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| Decreasing the Gel Temperature of Biodiesel |
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| Angela Nealen18 December 2009 |
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# ABSTRACT

North Americans are more dependent on fuel than ever before, spending on average 101 minutes per day in their vehicle (University of California, 2009) and using 19.5 million barrels of gasoline each day (U.S. Energy, 2009). Biodiesel can be the alternative fuel Americans need if the gel point temperature can be decreased. Biodiesel is a plant based fuel and adds no extra carbon dioxide to the air while also reducing carbon monoxide and cancerous exhausts (Summit, 2007).

In this report, four possible solutions to the problem of biodiesel gelling –biodiesel blending, use of additives, vehicular modifications, and production modifications – are examined. The four solutions are judged on their ability to meet three criteria: cost of materials, gel temperature decrease, and ease of implementation. Ultimately, the best solution based on the stated criteria is vehicular modifications. Although the cost of vehicular modifications is mostly upfront, the benefits will the reaped for many years to follow if they are used properly.

I recommend that the following steps be taken in order to make vehicular modifications to vehicles run on biodiesel: (1) educate the public on the benefits of biodiesel and the necessary precautions to take when the temperatures begin to drop below 40oF, (2) continue research on process modifications and biodiesel additives, (3) install a fuel filter warmer and either a fuel tank warmer or an in-line fuel warmer for all vehicles running on biodiesel, and (4) use B100 fuel when the temperature is above 40oF.

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# INTRODUCTION

Purpose

The purpose of this paper is to explore ways for biodiesel to be used at low temperatures.

Summary

As gas prices soar, many North Americans are looking for ways to become less dependent on foreign oils. The biodiesel industry is rapidly growing to meet this need (Pfalzgraf, 2007). Not only does biodiesel reduce dependence on foreign oils, it also improves the environment and provides opportunities for domestic agricultural products. A major impediment to biodiesel being widely used is its high cloud point. The cloud point, also known as the gel temperature or gel point, is the point when biodiesel begins to solidify (Cornell, 2007). As biodiesel solidifies waxy crystals form that can block fuel filters and clog fuel lines (Cooke McGraw, 1998). Since this occurs around 40 degrees Fahrenheit, many locations across the United States cannot use biodiesel for several months of the year (Cornell, 2007). The solutions being evaluated in this report are (1) blending diesel with biodiesel, (2) using additives to lower the gel point, (3) modifying vehicles running on biodiesel, and (4) modifying the biodiesel production process. These solutions will be assessed based on predetermined criteria-cost of materials, gel point temperature decrease, and ease of implementation-and a final recommendation will be made.

Present Status of the Problem

According to Pacific Biodiesel (2009), the first public demonstration of biodiesel was at the 1900 World’s Fair by the French government when they used peanut oil to run a diesel engine. The goal of the French government was to have a domestic fuel for their African colonies. Rudolph Diesel also did a vast amount of research and development on biodiesel and became a leading proponent on the concept. However, modern biodiesel did not get its roots until the 1930s, when a researcher in Belgium proposed converting vegetable oils into fatty acid methyl esters (FAME), the main component of biodiesel (Pacific, 2009). The industry did not have its onset in the United States until the late 1990s, but biodiesel has been commercially used in many countries since the late 1980s (*Biodiesel Basics*, 2009).

The cloud point of biodiesel is high compared to the cloud points of petroleum gasoline and petroleum diesel, thus causing a problem for biodiesel users when the temperatures begin to drop (*Biodiesel Blends*, 2005). For biodiesel to become a more widely used fuel, it is necessary to find solutions to the high cloud point problem. Biodiesel blending, mixing biodiesel with no. 1 diesel or no. 2 diesel, is a popular method used by biodiesel users to solve this issue (Hofman, 2006). No. 2 diesel is more commonly known as ‘road diesel’ and is the diesel used in trucks and some cars, whereas no. 1 diesel is similar to kerosene. Blending is usually done for one of two reasons: (1) no vehicular modifications are needed for blends of less than 20% biodiesel or (2) to lower the cloud point of the biodiesel.

