BIOFUEL VEHICLE PROJECT

FINAL REPORT

Calvin College

Engineering 333

Professor Matthew Heun

Fall 2013

Introduction

During the fall of 2014, the Engineering 333 class was asked the question, "what would it take for Calvin College to operate a biofuel vehicle from campus resources.[1]" The three primary considerations included:

- Determining the optimal biofuel feedstock in terms of availability, transportation, and processing.
- Selecting a biofuel vehicle for conversion or purchase to operate on the selected feedstock.
- Designing the infrastructure and process required for operating the selected biofuel vehicle.

The design and research described below proposes an environmentally sustainable and cost-effective method for integrating a biofuel vehicle into Calvin's existing infrastructure.

Procedures

The execution of this project was accomplished by dividing the team into four sub-teams, with a representative from each group to coordinate all activities among the groups plan the final report and presentation. A listing each sub-team and their primary objectives is as follows:

- Feedstock/Fuel Production
- Vehicle
- Infrastructure/Facilities
- Future Planning

The Feedstock/Fuel Production team chose Waste Vegetable Oil (WVO) per the decision matrix in Table 3: Fuel Decision Matrix. This decision narrowed the vehicles to diesel engine choices only. After the fuel was picked everything could begin motion. Several processes were examined which are explained in the Filter Research in Appendix 1-B. These processes were backed by experienced WVO users found on forums. Figure 1: Overall Process for Biofuel Project shows the process after the feedstock was chosen. The next question was how to get the WVO to the processing plant and then how will it be processed once it gets there. A biofuel vehicle can be chosen that will be used around campus.

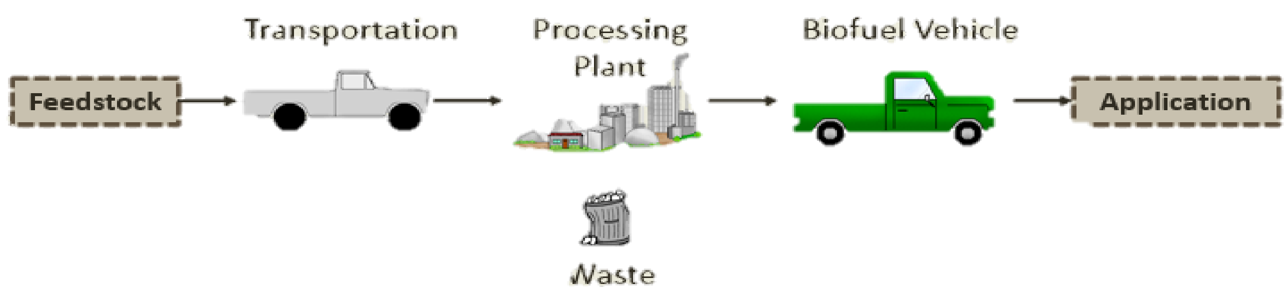

Figure 1: Overall Process for Biofuel Project

Data

WVO had been previously collected by Darling International. They gave weights for every month for the last three years and those were converted to gallons and can be seen in Figure 1. This gave overall fuel production for every month which would be enough to run one lawn mower.

[1] Huen, Matthew. Biofuel Vehicle Project Overview. Calvin College. Fall 2013

The costs associated with converting a lawn mower along with upfront cost of processing plant were combined with fuel savings for a payback period in about three and a half years as seen in Figure 2.

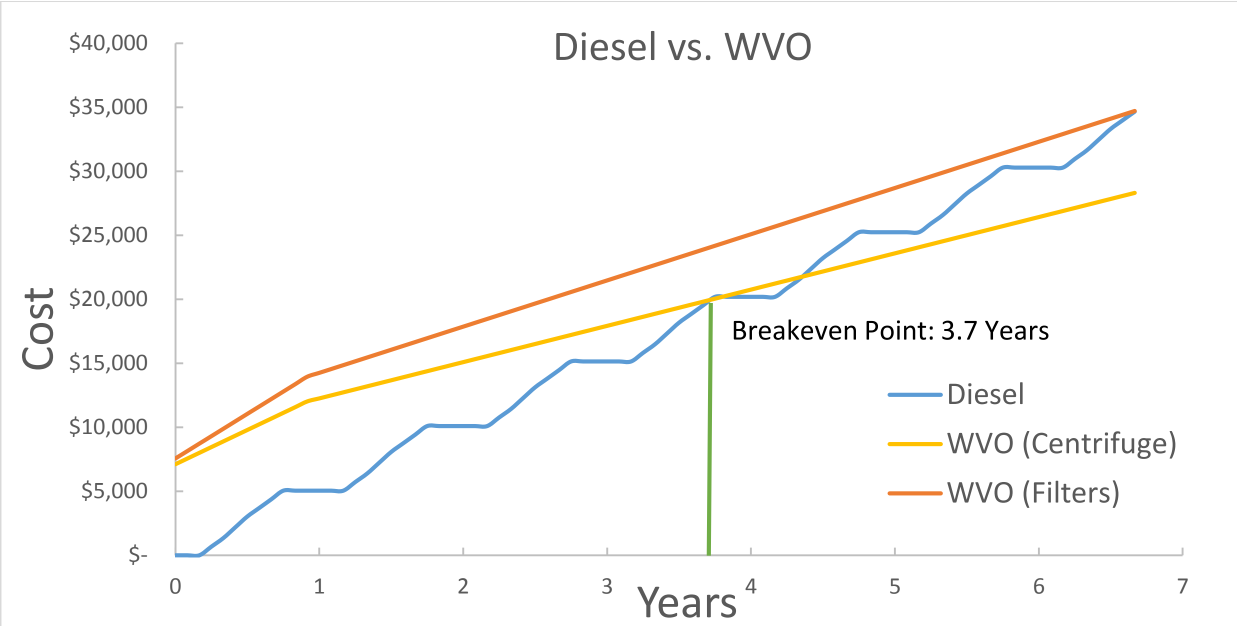

Figure 2: Final Design Breakeven Point

Conclusion

From a financial and environmental perspective this project is feasible. Figure 3 shows the overall process diagram filled in. The dining halls are the feedstock, with an already existing recycling truck picking up the WVO from the dining halls. The WVO will then be stored in the processing plant located in the physical plant. The WVO waste will be put in a dumpster that New Soil will pick up. The lawn mower will fill up at the processing plant and then used on campus lawns. All in all, the team proposes that Calvin begin operating one lawn mower on WVO beginning spring of 2015.

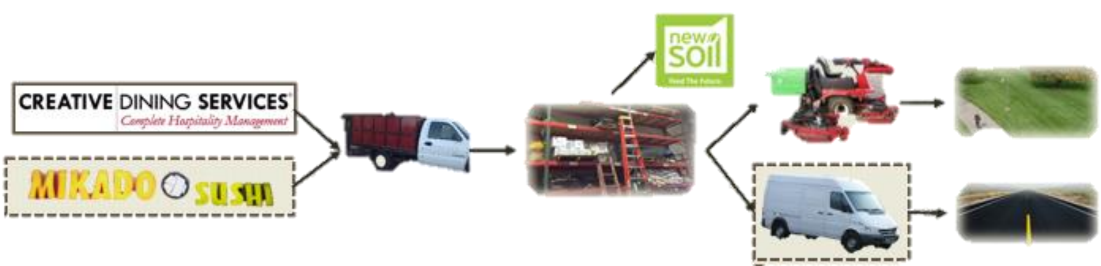

Figure 3: Filled in Overall Process for Biofuel Project

Future Considerations

Figure 3 shows that another source of WVO is Mikado Sushi. The WVO will be picked up in the same way as the WVO from the dining halls, and the processing plant will be able to handle the new stock with a third parallel process. This WVO will be used in a Dodge Sprinter van which can be used for long distance trips.

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Appendix I. Fuel Selection

Summary

Introduction

The Feedstock/Fuel Production sub-team was tasked with investigating the best possible biofuel resource available on Calvin College's campus and determining the optimal way of filtration for future use in a vehicle. Compost, grass clippings, and waste vegetable oil (WVO) from the dining halls were researched. Possible methods for fuel processing included an anaerobic digester, distillation tanks, and filtration with centrifuge and settling tanks. WVO was chosen for its ease in processing and low overall cost compared to other resources.

Procedures

The first task for the Feedstock and Fuel Production sub-team was to find a fuel. Four fuel possibilities were researched along with their sources: methane from compost (see Methane), ethanol from grass clippings (see Ethanol), biodiesel from WVO (see Biodiesel), and pure WVO (see Waste Vegetable Oil). Each potential feedstock was researched extensively. Results were in a decision matrix (see Table 3). Critical design constraints to the final feedstock selection included upfront cost, ongoing cost, and cost of retrofitting or rebuilding an engine for a vehicle (see Table 2).

Having selected a feedstock, the Feedstock/Fuel Production sub-team began analyzing various alternatives for cleaning the fuel. Online forums were valuable sources of information because they were written by individuals with experience in the filtration of WVO. In the end, three main options arose: covered filters, settling tanks, and centrifuges. After more in-depth study of the WVO quality coming from the dining halls, it was deemed that in-line filters would have very high operating and maintenance costs. Filtration purely by settling tanks would have a higher upfront costs than filters and also require extensive warehouse capacity and additional labor. Finally, a centrifuge would have the highest upfront cost, but the quickest processing time. To narrow down the decision, the team looked at financial case studies of filters only, a centrifuge and filter, and doing these two processes with no settling tank.

A third consideration of the Feedstock and Fuel Production sub-team was the WVO acidity, due to the presence of fatty acids in the oil. Tests were done and eventually, it was concluded that the WVO acidity level was within a tolerable range without the addition of baking soda.

Data & Calculations

WVO from the dining halls is collected currently by a company called Darling International. Figure 4: Waste Vegetable Oil Production Data shows volume data with a running average from the last three years and an overall average to show the possible supply capacity. The Facilities and Infrastructure portion of the report will discuss in greater detail the necessary warehouse space to manage this amount of WVO production (see

Appendix III. Facilities & Infrastructure Selection).

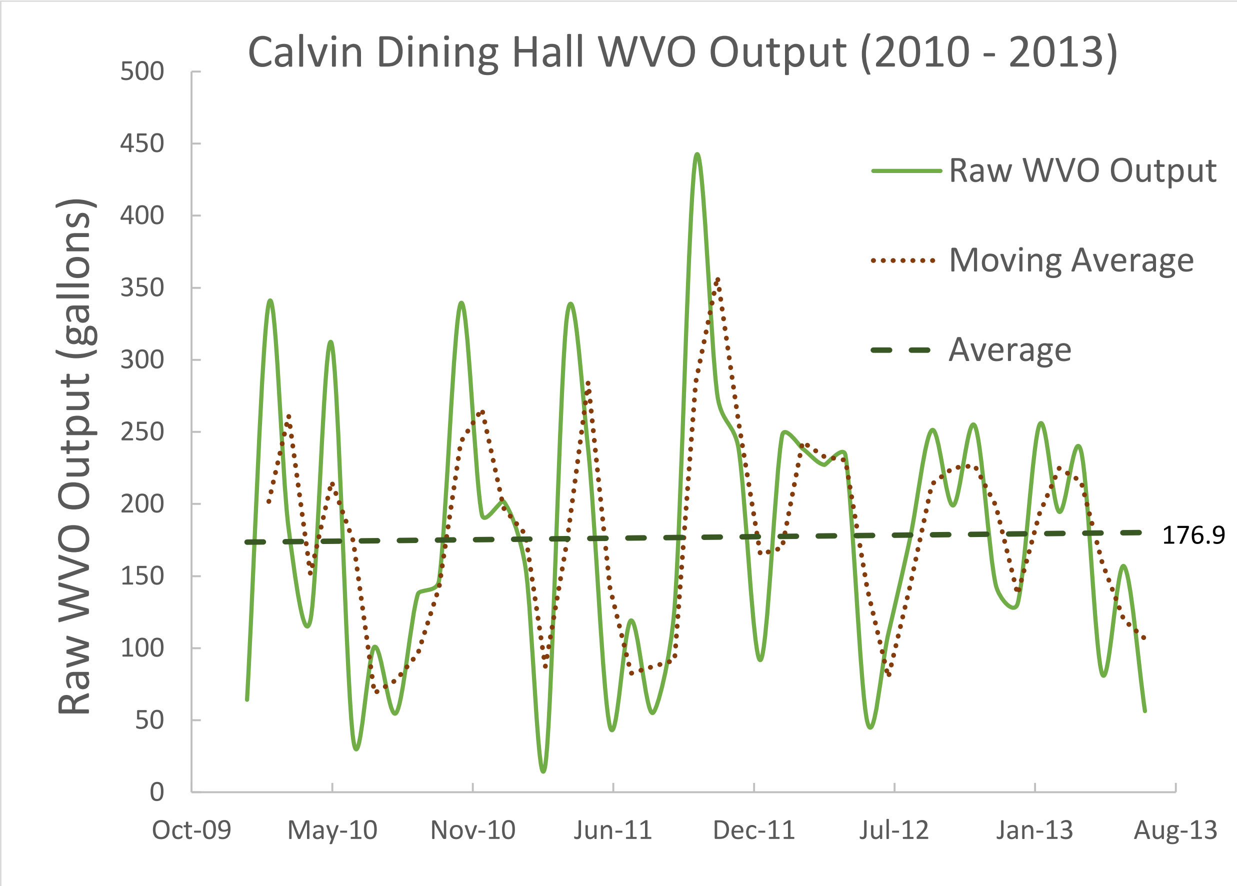

Figure 4: Waste Vegetable Oil Production Data

Conclusion

Waste Vegetable Oil was the chosen fuel for the on campus vehicle. The chosen filter and cleaning method was a combination of a large filter, several settling tanks, and a centrifuge for the best possible cleaning. With this method the team was confident that the WVO would be clean enough to put into the vehicle with relatively little maintenance problems for the vehicle engine.

Future Considerations

In the future, there may be need of additional WVO to support the biofuel vehicle(s) using it as fuel. To address this concern, the team has made connections with a few local restaurants who would be willing to provide their waste vegetable oil to Calvin at no cost, just as long as Calvin provides transportation. Refer to Appendix I-C. Future Considerations for further information.

Appendix I-A. Fuel Selection Process

Methane

Source

Methane was one of biofuel options researched by the Feedstock/Fuel Production sub-team. Most commonly, it is produced using anaerobic digesters because they increase the speed and efficiency of production. In summary, methane is produced in an anaerobic digester through the breakdown of biological waste. Bacteria feed on the biological waste and in the absence of oxygen, methane is produced as a byproduct. Another byproduct of this process is compost, which could be used on the Calvin's campus as a fertilizer for plants. A simplified diagram of the anaerobic digestion process is shown in Figure 5: Stages in an Anaerobic Digester.

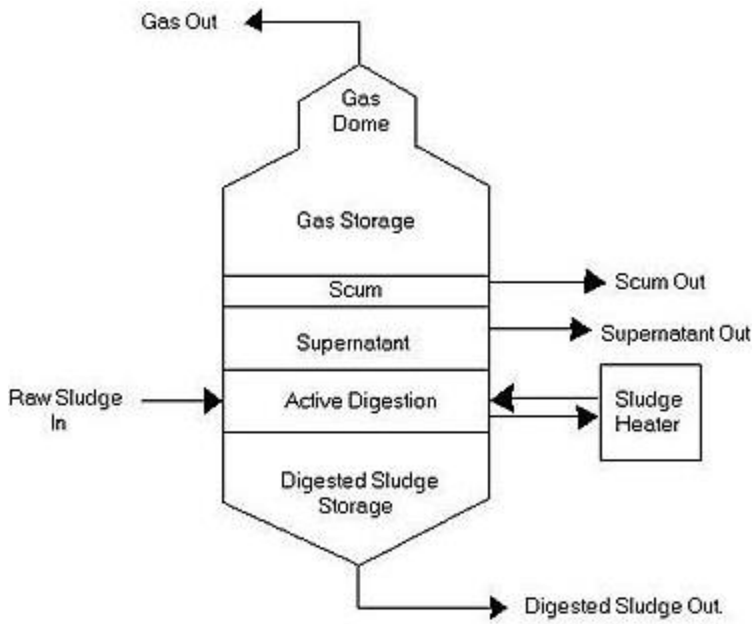

Figure 5: Stages in an Anaerobic Digester

While researching methane, it was important for the team to investigate the availability of resources on campus to produce methane. Calvin College currently has a compost pile on campus, and, according to Henry Kingsma from the Physical Plant, 250 cubic yards of compostable material is available on campus each year. The majority of the available material on campus consists of grass clippings, woodchips, and leaves during fall clean-up. The compost pile on campus takes a full two years for the compostable material to be broken down. The benefit of a digester would be the expedition of this process, decreasing the retention time of the material to approximately three months.

