Engineers for a Sustainable World
Rensselaer Chapter
Biodiesel Project Report

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[2] Biodiesel Fundraising Lead, 1st Year Grad, Mechanical Engineer, Rensselaer Polytechnic Institute, Cooper Union.
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[4] ESW-RPI Vice President of Fundraising, Junior, Physicist, Rensselaer Polytechnic Institute.

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Nomenclatures, Abbreviations, Acronyms, and Symbols

Term	Definition
^{0}C	Degrees Celsius
ESW	Engineers for a Sustainable World
GE	General Electric
NYSERDA	New York State Energy Research and Development Authority
RPI	Rensselaer Polytechnic Institute
SoE	School of Engineering
STS	Science, Technology and Society
U of R	University of Rochester
WeR	We Are the Spirit of Rensselaer
WVO	Waste Vegetable Oil

Chemical Formula (Mass)	Name	Chemical Formula (Mass)	Name
H_2O (18 g/mol)	Water	H_2S (34.08 g/mol)	Hydrogen sulfide
CO (28.05 g/mol)	Carbon monoxide	H_2 (2 g/mol)	Hydrogen
O_2 (32 g/mol)	Oxygen	SO_2 (64.07 g/mol)	Sulfur dioxide
C_2H_4 (28 g/mol)	Ethylene	CO_2 (44.01 g/mol)	Carbon dioxide
NaOH (39.9 g/mol)	Sodium hydroxide	$C_{20}H_{40}O_2$ (104 g/mol)	Biodiesel
$C_{16}H_{34}$ (62 g/mol)	Diesel	$CH_3(CH_2)_{16}CO_2H$ (284 g/mol)	Vegetable Oil

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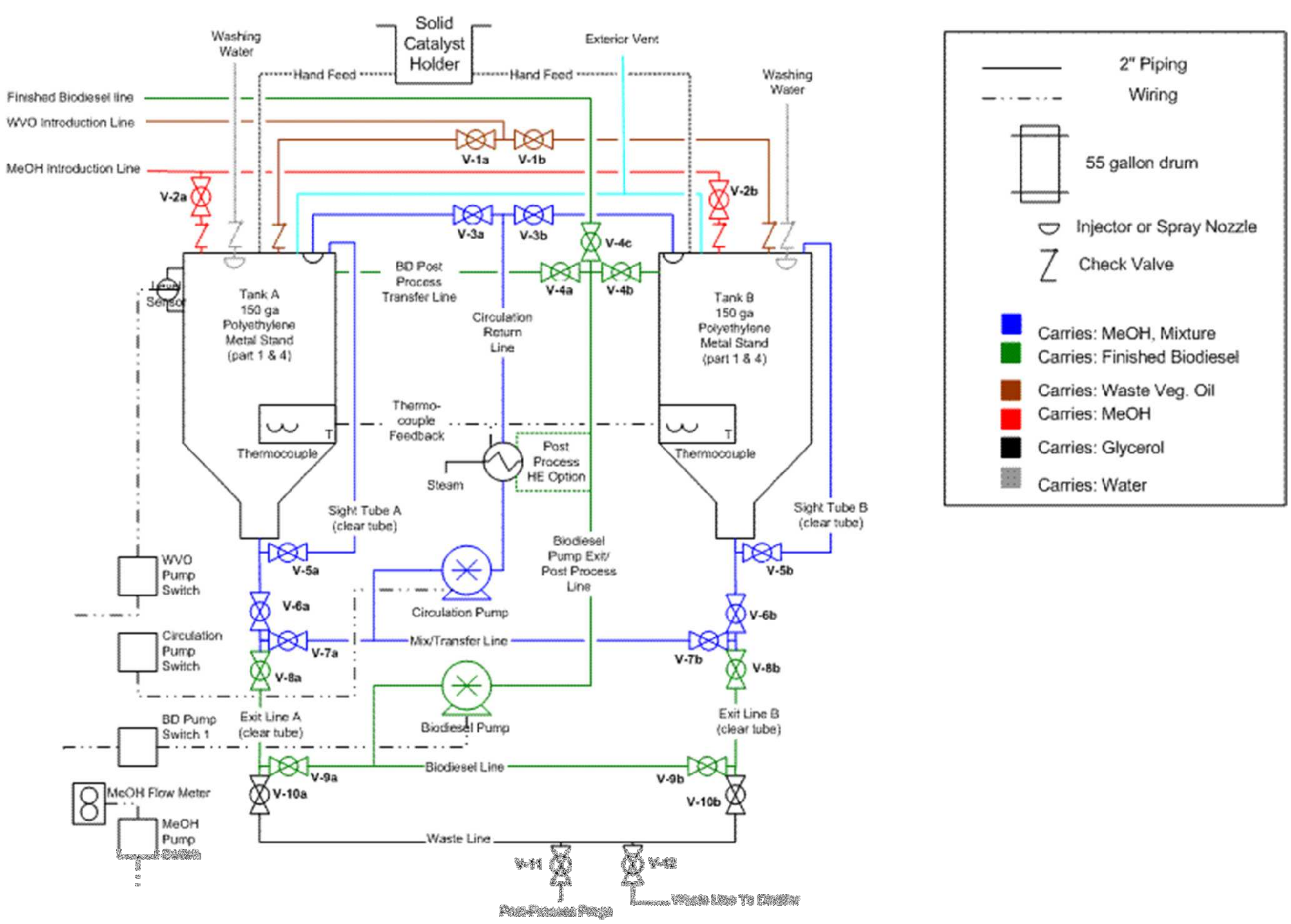