Research Procedure

The information for this report was gathered from various locations. I performed secondary research using the National Biodiesel Board’s website, along with the websites of the American Chemical Society, the U.S. Department of Energy, and the National Renewable Energy Laboratory. I also used the Biodiesel Magazine and its website.

## Organization

To present this material in the most straightforward fashion, I have organized it into sections, beginning with a discussion of the solutions examined and the criteria used to judge the solutions. After these informative sections, I analyze each solution based on the three criteria. Following each analysis is the conclusion reached for that criteria. The report is concluded with an overall conclusion and recommendations.

DECREASING THE GEL TEMPERATURE OF BIODIESEL

Of the many possible solutions to biodiesel gelling at a high temperature four appear to be superior: biodiesel and diesel blending, the use of additives, vehicular modifications, and production modifications. The four solutions are judged by the three most adequate criteria: cost of materials, gel point temperature decrease, and ease of implementation to determine the best solutions. Biodiesel can be created from various products; however, this paper focuses on biodiesel created from waste vegetable oil (WVO).

## Introduction to Possible Solutions

### Biodiesel Blending

The most common fuel blends used containing biodiesel are B20, and B5, whereB20 is 20% biodiesel and 80% diesel, and B5 is 5% biodiesel and 95% diesel (NREL, 2009). According to Gallehugh, splash and ratio are just two of the multiple techniques that can be used to create the blends. Splash blending, the most common technique, is adding B100, or neat biodiesel, into the tank and then adding the diesel. One disadvantage to this is that if the products have dissimilar density and viscosity the blend can stratify, or separate. Another disadvantage is that for the exact blend to be known the fuel tank would have to be empty before mixing. The second technique, ratio, consists of the two fuels being blended before they reach the tank of the vehicle. The amount of each fuel that is added is controlled through valves. This technique is desirable to larger fleets of biodiesel vehicles because the tank of the vehicle does not have to be empty for the supplier to know the exact specifications of the fuel in the vehicle after filling up (2008). The National Biodiesel Board points out that Colorado’s Aspen Resorts, The City of Keene, New Hampshire; Harvard University and Yellowstone National Park all use B20 year-round (2008).

### Additives

A simple solution to the gel point problem is to mix in an additive such as an anti-gel or a pour-point depressant with the biodiesel (Biodiesel in Winter). These cold flow additives work by interacting with the crystals to keep them small and able to flow (Kenreck, 2007). According to the Journey to Forever, most diesel anti-gels do not affect biodiesel’s gel point, but there are some additives that are made especially for biodiesel. Wintron XC30, Biodiesel Cold Flow, and B100 Cold Flow Additive for biodiesel are a few of the biodiesel additives. Some anti-gels depend on the quality of the fuel, for example, Arctic Express Biodiesel can only be used with biodiesel blends, not neat biodiesel. The picture below shows two containers of biodiesel, one is biodiesel with an anti-gel and the other is pure biodiesel. Both containers are at approximately 14oF. The container on the left contains no anti-gel and has solidified because of the temperature; however, the container on the right, containing Wintron XC30, is still liquefied. The biodiesel with anti-gel is slightly cloudy but it is still able to flow.



Figure 1: Biodiesel with an anti-gel and biodiesel without an anti-gel (Biodiesel in Winter).

When mixing in the additives Kenreck (2007) emphasizes, “the additives must be added and mixed well at temperatures well above the cloud point to be effective.” In order for the temperature to be high enough a heat make need to be installed in the storage container.

### Vehicular Modifications

Another solution to the gel point problem is to equip vehicles running on biodiesel with specific fuel heating devices. Journey to Forever explains that a quick fix to getting the vehicle running in the winter is to pour hot tap water over the fuel injectors, the fuel pump and the fuel filter. This will usually free up a fuel system clogged by gelled fuel enough to start the engine. Fuel tank warmers and fuel filter warmers have also been found to be an effective way to keep the fuel from gelling. However, all three of these solutions require the vehicle to be near either a hot water source or an electricity source, which is not always possible. It is necessary to keep the fuel tank warmers and the fuel filter warmers plugged in when the car is not running because they are meant to keep the fuel warm, not to heat it.

