Canakci 183-184). The benefits also include reduced particulate emissions, and longer engine life, due to increased lubricity (Tinckell 5). Petroleum diesel has been shown to cause significant health problems, especially in children, and substituting biodiesel in school bus fleets can vastly reduce the danger of exhaust fumes.

While the primary feedstocks for biodiesel are virgin plant oil or waste cooking oils, biodiesel can also be made from animal fats. The Alaska Energy Authority estimates that in Alaska alone, 13 million gallons of excess fish oil are dumped into the oceans every year. This oil has been shown to cause small, but measurable ecological damage (AEA 6). Should this oil be recovered, it could potentially be made into a renewable source of biodiesel. Biodiesel created from fish oil has been made at commercial facilities

¹ Anchorage Daily News. 3 Jun 2008

such as Pacific Biodiesel in Hawaii, and Unisea Fisheries in Dutch Harbor, Alaska, for several years (James 1). Additionally, in 2005 Denali National Park began experimenting with cold weather operations using fish oil biodiesel. This program was a success and continues to draw publicity today (AEA 8). Alaska has a unique opportunity to further exploit this underutilized resource as a feedstock for biodiesel, thereby displacing increasingly expensive petroleum diesel fuel.

I am personally interested in biodiesel for a variety of reasons, but most importantly, its potential to reduce total life time carbon dioxide emissions by as much as 78% (Phal 125). Fish oil biodiesel also makes sense from an economic perspective, given that 13 million gallons of wasted fish oil represents a huge amount of diesel fuel that could be displaced. In rural Alaska (where the majority of fish oil extraction takes place) this would be enormously beneficial in that diesel is used to heat homes, power villages and provides nearly all transportation. As of June 2008, diesel prices averaged well over seven dollars a gallon in rural Alaska. Not only would fish oil represent a significant cost savings, it would create jobs, utilize a harmful waste product, and be more environmentally friendly. Finally, I am a pilot, and biodiesel represents the next logical step after petroleum Jet-A fuel becomes scarce. Biodiesel has been blended with Jet-A fuel in small amounts and used in large jet engines, but I hope to show that small piston engine aircraft, which are so vital to transportation in Alaska, can be powered using biodiesel.

Motivation: Research Questions and Hypotheses

Question 1

Is it cost effective to use fish oil as a feedstock for biodiesel?

- I Primary hypothesis: Fish oil can substitute for vegetable oil as biodiesel feedstock with no discernible disadvantages in quality or price.
- II Alternative Hypothesis: Fish oil can substitute for vegetable oil as a biodiesel feedstock, however it is not practical due to higher costs or lower quality.
- III Null Hypothesis: Fish oil is not a viable substitute for vegetable oil as a biodiesel feedstock.

Question 2

Can fish waste be made into biodiesel using mainly recycled materials?

- I Primary hypothesis: A biodiesel reactor capable of utilizing fish oil can be efficiently created from recycled materials.
- II Alternative Hypothesis: Though a biodiesel reactor capable of utilizing fish oil can be created from recycled materials, it is too inefficient to be practical for large-scale operations.

- III Null Hypothesis: Making biodiesel requires sophisticated equipment that cannot be fabricated from recycled materials.

Methods

Answering these research questions required several independent tasks. To determine the cost effectiveness of fish oil biodiesel, I needed something to compare it against. As of June 2008, there is no commercial biodiesel available in Alaska, meaning that I had to make my own. I opted to use feedstocks available in my hometown of Seward, Alaska, and create different test samples. These four different types of biodiesel were made from: virgin soy oil, virgin corn oil, waste canola oil, and mixed waste cooking oils.



Locating these samples of oil turned into a more difficult task than originally expected, due mainly to a scarcity of waste cooking oil. The virgin oils were purchased at a grocery store. Waste cooking oil became scarcer throughout this project. There was an increasing competition for this resource as other local residents became interested in biodiesel. I collected around 30 gallons total, from many different restaurants around the local area. The majority of this oil, however, was of very poor quality, often contaminated with water, soap and other unidentified substances. I was eventually able to collect ten gallons of useable canola oil, from a higher end restaurant, and about four gallons of mixed cooking oil from a friend.

Locating fish oil turned out to be the most challenging aspect of this project. The main reason for this was timing; commercial fish processing is a summertime industry, and fish oil is most widely available from mid-June until mid-September. The local cannery in Seward, Icicle Seafoods, had not begun rendering fish waste at the time of my project. My first plan was to purchase fish oil from another source, such as another cannery, or a specialty grocery store. After many phone calls and research, I was still unsuccessful in locating any fish oil. Next, I investigated rendering fish waste into fish oil on my own. This process involved gathering fish carcasses left over from fish processing, and boiling them in a large pot. Eventually, the fats and oils rise to the top, where they are skimmed off and then filtered. This process is done on a large scale in many canneries throughout Alaska, and I was very hopeful to come across some of this professionally prepared oil. By happenstance, my parents were able to locate source of fish oil at a sporting goods store in the city of Anchorage. This fish oil was made from Herring, which represents more of a year round industry. It was expensive, but worth not having to do any rendering for myself.