Quality

The quality of the methane produced was also addressed by the team. One of the critical questions the team looked into was, "how much methane is currently produced from a given amount of compostable material?" Likewise, another question that arose was, "how much methane could be produced using only the compostable material available from campus?" Through research of different types of compostable material and the conversion rates for each, the team found that leaves and grass clippings had very low conversion rates.

Costs

Also considered were the costs associated with methane production. The big standout in cost for methane is the upfront cost of purchasing an anaerobic digester and a biogas engine for the vehicle. These two pieces of equipment alone will be over $20,000 considering the size of the digester needed. Other costs necessary to be considered are production costs. The compostable material is essentially free, as it is already being composted on campus. The cost of production is therefore broken down into labor costs and digester operating costs.

Decision

After researching methane production, the team came up with pros and cons of using methane as the fuel source. Pros for using methane included a relatively low production cost and the production process that is easy to maintain. The cons of using methane were that it has a large upfront cost due to the requirement of a digester to produce an efficient amount of methane and the need to purchase a new biogas engine to run the methane. A decision matrix was developed to compare methane with other feedstock options (see Table 3: Fuel Decision Matrix). In the end, the team decided that methane was not the best biofuel alternative.

Ethanol

Ethanol is also a biofuel source produced by breaking down the cellulose in various plant-based substances. These substances are referred to as feedstock, or raw materials. Examples of global ethanol feedstocks include: sugar cane, switch-grass, potatoes, fruits, corn, grain, wheat, and cotton. The important factor in each potential feedstock is its respective cellulose content. Wood chips, grass clippings, and leaves can be used as feedstock, however, their reduced cellulose levels in comparison with agriculturally farmed feedstock sources such as switch-grass, decreases their potential levels of fuel output (see Table 1. Ethanol Yield Based on Cellulose Content).

Table 1. Ethanol Yield Based on Cellulose Content[2]

Ethanol Yields of Selected Feedstocks

Feedstock	Theoretical Ethanol Yield (gal/dry ton of feedstock)
Corn Grain	124.4
Corn Stover	113
Rice Straw	109.9
Cotton Gin Trash	56.8
Forest Thinnings	81.5
Hardwood Sawdust	100.8
Bagasse	111.5
Mixed Paper	116.2
Switchgrass	96.7

[2] http://www.afdc.energy.gov/fuels/ethanol_feedstocks.html

Source

Currently, the Calvin College Grounds Crew collects and composts grass clippings, leaves, wood, and plants from all across campus. Permission was received to reallocate these resources if ethanol was chosen as the fuel for this project.

Quality

Similar to methane, the production of ethanol releases a waste byproduct. In total, 80% of the feedstock mass can be converted to useable ethanol, while the remaining 20% is removed into the waste stream.[3] This waste stream is composed mainly of water and lignin. Lignin is one of the three main components of organic compounds, the other two being cellulose and hemicellulose. Lignin can be easily disposed of by burning, or use as a fertilizer.[4] For the ethanol produced to be used as a biofuel, it must leave the distillation process consisting of roughly 95% pure alcohol.

Costs

One of the most important benefits of ethanol is that most of the required materials would be free, namely the previously mentioned yard waste. The final fuel would require the use of 5%to 15% gasoline, which would account for the majority of the ongoing costs. Estimations of these monthly operating expenses fell between $200 and $500, depending on the vehicle and ethanol-to-gasoline ratio. Pre-assembled machinery for processing the feedstock would cost around $10,000.

Collection & Storage

Calvin Grounds Crew currently composts the grass clippings and other waste products it collects. It would be a simple matter for them to transport these to the Physical Plant to be processed or to the compost pile for temporary storage.

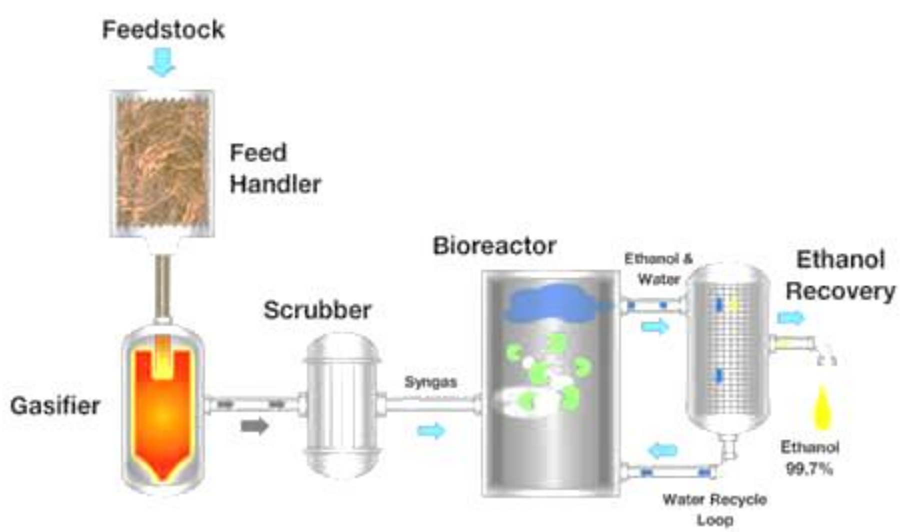

Figure 6: Ethanol Production Process[5]

[3] http://www.agmrc.org/commodities__products/energy/cellulosic-ethanol-profile-2739/
[4] "The Potential Environmental Impact of Waste from Cellulosic Ethanol Production." *Journal of the Air & Waste Management Association*
[5] http://zfacts.com/p/85.html

Figure 6: Ethanol Production Process shows the components necessary for producing ethanol. The average process can be stored in a 500 ft^2 area, or about the size of four 8-foot sections of inventory shelving in the physical plant warehouse.

Biodiesel

Biodiesel is a popular alternative for fuel in diesel vehicles. It is typically made by chemically reacting waste vegetable oil with an alcohol, resulting in the production of fatty acid esters. This chemical process is commonly called transesterification. Using biodiesel as a fuel alternative is rising in popularity in the United States, largely due to the Energy Policy Act of 2005, which provided tax incentives for alternative energy production.

Source

The source of the biodiesel would be the WVO collected by Calvin Dining Services. The alcohol needed to react with this WVO would have to be purchased, further increasing the overall cost of the biodiesel fuel choice. The annual WVO collected by the Dining Services (see Figure 4: Waste Vegetable Oil Production Data) was found to be enough to provide approximately 1,300 gallons of usable fuel. The storage and production requirements of biodiesel would be identical to that of using waste vegetable oil directly as a fuel source (see Waste Vegetable Oil).

Quality

The team concluded that the quality of the biodiesel fuel would not be a concern for the biofuel vehicle project, as the self-contained units are able to accept all levels of waste vegetable oil quality. As mentioned previously, biodiesel can be fueled directly into a standard diesel engine without any additional modifications required.

Process

The final production process that the team decided upon had several benefits. First, using biodiesel as the fuel choice for the biofuel vehicle project would result in no engine modifications, as biodiesel is able to be used in standard diesel engines without encountering additional problems. However, the complex chemical process and equipment necessary to produce the biodiesel required high overall upfront costs. In comparison, biodiesel was roughly 3-4 times more costly than the WVO (see Waste Vegetable Oil). Therefore, the team decided upon a common batch method for implementation of the transesterification reaction. Other methods considered included: supercritical processes, ultrasonic methods, and microwave methods. The common batch method was selected due to its low cost and relatively low operational difficulty. The supercritical process, ultrasonic methods, and microwave methods were around four to five hundred percent more expensive and the potential safety risk when using the necessary supercritical chemicals was much higher. The team was able to locate several companies that provide the infrastructure needed to run the complete operation. Of these options, the BIO100 unit provided by Central Bio-Diesel HTP[6] was the best option due to its low processing time and relatively low cost. This unit would have a batch time of approximately eight hours, with only one hour of direct processing time during which an operator would need to be present.

[6] http://www.centralbiodiesel.com/en/

Waste Vegetable Oil

The fourth and final option for a biofuel was pure waste vegetable oil (WVO). WVO is commonly used by restaurants, including Calvin's Dining Services, as oil for their fryers.

Source

The team contacted Rick Balfour, who is the head of Dining Services, to see how he currently disposes of his WVO. While meeting with him, he revealed to the team that all the used WVO is stored in two large containers; one on the Knollcrest dining hall dock and the other on the Commons dock. Once a month, a company named Darling International comes and pays Dining Services on a per pound basis to take the oil and dispose of it properly.

Figure 4 demonstrates the data given by Darling International of the weight totals collected over the past three years. From 2010 through 2012, the average total WVO produced by Dining Services per month was 176.9 gallons. The 2013 projections are in line with this annual value as well.

Quality

The continued use of WVO will gradually decrease its quality. The quality of the oil is critical for use in a biofuel vehicle as using low quality WVO will cause problems in the engine. High quality WVO will be light in color and have very small or no floating particles (see Figure 7: Various Vegetable Oil Qualities). In contrast, low grade WVO will appear cloudy and dark in color and have visibly floating large (see Figure 7).

Figure 7: Various Vegetable Oil Qualities[7]

Figure 8 is a sample of Dining Services WVO. The left half of the image shows that the darkness in the oil color. The right half of the picture illustrates the settled particles in the oil after having settled for one month. From these images, it is the used WVO quality from Dining Services is lower than "E" quality, as denoted in Figure 7. Likewise, if this particular biofuel were to be used as a feedstock, it would require heavy filtration in order to improve its quality.

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[7] http://journeytoforever.org/biodiesel_svo.html#gnl

Figure 8: Dining Services Oil Sample

Costs

In order to determine the cost of acquiring the waste vegetable oil from Dining Services, the team met once again with Rick Balfour. Mr. Balfour informed the team that Dining Services currently receives $0.05-$0.06 per pound of used WVO from Darling International. This totals to roughly $1500 annually. Fortunately, Mr. Balfour indicated that Dining Services would be willing to part ways with this additional revenue at no extra cost to the college if the used WVO were to be used in a biofuel vehicle. While potentially ongoing labor costs associated with the filtration system were seen as a potential downside, WVO seemed the optimal fuel source because of its availability and low purchased equipment costs.

Fuel Decision

Table 2 summarizes the overall cost analysis for each fuel option based on upfront cost, production cost, and vehicle conversion cost. From this analysis, it was clear that vegetable oil was the preferred option from a cost standpoint.

Table 2: Cost data for each fuel option

	Methane	Ethanol	Biodiesel	WVO
Upfront Cost	$20,000	$10,000	$5,000	$2,000
Cost to Produce	$500	$1,000	$1,200	$800
Vehicle Conversion	$2,000	$0	$0	$2,000

Beyond cost, the additional criterion considered when deciding upon WVO as the optimal feedstock are as follows:

- *Upfront Cost* – Cost of production equipment
- *Cost to Produce* - Cost of feedstock and materials needed in production
- *Cost to Outfit Vehicle* – Cost to modify vehicle
- *Ease of Production* – Cleanliness and simplicity of producing fuel
- *Production time* – Amount of time from raw materials to finished fuel
- *Amount of Resources on Campus* – Quantity of feedstock available from Calvin's Campus
- *Training Required for Future Production* – Level of difficulty to teach someone to operate and maintain production process
- *Environmental Impact* – Amount of waste resulting from production process
- *Cleanliness* – How clean the area will be as a result of the production
- *Access to Information* – Availability of technology in the industry and the quality and quantity of that data

Using the listed criterion, the team created a decision matrix, which appears in Table 3.

Table 3: Fuel Decision Matrix

	Scale	Ethanol	Methane	Biodiesel	WVO
Upfront Cost	0.20	3	1	8	10
Cost to Produce	0.10	7	10	6	9
Cost to Outfit Vehicle	0.10	10	4	10	7
Ease of Production	0.05	8	10	6	7
Production Time	0.05	8	9	4	4
Amount of Resources on Campus	0.15	5	8	6	8
Training Required for Future Production	0.05	6	6	8	8
Environmental Impact	0.10	9	7	5	7
Cleanliness	0.10	6	7	2	2
Access to information	0.10	3	9	9	10
TOTAL	1.00	5.95	6.35	6.6	**7.65**

As shown in Table 3 and Figure 9, it became evident that WVO was the most suitable biofuel option for this project.

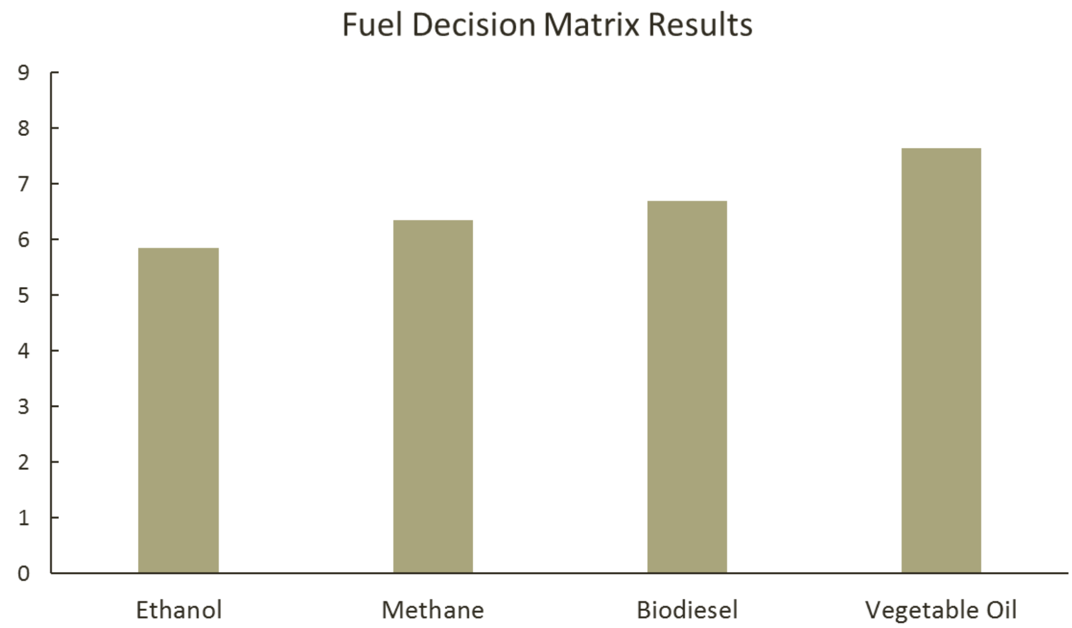

Figure 9: Fuel Decision Matrix Results

Appendix I-B. Fuel Quality

Acidity Research

While researching the potentiality of using waste vegetable oil as a fuel for the biofuel vehicle project, the team discovered an impending issue. The acidity of the WVO was a large concern, as overly acidic oil would lead to engine damage. The acidity of the WVO is a direct result of the level of free fatty acids (FFA) in the oil. Free fatty acids can cause damage to the vehicle components mainly through corrosion if the levels are too high. Unfortunately, these acids would not be removed through filtering alone. Therefore, determining the level of FFA in the WVO provided by Calvin Dining Services was of upmost importance in the consideration of WVO as a biofuel option.

The team therefore conducted a test to determine whether the levels of FFA in the oil were below the safe amount. This test was a simple titration, using a phenolphthalein indicator, sodium hydroxide (NaOH), isopropanol, and a sample of the oil. The sodium hydroxide was diluted to a 0.1% NaOH solution by volume with distilled water. This solution was then added drop by drop to an oil-isopropanol mixture, which included the phenolphthalein indicator. Once the oil-isopropanol solution turned and remained pink for fifteen seconds, the process was stopped and the milliliters of NaOH solution added was recorded. Based on the team's research, if less than 2 mL of 0.1% NaOH solution was added, then the level of free fatty acids in the waste vegetable oil was within the acceptable range. A result above 3.5 mL added is too acidic, meaning the vegetable oil would not be a viable option.

The team performed this titration and found that the amount of NaOH added was 1.5 mL, which was well within the limits imposed. Therefore, the team concluded that the waste vegetable oil collected by the Dining Services is within the acceptable acidity levels, and can be used as a fuel option.