### Process Modifications

The production process is the first place that biodiesel can be manipulated to create a more cold-weather friendly fuel (Kenreck, 2007). I will look at two production modifications: separations and cold soak filtration. To perform the separation the biodiesel is first heated and then cooled to near its freezing point (Journey to Forever). The saturated fats will crystallize and sink to the bottom of the solution. The clearer oil on the top of the solution can be used as cold weather biodiesel because it will now gel at a lower temperature. The precipitate, or the crystals on the bottom of the solution, can be kept and used during the summer months. According to Schroeder Biofuels, another type of process modification is cold soak filtration, which reduces the cloud point of biodiesel by removing the precursors of crystallization as an additional step in the production process (2009).

## Introduction to Criteria

### Cost of Materials

In order for biodiesel to become a more widely used fuel there has to be a cost effective way to lower the gel temperature. Cost comes into play in many different aspects of the biodiesel process including the catalyst used in production, the water for the wash process, and now a way to keep it from gelling. Many people use biodiesel because it is cheaper to make it on their own than it is to buy diesel fuel; however, they will no longer do this if a gallon of biodiesel costs more than a gallon of diesel.

### Temperature Range

Many locations across the United States experience temperatures below 40oF for at least three months out of the year. To not be able to use your vehicle for that period is simply ridiculous, yet this is what some biodiesel users are experiencing. During these colder temperatures biodiesel turn to diesel with cold flow additives to run their vehicles. Through my research, I hope to find a way for biodiesel to be used year round.

### Ease of Implementation

Since many biodiesel, users and brewers are farmers they do not have the time to implement a complicated solution. Therefore, the ease of implementation is important. In addition, most farmers are not experts in chemistry or engineering so the solution must be simple and straightforward.

## Applying the Solutions to the Criteria

### Analysis of Cost of Materials

#### Biodiesel Blends

The cost of blending biodiesel with diesel depends on the cost of diesel fuel. In 2007 and 2008, the average cost of a gallon of diesel was $2.94 and $3.81 a gallon respectively (U.S. Energy, 2009). In 2008 and 2009, the UMBC Biodiesel Project produced biodiesel for a $1.50 a gallon. The price of UMBC’s biodiesel is affected by the cost of methanol which is used as a catalyst for the reaction (Arnold, 2009). The table below shows the cost per gallon of different blends if splash blending and the diesel price average for October 2009 of $2.67 are used (U.S. Energy, 2009). If ratio blending is used the additional costs would include a high-density polyethylene container (U.S. Plastics, 2009)to store the blend in and a pump(Northern, 2009) to transfer the blend to the vehicle, which will incur a one-time cost of approximately $400 that would be absorbed within the 1st year of use.

|  |  |  |
| --- | --- | --- |
| Blend | Cost/gallon | Additional Cost/gallon |
| B5 | $2.61 | $1.11 |
| B10 | $2.55 | $1.05 |
| B20 | $2.44 | $0.94 |
| B50 | $2.09 | $0.59 |
| B80 | $1.73 | $0.23 |
| B100 | $1.50 | $0 |

Table 1: The most often used blends of biodiesel and diesel along with the cost per gallon and the additional cost incurred from mixing.

