

# **Biodiesel: Cost and reactant comparison**

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## **Abstract:**

Alternative fuel resources such as biodiesel are important to combat fossil fuel use and the broader impacts thereof; also to recycle, spread knowledge and gain momentum for carbon emissions reduction. Biodiesel is made through a process of transesterification that can be preformed in a variety of settings, including the Evergreen State College Campus. Through our small batches of biodiesel produced in the lab, we found that home-brewed biodiesel can be cost effective if the oil is obtained at little or no cost. Our quality tests and experiences in the lab revealed that ethanol, though arguably better for the environment, needs further research to eliminate inconsistencies in the transesterification.

## **Introduction:**

Exploring alternative fuel resources is important to combat fossil fuel use and the broader impacts thereof. Biodiesel is an organic fuel that can be used in any diesel engine with little to no modifications; natural rubber hoses and gaskets need to be replaced with synthetic counterparts, though not immediately if routine inspections occur. Because of the similar characteristics of petroleum diesel and biodiesel there is no need to alter existing fuel stations. Biodiesel is nontoxic, biodegradable, and less flammable than petro-diesel. (Canakci, 183-184) The benefits of biodiesel as a vehicle fuel include decreased particulate and gas emissions, cleaner diesel engines due to the solvency of biodiesel, and a lessened dependency on foreign oil. (Tickell; 37-38, 22) Home-brewing biodiesel has gained the interest of a diverse cross section of the United States. Farmers can make fuel for their equipment, restaurant owners have free waste oil disposal, environmentally conscious drivers can reduce carbon emissions, and garage tinkers have a new hobby, not to mention the throngs of motor sport enthusiasts who are ready to jump on the biodiesel bandwagon. It can be made from waste oils such as used cooking oil and tallow rendered in the slaughtering process; any organic oil works. Biodiesel is not sustainable as a direct replacement to petroleum diesel due to agricultural restraints and impacts, but it is a great way to spread knowledge, gain momentum for carbon emissions reduction and recycle.

For all of the above reasons and the pure pursuit of knowledge we have chosen to investigate home-brewing biodiesel. Personally, Sara plans to use the knowledge we gain from this research to enhance the Evergreen Biodiesel Project on campus. In the future she hopes to build a biodiesel processor and eventually brew her own fuel. Brodie and Burke are both intrigued by the innovations in aeronautical technology surrounding biodiesel fuels and the hopes of aircraft operating on biofuels. Burke is working on a contract to create a biodiesel processor in Alaska. We all hope to educate our friends and family of the merits of biodiesel.

## **Questions and Hypotheses**

### **Question 1**

Can we make biodiesel at a lower cost than purchasing biodiesel/petroleum diesel locally at the pump?

- i. Preferred hypothesis: Biodiesel can be produced at a lower cost than buying fuel at a gas station.
- ii. Alternative hypothesis: Buying fuel at the pump costs less than producing our own biodiesel.
- iii. Null hypothesis: The price of fuel at gas stations is incomparable to the cost of home-brewing biodiesel.

### **Question 2**

How does methanol versus ethanol affect the cost and efficiency of biodiesel in the production process?

- i. Preferred hypothesis: Ethanol used for transesterification costs less and is more efficient than using methanol.
- ii. Alternative hypothesis: Methanol used for transesterification costs less and is more efficient than using ethanol.
- iii. Null hypothesis: There is no significant difference between using ethanol or methanol in biodiesel production.

## **Methods:**

Biodiesel can be made with any new or Straight Vegetable oil (SVO), but the impacts of using a food source as a fuel, the price of SVO and the benefits of reusing lead us to the decision to use Waste Vegetable Oil (WVO) for our biodiesel. The production of biodiesel using WVO can be explained by titration and transesterification. Titration is an initial test to measure the free fatty acid (FFA) content of the feedstock, which determines the amount of catalyst needed to create biodiesel and is a necessary test for waste oil. (Alovert, 1) Transesterification is the process in which biodiesel is created by reacting alcohol, methanol or ethanol, with oil in the presence of a catalyst, typically lye. (Canakci, 184) After the transesterification the liquid needs to settle and separate into glycerol and biodiesel. (Blair, 1) The glycerol is removed and the biodiesel washed with water and allowed to dry. (Blair, 1) The end results are biodiesel, glycerol, waste water, oil and alcohol (the later two recycled or discarded depending on amounts). (Dennis, 3)