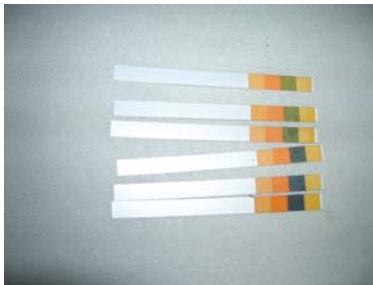
The other ingredients in biodiesel are an alcohol and a catalyst. Locating small amounts of these chemicals is relatively easy, as one can purchase them as products at a grocery store. Methyl alcohol, commonly called Methanol, is the only ingredient in HEET, which removes water from vehicle gasoline tanks. In previous research I found



Comparison of Biodiesel Feedstocks Common to Coastal Alaska

this to be the most suitable alcohol for a biodiesel reaction. This previous research also revealed that sodium hydroxide (NaOH) was the best catalyst in a biodiesel reaction. NaOH is also known as lye and is available mainly as a drain cleaner. Procuring these chemicals at the grocery store is fine for small amounts of biodiesel, but not at all practical for larger amounts. Locating a source for these chemicals was a bit more difficult, but I found a chemical distributor in Anchorage that had both. Unaviar Chemical was able to sell me a 55-gallon drum of methanol, as well as a 50 pound bag of NaOH granulates. Once I had such a large amount of both chemicals, I had a storage problem. It was impractical and dangerous to handle this much of either chemical, so I found smaller storage containers for day to day use. The storage containers needed to be portable, air and watertight, and accessible from a hardware store. I used found paint buckets and cans to be most preferable. This system proved to be practical and I was able to focus on the biodiesel making process, rather than the chemicals.

Depending on the feedstock oil, different amount of catalyst is needed to induce a biodiesel reaction. The catalyst, NaOH is used to neutralize free fatty acids (FFA's) present in the oil (Alovert 1). The amount of NaOH required varies depending on the FFA content of the feedstock oil. Oil that has been used to cook with has a high FFA level, and virgin oil has a low level of FFAs. The test to determine the correct amount of NaOH is called a titration. In this test isopropyl alcohol is mixed with the feedstock oil. In a separate container NaOH is dissolved into de-ionized water. This water/NaOH



mixture is added to the alcohol/oil 1 milliliter at a time, and tested for pH. When the pH rises significantly the free fatty acids have been neutralized (Tinckell 105). I performed a titration on my waste vegetable oils and the fish oil. My mother was able to procure some laboratory quality litmus paper with four separate colors per strip. These strips made reading the pH very easy and accurate. Each titration that I performed yielded expected results,

and I was able to add NaOH in the correct quantities for a biodiesel reaction. The process is detailed below.

When the chemical ingredients for biodiesel are mixed, the goal is to induce a chemical reaction. This reaction is called *transesterification*. To induce transesterification, sodium hydroxide (NaOH) is dissolved into methyl alcohol. For a 1 liter batch, the calculated amount of NaOH is added to 200 milliliters of methanol. Once the NaOH is dissolved the substance becomes sodium methoxide, which is then added to 1 liter of oil. The mixture is vigorously mixed for twenty minutes, which induces transesterification. The products of transesterification are biodiesel and glycerin. It typically takes around eight hours for these two products to separate from one another. Glycerin is heavier than biodiesel, so the biodiesel floats atop the glycerin (Blair 1). I chose to do this process in glass one liter jars, which I shook by hand. These jars were conical shaped, which allowed glycerin to be drained out easily. I had three of them on hand to standardize the process. All of my biodiesel samples were made in these “mini-reactors”.



Process

Filter: Waste Vegetable Oil (not required for virgin oils)

1. Gather waste cooking oils from various sources around town
2. Filter it through cotton fabric and into a large bucket
3. Heat oil to 100 Celsius and kept it at that temperature until it developed a glassy surface to evaporate any water particles
4. Filter hot oil through a paper coffee filter

Titration: Determine the amount of catalyst (not required for virgin oils)

1. Measure 1 gram of NaOH and 1 liter of de-ionized water
2. Fully dissolve NaOH into liter of de-ionized water
3. Measure 10 ml of isopropyl alcohol and mix with 1 ml of waste vegetable oil
4. Use syringe to drop 1 ml of NaOH/water mixture into oil/alcohol mixture and stir
5. Check pH using litmus paper
6. Continue until mixture reaches a pH between 8-9 to determine X amount
7. ($X+3.5 =$ grams of NaOH needed per liter of feedstock oil) varying levels of NaOH required per batch

Transesterification (biodiesel making):

1. Measure 1000 ml of feedstock oil; 200 ml of methanol; X grams NaOH
2. Fully dissolve catalyst into alcohol
3. Pour in 1000 ml of feedstock oil
4. Blend for 20 minutes
5. Allow glycerin to settle for over 8 hours
6. Biodiesel should separate and leave about 15% glycerin on the bottom