Cleanliness Research

One of the issues previously mentioned is the cleanliness of the oil. The oil that comes out of the Dining Services fryers has large quantities of particles of varying sizes which can potentially be detrimental to a biofuel vehicle's engine. In order to address this problem, the oil must be properly filtered through micron level filtration before it can be used as a fuel. One micron is .000001 meters and research has shown that in order to use vegetable oil as a fuel, it must be filtered down to at least 5 microns. If the oil is not filtered to this level, it can clog the car filter as well as deposit the particles in the engine. Over time, these particles will build up and eventually destroy the engine.

Filter Research

Types of Filters

Since the waste vegetable oil from Calvin Dining Services is of a very low grade, it is essential to have a filtration system meets the fuel quality requirements. The team researched three different filtration processes to be used for the waste vegetable oil: settling tanks, bag filtration systems, and centrifuge systems.

In a settling tank filtration system, the WVO will sit for a period of one to two months. During this time, waste particles will settle to the bottom because of a higher density than that of the oil. This results in better quality oil at the top of the settling tank. This better quality oil can then be drained from 1" below the top surface, and the sludge at the bottom of the tank can be drained from the bottom (see Tank Dispense). The process is simple and requires minimal operation as gravity will do the majority of the work. The settling tanks also provide a means of storage for the oil. The suggested tanks to be used for settling are IBC totes which each hold 330 gallons (see Fuel Storage).

Bag filtration systems are another common filtration method. A filter is placed in a housing, and the fluid is then pumped through the system while the bag collects waste particles. Filter bags come in different removal ratings, ranging anywhere from one micron to eight hundred micron. The quality required for the filtered vegetable oil is five micron. Upfront cost for a bag filtration system is relatively high priced at $575 when purchased from Fryer to Fuel.[8] The bag filters are each around $5, and the frequency that they will need to be replaced depends on the amount and quality of waste vegetable oil being pumped through them. The set up for the bag filtration system is to have three staged filters; the first filter will be two hundred micron rating, the second will be fifty micron, and the third will be five micron.

Another filtration method that the team researched was centrifuging. A centrifuge is a machine that spins the oil close to 3000rpm which forces all of the floating particles to the outside of the bowl and then catches them in a tray or on the side of the bowl. Centrifuges are very efficient at filtering oil. Running a batch of WVO through a centrifuge two or three times will filter the WVO down to less than one micron which is well in range of the the 5 micron minimum requirement. Centrifuges are also much quicker than other filtering alternatives. Centrifuges can process approximately 30 gal/hr whereas bag filters can take multiple hours to process a few gallons and settling tanks can take weeks or even months to completely process a large batch of oil. Another benefit of using a centrifuge is cleanliness. Centrifuges need to be emptied roughly every 30 gallons, a very quick and easy process. In addition, they have to be completely cleaned after approximately 300 gallons. This makes the possibility of having creating mess fare more unlikely than working with the bag filters which have to be changed out every 200 gallons if high quality oil is put through them or every 20 gallons for poor quality oil. Unfortunately, the down side of the centrifuges is their price. Although only one centrifuge is required for the process, they can cost between $1000-$2000, far higher than the filter bags or settling tanks.

Case Studies

Four different case studies were analyzed to determine which combination of filtration units would provide the optimum filtration system. The first case study involved a filter process that started with settling tanks and then went to a centrifuge. The positives about this process are that it is a clean and easy process to operate, while the negative is that it has a large upfront cost due to the cost of the centrifuge. The second case study is filtration through settling tanks to a bag filtration system. This case has a lower upfront cost than the first case, but the cleaning procedure for the filter bags is more difficult than that of the centrifuge. The third and fourth cases use just a centrifuge or just a bag filtration system, taking out the settling tanks. The positive of each of these is that there is reduced floor space, but the negative is that they both require more cleaning and operating time. The centrifuge and bag filtration system are required to do much more of the filtering because the settling tanks are not filtering the initial waste particles out of the system. Cost models were developed for each case, and a comparison of upfront costs and operating costs of each case in Figure 10.

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[8] http://fryertofuel.com/

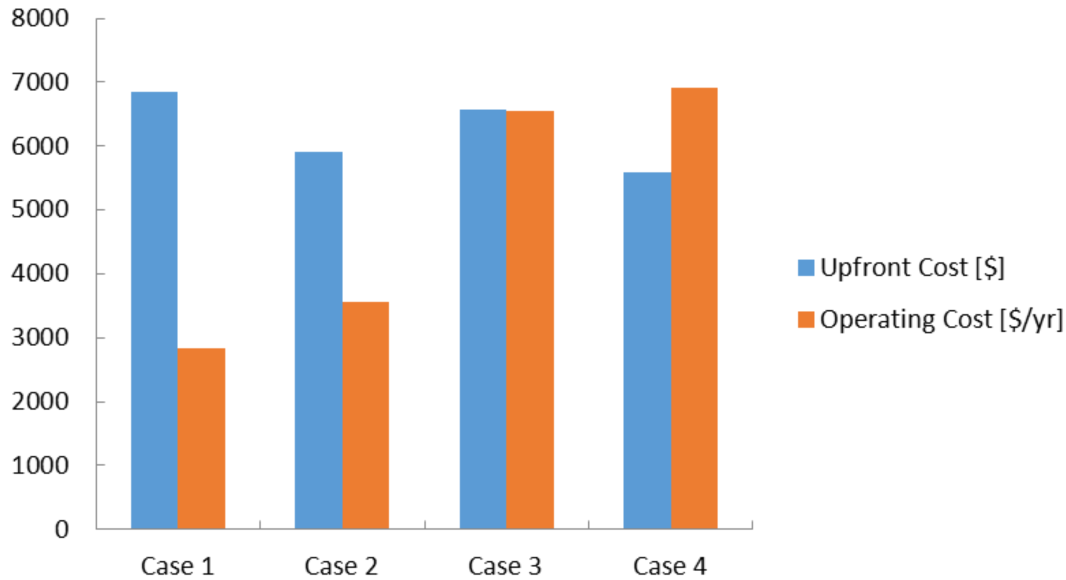

Figure 10: Case Study Cost Models

The team decided that the first case study, settling tanks and a centrifuge, provided the best filtration system design to be used to filter the waste vegetable oil. The team believes that this case provides the most fail-proof system and easiest system to maintain. The operating costs are lower than that of any other case. The upfront cost is high because of the centrifuge, but the lower operating cost and the ease-of-use overrule the upfront cost difference.

Appendix I-C. Future Considerations

Additional Fuel Sources

Due to limited accessibility of attaining WVO from only Calvin College dining halls, alternative fuel sources were required to provide enough fuel to run the converted vehicle without fuel outage. Hence two different methods were considered, getting more WVO from other college dining halls nearby that run by the Creative Dining Services, and convincing local restaurants to donate their WVO. The attempt made to Creative Dining Service to get more WVO from other colleges was not successful due to different regulations and methods each school follows on disposing their WVO. Richard Balfour, Director of Dining Services at Calvin College, via email said that it would be hard to get WVO from other college dining halls not only because they have their own ways of taking care of WVO, but also transporting the WVO almost daily would also be the major concern since they would not want to store WVO for longer than a few days especially during warm weathers. However, the second method of getting more WVO through local restaurants was partly successful. A few smaller restaurants were willing to donate their WVO without any compensation as long as their WVO is regularly taken care of by Calvin College. It was estimated by business owners that approximately 2-5 gallon of WVO would be provided each day per restaurant, so minimum of twice a week pick up is suggested. It was hard for larger sized (Franchises) restaurants to share their WVO due to regulations by each company they follow. A couple of restaurants including Marado on 28th street, Tokyo Grill on 44th street gave positive response towards donating their WVO.

Appendix II. Vehicle Selection

Summary

Introduction

After choosing WVO as the fuel source, the team was tasked with determining what vehicle to convert to run on WVO. This decision was restricted to diesel vehicles, which may be converted to run on both WVO and diesel fuel sources. This appendix outlines the vehicle decision criteria, vehicle choice, and process for converting the vehicle to run on WVO. This appendix also outlines the costs of conversion and the ongoing maintenance of the vehicle.

Procedures

In order to select a vehicle, a number of criteria were collected and analyzed using a decision process. This weighed the benefits and detriments of a number of proposed vehicles based on annual operating hours, campus visibility, campus importance, user friendliness, difficulty of conversion, and cost. These criteria examined both the upfront and maintenance costs of the machine. Additionally, this required a collection of diesel vehicle data from the Calvin College Physical Plant and communication between the WVO conversion kit vendors, the vehicle operators, and the vehicle mechanic.

Data & Calculations

As mentioned, data was collected on the availability of diesel vehicles at Calvin College and the annual operating time of each. This was necessary in determining a vehicle for conversion when considering the annual quantity of WVO available for fuel, after losses from processing. In addition to the vehicle selection, data was collected in response to the necessary criteria for a WVO conversion. In order to properly implement WVO as a fuel, the WVO must be heated to a minimum temperature of 160°F prior to introduction into the diesel injectors. This is to allow proper flow by reducing the viscosity of the fuel as the temperature increases. Similarly, the engine must be flushed of WVO from all fuel lines before final shutdown of the vehicle. In regards to this, a vehicle must be equipped with a secondary heated WVO tank and a supply valve in order to properly switch from diesel to WVO at the desired temperature and prior to shutoff. This data is provided in detail in the following report.

Results

The results obtained for this project provide the possibility and reinforce the feasibility to operate and convert a 2006 Toro *GROUNDSMASTER* 4000-D lawnmower using a WVO feedstock from the campus dining hall waste. This may be seen on the following page in Figure 8. A conversion kit will be purchased to include the necessary components for the conversion. A secondary tank will provide 8.7 gallons of heated WVO, amounting to approximately 5.5 hours of operation time. In order to provide safety to the operator, a safety cover will also be purchased to house and cover the heated tank on all external surfaces. With the WVO feedstock provided from the campus dining halls at no cost, this provides 1300 gallons of diesel fuel savings, amounting to approximately $4000 of diesel costs eliminated annually. The maintenance associated with this conversion amounts to one hour of monthly mechanic work, the purchase and implementation of fuel injector additives, and a monthly fuel filter replacement.

Future Considerations

Additionally, this project provides the feasibility and information needed to convert and operate an additional vehicle on WVO, specifically one purposed for off-campus use. This choice required the investigation of additional fuel sources, and several local Grand Rapids restaurants were contacted with regard to their willingness to provide additional WVO feedstock. For this selection, a 2002-2006 *Dodge* Sprinter Van was chosen, providing a large transport capacity and high visibility both within and outside of campus. With the addition of one local restaurant to the WVO supply, this transport vehicle has the ability to run for 24,000 miles a year and provide additional cost savings for the college.

Figure 11: Calvin College 2006 Toro GROUNDSMASTER 4000-D

Conclusion

This project proposes the conversion of the Calvin College 2006 Toro *GROUNDSMASTER* 4000-D (see Figure 11: Calvin College 2006 Toro GROUNDSMASTER 4000-D). This vehicle choice is ideal, having a *Kubota* diesel engine, operating for over 800 hours per year, dormant during the winter season, an expired warranty, and being a relatively nonessential vehicle in the event of necessary maintenance. Additionally, this vehicle is highly visible on campus and will provide a simple conversion process that may be duplicated for another lawnmower if the fuel is available.

This vehicle conversion amounts to an equipment cost of $1935 and a labor cost of $360 for 8 hours of conversion labor. The conversion kit will be supplied by *Greasecar Vegetable Fuel Systems (see* Figure 15: Toro GROUNDSMASTER 4000-D Fuel System Layout*)* and the labor will be supplied from the Calvin College Physical Plant. This project requires an upfront capital investment of $2295 for proper vehicle conversion and $76 per month of maintenance costs.

Appendix II-A. Criteria Influencing Decision

Criteria Influencing Decision

Cost of Conversion

The cost of conversion was essential to the future of this project and was therefore given a high priority in the decision matrix. In order to properly implement the project the upfront costs of converting the vehicle must be relatively low. Additionally, the cost of this conversion will influence how to proceed further if the project is successful and if another vehicle will be implemented.

Difficulty of Conversion

The difficulty of the conversion process was also very influential to the choice. However, the difficulty in converting WVO is relatively small and most of the conversion kits offered by vendors are marketed as do-it-yourself. Therefore, the difficulty for a mechanic to implement this system is relatively small, but must still be considered when evaluating the vehicle.

User Friendliness

The team required that the conversion process be relatively simple and easy to use for the operators of the vehicle. In order for the vehicle to be properly implemented, it must be easily handled by all operators, regardless of experience, skill, or age. Therefore the friendliness of the conversion process took an effect in the final vehicle choice.

Seasonal Usability

The seasonal usability of the vehicle was also a factor for proper WVO implementation. Because WVO is required to be heated prior to fuel implementation, it was necessary to factor in this additional time and difficulty from vehicles operated during winter months. Additionally, a seasonal vehicle provides the opportunity for fuel storage and processing throughout the dormant months, while continuing to process throughout the active season.

Vehicle total time of Use

The total annual usage of the vehicle was important when considering a vehicle, because it narrows the choice to vehicles which will provide a large diesel fuel savings and therefore cost savings to the college. Additionally, this will provide a shorter payback period, and therefore provide a much more financially viable option towards the overall project.

Maintenance/Failure Probability

Alongside cost, the maintenance and failure of the vehicle was the leading criteria in the vehicle decision. If the conversion process is to be successful, the maintenance required must be minimal and must not overcome the cost savings of the project. Therefore, the team required a vehicle with a very simple conversion process in which the possibility for error and failure was minimized.

Visibility

In order for the vehicle to be properly assimilated into the campus, the team required that the visibility of the vehicle also be considered. Because the project focuses on a sustainable initiative and promotes both a cost savings and a fuel savings, the vehicle must be visible to campus visitors and students.

Influence of fuel team on vehicle choice

The fuel processing also played a large role in vehicle selection by limiting what fuel will be implemented and what supply is available for operations. This limited the choice significantly.

Appendix II-B. Vehicle Selection Process

Choice of Diesel Vehicle

Because the choice was WVO as a fuel source, this necessitates that the vehicle to be used run off of diesel fuel. Vegetable oil may be used in diesel engines so long as it is first heated to a temperature of 160°F. A benefit of converting a diesel engine to run off of WVO is a reduction of emissions, including reduced carbon monoxide emissions by 47%[9]. An engine converted to run on WVO is, however, limited to start on diesel fuel until the WVO is heated to the correct temperature. The engine must also be purged with diesel fuel before the machine may be shut off. This is due to the fact that any extra, unburned WVO left in the engine's cylinders can gum up, and from a long-term perspective, potentially damage the engine. Due to the need to reach a higher temperature, along with the damage that can occur if the WVO is allowed to cool in the engine, it is more difficult and there is therefore more risk involved with running a vehicle off WVO during the colder seasons of the year, such as winter. Furthermore, due to the necessity of starting and stopping on diesel, a vehicle that runs for an extended period of time, without being shut off, is preferred. Because of these factors, a vehicle that runs for an extended period of time during the summer would be an ideal choice to convert to run from WVO.

Calvin's Diesel Fleet

There are a wide variety of vehicles owned and operated by Calvin College that run from diesel fuel. Figure 7: Various Vegetable Oil Qualities shows a list of these vehicle options.

Table 4: List of Diesel Vehicles at Calvin College

Toro GroundsMaster 4700-D Lawnmower
Toro Groundsmaster 4000-D Lawnmower
Toro Groundsmaster 4000-D Lawnmower
Toro Groundsmaster 3280-D Lawnmower
Toro GroundsMaster 325-D Leaf Blower
Toro GroundsMaster 328-D Leaf Blower
CAT 924 Front End Loader
CAT 914 Front End Loader
CAT IT420E Backhoe
Ingersol-Rand Pettibone
Kubota L4610 Tractor
John Deere 710 Small Tractor
Ford Sterling SL7501 Plow Truck
Ford F800 Dump Truck
Ford F600 Dump Truck

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[9] http://kvkpriyavaishu.synthasite.com/resources/Emission%208.pdf

Not surprisingly, the usage of these different vehicles varies. The team researched and obtained yearly operating hours for the major groups of vehicles. The results of the research can be seen in Figure 12: Operational Hours of Major Diesel Vehicle Groups at Calvin College.