Our experimental objective was to observe variations in WVO biodiesel when using different catalysts and alcohols. For the catalyst we began by using potassium hydroxide (KOH). The amount of KOH needed to react with the vegetable oil needs to be 0.90% (9 grams/liter of SVO), almost triple that needed when using NaOH. Sodium hydroxide (NaOH) uses around 0.35% (3.5 grams/liter of SVO). We completed two titrations after two separate filtering undertakings. The first titration resulted in an additional 2.5 grams of KOH per liter oil. The second titration was for the NaOH batches and 2 grams of NaOH was added per liter of oil.

Our first batch was a methanol + KOH. There was a miscalculation in the amount of KOH required and we used about half of the necessary quantity. Our second methanol + KOH batch had better results and we moved onto ethanol batches. We performed four ethanol batches in order to compare the differences in the alcohol. The ethanol batches would not separate and therefore the reaction was incomplete. We decided to force separation by adding more potassium and sodium ethyl oxides to the appropriate batches. Half the amount of catalyst (NaOH) and alcohol (ethanol) used in the initial reaction was mixed into the incomplete reaction for 20 minutes and poured into a separatory funnel. After allowing that to sit for over 8 hours we found that it separated so we forced our KOH ethanol batch which separated as well.

Our second methanol KOH batch was washed to get an idea in the differences in quality. A water wash is done to remove any remaining alcohol, catalyst, or glycerin that is in the biodiesel batch. In a complete reaction a water wash is unnecessary because 99.9% of the catalyst and glycerin settle to the bottom. (Tickell 70)

We attempted several tests to determine the quality of the different batches. Specific Gravity measures the density of the liquid and testing the specific gravity of biodiesel will determine how the fuel will perform in a diesel engine. The density of fuel relates to the viscosity of the fuel and if the specific gravity is over 0.900 g/cm<sup>3</sup> then the reaction was incomplete; the fuel could cause damage to the engine, increase emissions, engine wear and injector choking (Tickell, 72). A hydrometer is used to measure specific gravity, calibrated with respect to water, it will float in the biodiesel and the surface point will read the density. The 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)

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

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.

The pH scale measures the strength of acids and bases and is numbered 0 to 14. Water would be a 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 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 a 9 and the pH of vegetable oil should be about a 5-6. (Tickell 60)

## Processes

### Filter: Waste Vegetable Oil

1. We picked up our waste vegetable canola oil from Le Voyeur downtown, while on other errands.
2. Filtered it through sheets into a large bucket
3. Heated oil to 100 Celsius and kept it at that temperature until it developed a glassy surface
4. Filtered hot oil through a paper filter and funnel two times

### Titration: Determines the amount of catalyst needed for the WVO

1. We measured 0.1 gram of catalyst and 100 milliliters of deionized (DI) water
2. Then fully dissolved the catalyst into DI water
3. Measured 10 ml of isopropyl alcohol and mixed completely with 1 ml of WVO
4. Using syringe we dropped 1 ml of catalyst/water mixture into oil/alcohol mixture
5. Checked pH using litmus paper after each drop
6. Continued until mixture reached a pH between 8-9 to determine X amount (X= # of drops)
7.  $X+9$ =grams of potassium hydroxide (KOH) needed for 1 liter batch;  $X + 3.5$ =grams of sodium hydroxide (NaOH) needed for 1 liter batch
8. 2.5 drops plus 9 equals 11.5 grams; 5.75 grams of KOH needed for 500 mL batch
9. 2 drops plus 3.5 equals 5.5 grams; 2.75 grams of NaOH needed for 500 mL batch

### Batches:

1. We measured 500 ml of WVO; 100 ml of methanol or 150 ml of ethanol (used an additional 75 mL ethanol for forcing batches); the predetermined grams of KOH or NaOH
2. Fully dissolved catalyst into alcohol
3. Poured into 500 ml of WVO
4. Blended for 20 minutes
5. Allowed glycerin to settle for over 8 hours
6. Biodiesel separated in all methanol batches and left about 15% glycerin on the bottom
7. We drained the glycerin layer and stored the biodiesel in 1000 mL beakers in a lab hood
8. The ethanol batches did not separate and we decided to force the separation of 2 batches