#### Additives

One additive than can be used is Wintron Synergy. It is available for purchase in various quantities through Biofuelsystems.com (2009). A 6.6-gallon drum costs $293 and can be used for 2200 gallons of biodiesel at the suggested treatment rate of 0.3% (Biofuel, 2009). The added cost per gallon of biodiesel is $0.13. Biodiesel-kits-online sells another additive, B100 Cold Flow Improver, which has been shown to reduce the cloud point of biodiesel to 30oF at a treatment rate of 0.13 volume percent (2009). According to the biodiesel-kits-online website the product is sold in cases of 12- 32oz. bottles for $270 and each case treats 2220 gallons of biodiesel for a cost of $0.12 per gallon (2009). The final additive I researched was Biodiesel Cold Flow Additive produced by Biodiesel Chemicals (2009). It costs $55 for a half gallon that treats 375 gallons of biodiesel, the same treatment rate as B100 Cold Flow Improver (Biodiesel Experts, 2009). The additional cost per gallon of biodiesel with this additive is $0.15 A 70 gallon high-density polyethylene container (U.S. Plastics, 2009) is also needed to store the biodiesel in along with a pump (Northern, 2009) to transfer the biodiesel. This will cost approximately $400.

#### Vehicular Modifications

A simple and quick solution to the gel point problem is pouring hot tap water over the fuel injectors, the fuel pump and the fuel filter to free up the gelled fuel enough to start the engine. This solution is the most cost effective as long as the vehicle is near a hot water source. A significant flaw in this procedure is that the amount of water needed to unclog the filter is unknown. Another solution is to use fuel filter warmers. They can be purchased from Wolverine Heaters for a onetime cost of $60 per unit (2009). According to their sales representative, the warmers are designed to be plugged in all night to keep the fuel warm (2009). Another cost that cannot be accounted for, but will affect the cost greatly is the cost of electricity. All of these options must be run off electricity when the temperatures are low and the car is not running. The warmers require no maintenance and most last for over 15 years (Wolverine, 2009). The fuel filter warmer should be used in conjunction with fuel tank heating pads that can be purchased for approximately $150 (Biodiesel in Winter) or an in tank fuel warmer which can be purchased from Arctic Fox for $220 (2009). Most fuel tank heaters and in-line warmers should be replaced after 5 year or 600,000 miles (Arctic, 2009). For a vehicle that gets approximately 25 miles to the gallon, using the fuel filter warmer and heating pads combination will cost about $0.01per gallon and the combination with the in-line fuel warmer costs about $0.02per gallon.

#### Production Modifications

To perform the separation a high-density polyethylene container and a pump is needed. The cost for a 55-gallon tank and an 18gpm pump is approximately $310 when they are purchased from US Plastics (2009) and Northern Tool (2009) respectively. A heater, that can be purchased from biodiesel-kits-online for $170 is also required to heat the biodiesel to above the gel temperature, (2009). If the pump and the heater remain in working condition for 2 years without repairs, the additional cost per gallon of biodiesel would be $0.24. Schroeder Biofuels sells Cold Clear, cold soak filtration system, costs $3,200 for the basic setup and the replacement filters are $54.50 each. Each filter is designed to have 15000 gallons of biodiesel run through it, so for the average biodiesel home brewer a filter will last approximately 15 years (2009). The additional cost is $0.21per gallon, if the installation is performed by the brewer. If someone must be hired to perform the installation, the cost would be absorbed within the first t two years of production.

#### Conclusion

The most cost efficient solution is making modification to vehicles running on biodiesel. Either combination of modifications is going to be a cost effective solution to the problem with an additional cost of one to two cents per gallon. The next most cost effective solution is the use of additives, which will only add an additional $0.12-$0.15 per gallon of biodiesel. At $0.21 and $0.93 per gallon, the final two solutions are expensive when compared to the other two solutions. I chose to evaluate the B20 blend because it is the most commonly used.

### Gel Point Temperature Decrease

#### Biodiesel Blends

Blending biodiesel with diesel reduces the gel temperature while also reducing the negative diesel emissions (Biofuel: A Short, 2008). According to Alleman, the average cloud point for neat biodiesel, B100, is approximately 38oF. When a blend of 20% biodiesel and 80% #1 diesel with a cloud point of -40oF, B20, is tested, the average cloud point lowers to 12.6oF.(2009). B20 is the most popular blend because it is a balance between cost, emissions and cold weather performance (NREL, 2009).