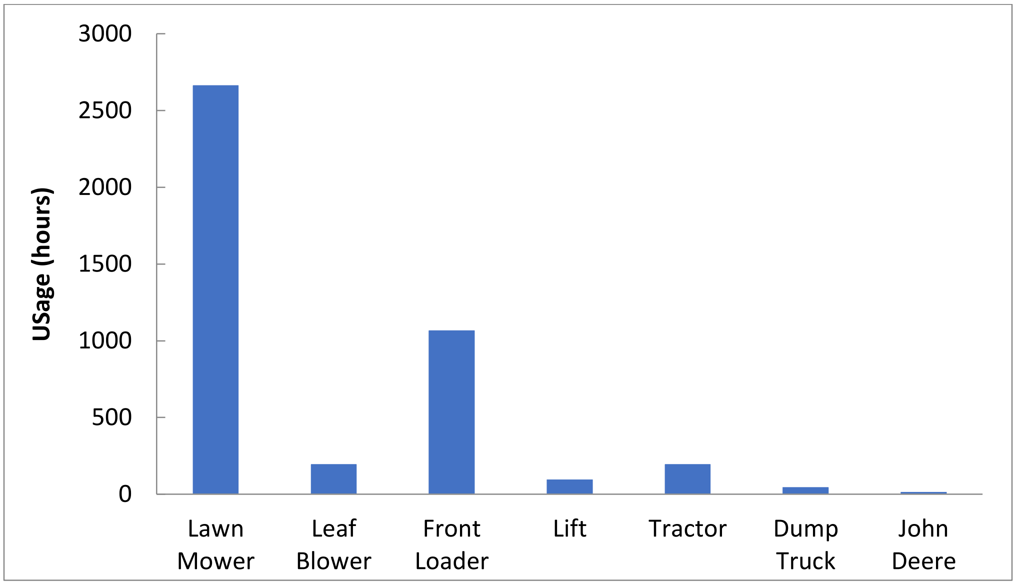

Figure 12: Operational Hours of Major Diesel Vehicle Groups at Calvin College

Lawnmower Model Choice

As previously mentioned, a vehicle that runs for extended periods of time during the summer would be the ideal candidate. It can also been seen from Figure 12 that the lawn mowers at Calvin College are used for the greatest amount of time. Because of this, along with fact that the lawn mowers are not used in the winter, the team chose to focus on what it would take to convert a lawn mower to run off of WVO.

There are three different types of lawn mowers currently being used at Calvin College. Their yearly usage data is shown below in Figure 13.

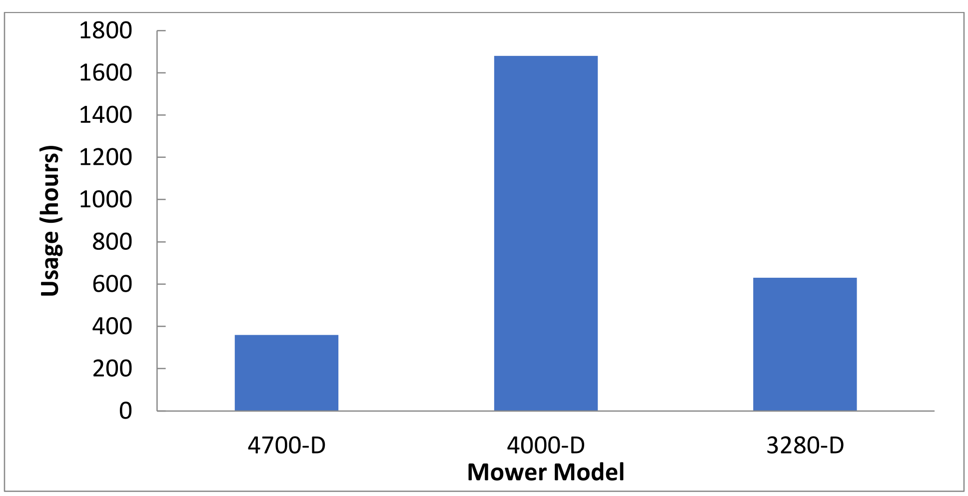

Figure 13: Yearly Usage of Lawn Mowers at Calvin College

Since it leads in operational hours, is no longer under any sort of manufacturer warranty, and is highly visible on campus, the Toro *GROUNDSMASTER* 4000-D was selected. An additional advantage to selecting the Toro *GROUNDSMASTER* 4000-D is that, in the event of needing maintenance, there are other lawn mowers that can replace the missing machine. Further reasons proving the Toro *GROUNDSMASTER* 4000-D to be the best option for conversion are detailed below.

Conversion Research

In order to obtain a better understanding of what the lawn mower conversion process might look like, the team focused on finding other people who have done a similar conversion. The team believed that to pioneer the conversion of a Toro *GROUNDSMASTER* lawn mower to run on WVO was an unacceptable option, due to the fact that it would require much more monetary investment and time in order to work well. When researching if others had converted a lawnmower to run from WVO, the team came across Bowling Green State University located in Ohio. Bowling Green State University has created their lawnmower conversion kit from scratch, shown below in Figure 14. The team contacted Bowling Green State University, and after discussions with the person who had performed the WVO conversion, the team decided that creating a WVO system from scratch was not ideal. This came from the large amount of trial and error involved in creating a unique system. As building a WVO system from scratch was not a good idea, the team looked for systems that already existed. Only a select number of different companies exist to create WVO systems. The first was Full Circle Fuels/Gold Coast Fuel Systems. Full Circle Fuels has been creating WVO systems since 2005, and has already converted a Kubota engine that is similar to the engine that is used in the 4000-D, which is the engine of the lawnmower used on campus.[10] Also, the owner of the company lives off the grid, and runs a generator and utility vehicle on WVO, both of which have Kubota engines similar to the Toro *GROUNDSMASTER* 4000-D. A second company researched was Greasecar. Greasecar, located in Massachusetts, has been manufacturing and selling WVO system kits since 2000, and therefore has a very good reputation for providing an extremely robust and reliable system.[11]

Figure 14: Bowling Green State University WVO converted lawnmower

[10] "Welcome to Full Circle Fuels." *Full Circle Fuels*. N.p., 2012. Web. 02 Dec. 2013.
[11] "About Greasecar." *Greasecar Vegetable Fuel Systems*. Greasecar, 2010. Web. 02 Dec. 2013.

Choice of Toro GroundsMaster 4000-D

The team decided to choose the Toro *GROUNDSMASTER* 4000-D lawnmower for several reasons. The first reason is that lawnmowers have the longest operation time of any diesel vehicle on campus, as shown in Figure 12: Operational Hours of Major Diesel Vehicle Groups at Calvin College.

Another reason that the team chose to go with the 4000-D was that Calvin has two of the 4000-D lawnmowers currently in use. This means that if something were to happen to the lawnmower converted to run on WVO, there would still be an alternate lawnmower of the same size that could fulfill its duties while it was down for maintenance. Having two of the same model lawnmowers is also an advantage, because if the conversion to WVO is successful on one mower, then there could be the possibility of easily converting the other to run on WVO. Also, Table 5 shows the warranty status of Calvin's lawnmower fleet, as well as when each mower is expected to be replaced.

Table 5 shows that the two 4000-D lawnmowers are due to be replaced in 2014 and 2015. However, after speaking with the Physical Plant, it was determined that if the mowers were to be used for a WVO conversion, their years of replacement could be pushed back by 2-3 years, or even more dependent upon how well the conversion works[12]. Other reasons that the team chose to go with the 4000-D was that it is highly visible on campus. During the summer and at the beginning and the end of the school year, the mowers are out maintaining the lawns and are viewed by many people. Also, the engines in the mowers are similar to engines that other people have converted to WVO, as previously explained.

Table 5: Calvin's Lawnmower Fleet Warranty Status

Toro Grounds Master Model	Model Year	Current Warranty	Year to be Replaced
4000-D	2006	No Warranty	2014
4000-D	2007	No Warranty	2015
3280-D	2012	5-Year Warranty	2017
4700-D	2012	5-Year Warranty	2020

Conversion Component Sourcing

After the vehicle was chosen and approved from physical plant, it became necessary to begin researching the exact methodology behind the WVO conversion process. For reliability purposes, the team chose to seek out a more experienced party to pursue this conversion. In this regard, there exists two major companies offering the services required: *Frybrid LLC* and *Greasecar Vegetable Fuel Systems*. Each of these companies market a do-it-yourself (DIY) kit for converting a diesel vehicle to WVO. These kits come with the required components and an easy to read schematic outlining the assembly process and labor necessary to adapt the engine.

The team believes that purchasing a kit through one of these companies would be ideal especially in the event that any tech support is needed in the assembly process. Furthermore, these companies provide tech support for maintenance along with vast amounts of online information for maintaining and repairing system components. Likewise, the components offered through these companies will simplify any purchases of replacement parts. All the components supplied in the kit, may be easily found through the

[12] Van Berkel, Geoffrey. "Questions for you." Message to the author. 14 Oct. 2013. E-mail.

company as individual, replacement parts. If the Calvin College Physical Plant were to develop a specific kit for the Toro mower, a secondary option considered, the risk and work inherent in this would not warranty the slight decrease in cost. In order for this kit to be assembled, a list of components would be needed and alterations to any purchased filters and valves would also be necessary to introduce a heating source to the WVO fuel stream. Although possible, the team viewed this solution as an unnecessary risk to the life of the mower and therefore opted to select a DIY kit from a reputable company, experienced in the conversion.

After contacting both companies via email, it became clear that Greasecar held the better customer service and was willing to assist in troubleshooting. In addition to the community behind Greasecar, the company also offers a one-year warranty on all parts and kits purchased. This will provide a peace of mind in regards to the reliability of the kit, while also providing a security if an unforeseen problem was to occur. Because there is very little experience or knowledge in converting a lawnmower to run on WVO, no specific kit is available for this model. However after further contact with Greasecar, Justin Carven (justin@greasecar.com), the company founder, recommended a general kit for this conversion and assured the team of the reliability of this kit. In order to supply the necessary kit, Justin emphasized the need for a complete fuel layout of the Toro system. This was found from the Toro service manual and may be seen below in Figure 15: Toro GROUNDSMASTER 4000-D Fuel System Layout. Similarly, the engine layout was necessary to locate the fuel injectors and coolant flow system. This may be found below in Figure 16: Toro GROUNDSMASTER 4000-D Engine Layout.

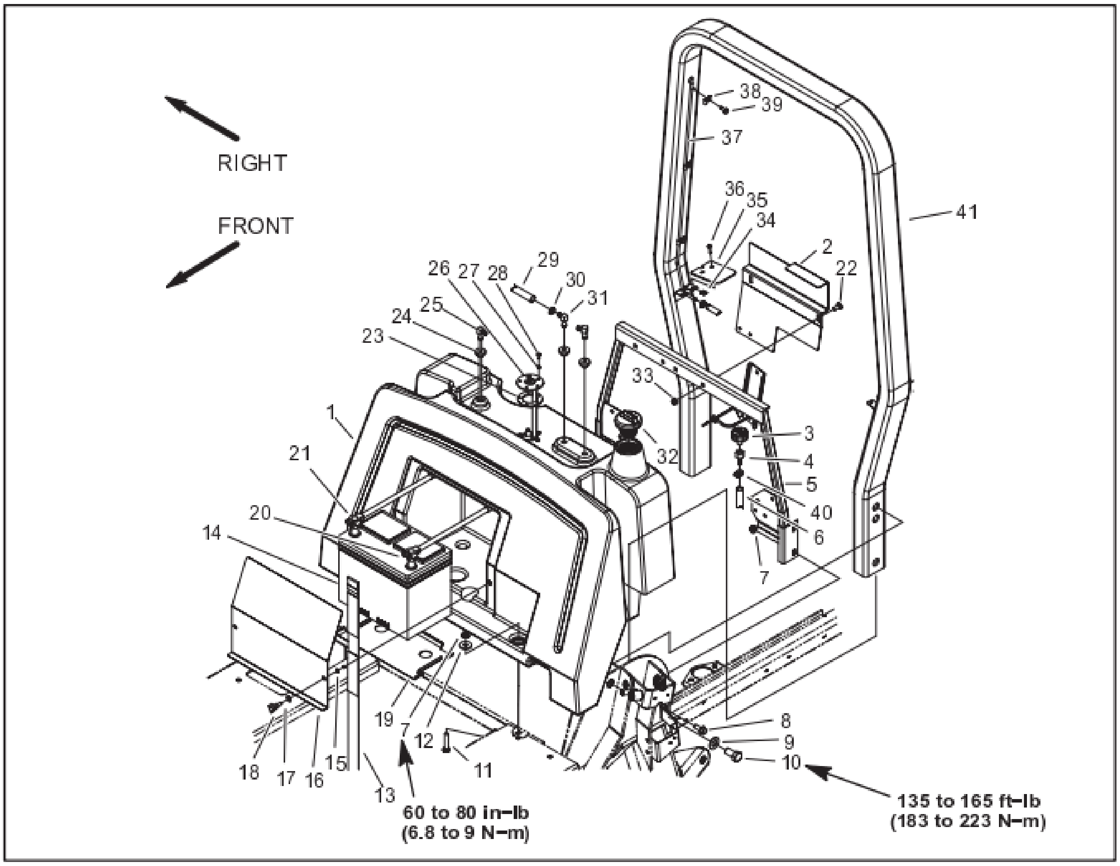

Figure 7

1. Fuel tank
2. Fuel tank bracket
3. Air breather
4. Female hose barb
5. Tank support assembly
6. Fuel hose
7. Locking flange nut
8. Cap screw
9. Flat washer
10. Cap screw
11. Carriage screw
12. Washer
13. Battery strap
14. Battery
15. Retaining ring
16. Battery cover
17. Flat washer
18. Knob
19. Battery plate
20. Negative cable
21. Positive cable
22. Carriage screw
23. Gasket
24. Bushing
25. Stand pipe
26. Fuel sender
27. Lock washer
28. Phillips head screw
29. Fuel hose
30. Hose clamp
31. Elbow fitting
32. Fuel cap
33. Locking flange nut
34. Speed nut
35. Tank cover
36. Phillips head screw
37. Vent tube
38. Insulated clip
39. Washer head screw
40. Hose clamp
41. ROPS assembly

Figure 15: Toro GROUNDSMASTER 4000-D Fuel System Layout

Engine

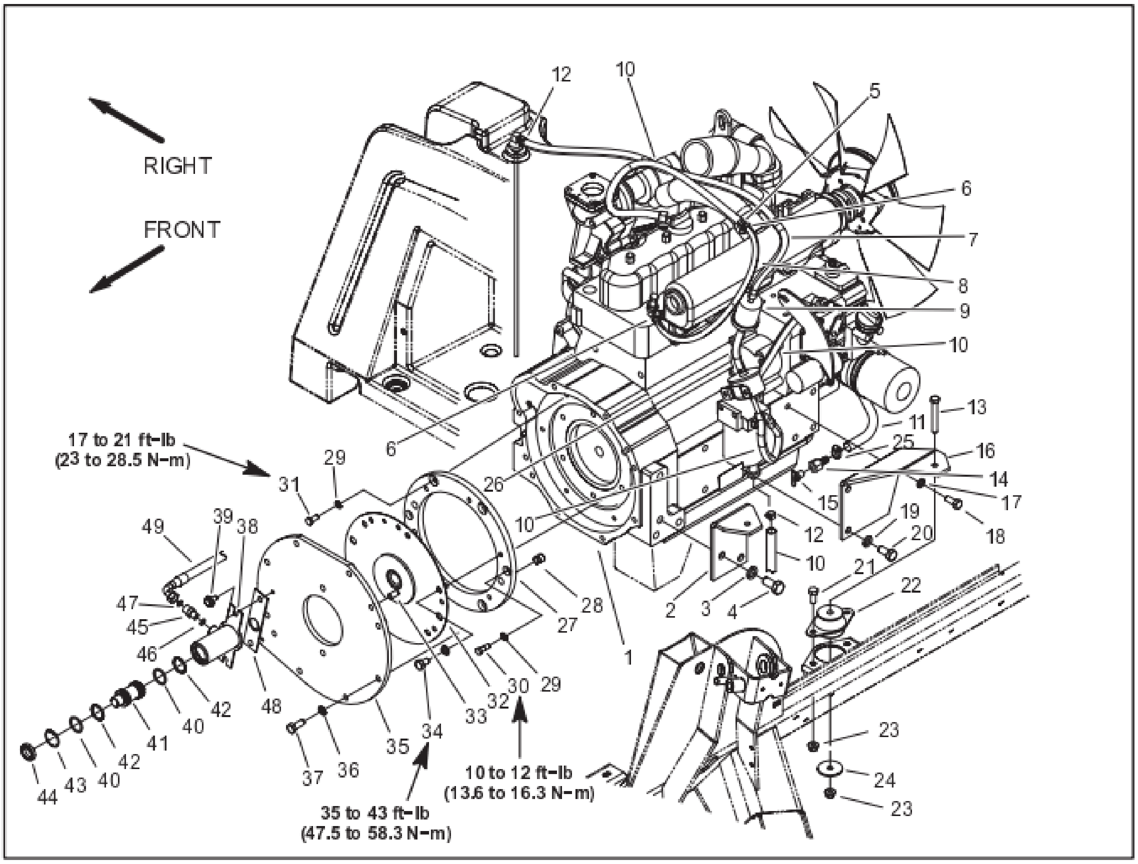

Figure 9

1. Engine
2. Engine mount bracket (RH shown)
3. Lock washer
4. Cap screw
5. Barb fitting
6. Hose clamp
7. Hose
8. Fuel line
9. Fuel filter
10. Fuel line
11. Coolant drain hose
12. Hose clamp
13. Cap screw
14. Barb fitting (female)
15. Coolant drain cock fitting
16. Engine mount bracket (RH shown)
17. Lock washer
18. Cap screw
19. Lock washer
20. Cap screw
21. Cap screw
22. Rubber engine mount
23. Flange head locking nut
24. Rebound washer
25. Hose clamp
26. Fuel line
27. Coupler spacer
28. Dowel
29. Lock washer
30. Shoulder bolt
31. Cap screw
32. Spring center coupling
33. Plate pin
34. Cap screw
35. Pump adapter plate
36. Lock washer
37. Cap screw
38. Traction cylinder assembly
39. Cap screw
40. O-ring
41. Cylinder piston
42. Back-up ring
43. Retaining ring
44. Seal
45. Hydraulic fitting
46. O-ring
47. O-ring
48. Shim plate
49. Hydraulic hose