### Forcing:

1. We measured 75 mL ethanol and 1.375 grams of NaOH/ 2.875 grams KOH
2. Fully dissolved catalyst into ethanol
3. Poured into the unseparated ethanol biodiesel batches
4. Allowed glycerin to settle for over 8 hours
5. Biodiesel separated and left about 32% glycerin on the bottom
6. We drained the glycerin layer and stored the biodiesel in 1000 mL beakers in a lab hood

**Wash:**

1. Measured 450 ml of DI water
2. Poured into a 450 ml biodiesel batch
3. Agitated for 5 minutes
4. Allowed to settle for 72 hours
5. Repeated with 200 mL DI water

**Tests:**

## Specific Gravity Test:

1. We poured biodiesel into graduated cylinder, so that there was 10 inches of vertical fluid (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. We repeated for our 5 completed batches.

## Cloud Point Test:

1. Measured 10 mL of biodiesel and put into a 20 mL beaker.
2. We placed the batch into a freezer.
3. Every minute we checked for visual clouding.
4. When clouding was observed we removed the beaker from the freezer and determined the temperature.
5. Repeated and recorded for each biodiesel batch and WVO.

## 3/27 Test

1. We 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. We observed and recorded the amount of remaining fatty acids for each batch.

## pH Test:

1. We used pH paper to determine the approximate pH of each of our batches and the WVO.
2. The paper was immersed in the batch and determined through consensus the approximate value based on the chart provided with the paper.

**Results:**

Batches	Tests			
	Specific Gravity	Cloud Point Test	3/27 Test	pH
Methanol KOH	0.880 g/cm <sup>3</sup>	9°C	1 ½ mL nonconverted oil	8
Methanol NaOH	0.885 g/cm <sup>3</sup>	8°C	1/3 mL	7 to 8
Methanol KOH (Washed)	0.880 g/cm <sup>3</sup>	9°C	1/6 mL	6 to 7
Ethanol KOH	0.875 g/m <sup>3</sup>	12°C	0 droplets	8 to 9
Ethanol NaOH	0.875 g/cm <sup>3</sup>	11°C	> 1/8 mL	8 to 9
WVO	0.905 g/cm <sup>3</sup>	7°C	N/a	5 to 6

All of our biodiesel research was conducted at the Evergreen Laboratory, using checked out equipment, some free chemicals and some that we paid for. The laboratory is a controlled environment, and does not necessarily reflect real world costs. Because our original research question asked, "Can we make biodiesel at a lower cost than purchasing biodiesel/petroleum diesel locally at the pump?" it makes sense to estimate costs outside of the laboratory. We are making a few assumptions about these prices, like purchasing in larger amounts than we used, and that some materials can be obtained locally.

First, we need alcohol, both methanol and ethanol. After some internet research we located a local company called Tarr, Inc., which sells methanol in Seattle. For one gallon of Methanol, Tarr, Inc. quotes \$3.05. Ethanol is more difficult to purchase, and the cheapest place we were able to find it was online from Jamestown Distributors. One gallon is priced at \$12.34 plus \$11.37 shipping, for a total of \$23.71. Our hypothetical grand total for alcohols would be: \$26.76.

The other ingredient in biodiesel is lye. We experimented with both potassium hydroxide (KOH) as well as sodium hydroxide (NaOH). These chemical are commonly used in soap making, and therefore easily bought online through a number of companies catering to hobbyist soap makers. We opted to purchase a larger amount than necessary for our initial experiments, for a cost savings. The best price for potassium hydroxide is from a company called Briantan, and one pound will cost us \$3.25. One pound of sodium hydroxide can be purchased from Certified Lye for \$4.99. Our hypothetical grand total of lye would be: \$8.24

To determine the correct amount of lye to mix into the alcohol, we performed a titration. This procedure involved isopropyl alcohol and litmus paper. Sixteen ounces Isopropyl alcohol can be bought at Safeway for \$1.79, and litmus paper is priced at \$1.95 from Edmunds Scientific on the internet. Our hypothetical grand total of titration supplies would be \$3.74.

The final ingredient in biodiesel is some sort of animal or plant oil. For our experiments we chose to use waste vegetable oil. We acquired five gallons of waste canola oil from a local restraint at no cost. Had these experiments been carried out somewhere besides the laboratory, the cost of oil would still be nothing.