To answer the second research question, “Can fish waste be efficiently made into biodiesel using mainly recycled materials?”, I designed and built a 60 gallon biodiesel reactor. The majority of the reactor plans that I was able to find called for a conical bottom. This creates an area for glycerin to collect at the bottom. From there the unwanted glycerin can be drained out of the reactor, minimizing the chance for it to re-mix with the biodiesel. I decided that although this was a more difficult design to build, it would make the best reactor for the project. In keeping with my research question, I used as many recycled components as possible, which also helped minimize costs. The body of the reactor is an oil drum that was scrapped by the Shoreside Petroleum. This drum had contained gasoline, so it was easy to clean and had no interior rust. With an air hammer, I removed the bottom of the drum and prepped it for a conical bottom. The reactor plans called for 16 gauge sheet



metal, which was not a recycled material. I located a 1988 Dodge and removed the hood. The 11/16 inch radius circle, battery powered saw. to 112 and 1/3 degrees cone. I formed the



expensive to purchase and was able to improvise with vehicle engine hood. I Shadow at the dump and reactor plans called for a 16 which I roughly cut using a The circle was precision cut on a band saw to make the conical bottom by hand, and

took the entire set up to a professional welding shop. After an unfortunate mishap at the welding shop, I took the reactor to a welding trade school, where the instructor was able to weld the cone and drum together, while verifying that the seam was watertight. For the glycerin and biodiesel to drain out of the reactor, I had to purchase a new brass ball valve, as there was no recycled alternative. The valve was welded to the bottom of the reactor, and again checked for leaks. To keep the reactor in place I temporarily used a tire and two sawhorses. The tire cradled the reactor without putting pressure on any specific place. I originally intended this setup to be only temporary, however, the tire also has a springy quality, which aids mixing inside the reactor. As of June 2008, the reactor is still using this set up, and has been used on one 38-liter (10 gallon) batch with waste cooking oil.

One unintended consequence of this research project was the construction of a basic biodiesel laboratory from the ground up. Very quickly in the research it became apparent that I did not have many of the tools and equipment needed. Consistent with my second research question, I was again used as many recycled materials as possible. In this case, I used 1-liter glass soda bottles as separatory funnels for biodiesel reactions, and mason jars to hold biodiesel samples. These glass containers were the only things that were reused. For the research I had to purchase a bung wrench, a metric scale, containers for methanol and NaOH, a measuring cup, digital thermometer, litmus paper and various other pieces of equipment. All of these objects represent an initial one-time investment, so it makes sense not to include these costs, which total \$70, in the cost per gallon of biodiesel. I do plan to account for these costs in the project total however.

Biodiesel Quality Testing methods

(From author's previous work, available at

<http://academic.evergreen.edu/curricular/energy/0708/research/projects/Biodiesel.pdf>)

I conducted several tests to determine the quality of the different biodiesel batches. Specific Gravity measures the density of the liquid, and testing the specific gravity of biodiesel can determine how the fuel will perform in a diesel engine. The density of fuel relates to the viscosity of the fuel; if the specific gravity is over 0.900 g/cm³ then the biodiesel production reaction was incomplete and the fuel could cause increasing emissions, engine wear and injector choking. A hydrometer is used to measure the biodiesel and the surface point specific gravity should read between 0.860 and 0.900 but is at highest quality at 0.880 at 60°F and should always be significantly less viscous than the waste vegetable oil used (Tickell 72-73).



Gel point test verifies the temperature at which biodiesel will begin to gel and/or freeze into a solid. In cold temperatures biodiesel begins to decrease in efficiency and could begin to solidify in the fuel tank, fuel lines or diesel engine itself. The lower the gel point the higher the quality. When the gel point is fairly low biodiesel has a better chance of running an engine in cooler weather (Tickell 72).

The pH scale measures the strength of acids and bases and is numbered 0 to 14. Water has pH =7 and is considered neutral; numbers lower than 7 are acidic, and numbers above 7 are basic. Vegetable oil is an acid while the alcohol and our catalysts are both

bases. The amount of catalyst needed in a biodiesel reaction will be determined by the acidity of the vegetable oil used. The pH of unwashed biodiesel should be about 9 and the pH of vegetable oil should be about 5-6 (Tickell 60).

The 3/27 test is designed to observe the degree of conversion of oil to biodiesel: the amount of oil left as fatty acids. 3 parts biodiesel is mixed with 27 parts methanol (1:9). Biodiesel is soluble in methanol and the fatty acids that did not convert to biodiesel floats to the bottom of the graduated cylinder, to be observed.

Biodiesel Quality Testing Process:

Specific Gravity Test:

1. Poured biodiesel into graduated cylinder, so that hydrometer was able to float (quantity is not important, just enough to register a reading on the hydrometer)
2. Placed hydrometer into biodiesel, verified it was afloat
3. Recorded the specific gravity measurement from the hydrometer at the surface level of the biodiesel
4. Repeated for our 5 completed batches

Gel Point Test:

1. Measured 10 mL of biodiesel and put into a 20 mL beaker
2. Placed all batches into a freezer
3. Returned after five minutes and removed one batch, verifying that it had gelled
4. Placed thermometer in batch and let it warm into a liquid
5. Observed temperature at which biodiesel gel “melted”. (Melting is indicated by biodiesel changing state from solid to liquid)
6. Repeated and recorded for each biodiesel batch

3/27 Test

1. Measured 27 mL of methanol and 3 mL of biodiesel
2. The methanol and biodiesel were then blended together
3. The mixtures were allowed to settle for 30 minutes
4. Observed and recorded the amount of remaining fatty acids for each batch

pH Test:

1. Used pH paper to determine the approximate pH of each batch and the fish oil.
2. The paper was immersed in the batch and determined through consensus the approximate value based on the chart provided with the paper.