Figure 16: Toro GROUNDSMASTER 4000-D Engine Layout

After the proper kit was formed, Justin prepared a detailed invoice for the DIY kit required. This invoice may be seen below in **Error! Reference source not found.**4. Justin also assured the team that Greasecar ffers extensive phone and email support for any assistance required in the conversion process. The only additional design work necessary for this kit is decisions involving where to mount the additional components and the fabrication of simple mounting brackets. The kit amounts to a cost of $1,595, shown by the quote in Figure 17: Greasecar Vegetable Fuel Systems Invoice.

greasecar vegetable fuel systems

Invoice

October 29, 2013

Greasecar Vegetable Fuel Systems

19 Norman St
West Springfield, MA 01089
Phone: 413-372-5013
FAX: 413-372-5015
Email: info@greasecar.com

20133

Bill To:	Ship To:
Calvin College Michael Houtman Grand Rapids, MI Phone: Email: mhh6@students.calvin.edu	*Calvin College* *Michael Houtman* *Grand Rapids, MI* *Contact: Calvin College*

Seller	Payment Terms	FOB Point	Shipping Terms	Ship Via	Req. Ship Date
JustinC	CIA	Origin	Prepaid & Billed	UPS Ground	10/29/13

Item #	Type	Item / Description	Unit Price	Qty Ordered	Extended Price
1	Kit	GC- VW400 - For All VW's with TDI PD engines (except Beetles) 04-06	$ 1,295.00	1 ea	$ 1,295.00
2	Sale	AC-Manual Controller w/ TDI Console Bracket - Manual Controller with TDI Console Bracket	$ 0.00	1 ea	$ 0.00
3	Sale	AC-SV100 2pk - SV 100 valves boxed (2pk) For Sale	$ 0.00	1 ea	$ 0.00
4	Sale	AC-Tank 24 - 24' Tank Assembled for Sale	$ 0.00	1 ea	$ 0.00
5	Sale	A-H-BIO-5/16-15ft - 15ft Coiled 5/16 bio Fuel Line	$ 0.00	1 ea	$ 0.00
6	Sale	A-H-PEX-1/4 - 20ft Coiled PEX	$ 0.00	1 ea	$ 0.00
7	Sale	AC-WalbroLPK with two pump harness - Walbro aux pump with old screen removed and new one installed plus harness	$ 0.00	1 ea	$ 0.00
8	Sale	FAS-HC-#4-5/16 - SMALL HOSE CLAMP #4	$ 0.00	2 BX10	$ 0.00
9	Sale	AC-FHE-5/16 Auto Heat Exchng - 5/16 Filter Heat Exchange	$ 0.00	1 ea	$ 0.00
10	Sale	A-Man-VW400 - YELLOW TDI PD 04+ INSTRUCTION MANUAL	$ 0.00	1 ea	$ 0.00
11	Sale	A-H-STD-5/8 Red-35ft - Assembled 5/8 heaterhose 35 ft	$ 0.00	1 ea	$ 0.00
12	Sale	FAS-HC-#8-5/8 - HOSE CLAMP #8 (5/8')	$ 0.00	1 BX10	$ 0.00
13	Sale	AC-5/8 Hose Hangers - 5 Hose hangers with long self tapping screws for 5/8 coolant lines	$ 0.00	1 ea	$ 0.00
14	Sale	AC-Window decal - window Decal	$ 0.00	1 ea	$ 0.00
15	Sale	FT-FB-T1-5M Single - Single bag	$ 0.00	1 ea	$ 0.00
16	Sale	AC-Hatch Plate Bag - Parts needed to seal hatch plates on all tanks	$ 0.00	1 ea	$ 0.00
17	Sale	MISC - Misc Part Custom tank charge	$ 300.00	1 ea	$ 300.00

Approval:____________________________ Date:____________

SubTotal	**$ 1,595.00**
Sales Tax	**$ 0.00**
TOTAL	**$ 1,595.00**

October 29, 2013 9:44:59 AM EDT

Page 2 of2

Figure 17: Greasecar Vegetable Fuel Systems Invoice

Description of Parts

The previously mentioned kit, supplied by Greasecar, necessitates a two-tank system. In order for the WVO to achieve a suitable flow through the injectors and a reliable burn in the cylinders, the vegetable oil fuel must reach a minimum temperature of 160°F, as previously stated. This increase in temperature functions to reduce the viscosity of the fuel, providing more reliable injector flow. Because of this high relationship of viscosity and temperature, shown in Figure 18. The Relationship of Temperature to Viscosity for both WVO and Diesel, a second tank is needed to hold the WVO until a desired temperature may be reached prior to a fuel switch over.

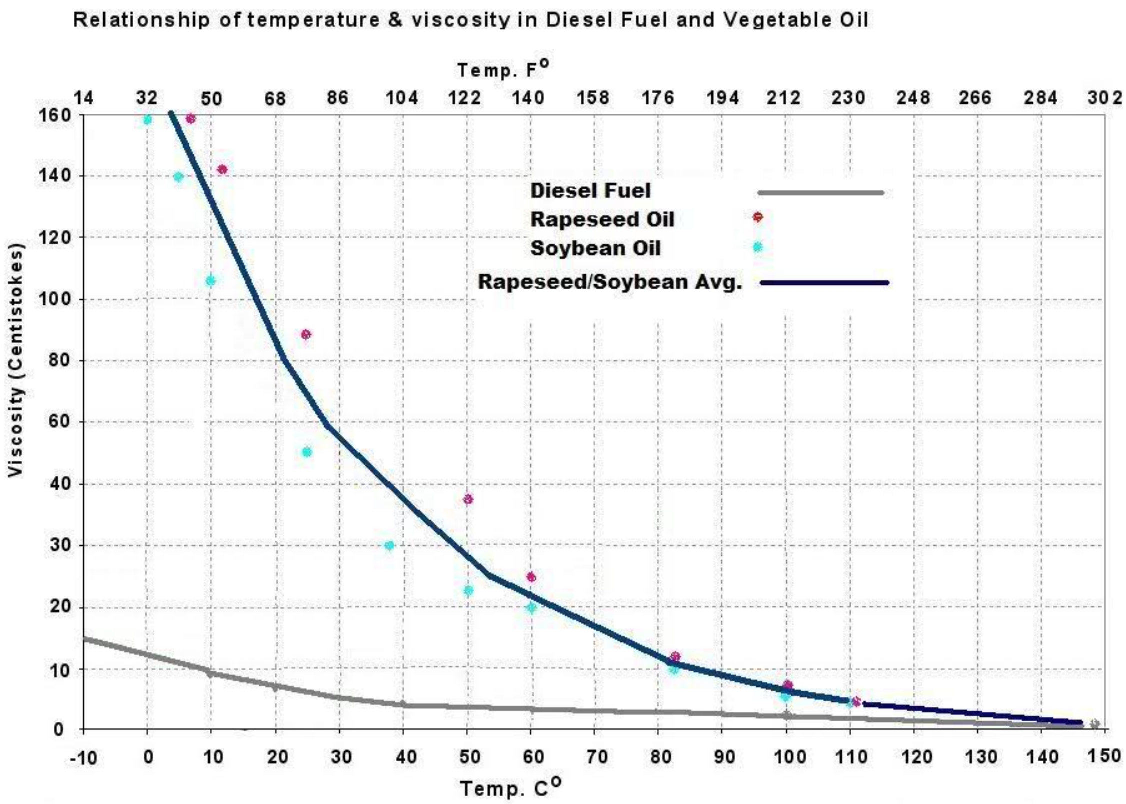

Figure 18. The Relationship of Temperature to Viscosity for both WVO and Diesel[13]

This secondary tank is a custom made, aluminum tank supplied by Greasecar according to provided specifications. The specifications of the tank chosen correspond to the mounting location of the tank, above the right fender next to the operator control dashboard, see Figure 18. The Relationship of Temperature to Viscosity for both WVO and Diesel. This location permits a 21" length by 8" width by 12" high, or 8.7 gallon, secondary tank. Assuming a constant fuel consumption rate of 1.57 gal/hr of operation[14], this corresponds to 5.5 hours of sustained operating time. Similarly, the two-tank setup allows for flexibility to switch to diesel if a longer mowing time is required before refueling the WVO tank.

[13] http://voconversionbasics.forumchitchat.com/post?id=3578278
[14] http://www.toro.com/en-us/Golf/Mowers/Rough/Pages/Model.aspx?pid=Groundsmaster-4000-D

Figure 19. Location of the Toro GROUNDSMASTER 4000-D Control Dashboard and Right Fender

The tank will come equipped with a fuel gauge and screw cap fill port. Internal to the tank is a coiled tube, copper heat exchanger necessary to reduce the viscosity of the WVO. This heat exchanger utilizes the engine coolant fluid as a heating source. This utilizes the waste heat from the engine, but necessitates a diesel start and warm-up in order to obtain heated WVO.

In addition to the need for an additional tank and heat exchanger, a network of fuel hosing, switching valves and pumps are also included in the recommended kit. A simplified and general schematic of the system present in this kit is shown below in Figure 20. Because of the nature of this conversion, a general and unspecific conversion kit is required from Greasecar. For that reason, the schematic below is only a representation of the process behind the system and is not to be used as a reference to the system installation. The kit will contain a more detailed schematic with it when purchased.

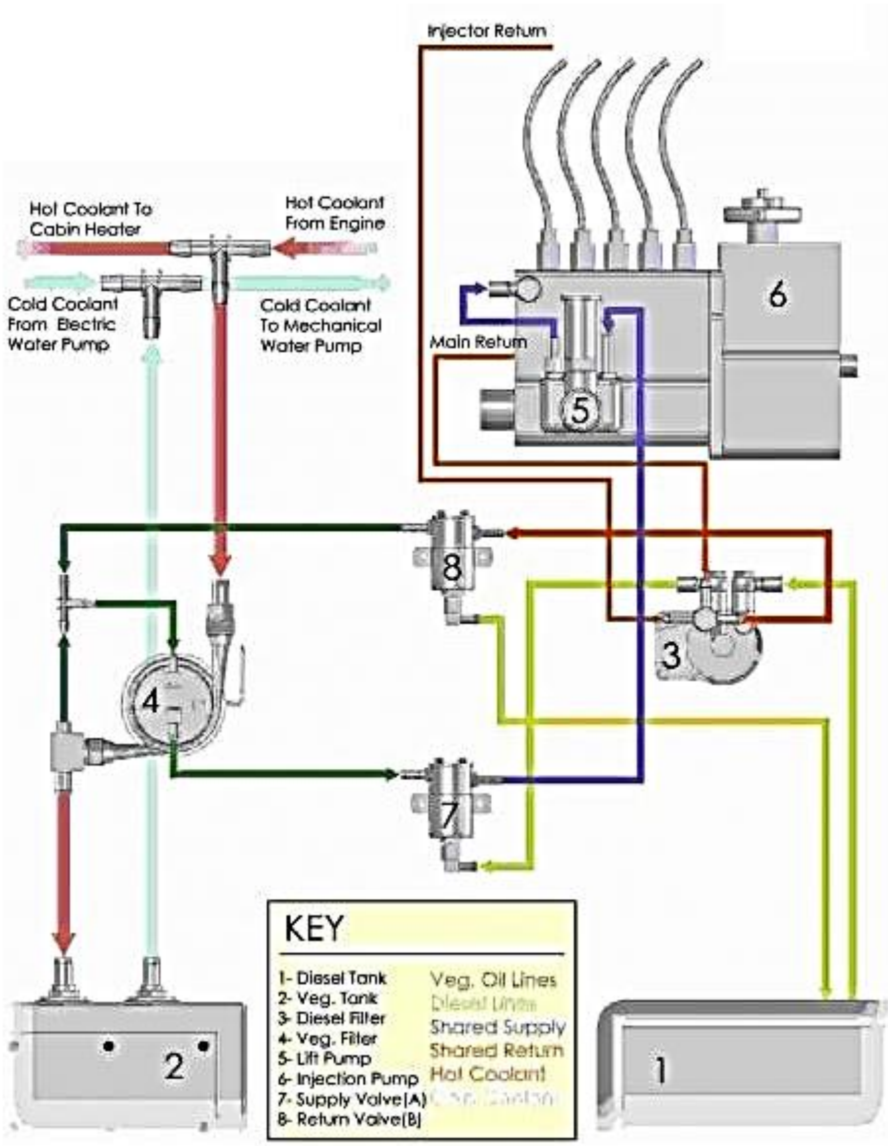

Figure 20. General Assembly and Layout for a Greasecar supplied WVO Conversion Kit

As shown in Figure 20, the system is comprised of a heated vegetable oil filter, an additional fuel pump, and two fuel valves: a supply valve and a fuel valve. Much like the heat exchanger found in the secondary WVO tank, the heated veg. filter utilizes the engine coolant as the means to preheat the waste vegetable oil. This heating element consists of a coiled, copper tube heat exchanger surrounding a 5-micron level fuel filter. After passing through the filter, the fuel next encounters the supply valve. The supply valve is a solenoid equipped, three-port valve controlling the flow between the two fuel tanks. This valve is electronically equipped to easily switch from diesel to WVO from within the compartment of the vehicle. The power necessary to bring the WVO fuel to the injectors is supplied from the lift pump, immediately following the supply valve. The lift pump is outfitted with an adjustable pressure regulator for the outlet fuel stream. This fuel stream is pumped into the injector pump and directly into the cylinders for combustion. A secondary valve, the return valve, is positioned to return any excess WVO pumped to the injector pump back to the secondary tank.

In addition to the technical specifications of the components contained in the system, it is also important for the user to understand the operations associated with this kit. The basic conversion kit is equipped with a manual electronic switch to control the supply valve, to be used for heating up and purging fuel switch-overs. However, an additional electronic controller and temperature sensor may be purchased for $300, in addition to the kit. This "Co-Pilot" computer controller gives the user an LCD readout of the internal secondary tank temperature, as well as the ability to automatically control the supply valve. This "Auto function" will automatically switch to the secondary tank after the preset internal tank temperature is reached. Also, a timed purge and shutdown alarm will assist the operator in recognizing the proper time required for purging before shutdown. The team recommends this addition to ease the operation between varieties of different operators. This brings the purchased equipment cost of the vehicle conversion to $1,895.