#### Additives

The final gel point temperature of the biodiesel is going to depend on the type of additive that is used. The table below shows the gel point temperature of the biodiesel after each additive was added.

|  |  |  |
| --- | --- | --- |
| Additive | Cloud Point Decrease (oF) | Cloud Point (oF) |
| Wintron Synergy | 6 | 32 |
| B100 Cold Flow Improver | 30 | 8 |
| Biodeisel Cold Flow Additive | 26 | 12 |

Table 2: The three additives that were researched with their corresponding cloud point decrease and final cloud point temperature.

Many additives only lower the gel point temperature a few degrees, which can be seen by Wintron Synergy in the above table. To make up for this, many of the additives suggest mixing biodiesel with diesel and then applying the additive for a greater gel point temperature decrease.

#### Vehicular Modifications

The hot tap water method has only been found useful when the outside temperature is slightly below the gel point. However using the fuel tank and fuel filter warmers have been found effective at air temperatures as low as -40oF (including the wind-chill) when they are used properly, according to the Wolverine Heaters sales representative.

#### Production Modifications

The separation method lowers the gel temperature of biodiesel only slightly because it is hard to cool the biodiesel to the necessary temperature without it completely gelling (Biodiesel in Winter). As for the cold soak filtration method there is no data on the decrease in the gel point temperature, however, there is data concerning the cold soak filtration test times. The cold soak filtration test is becoming a popular way to test biodiesel’s cold flow properties. The test consists of timing how long it takes a specified amount of biodiesel to flow through a 0.7-micron patch (Kotrba, 2009). The Clear Cold apparatus has been shown to decrease these times from 430 seconds to 35 seconds for biodiesel made from waste vegetable oil, over a 1200% decrease (Schroeder, 2009). These results cannot be directly converted into cloud point temperature decreases but they do imply a notable decrease in the cloud point.

#### Conclusion

Once again vehicular modifications seem to be the best solution. These modifications have been shown to be effective to temperatures much lower than the other three solutions. The solution with the next closest gel point temperature decrease to vehicular modifications is additives. B100 Cold Flower Improver from biodiesel-kits-online lowers the gel point temperature to 8oF, a decrease of 30oF. The final solution that can be compared is the B20 blend, which has a gel temperature decrease of 26oF. The production modification of separation has only been shown to lower the gel temperature approximately 5oF and there is no data to compare the cold soak filtration method.

### Ease of Implementation

#### Biodiesel Blends

Blending biodiesel and diesel is very simple to implement. The main item used for this solution is a high-density polyethylene container to mix the diesel and biodiesel.

Simple math is required to calculate the quantity of diesel that should be added to the biodiesel and a chart can be constructed with the different ratios so that the blend is insured to be the desired blend. The chart is a quick and easy solution for people who are uncomfortable about doing math. Refilling the container before it is empty complicates the math therefore, the simplest way to reduce the amount of math needed to calculate the proper blend ratio is to use all of the biodiesel in the container before blending a new batch. As explained about there are a range of blends and the math will be slightly different for each blend.

#### Additives

The additives researched are all simple to use. The biodiesel will need to be stored in a high-density polyethylene container at least 5-10oC above the cloud point of the biodiesel for each additive to be used (Kenreck, 2009). If the biodiesel is not being stored in a heated or insulated container it may need to be heated before the additive can be added. The additives are all safe to use, so there is no need to purchase special safety equipment nor become educated about harmful substances. Each additive contains its own warnings and hazards labels indicating general cautions that should be taken.

#### Vehicular Modifications

The ease of implementation for vehicular modifications is dependent of the level of mechanical knowledge the user has. Many farmers would be able to perform the installation themselves without the purchase of any new tools. Both the fuel tank and fuel filter warmers have stick-on applicators, Thus the only difficulty in installing them is finding the correct location to place them. The fuel tank warmer is placed on the bottom of the fuel tank so that it can heat from the bottom up and the fuel filter warmer is placed on the outside so that it can heat from the outside in.