Results:

Tests

<u>Batches</u>	<u>Specific Gravity</u> (at 60°F)	<u>Gel Point Test</u>	<u>3/27 Test</u>	<u>pH</u>
Fish oil Biodiesel	Solid at room temp	41°C	1.75 mL	7
Straight Herring Oil	.820 g/cm ³	2.8°C	n/a	6-5
Corn Oil Biodiesel	.876 g/cm ³	-3.5 °C	<1/8 mL	7-8
Olive Oil Biodiesel	.880 g/m ³	-3.5 °C	0 droplets	8-9
Mix Oil Biodiesel	.879 g/cm ³	-4.5 °C	1/3 mL	7
WVO Biodiesel	.877 g/cm ³	-8 °C	1/4 mL	9-10
Ideal Biodiesel	0.8750 ± 0.20 g/cm ³	Not higher than -2 °C	none	8-9

Discussion of Costs

All of this biodiesel research was conducted at my home in Seward, Alaska. As noted above, a basic laboratory was constructed purely out of necessity. While I attempted to use as many recycled materials as I could, the laboratory mainly consisted of purchased materials. This represents a one-time investment, so I chose not to incorporate these costs into the cost of biodiesel. However, I will include these as total project costs.

The first purchased ingredient in biodiesel is alcohol, and I acquired a significantly larger amount than was actually used in the project. I bought a 55-gallon drum of methanol for \$314.88. Only a small fraction of this methanol was used, with the remainder for use in later experiments. I have incorporated methanol at \$1.51 per liter in the price of biodiesel, and the rest I will incorporate into the total project cost. (\$314.88/208 L=\$1.51)

The second purchased ingredient in biodiesel is the catalyst, sodium hydroxide. I opted to buy a larger amount than necessary for the initial experiments, at a significant cost savings. The best price for sodium hydroxide (NaOH) was a 50-pound bag for \$65.00. Meaning that one gram of NaOH cost \$.003 or 1/3 of a cent (\$65/22679.6 grams=\$.003). The remainder will be used in future experiments, but nonetheless I have included all of it into the total project cost.

To determine the correct amount of NaOH to dissolve into the methanol, I performed a series of titrations. This procedure involved isopropyl alcohol, de-ionized water, test oil and litmus paper. Sixteen ounces of Isopropyl alcohol can be bought at Safeway for \$2.29, and one gallon of de-ionized water was \$1.50. The oil which I used was all obtained for free, and roll of litmus paper is priced at \$6.95 from Anchorage Restaurant Supply. The grand total for titration supplies is \$10.74.

The final ingredient in biodiesel is some sort of animal or plant oil. I used a combination. In total I used 39 liters of waste oil, 1.5 liters of fish oil, 1 liter of corn oil, 500mL of olive oil, and 500mL of mixed waste oils. The waste oil was collected at no cost, from a variety of sources. Both virgin olive and corn oil were purchased at the grocery store for \$18.49 and \$8.75 respectively. The fish oil was very expensive at \$20.00 per liter, and I bought two bottles. In all I spent \$67.24 on feedstock oil.

So, the grand total of this project is: \$527.86. However, in my experimentation, I did not use the full amount that was available. To find out actual ingredient costs, I

converted to metric then calculated how much of each ingredient was used on this project.

Now a break down of costs:

Supply	Total cost (US\$)	Cost per unit (US\$)	Amount used	Total Amount used in Project (US\$)
Methanol	\$314.88 for 208 L	\$1.51 per L	8.5 L	\$12.84
Sodium Hydroxide	\$65.00 for 22.7 kg	\$.003 per g	223 g	\$0.66
Herring Oil	\$40.00 for 2 L	\$20.00 per L	1500 mL	\$30.00
Olive Oil	\$18.49 for 2 L	\$9.25 per L	500 mL	\$4.63
Corn Oil	\$8.75 for 1.4 L	\$6.25 per L	1000mL	\$6.25
Waste Oil	\$0	\$0	38 L	\$0
Isopropyl Alcohol	\$2.29 for 437.2 mL	\$.005/mL	20 mL	\$0.10
Litmus Paper	\$6.95 for roll	0.03/strip	35 strips	\$1.05
De-Ionized Water	\$1.50 for 3.79 L	\$.40 per L	2 L	\$0.80
Misc, lab eqt.	\$70 total	-	-	-
TOTALS:	\$527.86	-	-	(\$56.33)

This above amount represents the cost of materials that were used in the project. To answer research question one, “Is it cost effective to use fish oil as a feedstock for biodiesel?” we need to determine a cost per gallon of each of the 5 batches that I made. These figures represent 1 liter batches. From there we converted liters to gallons by multiplying by 3.79.