So, our hypothetical grand total of biodiesel ingredients and supplies is: \$38.74. However, in our experimentation, we did not use one full gallon of either alcohol, nor did we use anywhere near one pound of either lye. To find out actual chemical costs, we converted the chemicals to metric then calculated how much of each ingredient we used on this project. One gallon equals 3.79 liters, and 1 pound is equal to 453.59 grams. Additionally, 16 ounces equates to 437.18 milliliters. We used 100 ml of Methanol in three different batches, for a total of 300 milliliters of Methanol. Our ethanol biodiesel was more difficult, and we mistakenly made two batches using 150ml per batch then used 225ml on two more batches. Thus, our total Ethanol use for this project was 750ml. As for lye, we used a total of 6.895g of NaOH and 28.25 g of KOH. In titration, 100ml of Isopropyl alcohol was used along with five pieces of litmus paper.

Now we can break down our costs:

Supply	Total cost (US\$)	Cost per unit (US\$)	Amount used	Total cost (US\$)
<b>Methanol</b>	3.05 for 3790 mL	0.0008/mL	300 mL	0.24
<b>Ethanol</b>	23.71 for 3790 mL	0.006/mL	750 mL	4.50
<b>Sodium Hydroxide</b>	4.99 for 453.59 g	0.011/g	6.895 g	0.08
<b>Potassium Hydroxide</b>	3.25 for 453.59 g	0.0071/g	28.25 g	0.20
<b>Isopropyl Alcohol</b>	1.79 for 437.18 mL	0.00041/mL	100 mL	0.04
<b>Litmus Paper</b>	1.95 for 100 strips	0.0195/strip	5 strips	0.10
<b>PROJECTED TOTAL MATERIAL COST</b>				<b>\$5.16</b>

This above amount represents the cost of materials that were used in our experiments.

To answer our original research question one, “Can we make biodiesel at a lower cost...” We need to determine a cost per gallon of each of the 5 batches we made. When we transesterified our batches all yielded 500ml of biodiesel. We calculated the cost of each 500 ml batch then multiplied that figure by two to get the cost per liter. From there we converted liters to gallons by multiplying by 3.79.

Batch Type	Alcohol Quantity	Price \$	Lye Quantity	Price \$	+ 3¢ Isopropyl Alcohol & litmus paper	\$ Cost per Liter	\$ Cost per Gallon
Methanol KOH	100ml	0.08	5.75g	0.04	0.03	0.25	0.99
Methanol KOH (washed)	100ml	0.08	5.75g	0.04	0.03	0.25	0.99
Methanol NaOH	100ml	0.08	2.75g	0.03	0.03	0.24	0.90
Ethanol KOH	275ml	1.65	8.625g	0.06	0.03	3.53	13.64
Ethanol NaOH	275ml	1.65	4.125g	0.05	0.03	3.51	13.57

## **Discussion:**

### **Processes**

Waste vegetable oil as a feedstock requires a filtration process that is not need for new oil. Using a waste product eliminates the impact of the farming and oil manufacturing because that impact is calculated as the cost of the original oil. There is an abundance of waste vegetable oil; Olympia alone has a resource of 2,280,000 lbs/year of yellow and trap grease (Canakci, 186). For our research we decided to test ethanol (ethyl esters) as well as methanol (methyl esters) in order to compare the financial and environmental costs. Methanol is most commonly used in biodiesel production because

less is needed, the reaction is more stable and methanol is less expensive. The transesterification requires more ethanol than methanol per liter however ethanol is less toxic and is always produced from a renewable resource such as grain. Methanol is generally made from coal, natural gas or wood and therefore has a higher net greenhouse gas output. (Tickell 59-60, 69) KOH is a cheaper commodity and is used more often in home-brewing operations for that reason, so we began our experiments with KOH. After our difficulty with the ethanol batches we decided to produce biodiesel batches with NaOH in the hopes that the ethanol would complete the transesterification process with a different catalyst. Ethanol is more temperamental to work with and is therefore more time consuming and less desirable for transesterification.