#### Production Modifications

The separation method requires the user to have basic knowledge of chemistry. The biodiesel must be heated and then allowed to cool until it reaches a temperature right above the gel temperature. (Biodiesel in Winter). The supernatant, the liquid on the top, is then pumped off and used during the winter months. The precipitate is then reheated until it becomes liquid and is used as fuel during the summer months. The cold soak filtration system requires no knowledge or maintenance until the filter needs to be replaced. The system is installed as an additional step in the biodiesel production process. However, using the cold soak filtration system is only an option for biodiesel users who are also brewers.

#### Conclusion

All four of the solutions are very simple to implement. They all require a minimum amount of additional knowledge and/or work to use. Therefore, the ease of implementation is not going to contribute strongly to the ultimate judging of the best solution.

# CONCLUSION

In this report, four possible solutions to biodiesel gelling at a high temperature -biodiesel blending, use of additives, vehicular modifications, and production modifications – are examined. The four solutions were judged on their ability to meet three criteria: cost of materials, gel temperature decrease, and ease of implementation. Ultimately, the best solution based on the stated criteria is vehicular modifications. Though the cost of vehicular modifications is mostly upfront, the benefits will the reaped for many years to follow if they are used properly.

# RECOMMENDATIONS

I recommend that the following steps be taken in order to implement vehicular modifications to biodiesel run vehicles as a solution to the biodiesel gel temperature problem:

1. Educate the public on the benefits of biodiesel and the necessary precautions to take when the temperatures begin to drop.
2. Continue to do research on process modifications and biodiesel additives.
3. Install a fuel filter warmer and either a fuel tank warmer or an in-line fuel warmer for all vehicles running on biodiesel
4. Use B100 fuel when the temperature is above 40oF.

Following these recommendations will lead to less issues caused by biodiesel gelling and a greater public awareness of biodiesel.

# REFERENCES

Alleman, T. L., & McCormick, R. L. (2009, February 2). 2008 B20 Survey Results. Retrieved December 5, 2009

Arctic Fox. (n.d.). Product Catalog. Retrieved December 5, 2009

Biodiesel Basics (2009). Retrieved November 4, 2009, from <http://www.biodiesel.org/resources/biodiesel_basics/>

Biodiesel Blends. (2005, April). Retrieved November 4, 2009, from http://www.nrel.gov/docs/fy05osti/37136.pdf

Biodiesel Experts International. (2009). Biodiesel Cold Flow Additive. Retrieved December 5, 2009

*Biodiesel in Winter*. (n.d.). Retrieved December 5, 2009, from http://journeytoforever.org/biodiesel\_winter.html

Biodiesel: A Short Review. (2008, February 17). Retrieved December 5, 2009

Biodiesel-Kits-Online. (2009). Biodiesel Antigel & Winter Fuel Additives. Retrieved December5, 2009

Biodiesel-Kits-Online. (2009). Cold Soak Filtration System. Retrieved December 5, 2009

Biodiesel-Kits-Online. (2009). Flexible Oil Drum Heaters. Retrieved December 5, 2009

Biofuel Systems Group LTD. (2009). *Wintron Synergy*. Retrieved December 5, 2009

Clean Air Act. (2009, May 12). Retrieved October 10, 2009, from <http://www.epa.gov/air/caa/>

Cooke McGraw, L. (1998, April). Better Cold-Weather Starts for Biodiesel Fuel [Electronic version]. *Agricultural Research Magazine*.

Cornell, C. B. (2007, April). Green Myth-Busting: Biodiesel. Retrieved November 4, 2009, from <http://claytonbodiecornell.greenoptions.com/2007/04/05/green-myth-busting-> biodiesel/

Frequently Asked Questions. (2006). Retrieved October 7, 2009, from <http://yourgrease.com/faq.html>

Gallehugh, J. (2008, July). Biodiesel Blending Techniques Key to Quality Fuel [Electronic version]. *Biodiesel Magazine*.