Feedstock	Methanol Quantity	Price \$	NaOH Quantity	Price \$	1 L of Feedstock Oil \$	\$ Cost per Liter	\$ Cost per Gallon
Fish Oil	200ml	0.30	3.5g	0.01	20.00	20.31	<i>76.97!</i>
WVO	200ml	0.30	5.75g	0.02	0	0.32	1.21
Mix WVO	200ml	0.30	5.75g	0.02	0	0.32	1.21
Virgin Corn Oil	200ml	0.30	3.5g	0.01	6.25	6.56	24.86
Virgin Olive Oil	200ml	0.30	3.5g	0.01	9.25	9.56	36.23

The price of the biodiesel reactor is quite a bit simpler. The main body of the reactor is constructed from a scraped oil drum, and the conical bottom from a junked car hood. Both of these items were essentially garbage and therefore free. The brass ball

valve was the only item on the reactor that was purchased, and it cost \$18.99. Friends did the welding for free, and the reactor is sitting on a stand that was also constructed at no cost. Not including time, the grand total for the biodiesel reactor is only \$18.99. (*note: the price for the reactor is not included in total project costs as this answered research question #2*)

Discussion of Results

Is it cost effective to use fish oil as a feedstock for biodiesel?

Processes

Fish oil biodiesel made from herring oil presents some very serious problems. Firstly, it is solid at room temperature. This property alone answers the research question, “Is it cost effective to use fish oil as a feedstock for biodiesel?” I find this fact very bizarre given that the herring oil I used as a feedstock was *liquid at room temperature*. The first conclusion I could draw from this was that I had not made biodiesel, but there was a clear separation between biodiesel and glycerin layers. I assumed that I had miscalculated the amount of catalyst needed, but I attempted several batches afterwards, using differing amounts of NaOH and always got the same result. Another important factor was that I needed three 500 mL batches to collect enough biodiesel to test. That kind of recovery ratio is simply unacceptable. And biodiesel that I was able to recover was of very low quality. Clearly, biodiesel made from herring oil is not a viable substitute. There are other factors that confirm my null hypotheses.



This being said, I do not believe that the fish oil biodiesel is a bad choice for Alaska. I conducted my experiments with herring oil, while most published experiments with fish oil use salmon as a feedstock. Previous experiments have shown that salmon oil biodiesel works well all over Alaska in a wide range of climates. Additionally, crude oil prices continue to increase, while fish oil prices are stable. One important factor to take in to consideration though, is that salmon oil is only available seasonally in the summer, when diesel fuel consumption is lower. I believe that my research has shown that on a small-scale it is difficult to use fish oil as a feedstock, but other research has confirmed that fish oil works well in large-scale facilities.

Regarding other test batches of biodiesel, I was surprised at the difficulty of obtaining waste cooking oil later in the project. There has been a noticeable surge in interest about biofuels here in Seward over the two months of this project. I now have at least four competitors for the waste oil that I am aware of. The biodiesel made from waste oil turned out to be the best suited to local use due to its lower gel point, allowing it to remain a liquid at lower temperatures. This was a surprising fact given that virgin oil feedstocks generally yield a higher quality biodiesel.

Tests

The quality tests confirmed that the fish oil biodiesel was of very poor quality. I was not even able to conduct a specific gravity test because at 60 degrees F the biodiesel is a solid jelly. In cold climates the gel point is the most important test, due to the

relatively high gel point of all biodiesel. It was surprising that waste vegetable oil yielded the lowest gel point, given that it is a lower quality. I attribute this low gel point to the fact that the waste vegetable oil was Canadian canola oil, which is reported to have the best cold flow properties of vegetable feedstocks. The specific gravity tests showed that olive oil biodiesel has the highest quality, which is not surprising given that olive oil is such a refined product. Corn oil had lower quality than the mixed batch, another surprising result.

Costs

With the herring oil feedstock I was using, biodiesel sold at cost would be \$76.97 per gallon. This *extravagantly* high price seems to answer the research question. However, \$76.97 a gallon does not reflect a real world scenario where salmon oil could be bought in bulk at a much cheaper price. I was quoted at Seward Fisheries that *[raw?]* salmon oil from canneries is generally sold at or under \$5 a gallon. Even at \$5, salmon oil biodiesel would be competitive with petro diesel, which is currently retailing at \$5.25 a gallon. I can only speculate on the cost effectiveness of salmon oil biodiesel, but obviously, herring oil is in no way competitive with even the second most expensive test, olive oil. Olive oil biodiesel would cost \$36.23, roughly half the cost of herring oil biodiesel. As suspected the most economical biodiesel is made from waste cooking oil as a feedstock, and would cost \$1.21 a gallon to produce.

Can fish waste be made into biodiesel using mainly recycled materials?

Although the reactor built for this project has not yet used fish oil, I believe that I have shown it is possible. One 38-liter batch of waste oil biodiesel was made in the reactor and it functioned as planned. I can reasonably extrapolate that *fish waste can be made into biodiesel using recycled materials.*

Future Work

Although multiple tests showed herring oil was not a suitable biodiesel feedstock, this does not mean that *all* fish oil is unsuitable. I would like to test salmon oil, and possibly Pollock oil, as these two sources are available in large quantities, albeit seasonally. I see this research as a first step in the ultimate goal of powering an aircraft by biodiesel. As of this writing, commercial biodiesel is still not available in Alaska, so in my continuing research, I will be responsible for making my own biodiesel. Jet-A fuel is becoming increasingly more expensive, and there has been talk in the US Environmental Protection Agency about phasing out aviation gasoline (Avgas) for several years. Avgas is 100 octane and leaded, and has a shrinking customer base. I see the demise of Avgas as an inevitable outcome, and hope to have a viable alternative liquid fuel at that time.