This additional control interface may be mounted to the controller dashboard, previously shown above in Figure 19. However, because some of the Calvin College lawnmower operators are elderly, there are some preventative measures that the team has taken to aid in operating a WVO fueled lawnmower equipped with the Greasecar conversion kit, described above. In addition to these directions, the team also became concerned of the external wall temperature of the secondary tank, given its close proximity to the operator. If wall temperatures exceed 150°F, injury from burns may occur to direct skin contact. This fear was confirmed from Mr. Justin Carven, who also advised an insulation cover to protect the operator from any burn hazard. Therefore the team has recommended the purchase of a safety insulating cover on the topmost surface of this tank as well as a safety label. This insulating cover may be fabricated from a therma-cel silicon rubber insulation sheet. This amounts to a minimal cost of $40.[15] This insulation was chosen, having fulfilled the necessary R-value of 1.9 $\frac{hft^2 {}^\circ F}{Btu}$ or 0.34 $\frac{m^2 {}^\circ C}{W}$. This will effectively reduce the external wall temperature to 100°F. This is sufficient to reduce the burn hazard, while simultaneously preserving the heat in the system. A complete document of the calculations may be found in the accompanying *Engineering Equations Solver* (EES) file.

Furthermore, for ease of operation, it was suggested that the controls for the WVO system be connected into a "high-low" switch on the mower. The "high" gear on the mower is intended for travel to and from lawn areas. In the typical situation, the mower will have a 3-4 minute drive to a location prior to mowing. However, the mower can only have the blades turned on when it is in "low" gear. Therefore, all mowing is done in "low." By connecting the controls for the WVO system into the "high-low" switch, the thought was that the WVO system would not be allowed to turn on unless the mower is in "low" gear. This is a benefit due to the fact that it would allow time for the WVO system to warm up while traveling in "high" to a lawn area, and to purge out the system while traveling in "high" from the lawn area. However, after further research was performed, it was determined that the ending purge cycle on the mower only takes approximately one minute. Information from Calvin Physical Plant revealed the typical lawn mower schedule to consist of the following: the mower returns to the plant for break at 9 AM, lunch at 12 PM,

[15] Zoro Tools, http://www.zorotools.com/g/00058735/k-G3442731?utm_source=google_shopping&utm_medium=cpc&utm_campaign=Google_Shopping_Feed&kw={keyword}&gclid=CIiFgezslrsCFdE-Mgod4T4Acg

and quitting time at 3:15 PM. Each time the mower uses the "high" range to go to and from the grass area. After talking with Geoff from the Physical Plant, it was determined that, due to a short purge cycle time of one minute[16], connecting the WVO system to be automatically engaged by the "high-low" switch on the mower would result in unnecessary burning of diesel rather than WVO.[17] Therefore the decision was made to stick with the "Co-pilot" controller which requires the operator to select when they desire to purge out the system. While this does place the responsibility of ensuring to purge out the system at the end of use on the operator, the controller contains a shut-down alarm that will sound and provide warning should the operator try to perform an improper shut down.[18]

Implementation

The costs for all the parts required to convert a lawn mower to run off of WVO along with labor required for the implementation is $2295. This conversion would be performed by Jeremy from the Physical Plant on campus. Jeremy has shown interest in this project and is excited at the opportunity to get involved.

Benefits of WVO

One of the main benefits of running a lawnmower on waste vegetable oil is not using diesel as fuel. By not running the lawnmower on diesel the college will not need to purchase as much diesel. Currently, one Toro 4000D lawnmower is run for 840 hours per year. This leads to the college using approximately 1300 gallons of diesel per year for one lawnmower. By running the mower on waste vegetable oil the college will not have to purchase the 1300 gallons of diesel per year for the lawnmower, and with diesel estimated at a price of $3.36 per gallon the college will save $4400 dollars per year.

Appendix II-C. Future Considerations

Preventive Vehicle Maintenance

In order to ensure that the lawn mowers will continue to run for future years, the team researched various different forms of preventative maintenance. First, in order to prevent the possibility of the fuel injectors becoming plugged by leftover vegetable oil, the team suggests treating every fifty gallons of fuel with a bottle of anti-gelling fuel injector cleaner. This cleaner costs around $8 and approximately two bottles will be required each month. In addition, the fuel filters should be changed more often than for a standard diesel lawn mower. The team suggests changing the filters monthly at approximately $15 per filter. After the lawn mower is fully converted, the team also suggests running some tests to check for other unforeseen problems that could occur. Initially, the team suggests that the mower be run for one week to evaluate its performance. After this week an oil sample should be taken to a lab for complete engine oil analysis and the fuel filter and injectors should be inspected. Including mechanic labor, the monthly total for preventative maintenance was estimated to be $90.

Spare Parts Inventory

In addition to the preventive maintenance that has been previously mentioned, the team also suggests that additional parts be kept on hand at the Calvin College Physical Plant. These parts should include fuel filters, fuel injectors, and fuel injector cleaner. More parts will be added after the mower is converted if any major problems come up.

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[16] Frybrid.com

[17] Van Berkel, Geoffrey. "Biofuel Lawn Mower Project." Message to the author. 8 Dec. 2013. E-mail.

[18] Greasecar, http://greasecar.com/accessories/co-pilot-computer-controller

Additional Vehicle Options

In order to provide the second phase option in case the project becomes very successful in the future, two other vehicle options were considered. The two options were chosen by the decision criteria that previously mentioned. A campus safety vehicle was first analyzed for feasibility, and it seemed to fit well with the team's need. It was highly visible on campus as well as high running time to help publicizing the project and to shorten the payback period by using the vehicle more, as seen in Figure 21.

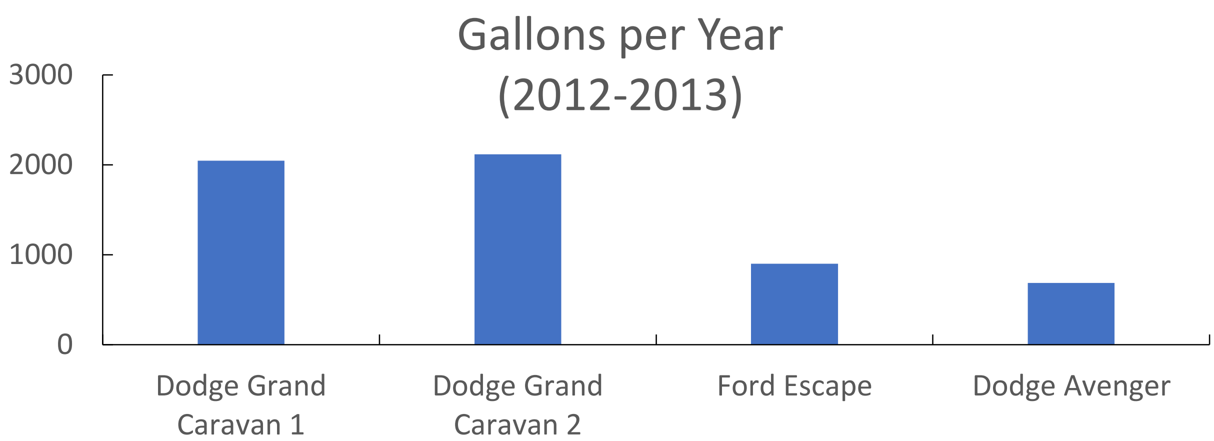

Figure 21. Campus Safety Vehicle Usage

Through some researching, the group was able to find a couple of vegetable oil convertible vehicles, such as pre-2008 Volkswagen Jetta, shown in Figure 22. However, the conversion of campus safety vehicle was no longer considered when it was indicated that campus safety vehicles must be newer models in order to provide "professional" and "safe" visuals to students and other noticeable people. This was a major challenge for the group since newer automobiles are made with complicated sensor system to control emissions which was beyond what the group was able to do with given period of time and level of knowledge. Another concern with campus safety vehicle option was the pre-heating requirement of vegetable oil before using. This fails one of the critical essentials for Campus Safety, which is emergency response readiness.

Figure 22. Second Phase Vehicle Options

The next vehicle that was considered was a transportation van, which are used for longer distance travels. The fact that these transportation vehicles go longer than just a couple of miles was very suitable for the project as well as the easy conversion process. The only major concern with this option was that these vehicles were difficult to find with the team's specifications. Most of these transportation vehicles have gasoline engines rather than diesel; these vehicles would also have to be made before 2008 to avoid the complicated post-2008 diesel exhaust regulation system. After brief researching, the group determined that 1999-2003 Ford E-350, 2002-2006 Dodge Sprinter, and 1997-2001 Chevy Express Van were possible options to run with vegetable oil without excessive amount of engineering work and labor needed.

A return of investment analysis was conducted for two of these options, Ford E-350 and Dodge Sprinter, and the result showed that the Ford E-350 would be the option providing quickest payback period with ROI of approximately 11,200 miles. This is equivalent to roughly 52 round trips to Albion College. The analysis was done for WVO conversion cost only, assuming $3.60 per gallon diesel saved and base vehicle cost is already accounted in college budget, meaning purchasing cost of the vehicle is not included in the calculation (Avg. cost $20,000). However, the result showed is that Ford E-350 provides quicker payback point than Dodge Sprinter only because its fuel mileage is lower (13 mpg) than Sprinter's. Dodge Sprinter's ROI was calculated to be 17,200 miles at 20 mpg. After considering this, the group choose to recommend the 2002-2006 Dodge Sprinter. This decision came out of concerns that an acceptable 1999-2003 Ford E350 would be very difficult to find. There is a much better selection of acceptable Sprinter vans and WVO conversion kits are much more widely available for the Sprinter.

Appendix III. Facilities & Infrastructure Selection

Summary

Introduction

Once the team had selected a biofuel feedstock and vehicle, the question arose of where and how to process, purify, and store the waste vegetable oil (WVO). Subcomponents of this task included:

- Determining the optimal location for fuel processing and lawnmower refueling.
- Designing the WVO purification process to minimize cost and space requirements.
- Sizing the WVO production rates to ensure adequate storage capacity.
- Ensuring efficient WVO transportation and waste disposal.
- Assuring cleanliness and safety in the design and operation of the system.
- Forecasting necessary labor requirements by setup and operation.

The design and research described below met these requirements, and provided a cost-effective method for refining the WVO for use in the lawnmowers at Calvin.

Procedure

Once the Feedstock/Fuel Production sub-team had decided to use WVO, developing a process design and finding a location could be considered. After finding several possible locations that would be considered, preliminary designs could begin. During the design of the process, the Infrastructure/Facilities sub-team discovered certain pros and cons to various WVO processing designs, which each impacted the location selection. The team was also in contact with David LaGrand, a current producer of WVO biofuel, about some of the problems he encounters with processing WVO. Using his experience the team could then start finalizing the type of process that would be used. The team had four very different designs considered throughout the design phase. The design requiring the least amount of labor and changeovers came became most appealing from a cost standpoint (see Appendix III-C. Cost Analysis). After talking to Geoff Van Berkel and Phil Beezhold, the team found a great location on campus equipped with with enough space, industrial storage racks, and proper heating for the WVO filtration. Having selected this location, the team could finalize the design and optimization of the proposed processing/filtration plant.

Data & Calculations

The majority of the calculations discussed in

Appendix III. Facilities & Infrastructure Selection involved the space requirements necessary for storing and processing the WVO. Since a lawnmower was chosen to operate on the WVO, the need for an adequate place of storing the feedstock during the winter became apparent. After selecting the physical plant warehouse as the location for the WVO filtration system and taking measurements on the IBC totes for use in the suggested settling tank filtration system, the team came up with the following proposal of how to structure the system itself.

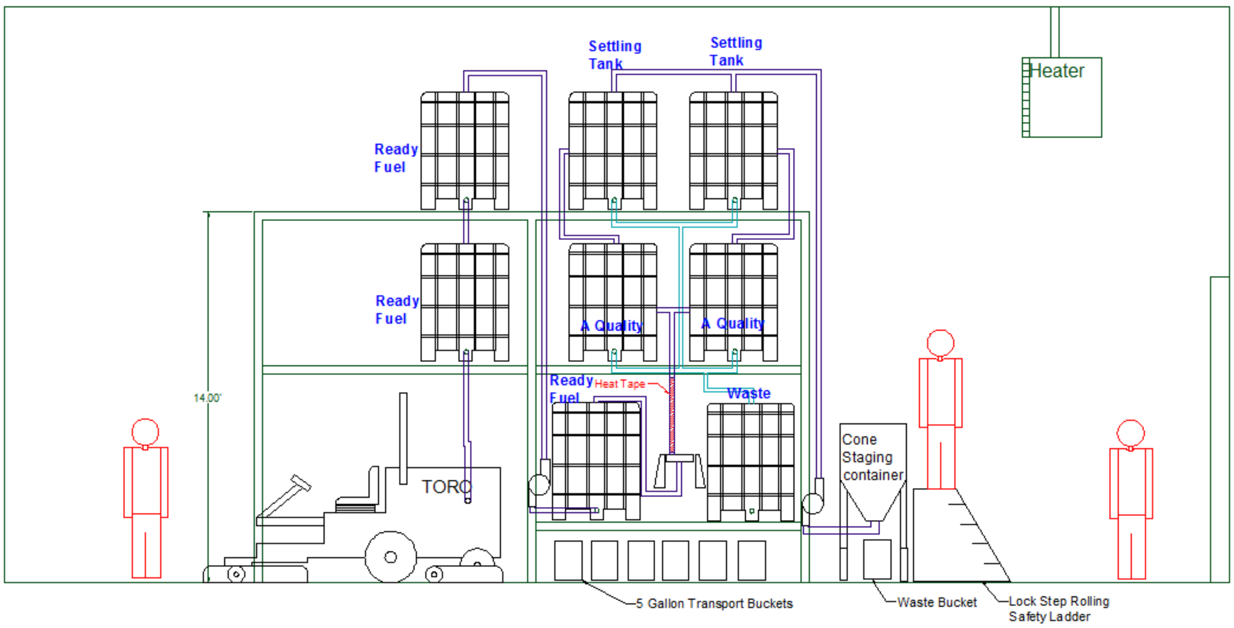

Figure 23: WVO Processing System Schematic

The model demonstrated in Figure 23 combines the functionality, ease-of-use, safety, and cost design constraints seen in Appendix III-A. Design Constraints. By combining the upfront and ongoing costs accrued by filtering the fuel, conversion of the vehicle, and construction of the WVO processing plant, the team concluded on the following budget, seen in Table 6: Overall Project Proposal Upfront and Operating Costs.

Table 6: Overall Project Proposal Upfront and Operating Costs

	Upfront Costs	Monthly Operating Costs
Year 1	$ 6,680.35	$ 360.00
Year 2+	$ -	$ 236.00

Conclusion

In summary, the team proposes that the Physical Plant use its warehouse capacity to house the WVO filtration center. In addition, the team proposes that Calvin's recycling center handle the transportation of unprocessed WVO from the dining halls. For further analysis, see Appendix III.

Future Considerations

This section describes the actions necessary for preventative maintenance on the process equipment, the possibilities for involving student and visitor education, and the possible sources of labor that were considered and selected for the project. The success of this project relies not only on the effective production and use of fuel-ready waste cooking only, but on the long-term integration of the project into the fabric of the college. This includes not only the day-to-day operation of the Physical Plant, but also the educational opportunities of the project and the faculty and students who will work directly with the Physical Plant. A full description can be seen in Appendix III-D. Future Considerations.

Appendix III-A. Design Constraints

Total Cost

Total cost was one of the team's biggest concerns. In order for this project to really take off it would need to be feasible financially. The team wanted to come up with a process design with low upfront capital and monthly operating costs. In designing the process, the team wanted to make sure that as much of the equipment purchased would remain usable over a long period of time. Along with that, the team desired that the process be simple and require little labor to operate. These design goals would help reduce the monthly operating cost of the waste vegetable oil processing plant, and thus the cost of the system over time.

Available Space

Finding the appropriate space large enough to fit where the processing system was another large concern. In the very beginning stages of the project, the team knew that the location was important. After some reiterative steps in the design of the process, it was determined that the process would require around 120 square feet of space. There were only a select few areas on campus that had the space the team wanted.

Cleanliness

The team also realized that the designed system must be clean, because not only will it be more appealing to the customer, but also ease the stress on necessary manual labor The team did not want to design something that would be dripping oil on the ground or smelling distasteful and causing complaints. In order to make the system as clean as possible, many options, such as having a non-rigid system, were thrown out because of this constraint. Keeping the process as clean as possible could limited the choices for the design.

Safety & Ergonomics

Safety and ergonomics should always be addressed. Throughout the design process, the team wanted to make sure no one was put at risk of injury in any way. During the design process the team kept in mind how a typical person would go about operating the system. The team made sure to think about the steps in the process and how the person working on it would be moving and transferring the waste vegetable oil. This limited some of the design options.