Gerpen, J. V., Shanks, B., Pruszko, R., Clements, D., & Knothe, G. (2004, July). *Biodiesel Production Technology*. Retrieved December 5, 2009

Hofman, V. B., Wiesenborn, D., & Rosendahl, M. (2006, January). Biodiesel Use in Engines. Retrieved November 4, 2009, from http://www.ag.ndsu.edu/pubs/ageng/machine/ae1305w.htm

Howell, S., Nazzaro, P., Selvedge, C., Stanko-Marathon, R., & Lawrence, R. (n.d.). Biodiesel Cold Weather Blending Study. Retrieved December 5, 2009 from <http://www.dlnet.vt.edu/repository/previewRepository/BE000000/BE003000/>

BE003004/DISK1/DLNET-01-16-2003-0128/resources/biodiesel\_handling.pdf

Kenreck, G. (2007, February). Improving Biodiesel Stability with Fuel Additives [Electronic version]. *Biodiesel Magazine*.

Kotrba, R. (2009, May). 'Cold Soak' or Wet Blanket?. Retrieved December 5, 2009

Kram, J. W. (2008, February). No Need to Splash. *Biodiesel Magazine*. Retrieved December 5, 2009

National Biodiesel Board. (2008). Biodeisel Beats the Cold. Retrieved December 5, 2009

National Biodiesel Board. (2009, March). Commonly Asked Questions. Retrieved October 7, 2009, from <http://www.biodiesel.org/pdf_files/fuelfactsheets/CommonlyAsked.PDF>

National Renewable Energy Laboratory. (2005, April). Biodiesel Blends. Retrieved December 5, 2009

National Renewable Energy Laboratory. (2009, January). Biodiesel Handling and Use Guide. Retrieved October 7, 2009, from <http://www.nrel.gov/docs/fy09osti/43672.pdf>

Northern Tool and Equipment. (2009). Tuthill Diesel Fuel Transfer Pump. Retrieved December 5, 2009

Pacific Biodiesel. (2009). History of Biodiesel Fuel. Retrieved November 11, 2009, from http://www.biodiesel.com/index.php/biodiesel/history\_of\_biodiesel\_fuel

Parts Systems. (2009). Arctic Fox In-Tank Fuel and Fluid Warmer. Retrieved December 5, 2009

Pfalzgraf, L., Lee, I., Foster, J., & Poppe, G. (2007, November). The Effect of Minor Components on Cloud Point and Filterability [Electronic version]. *Biodiesel Magazine*.

Proc, K., Barnitt, R., Hayes, R., Ratcliff, M., McCormick, R. L., Ha, L., et al. (2006). 100,000-Mile Evaluation of Transit Buses Operated on Biodiesel Blends (B20) [Electronic version].

Schroeder Biofuels. (2009, July). Cold Clear BCC100 Series. Retrieved December 5, 2009

Summit Enterprises LLC. (2007). Biodiesel FAQ. Retrieved October 10, 2009, from http://www.ezbiodiesel.com/faq.htm#What%20are%20the%20drawbacks

Tyson, K. S. (2001, September). Biodiesel Handling and Use Guidelines. Retrieved December 13, 2009

U.S. Energy Information Administration. (2009, December 7). Annual Retail Gasoline and Diesel Prices. Retrieved December 9, 2009

U.S. Plastics. (2009). Retrieved December 5, 2009

University of California. (2004, March 10). Americans Spend More Energy Watching TV Than on Exercise. Retrieved December 5, 2009

Wolverine Heaters. (2008). Retrieved December 5, 2009, from <http://www.wolverineheater.com/index.shtml>

# Appendix A

On December 1, 2009, I spoke briefly with Dr. Bradley Arnold, the UMBC Biodiesel Project’s advisor, about the cost of biodiesel production. He informed me that the club produced biodiesel in 2008 and 2009 for approximately $1.50, but the cost varied slightly depending on the cost of methanol. Methanol is used in the process as a catalyst.