Acknowledgements

I would like to thank my parents for allowing me to turn their garage into a laboratory, and their driveway into a biodiesel refinery. They have been gracious and understanding, and are excited that the project has come to a close - little do they know... I am also

grateful to Roger Hohl and the Alaska Vocational and Technical School welding program, for their painstaking work on my biodiesel reactor. Without them I would not have finished it. My good friend and former shop teacher Ronn Hemstock, has been an integral part of this project as well, continually giving me advice about how to proceed. Finally, I would like to thank Sara Keehfuss and Brodie Pettit for helping me establish a foundation to build upon and their enthusiasm for the cause.

Sponsored by Dr. E.J. Zita, The Evergreen State College, Olympia WA

Bibliography

1. **Alaska Energy Authority. “Renewable Energy Atlas of Alaska”.**
[http://www.akenergyauthority.org/programs/alternative\(2\).html](http://www.akenergyauthority.org/programs/alternative(2).html)

The Renewable Energy Atlas of Alaska is a collection of maps and literature regarding the renewable energy possibilities for the state of Alaska. It is a comprehensive collection of hydro, solar, wind biomass and geothermal potential and existing facilities.

The section on biomass fuels is specifically useful to me, as it discusses biodiesel, and fish oil biodiesel. The rest of this book is fascinating as it shows the vast potential for energy that the state possesses. It is very encouraging.

2. **Alovert, M.; Blair, Graydon; et. al. “Getting Started Making Biodiesel.”**
<http://www.biodieselcommunity.org/gettingstarted/>

1

Graydon works for a biodiesel supply company that provides the materials needed to make your own biodiesel. In this article he outlines the precautions, process, timing, equipment and uses of producing biodiesel. He goes into checking with local authorities about chemical storage and taxes as well as getting to know the local biodiesel community. This website contains many other articles that played significant roles in our research and development of our own procedures.

We tried to find articles in scientific journals about homebrewed biodiesel, but to no avail. This article is straight forward and written by someone who makes his livelihood off of biodiesel. Overall, we believe that the information provided is accurate and useful for making our own processor. The main site itself provides detailed information on making biodiesel from the lab to the garage. Diagrams, photos, step-by-step instructions, tips and tricks aid homebrewers in the search for the perfect batch. It is collectively compiled by homebrewers around the nation, and features info on the popular Appleseed Processor. I think there is little better than a forum of people dedicated to biodiesel for personal, not monetary reasons.

3. **Brock, Ed. “Out of the frying pan and into the gas tank.” The American City and Country. 7 (2007) Vol 122 pages:17-18**

In *Out of the frying pan and into the gas tank*, Brock describes some new policies in the city of Hoover, Alabama. The Fleet Management Department has been collecting used cooling oil from restaurants around the region and been converting it into biodiesel. They are currently running ten city vehicles on their biodiesel. Collecting the cooking oil had been beneficial to the city not only in reduced fuel costs, but “the majority of Hoover, Ala.'s sewer service calls are for problems caused by grease” and the waterworks

¹ (Previous Work)

department has seen a decrease in service calls. Brock notes that the city has plans to institute a grease collection service from private homes as well, to further reduce sewer maintenance problems while reducing fuel costs.

Out of the frying pan and into the gas tank is useful to our research project in that the Hoover, AL city government has found biodiesel made from waste oil to be cost effective. If a government body is able to find biodiesel cost effective, it is reasonable to assume that an individual will be able to duplicate the process and find it to be equally as cost effective.

4. Canacki, Mustafa. “The potential of restaurant waste lipids as biodiesel feedstocks.” Bioresource Technology. 98 (2007) 183-190.

1

This study researched the viability of used cooking oil, specifically yellow and brown grease, and rendered animal fat as a “feedstock” (original material) to produce biodiesel. Canacki first explained the history of vegetable oil and biodiesel research, and the obstacle of discovering a production method that would bring the cost below that of conventional diesel fuel. Then he dissected the process and benefits of transesterification, mainly to reduce the viscosity of the biofuel. The abundance of waste grease is displayed with figures from a National Renewable Energy Laboratory study. Waste grease is much cheaper than soybean and other food grade vegetable oils, but it needs to be modified prior to transesterification. The technique for converting used cooking oil to biodiesel is explained in detail. Utilizing waste grease as a biodiesel feedstock can reduce the cost of production and hopefully replace a portion of the imported diesel in the US. The author states that the cold flow properties of biodiesel produced from the waste grease has not yet, but should be tested.

This article is from a peer reviewed source with a 10 month review process before it was accepted. The telephone, fax number and e-mail address for the author is given on the first page of the study and numerous references are cited. The information progressed logically and the conclusions matched the data of not only the author, but the references provided. Canacki showed the benefits as well as the drawbacks of using waste grease as a feedstock for biodiesel production. For all of these reasons I believe that this article is reliable and the information provided is accurate. The figures on WVO availability and the benefits of using a waste product guided our decision to use WVO instead of SVO.