The team knew that periodic cleaning was necessary for the centrifuge, thus the design was made such that the centrifuge was easily accessible, limiting how much the employee would need to bend or reach.. The team also made sure that the waste vegetable oil could be inserted into the system easily. Along with these considerations, safety concerns also played a role in the cleanliness aspect mentioned above as well. Making sure as little oil as possible would be on the ground, hence reducing the risk of slipping and falling.

Ease of Production

Throughout the design process, the team also considered how easy it would be to produce the quality oil needed to run the vehicle that would be operating on it. The team discussed two alternatives of having oil produced in a fast manner resulting in ready fuel sooner versus letting the oil sit for long periods of time to help settle out unwanted sediment. After determining that a lawn mower would be used as the vehicle, the second alternative seemed more appealing to the team because letting oil sit over the winter was not a real concern as lawn mowers do not run in the winter (see Filter Research). If in the future, a non-seasonal vehicle is to be used, this constraint will become a bigger concern.

Transportation

Transportation is another key component of the process. Similarly, transportation methods would differ based on the WVO processing location. Originally, the team considered the commons boiler room as a possible location. This would have been very effective in terms of transportation because half of the WVO would already be in the same building. Any other location would require picking up the WVO from each dining hall and taking it around campus to wherever the processing plant was located. With Calvin's on-campus resources, transportation was not a significant problem. However, the team also knew that it would be added work for anyone who was required to do it. Fortunately, the team was informed that the physical plant already makes stops at the dining halls with their utility vehicles for recycling pickup. These vehicles could be easily arranged to also pick up the unprocessed WVO to transfer it to the physical plant. This option required the least time and effort.

Cleaning & Maintenance

Cleaning and maintenance of the designed system put in place was another high priority concern. Creating a system that needed constant attention would cause the price of operation to rise. In several of the team's design considerations, filters were used to clean the oil. Using filters would require frequent maintenance, hence adding more labor costs to the process. This would have a big impact on the break-even analysis (see Filter Research).

Production Time

Production time was a concern because the team did not want to wait long periods of time for usable oil. However, after determining that a lawn mower would be the primary vehicle, the team quickly realized that having a slower production time would not cause obstacles as much as originally thought. Stockpiling the WVO supply during the winter was acceptable because lawn mowers are not in action during that time period. This allowed the team to use the method of long period settling. The drop in demand of fuel in the winter meant that a slower production time design was acceptable and beneficial because it allowed the team to come up with safer, cleaner, and cheaper methods of production.

Appendix III-B. Design Alternatives and Decisions

Location

Determining the location of the processing plant was one of the team's primary tasks throughout the design process. The team needed to find a location that would meet the needs of the processing plant and also be located on Calvin's campus.

Space Availability

Space availability played a big role in how the team designed the system. A smaller space would mean that it would be unable to store all the waste oil as previously planned. Also a smaller space would mean that the process would need to be faster in order to meet the fuel requirements of the vehicle. A bigger space however allowed the team to think of a different process that could store more fuel and slow down the filtration time which resulted in more financial savings. Various locations of housing the system were analyzed, including one which incorporated a movable trailer to house the processing equipment. Unfortunately, the size requirements of the system ruled out this option early on in the design process. Eventually, the two most appealing spaces found by the team were the boiler room under commons and the physical plant. The two locations are shown in Figure 24.

Figure 24: Boiler Room (left) and Physical Plant Warehouse (right)

Heating

Heating is another key factor in the filtration of the WVO. The WVO requires higher temperatures for ease-of-filtration. At low temperatures, the oil becomes viscous and this can lead to slow moment through pipes and a less successful settling process. The team did not want to place the process in a cold environment because the settling process is a very key component of the filtration process. The team also did not want to risk clogging the pipes. This being said, the two most feasible options were the commons boiler room and the physical plant. The physical plant has a heater in place (see Figure 25) next to the racking that the team plans to use. This heater will supply proper heat throughout the winter and will be very beneficial for the process. The boiler room was another good option because it naturally stays warm during the year due to all the running equipment. The boiler room was not chosen in the final design because of the distance from the fueling pumps at physical plant and storage of the lawnmower.

Figure 25: Physical Plant Warehouse Heating Unit

Shelving

The team saw value in a gravity feed process. This process would require the least amount of manual labor and limit the amount of equipment that would need to be purchased. For this reason, shelving was very important. In order to utilize gravity, it was decided to place the storage and settling tanks at various heights. Without proper shelving this could not be accomplished. The Physical Plant already has industrial shelving units that are not used to their full potential, see Figure 26. This allowed the team to utalize this space for a better purpose. These shelves made it easy to design our system using gravity as much as possible.

Figure 26: Customizable Industrial Shelving Units

Process Design

Fuel Storage

Fuel Storage was an immediate concern once the team had decided to go with the lawn mower as its waste vegetable oil user. Having a vehicle that runs only in the summer meant that all the waste oil collected in the winter would need to be stored somewhere until it could be used again the following summer. Additionally, majority of the volume of VWO comes during the winter because that's when the dining halls are open the most. In order to deal with this problem the team looked at the records for the dining halls waste oil. With previous year's output volume for each month, the team calculated what the monthly volume of waste oil would be in the future years. Knowing this while adding some safety factor to the raw numbers and using the assumption that 6 months out of the year the oil would be stored, the team could determine the volume capacity needed to store all the fuel. The units being used to hold the fuel during storage are IBC totes and one conical tank, as shown in Figure 27. The appropriate storage volume is achieved by using three IBC totes, two on the shelving system at a height to provide pressure head for fueling transfer, and one below the centrifuge, to receive clean oil after processing.

Figure 27. WVO Storage and Settling Tanks

Fuel Transfer

While designing the oil cleaning process, it was brought to the team's attention that a member of physical plant could easily move IBC totes with a forklift to positions on the shelf, and thereby eliminate the need for a pump. While the team considered this, the implications of having a system which needed oil-carrying connections to be made on a regular basis were strongly negative. Making these connections would require a worker to climb a ladder, which the team had been avoiding for safety reasons. In addition, the changes of spilling or leaking would be much greater for a "non-rigid" system than with a "rigid" system. Oil in the work environment introduces additional hazards and goes against the design principles set forth by the team.

Additionally, the team debated whether to have a "pull" system, where settling containers are filled, stored, and opened sequentially, with enough time for settling to occur, or a "batch" system, where a large amount of oil is treated at once. The pull system had the disadvantage of requiring physical flexibility of a non-rigid system, and the batch system was not as effective at providing the flexibility and space efficiency that was required by the demands of varied use and varied input.

The team decided to use the flexibility of the pull system in a rigid profile in what they called a hybrid parallel system. This system transfers oil between containers at different stages of settling similar to a batch system, but yet allows the filling of a container continuously. Additionally, the system processes the oil relatively in a time-frame between the batch and pull systems, providing the flexibility and variability required by the variable use and feed profiles, but also allowing greater space efficiency.

Process Flow

The fuel cleansing and preparation process was designed in order to address the team's objectives of low cost, cleanliness, minimal maintenance, and high yield. Several cases were analyzed and the system that best addressed the team's needs was selected. The cases consisted of several methods configured such that each would clean the oil to a certain extent. The three methods we selected were settling, filtration through a bag filter or canister filter, and forced settling through a centrifuge.

Each method had distinct characteristics that made it suitable for a portion of the process. Settling in a tank is the most cost and labor-effective method for removing large quantities of dirt and pollutants from the oil. This method is used heavily by Mr. LaGrand because of its low cost. Filtration through either filter medium is a very precise method of cleaning the oil. It also is straight forward and clean with regards to maintenance and replacement of the filters. However, filters can require a pump to provide additional pressure, and when being used with very dirty oil they can quickly clog and need replacement at significant cost. Forced settling using a centrifuge can provide results comparable to filtration, only at a higher up-front cost. The benefits lie in greatly reduced variable costs, as the dirt separated in the centrifuge can be disposed of without discarding any components of the centrifuge. Further research on the centrifuge and other filtration methods can be found in Appendix I-B.

Based on the characteristics of each cleaning method, the team assembled cases for cost analysis. The results of this analysis can be found in the cost analysis section in Appendix III-C.

The selected processing method involved a centrifuge and settling tanks, as seen originally in Figure 10: Case Study Cost Models. The proposed process schematic, shown in Figure 23, would remove the majority of the sediment using two stages of settling, spanning 1-1.5 months each. It then processes the oil further using a centrifuge, and stores the clean fuel oil for use. The process was also designed as a staggered parallel process, so that the settling can occur uninterrupted in one process stream, while the other stream is filled with fresh WVO. The team's design uses minimal tanks and piping for this system, and is designed to provide acceptable oil at the required rate. When designing the process, the team also concentrated human involvement into a few hours per month. The most time-intensive process is running and cleaning the centrifuge, and can be done while oil is being transferred after settling. This minimizes required labor and provides work to be done without interspersed periods of waiting.

The proposed process flow begins with the pickup of WVO from the dining halls in 5-gallon buckets (as suggested in Figure 28: WVO Processing Flow Diagram. Physical Plant’s recycling trucks are able to transport this oil along with the recycling to physical plant at no additional cost. There, the buckets will be placed under the shelf holding the IBC storage and settling totes until the student worker pours the WVO into the staging container shown in Figure 23: WVO Processing System Schematic. This is done weekly, depending on the availability of oil and the student worker. After the fuel settles in the staging container, the worker first drains the sludge that has settled into a waste bucket, and then activates the pump to deposit the remaining WVO into a settling tank. Once this tank is filled, which is calculated to take about 1 month, the tank is left to sit, and the new WVO is pumped into the second upper settling tank. After 1 more month, when the second upper settling tank has been filled, the student worker initiates the draining of the clear oil and the waste into the first upper settling tank into the first lower settling tank and the waste container, respectively. The first upper settling tank is then ready to be filled again with oil from the staging container. About one month later, the second upper settling tank is ready to be drained into the second lower settling tank and the waste container, in the same manner as the first was drained. At this time, the first lower settling tank has settled for one month, and is ready for draining. Clear oil is passed through the centrifuge for final cleaning, and waste is drained into the waste container. This process of settling and draining is repeated for the second lower settling tank one month later, and the cycle repeats. This cycle is capable of processing oil to the degree required by the vehicle at the rate provided by the dining halls at peak production. In addition, the system is kept warm by a heater in close proximity to aid settling, and the oil passing through the centrifuge is heated by heating tape and an add-on heater to the centrifuge. Increasing the temperature of the oil above room temperature significantly lowers its viscosity (see figure 13), and help filtration occur more efficiently and thoroughly.

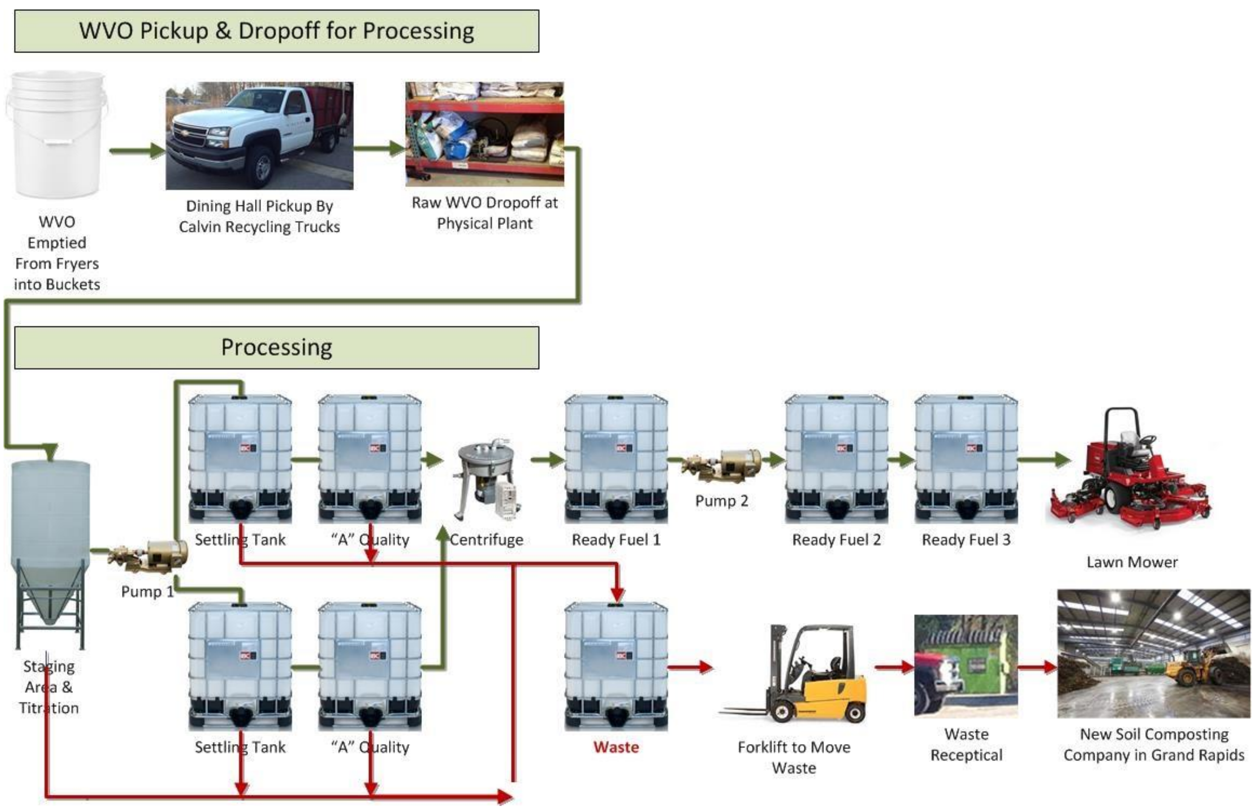

Figure 28: WVO Processing Flow Diagram

Tank Dispense

The settling process assists in cleaning the oil by separating the majority of the contaminants from the "pure" oil using gravity. The lighter clean oil floats to the top of the tank, while the heavier sediment and water sink to the bottom. Once the settling process is finished, both quantities are to be drained from the tank as part of the process. Several options for this draining procedure were considered. The most simple was using the included bottom port to first drain out the sediment and water, and at a determined level, the B and A quality oils would be transferred to their respective locations for further settling or processing in the centrifuge. While this method required no modifications to the tanks (IBC totes), it introduces the possibility of re-contaminating the “B” and “A” quality oils with dirt and sediment remaining in the pipes.

The second option the team considered was using three separate taps to remove quantities from cleanest to dirtiest. This method directly addresses the concerns of the first method. However, it has the potential of greatly extending transfer time by decreasing the available pressure head by which the oil drains. Of greatest concern are the implications for the dirt and sludge at the bottom, because a lack of pressure head could leave sludge at the bottom, to be disturbed and mixed with the next batch of oil. In addition, this method would require two additional ports to be placed in the IBC tote, which increases the potential for leaks and failure

The third and optimum method is a hybrid of the first two. Like the first method, the sludge is drained first to utilize the additional pressure head provided by the clean oil above. The A quality oil is then drained from a port which is fed by a floating feed. This ensures that only clean oil is removed, and the remaining oil, which is determined by a level on the tank wall, is left in the settling tank as B quality oil. This oil still has particles that require more time to settle out. The team decided upon this method because it provides both the cleanliness of oil and the higher pressure head to decrease transfer time. Also, the relatively few modifications to the tank are an acceptable trade-off to achieve both the aforementioned benefits.