Figure: Piping and Instrumentation Diagram Excerpt

Abstract. The Biodiesel Project is a new ESW-RPI project. Its long term goal is to assemble everything needed for a biodiesel production facility that will convert waste vegetable oil into usable quantities of biodiesel for RPI and the surrounding area. Biodiesel is a cleaner and more renewable form of standard petroleum diesel and has a huge advantage over other alternative fuels. It can be used in any standard diesel engine without expensive modifications or design changes and burns cleaner than any petroleum or fossil fuels. Used vegetable oil, which is often treated as a waste product and discarded in large volumes by dining halls and restaurants, can be converted into biodiesel by chemically mixing it with Sodium Hydroxide and Methanol in a process that creates biodiesel. The process is not new and has a history of success. The University of Rochester has been doing this for about four years now and has tremendous success. They have taken an old school bus and have used their biodiesel to power the bus on sustainable biodiesel. If U of R can do this, Rensselaer Polytechnic Institute can do it even better.

This report details the current state and direction of the RPI Campus Biodiesel Project with an emphasis on process design. The overall goal of the campus biodiesel project is to produce a fuel that can be used in the campus shuttles. The main feedstock in the reaction is used cooking oil to be provided from the campus dining halls. An added bonus is in the fact that it will reduce the amount of waste oil the campus must dispose of. The intent of the project is not only to experiment with future energy systems but also to serve as a learning tool for high schools and to provide a valuable educational and research tool for Rensselaer students.

The current direction of the project is being focused around the production of biodiesel using a standard alkali catalyzed reaction. This reaction is a transesterification process in which sodium hydroxide (NaOH) is dissolved in methanol and then mixed with waste vegetable oil to produce biodiesel and glycerol. This technique was chosen because of its simplicity and cost-effectiveness compared to other biodiesel production techniques.

A 200-gallon batch process is going to be constructed in Blaw Knox. The reactor will be a dual tank design that will implement circulation mixing. Waste vegetable oil will be stored in an adjacent room and pumped into the reaction vessel. The process will be laid out to allow the greatest number of production and processing techniques, and to maximize experimental possibilities. Waste vegetable oil and finished biodiesel will be transported to and from Blaw Knox by the campus hazardous waste disposal service.

I. Introduction

The project is headed by Ray Parker, a sophomore chemical engineer, and it is poised to move from the planning stage to production. All that is needed is funding for equipment. We have been in contact with RPI Facilities regarding a potential location to house the biodiesel facility in Blaw Knox, but due to it being a biohazard, we are now in the processes of moving to the greenhouses near where the ESW-RPI Biodigester project is located. We have also been in communication with the RPI dining halls, Sodexo, Terra Cafe, and even local businesses for sources of used vegetable oil. We are confident that our needs for waste vegetable oil can be met by the local community. Sodexo stated that they produce up to 50 gallons of used vegetable oil each week, which will be more than enough for us to start a small scale production of biodiesel for now.