5. Dennis, J.S.; Harding, K.G.; Harrison, S.T.L., von Blottintz, H. “A life-cycle comparison between inorganic and biological catalysis for the production of biodiesel.” Journal of Cleaner Production. www.sciencedirect.com. (2007)

1

¹ (Previous Work)

Vegetable oil undergoes the process of transesterification to become biodiesel. For industrial purposes a catalyst (typically potassium hydroxide) and an alcohol (usually methanol, but also ethanol) react with the oil to produce biodiesel, glycerol, waste water, oil and methanol (which is recycled or discarded). This study researches production alternatives and follows five cases conceptually through the production cycle. The researchers then produce and compare life cycle analysis for the cases. The variables tested were alcohol (methanol and ethanol), catalyst (inorganic potassium hydroxide or organic enzyme lipase), and methanol recovery percentage. It is found that methanol production impacts all of the studies, so it is especially important to recycle as much of the alcohol catalyst as possible. The life cycle analysis of the cases comparing methanol and ethanol are mixed. The organic enzyme has production advantages; lower pressure, lower temps and less catalyst used; but require a longer process time. Potassium Hydroxide requires more alcohol to yield similar purities and higher processing temperatures and pressures.

This article logically flows and the conclusion follows the evidence. I would like to see tangible results rather than life cycles based on flow chart data, but it is a good start to further research. I would not heavily rely on the values of the data, but more on the trends of the information. One of the most significant differences of the environmental impacts of methanol versus ethanol production was the large terrestrial impact of ethanol. As ethanol technology progresses and alternatives to farmed fuel sources develop I think this impact will reduce and ethanol will be more advantageous to use in transesterification. This article provided a theoretical base for our ethanol experiments. It is unfortunate that the real world does not always behave like the theoretical one.

6. Estela Hernández-Martín and Cristina Otero. “Different enzyme requirements for the synthesis of biodiesel: Novozym[®] 435 and Lipozyme[®] TL IM.” Bioresource Technology. (1 2008) Volume 99, Issue 2, Vol 122 pages:277-286

1

This article describes different vegetable and animal fat oils used with an ethanol vs. methanol alcohol content. The different materials used are listed and information is given that depict the greatest result. It calculates what materials would be best to produce successful batch of biodiesel.

We chose this article because it gave use an idea of which materials to use in creating useful biodiesel. The results of different tests are given to help decide practical applications.

7. Estill, Lyle. “Biodiesel Power.” New Society Publishers. Gabriola Island, BC. 2005

¹ (Previous Work)

In *Biodiesel Power* Estill describes his experiences in the fledgling days of the biodiesel movement. He details first experimenting with biodiesel, moves on to organizing a co-operative business, growing the business, and then moving on to small scale commercial production. Much of his book is taken directly from his *Energy Blog*, where he describes the trials and tribulations of the movement. This book is very small scale and local in orientation.

Biodiesel Power was helpful to this research project because many of the problems Estill describes are precisely the problems that I ran into. It was also interesting to see the recent history of the movement and realize just how far biodiesel has come since the beginning of the decade.

8. Isayama, Yohie; Saka, Shiro. “Biodiesel production by supercritical process with crude bio-methanol prepared by wood gasification.” Bioresource Technology. (2007) In Press

In *Biodiesel production by supercritical process with crude bio-methanol prepared by wood gasification*, authors Isayama and Saka explain that to produce biodiesel, methanol is needed to reduce viscosity of the feedstock oil. This methanol is usually derived from natural gas and thus detracts from biodiesel’s image as a petroleum free fuel. Isayama and Saka have developed a technique that produces syngas, which can be used as substitute for methanol. Their technique uses wood gasification to make this syngas. By conducting various tests and procedures Isayama and Saka were able to create a syngas methanol with relatively few impurities. The biodiesel made from this syngas was then tested against methanol biodiesel, with Isayama and Saka finding few differences.

Biodiesel has a reputation as a “green fuel” because it is made of renewable oils, non-toxic and vastly less polluting. One weak link however, is the methanol or ethanol needed to convert the oils. This new technique allows biodiesel be totally petroleum free. This will not only make it more environmentally friendly, but may become necessary when petroleum products become scarce. Syngas methanol is worth considering for its potential environmental benefits. This article provided the insight into methanol that lead to testing ethanol.

9. Ji-Yeon, Park; Deog-Keun, Kim; Joon-Pyo, Lee; Soon-Chul, Park; Young-Joo, Kim; Jin-Suk, Lee. “Blending Effects of Biodiesels on Oxidation Stability and Low Temperature Flow Properties.” Bioresource Technology. 7 (Spring 2007) Pgs: 1-8

¹

In, *Blending effects of biodiesels on oxidation stability and low temperature flow properties*, the authors are interested in lowering the temperature at which biodiesel fuel begins to gel. The article outlines work done at the Korean Institute of Energy Research. The authors briefly introduce biodiesel and some of the challenges associated with using it. The article specifically addresses the cold filter plugging point; at which biodiesel can

¹ (Previous Work)

no longer flow freely through fuel lines. The research consisted of mixing varying amounts of rapeseed, palm and soybean oils, to find the most favorable consistency. The article is quite technical about the properties of the various mixes.