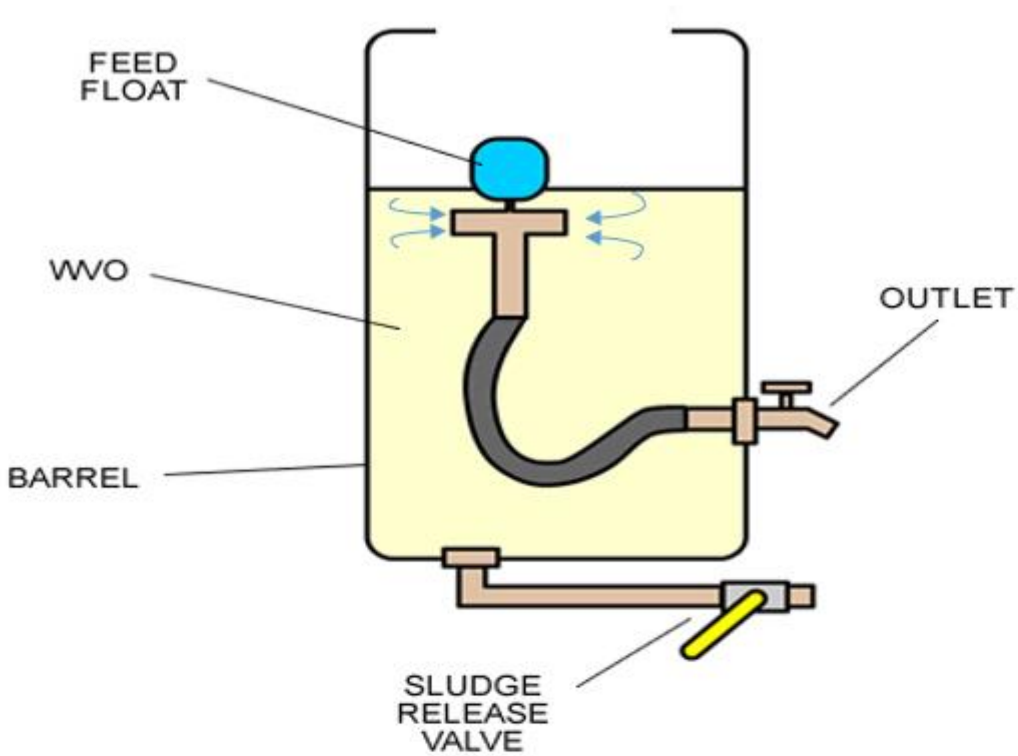

Figure 29: Settling Tank Schematic[19]

Valves

The process requires several valves for the controlled transfer of oil between settling tanks, through the centrifuge, and from the staging container to the settling tanks. While some of these valves are easy to

[19] http://www.vegoilcar.co.uk/wvo_filtering_setup.php

reach, some are high on the shelving system, and would require a ladder to operate. The team weighed the risks of injury from working at a height against the additional cost of electronically actuated valves, and decided that the convenience and safety warranted additional expense, as shown in Figure 30.

The valves will be actuated with a DC electric motor operating at a safe voltage (12V or under), and will be operated by a panel of switches located in an easily accessible location. An initial layout of the panel is shown below in figure 24.

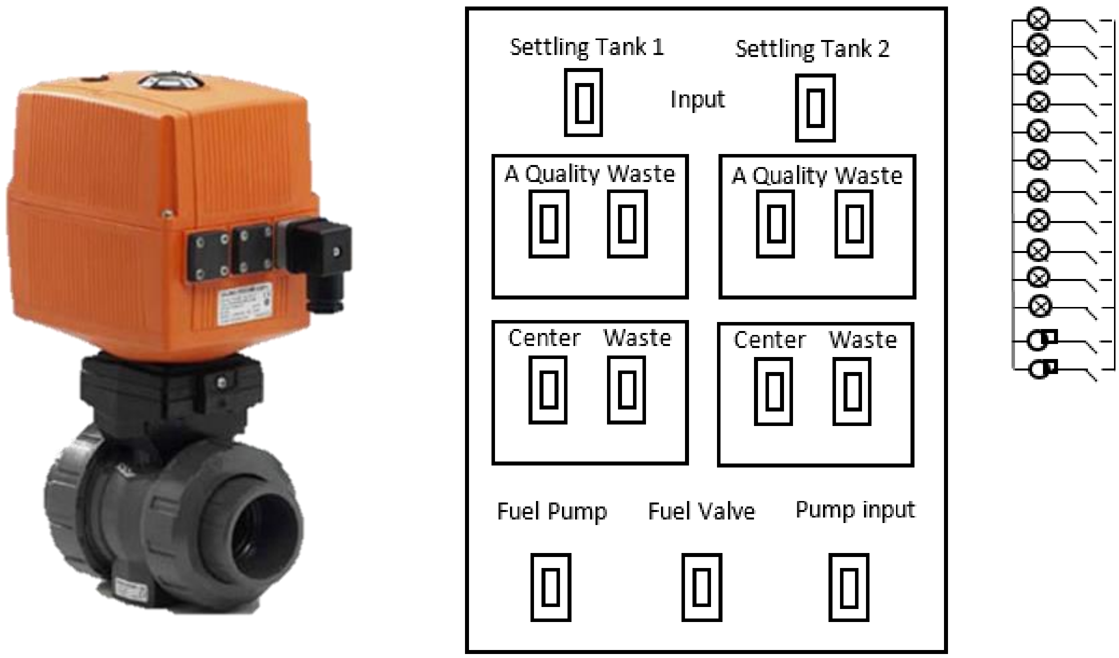

Figure 30: Electric Actuated Valves and Switch Board[20]

Transportation

Unprocessed WVO

The team encountered the problem of transporting unprocessed WVO. There were three kinds of transportation considered: golf cart, trailer, and recycling truck. Physical plant owns several golf carts and it was suggested that they could be used to transport the unprocessed WVO from the dining halls. Golf carts have the advantage of being easy to use and nimble, however, available 'trunk' space and engine power were limited. Trailers owned by physical plant were also considered to be used to transport unprocessed WVO. Using trailers would minimize on-road transportation, thus decreasing the chances of spilling.

[20] http://www.esi.info/detail.cfm/George-Fischer-Sales/Electric-actuated-valves/_/R-35725_CV22ST

However, the team had decided to use the Physical Plant's current recycling truck for unprocessed WVO

transportation, illustrated in

Figure 31. Currently, the truck takes daily trips to Commons and Knollcrest Dining Halls for recyclable plastic and paper products. These recyclable goods are then taken to the recycling center, located approximately one hundred feet away from the proposed processing plant location. Therefore, the team proposes the following procedure to transport the unprocessed WVO.

1. All unprocessed WVO would be emptied from the fryers into five gallon plastic buckets with lids, already in abundance at the Physical Plant and Dining Hall.
2. These buckets would then be picked up daily by the recycling truck
3. Once brought to the WVO processing plant, the five gallon plastic buckets would be offloaded to the storage area, space under the last rack on the proposed WVO processing system.

Henry Kingsma, director of Calvin's recycling service, has already agreed to have his workers do this at no extra cost. Once a week, someone must then empty the five gallon buckets into the conical staging tank. Since this process require no additional transportation, this method is both simple and cost-effective.

Figure 31. Physical Plant Recycling Truck

Waste Byproducts

The waste byproducts from the processing of WVO are precipitate-able incompatible components that could ruin the biofuel vehicle engine, shown in Figure 32. The team searched for ways to dispose of this byproduct, also referred to as "sludge." It was known, through research, that sludge could be mixed with wood chips and burned. This could potentially become an additional energy source to Calvin, however this would require additional equipment, increasing Calvin's carbon footprint and disturb students, faculty, staff and neighbors due to odors. The team was also aware that WVO could be used as weed suppression. However, it quickly became clear, with expertise from the Physical Plant, that the smell would not only disturb people of and around Calvin, but also attract more critters.

Figure 32: WVO Waste Byproduct[21]

It was also known that Calvin disposes waste to the Kent county incinerator and compost. Since components of sludge were known to be organic, it would be compatible for compost. Further research and inquiries to the Physical Plant showed that an existing compost container, Figure 33, from New Soil already exists and was emptied three times a week by a hauler, a paid service costing $270 from Arrowaste.

Figure 33 New Soil Compost Container

It was also known that a New Soil compost containers is 6 cubic yards in volume and is about half full when emptied. The available volume in the compost containers far exceeded the ~150 gallons of sludge dumped at one time. The team decided to use the compost container to dispose of sludge because such service was already available to Calvin, no additional costs were incurred, thus a better utilization of the sunk cost.

The team designed and specified a process in which the sludge would be disposed of, as follows:

1. Sludge would be let out by the student worker via a valve from their respective IBC totes, gravity fed, to another IBC tote designated to contain sludge.

[21] http://www.peachparts.com/shopforum/alternative-fuels/122655-wvo-great-junk-oil.html

2. Once all sludge was gathered in the sludge IBC tote, the valves were turned off.
3. The one valve that led to the sludge IBC tote would be disengaged and cleaned.
4. The sludge IBC tote would then be fork lifted to the composite container by a physical plant employee.
5. The contents would be let out of the sludge IBC tote into the composite container via a valve and gravity fed, by the student worker, while the tank was still fork lifted.
6. Once emptied, the sludge IBC tote would be fork lifted back to the WVO treatment facility.
7. The student worker would then reengage the appropriate valve to the sludge IBC tote.

Appendix III-C. Cost Analysis

Perhaps the most critical objective of the biofuel vehicle project was minimized cost. As indicated previously in in the feedstock and vehicle appendices, upfront capital and ongoing operational expenses have been the two major budgetary considerations throughout.

Procedure

Early on in the project, a preliminary budget was set at $10,000 for the first year's total cost. When it was realized that labor was the significant cost constraint, the team switched to overall breakeven point in years as a better indicator of the project's total cost to the college. By plotting monthly operating costs versus the current cost of operating the lawn mower on diesel, the team compared each design iteration.

Labor Rates

Phil Beezhold indicated to the team that an approximate labor rate for the Physical Plant was $45 an hour. Likewise, Pam Moura, Calvin Student Employment Assistant, said that "student interns get paid $10-$12 an hour.[22]" Using this data, the team determined that the WVO plant's first year of operation would require 30 hours per month of student labor at a rate of $12 an hour. This figure incorporates the additional labor demands due to system setup and initial implementation. For subsequent years thereafter, this student labor rate was reduced to 15 hours per month at $10 an hour.

Final Decision

After many iterations, it was determined that a settling tank, centrifuge system was the best choice with a breakeven point in 3.7 years, as seen in Figure 2.

The total upfront cost for the final design was $6,680, as demonstrated in Table 7: Final Decision Cost Breakdown and Bill of Materials. In addition to componentry, this capital cost includes installation time for both the vehicle conversion kit and WVO processing plant. The ongoing operating cost for the entire WVO system after the first year was calculated to be $236 per month. This includes all labor, preventive maintenance, and spare parts requirements for the vehicle, as well as the energy required for powering the centrifuge and pumps. The $4/ft^2/month average cost of industrial warehouse space in Grand Rapids is not included in the monthly operating cost because the Physical Plant's warehouse space has been assumed a sunk cost.

Bill of Materials

The items in Table 7 describe all costs of the system, including the necessary upfront and operating component requirements. The original spreadsheet is hyperlinked to each part vendor's web-enable URL for ease-of-purchase.

[22] Moura, Pam. Calvin Student Employment Assistant. Nov.19 2013

Table 7: Final Decision Cost Breakdown and Bill of Materials

Case 1 Cost Breakdown (Centrifuge)

Upfront Costs

Description	Vendor	Cost	Quantity	Total Cost
Lawn Mower Kit	Greasecar	$ 1,895.00	1	**$ 1,895.00**
Installation Time	Calvin Physical Plant	$ 45.00	8	**$ 360.00**
Raw Power Centrifuge	WVO Designs	$ 1,197.00	1	**$ 1,197.00**
Centrifuge Bolt-on Heater	WVO Designs	$ 297.00	1	**$ 297.00**
275 gallon IBC Tote	Craigslist	$ 30.00	8	**$ 240.00**
Duda 110 Gallon Cone Tank	DudaDiesel	$ 188.00	1	**$ 188.00**
25gpm Industrial Oil Transfer Pump	WVO Designs	$ 350.00	2	**$ 700.00**
2" PVC Piping (per foot)	Lowes	$ 2.04	150	**$ 306.00**
PVC Schedule 40; 2" Ball Valves	Lowes	$ 14.85	13	**$ 193.05**
Ball Valve Actuator	MegaHobby	$ 15.50	11	**$ 170.50**
Male/ Female Connectors	Lowes	$ 2.60	7	**$ 18.20**
PVC 90 Degree Joints	Lowes	$ 15.00	12	**$ 180.00**
Heating Tape ($/ft)	ACE Hardware	$ 1.67	24	**$ 40.00**
Uniseal for 2" Pipe	Tank Depot	$ 5.00	4	**$ 20.00**
Installation Time	Calvin Physical Plant	$ 30.00	20	**$ 600.00**
Floats	Walmart	$ 12.60	4	**$ 50.40**
Tubing (33ft)	WVO Designs	$ 60.00	1	**$ 60.00**
Manual Trigger Nozzle	AdBlueOnline	$ 44.00	1	**$ 44.00**
Light switches	Lowes	$ 0.69	8	**$ 5.52**
250 ft Wire	Lowes	$ 63.24	1	**$ 63.24**
Plug	Lowes	$ 4.34	1	**$ 4.34**
AC to DC converter	Lowes	$ 31.90	1	**$ 31.90**
1/4" Ready Fuel Hose ($/ft)	Delcity	$ 1.08	15	**$ 16.20**
Total Upfront Costs				**$ 6,680.35**

Operating Costs

Description	Vendor	Cost	Quantity	Total Cost
Student Worker Wages (Year 2)	Calvin College	$ 10.00	15	**$ 150.00**
Additional Preventive Maintenance Labor	Calvin Physical Plant	$ 45.00	1	**$ 45.00**
Fuel Filters	Greasecar	$ 15.00	1	**$ 15.00**
Fuel Injector Cleaner	Ryder Fleet Products	$ 8.00	2	**$ 16.00**
Energy	Consumers Electricity	$ 10.00	1	**$ 10.00**
Total Operating Costs				**$ 236.00**
Total First Year Costs				**$ 9,512.35**

Appendix III-D. Future Considerations

Facility Preventive Maintenance

There are three main areas for facility preventative maintenance: oil spill containment and IBC tank replacement. Team visits to local WVO producer David LaGrand's garage showed that this process is potentially very dirty. For the Physical Plant to remain safe and professional, much care will be needed to contain the mess from WVO processing. Like all maintenance shops, the Physical Plant is already equipped spill kits and some oil absorbent products. The team further suggests that oil absorbent mats and socks be placed around the base of the staging container, waste buckets, and waste tanks. These may be changed as needed to ensure a safe and clean work area. In addition, loose absorbent should be kept nearby in the case of handling spill.

After many gallons of processing, some sludge may remain in the bottom of the IBC tanks, particularly the settling tanks and waste tank. Eventually, this sludge may render the IBC tank unusable for further oil processing. Because cleaning the interior of these tanks may prove challenging, time consuming, and in some cases ineffective, the team suggests that replacement tanks be purchased from the usual sources.

Educational Integration

In order to maintain this project for many years ahead, the team has proposed varies ways to implement it further into Calvin College, and more specifically the Engineering Department. First, the team suggests that Engineering 101 professors look into the possibility of dedicating one class to a tour of the vegetable oil processing facilities. This will allow new students to see an example of what they might be able to do in their future years at Calvin College. The project should also be advertised during Friday's at Calvin, especially the special Engineering Department Friday's at Calvin, to show perspective students what Calvin College has done to make the campus more environmentally friendly. In addition, the lawn mowers could be explained during campus tours if one happens to drive past the tour group. Finally, the team suggests that annual Engineering Department seminars be held to outline the success and failures of the project over the year, while talking about the future of where the project could be headed.

Labor Sources

The construction of the processing site, as well as the on-going WVO processing, requires no small amount of human labor. The various labor options are described in the table below.

Table 8: Potential Labor Resources

	Physical Plant Staff	Current CERF Intern	New Biofuel CERF Intern
Pros	▪ Professional, capable ▪ Familiarity with Phys. Plant equipment ▪ End-user has vested interest in project	▪ Familiarity with project and financial accountability ▪ Cheap ($12/hr) ▪ Connection with ENGR department	▪ Project ownership ▪ Student involvement ▪ Cheap ($12/hr) ▪ Connection with ENGR department
Cons	▪ Expensive ($45/hr) ▪ Not an added-educational experience	▪ Already very busy with CERF projects	▪ New position requires additional managerial resources

As shown in Table 8: Potential Labor Resources, employing a physical plant staff member for this project is the most expensive option. At a standard rate of $45/hour, this is almost four times greater that the cost of a student intern. For this reason, the staff member was ruled out as a labor source. The CERF Intern seemed like a natural fit for the position; he or she would already be familiar with the project and have the necessary skills for managing the fuel procesing procedure. However, because of the projected necessary time commitment, the CERF intern would likely be overburdened by the additional workload. For these reasons, the team suggests creating a new position: Biofuel Intern.

The Biofuel Intern would be managed by the director of CERF. This person would be responsible for procession the WVO, as well as managing the initial construction and installation of the process equipment. This intern would also serve as a liason between the Engineering Department and the Physical Plant.