### **Tests**

From the test results in the above chart we decided that the methanol KOH batch is the highest quality. The KOH seems to work best with methanol however the NaOH seems to have a lower freezing point and would do better in cooler weather. The methanol KOH has an accurate pH, an ideal specific gravity and a low cloud point. This would be the batch that would run best in a diesel engine. The ethanol had better 3/27 tests, most likely because of the large amounts of alcohol and catalyst required to force the reaction. Analyzed with the results of the other tests, the methanol batches merely need to be washed to decrease the amount of non converted substances in the final outcome.

### **Costs**

When batch cost amounts are compared to the Petroleum Diesel price of \$3.85/gallon, we find that the methanol batches are all cheaper, but the price of ethanol makes those batches too expensive for mass consumption. At this point Biodiesel prices are mimicking the petroleum counterpart, and the cost is typically the same. When the quality tests and the costs of each batch are reviewed we find that it is indeed cost effective to brew your own biodiesel.

### **Future Work:**

Sara is going to continue with biodiesel research with the Evergreen Biodiesel Project at the Organic Farmhouse. There she will develop lab procedures that can be easily duplicated from the initial titration test to the final quality tests. Firsthand experience with Evergreen's reactor will help guide a personal Biodiesel Processor project. In the hopes for a more sustainable future, Sara will try to run as many of her vehicles on biodiesel rather than fossil fuels.

Burke has plans to build a biodiesel reactor in Alaska, and hopes to show that waste products from the fishing industry can be used for biodiesel. He eventually intends to design a biodiesel powered aircraft, which will address the unique transportation and energy needs in Alaska.

Brodie plans on continuing research at the Evergreen Biodiesel Facility on campus. She is interested in a larger scale production and would like to learn about dual tank diesel engine conversion in order to run solely off of filtered WVO. Biodiesel airplanes are of interest as well and she hopes to join a project in Bellingham focused in building an aircraft and running it off of biodiesel.

## Annotated Bibliography

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

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.

2. **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 cooking 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 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.

3. **Canacki, Mustafa. "The potential of restaurant waste lipids as biodiesel feedstocks." Bioresource Technology. 98 (2007) 183-190.**

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. Canakci showed the benefits as well as the drawbacks of using waste grease 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.

**4. 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](http://www.sciencedirect.com). (2007)**

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.

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

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.

- 6. 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.

- 7. 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**

*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 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.

**8. Krotscheck, Christian; Narodoslowsky, 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.

**9. Narodoslowsky, Michael; Niederl-Schmidinger, Anneliese. "Life Cycle Assessment as an engineer's tool?" Journal of Cleaner Production, 16 (2008) 245-252**

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." ( $\text{m}^2 \text{ a/MJ}$ ) (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.

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.

**10. 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**

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 Tickell’s 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.

**11. 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.**

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.

## 12. Pricing references

### **Methanol:**

Toys for Trucks\* or Tarr Inc.

<http://biolyle.com/process/supplies.html>

From Tarr, Inc. : methanol (55 gal) \$2.90-3.05 / gal

### **Ethanol:**

Jamestown Distributors

Total \$23.71

<http://www.jamestowndistributors.com/userportal/main.do>

### **Sodium hydroxide**

Top of Form

Certified Lye

<http://www.certified-lye.com/>

<b>Quantity</b>	<b>Price per Lb</b>	<b>Total Price</b>
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<b>1.25 lbs</b>	<b>\$3.99</b>	<b>\$4.99</b>
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<b>2.50 lbs</b>	<b>\$3.99</b>	<b>\$9.98</b>
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<b>3.75 lbs</b>	<b>\$3.79</b>	<b>\$14.21</b>
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<b>5.00 lbs</b>	<b>\$3.79</b>	<b>\$18.95</b>
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<b>6.25 lbs</b>	<b>\$3.49</b>	<b>\$21.81</b>
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<b>7.50 lbs</b>	<b>\$3.49</b>	<b>\$26.18</b>
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<b>15.00 lbs</b>	<b>\$3.49</b>	<b>\$52.35</b>
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<b>22.50 lbs</b>	<b>\$3.49</b>	<b>\$78.53</b>
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### **Potassium Hydroxide (KOH)**

Briantan.com

[http://www.briantan.com/Merchant2/merchant.mvc?Screen=PROD&Store\\_Code=1&Product\\_Code=KOH50lbs](http://www.briantan.com/Merchant2/merchant.mvc?Screen=PROD&Store_Code=1&Product_Code=KOH50lbs)

Code: KOH50lbs

Price: \$120.00