This article is quite technical, and has quite a bit of jargon to sort through. It is challenging to comprehend information from, but nonetheless directly addresses our research. Curiously, the research does not concern itself with various blends of biodiesel and petroleum diesel or kerosene, all known to lower the gelling temperature of biodiesel. Had this information been included the article would have been more useful.

10. Krotscheck, Christian; Narodoslawsky, Micheal. “The Sustainable Process Index a new dimension in ecological evaluation.” Ecological Engineering. 6 (1996) 241-258

“The Sustainable Process Index (SPI) is a measure developed to evaluate the viability of processes under sustainable economic conditions.” This measurement is used in Life Cycle analysis as a way to determine if a method, fuel or process is sustainable and the basic unit is area. The paper outlines the mathematical calculations and reasoning for all factors considered in the SPI. Factors are dissected as well as ways to make practices more sustainable. A case study of sugar beet ethanol is used to show application.

An ecological impact measurement is a great tool to use for sustainability assessments. Standardization is key for accurate comparisons, though the tool is only as useful as its popularity. It will be useful in calculating impacts of biodiesel. This index is very convoluted and tracks costs associated with larger operations than home-brewing.

11. Narodoslawsky, Michael; Niederl-Schmidinger, Anneliese. “Life Cycle Assessment as an engineer’s tool?” Journal of Cleaner Production. 16 (2008) 245-252

1

A case study of Life Cycle Assessments (LCAs) of the environmental impact of biodiesel made from tallow and used vegetable oil are compared to show how engineers can use LCAs in determining sustainable processes. The Sustainable Process Index method (SPI) was used for impact assessment in this study. “The SPI is a measure of ecological sustainability that expresses pressure on natural systems as area needed to embed the respective activities sustainably into the ecosphere.” (m² a/MJ) (248). By breaking down the processes and finding the percentage of the total foot print, areas that need improvement can be pinpointed. For example combustion emissions represent almost 43% of the overall footprint. Price and mass allocations are both shown as well as biodiesel from tallow including rendering or considering it a waste product. Waste oil and the waste tallow begin at the collection instead of considering the rendering (that is allocated with the product, not byproduct). A comparison table makes the results easier to compare.

¹ (Previous Work)

This study is useful if you are considering sustainability with biofuels from waste products, but that is a finite amount and could only replace a small fraction of the total oil consumption. I would like to see the LCA of a farmed fuel compared to petroleum counterparts. The math is fairly straightforward and since this is from a peer reviewed source, probably accurate. I feel comfortable trusting these results.

12. Phal, Greg. “Biodiesel: Growing A New Energy Economy”. Chelsea Green Publishing Company. White River Junction, VT. 2005

In *Biodiesel: Growing a New Energy Economy* Phal describes the early days of the diesel engine, Rudolph Diesel, and his vision, the earliest biodiesel tests, biodiesel in Europe and around the world, and a significant portion on biodiesel in the United States. Phal mainly details the state of the industry and the major players and issues.

Biodiesel: Growing a New Energy Economy is the other side of the story that Estill presents in *Biodiesel Power*. Phal writes this book from a perspective of large scale producers and government agencies. It is interesting to see the other side of the same issues that Estill brought up. Additionally the history surrounding both diesel technology and biodiesel is quite fascinating.

13. Tickell, Joshua; Tickell, Kia. “From the Fryer to the Fuel Tank: The Complete Guide to Using Vegetable Oil as an Alternative Fuel” Tickell Energy Consulting. July 2000

1

In the book, *From the Fryer to the Fuel Tank*, the Tickells discuss four major topics. These are; running a vehicle on biodiesel, running a vehicle on kerosene, running a vehicle on vegetable oil, and building a homemade biodiesel processor. In addition, the Tickells discuss the necessity of weaning the economy from fossil fuels and more towards sustainability. The majority of *From the Fryer to the Fuel Tank* is spent discussing homemade biodiesel, including procedures, equipment, suppliers, organizations, government regulations, and troubleshooting.

The Tickells’ book is useful to our project in several important ways. Firstly, it contains an easy to understand step by step procedure for making test batches of biodiesel. The book clearly outlines what equipment is needed, where to find it, and any safety concerns. Included are pictures and as illustrations, which put biodiesel production in layman’s terms. Secondly, it contains information about constructing a homemade biodiesel processor. The Tickells strive for low cost, therefore they advocate the use of free and recycled parts, including 55 gallon drums, water heaters, vehicle starters, and scrap steel. This book was our bible when it came to the process of transesterification and the quality tests. The information on ethanol is dated, due the massive interest and advancements in the biodiesel world.

¹ (Previous Work)

14. Weiksner, P.E., JM. Sr. “Understanding Biodiesel Fuel Quality and Performances.” 2003 Dec 12 US Department of Energy. US Department of Commerce, National Technical Information Service. Energy Citations Database.

1

This article illustrates how to best manufacture, blend and store biodiesel. Higher saturated fat content in oils (coconut or palm kernel) will produce a more stable biodiesel.

We chose this article because it shows how to best store with a longer shelf life. Weiksner also specifies which oils to use that will be most productive.