# Appendix B

Extended Definition:

Biodiesel

**Introduction**

Biodiesel is a renewable resource created from animal fats, waste vegetable oil, plant oils, and even algae. Biodiesel has many advantages over petroleum-based diesel, including it is biodegradable and free from aromatics (fragrances). Individuals with diesel engines and a high demand for fuel or with excess vegetable oil commonly produce biodiesel. This occurs most often on farms when there is a demand for diesel in tractors. Biodiesel can sometime be confused with ethanol and raw vegetable oil, however, there are some differences.

**Production of Biodiesel**

According to the Biodiesel Handling and Use Guide, the process to make biodiesel is referred to as transesterification. This process involves converting oils and fats into methyl esters, also known as biodiesel. Figure 1 is a simplified diagram of the process. To produce 100 pounds of biodiesel, 100 pounds of oil or fat are reacted with 10 pounds of an alcohol, usually methanol, in the presence of a catalyst, usually potassium hydroxide. About 10 pounds of glycerin, another product of the process, is also produced. Glycerin can then be used to make soap, therefore all of the products can be used (National Renewable, 2009).

Ethanol, another alternative fuel, is produced from sugars for use in gasoline type engines as opposed to diesel engines. Raw vegetable oil does not meet the biodiesel fuel specifications. Biodiesel can be interchangeable with petroleum-based diesel because they have similar viscosity, whereas vegetable oil has a much higher viscosities and will not work in standard diesel engines without major modifications. Some small modifications may be required to run biodiesel in engines containing rubber because it is incompatible with some rubbers (National Biodiesel, 2009).



Figure1: Basic Transesterification Process1

**Biodiesel Advantages**

There are several advantages to using and producing biodiesel, a few of them are listed below.

* According to biodiesel.org, biodiesel is the only alternative fuel to have fully completed the health effects testing requirements of the Clean Air Act.
* There are almost no sulfur oxides or sulfates in biodiesel emissions.
* Biodiesel has almost fifty percent less smog forming potential from its hydrocarbon exhaust emissions compared to diesel fuel.
* Biodiesel is the best greenhouse gas improvement strategy for medium and heavy-duty vehicles.
* The storage and handling methods of biodiesel are the same as petroleum based diesel.
* Biodiesel blends of up to twenty percent biodiesel can be used in normal diesel engines without any modifications, and only slight modifications are necessary for blends of more than twenty percent biodiesel.
* Biodiesel is a diversified fuel because it is produced from several renewable resources including waste vegetable oil, plant oils, and animal fat.
* It is less toxic than table salt and biodegrades as fast as sugar.
* For every unit of fossil energy it takes to create biodiesel, 3.5 units of energy are gained.
* Biodiesel can be produced from renewable resources available in the United States, decreasing our dependence on foreign oil (National Biodiesel, 2009).

**Biodiesel Disadvantages**

Despite the numerous advantages of using biodiesel, there are some drawbacks.

* The National Biodiesel Board says that nitrogen oxides emissions of biodiesel engines could be slightly increased compared to diesel engines depending on the duty cycle of the engine and the testing methods used.
* Biodiesel has a higher gel temperature than standard petroleum based diesel. This means that straight biodiesel should not be used at low temperatures, but twenty percent blends can be treated as regular diesel in low temperature situations (National Biodiesel, 2009).
* Biodiesel releases deposits from the tank walls during the initial uses, which can cause filter clogging. Because of this, great caution should be used when converting over vehicles with over 80,000 miles (Summit, 2007).

**Conclusion**

Biodiesel is a great biofuel whose popularity is on the rise. America has become a nation filled with fast food restaurants and citizens addicted to fried foods, which has lead to large amounts of waste vegetable oil (WVO), about 4.5 billion gallons per year (Frequently, 2006). Four and half billion gallons of waste vegetable oil equals 4.5 billion gallons of biodiesel per year if companies began using proper disposal techniques and sold or donated their WVO to biodiesel producers instead of dumping it in landfills. Biodiesel’s popularity is growing in every direction from the small-scale productions by home brewers to school organizations to large-scale incorporated companies producing biodiesel for profit.