While the conversion of waste to useful energy is always exciting, this project also has significant educational merit. Few students, even among chemical engineering majors, have the opportunity to apply their chemical engineering and general engineering knowledge to the real world. If the facility can be successfully installed, it can be used as an academic resource. The educational benefits will reach far beyond the original design team. We will start off with a simple batch processing, and continually, over time, build up to a more advance continuous processing faculty.

We've been in contact with a couple of professors and graduate students and they have been helping to figure out some of the questions we have had. Currently, we have been submitting to about three different grant proposals/funding opportunities and are continuing to build on this, but we haven't won any more money to move forward with the project. We meet with an expert, Judy, on biodiesel and biofuel on October 28th; she is from the NYSERDA and will be helping us in our project. We've been in contact with a couple of alumni who are willing to help us out with it as well. We have a couple of people who are familiar with the process of making biodiesel, a couple people who have contacted a couple of biodiesel companies in the area, a couple of people who have been working on grant proposals and some others working on figuring out budget issues.

Our goals for this project as an independent study include 1) getting funding, 2) beginning to run small test experiments, 3) figuring out where to build the plant and 4) ordering and begin building the materials. This only works if we are able to get funding for our project, which hopefully happens. We've been trying to get funding, but some of the deadlines don't come until sometime next year. We've contacted several companies in the area regarding biodiesel. No response back. Talked to the SoE regarding funding and now we can use it.

-List of Materials for Small Scale Testing: Used/New Vegetable Oil, Beakers, Flasks, Pipets, Sodium Hydroxide and Methanol, Phenolphthalein, Heater, Graduated Cylinder, Vegetable Oil, isopropanol.

We have are now trying to get a place to test and do a small scale test. We've trying to find a lab, but we were just thinking about testing inside of Blaw Knox or somewhere else. We've ordered materials and have gathered them to make our oil. We've contacted Sodexo about picking some of it up.

II. Procedures, Testing and Proposals

1. WeR Gold Funding Proposal

ESW-RPI Biodiesel submitted to the 2013WeR Gold Funding Opportunity in October of 2013 and we recently received news that we were selected as a featured project in the first round groupings of projects with a fundraising goal of $3,500 dollars next semester.

Project Timeline

Fall 2013 - Obtain funding.
Winter 2014 - Begin refining plant location.
Spring 2014 - Begin ordering parts
Fall 2014 - Begin assembling and doing small scale testing
Spring 2015 - Begin full scale production of biofuel.

Project Members

Ray Parker '16 Chemical Engineering, Jake Weber '16 Chemical Engineering, Alvin Zhang '18 Mechanical Engineering, Amrita Bajwa '15 Biology, Jenny Li '16 Chemical Engineering, Liam Moynihan '15 Physics, Jinyuan Yu '16 Chemical Engineering.

Alumni Interactions

ESW-RPI does interact with alumni. We have had many outreach programs with our alumni, of whom are glad to help us with our projects. I have been approached by many alumni offering assistance in their field of expertise, including solar panel water heating and biofuel.

Alumni Donations

I plan on trying to communicate with my donors by email or phone calls. We are currently going through grants and fellowships through the government and other funding organizations. In the past we have tried to submit our plan to business plan competitions, but we did not receive any funding. We are now working on acquiring funding through Rensselaer and other funding competitions.

2. Small Scale Biodiesel Process Test Procedure

ESW-RPI Biodiesel has created an experimental testing procedure to help develop small batch samples of biodiesel to help familiarize ourselves with the process of biodiesel production, before we move onto a larger scale manufacturing plant. Currently, we are working on ordering chemicals through the School of Engineering, which is proving to be difficult due to complications with liability and bureaucratic policy.

Materials:

1 liter Used/New Vegetable Oil
2 Beakers
2 Erlenmeyer Flasks
2 Pipets/Measuring Devices
Sodium Hydroxide
Methanol
Isopropanol Alcohol
Phenolphthalein
1 Hot plate
1 Graduated Cylinder

If used vegetable oil is used, evaporation (water removal) and filtration (solid residuals removal) are needed.

Procedure:

Step 1: Titration (To determine how much catalysis to use)

1. Measure 10 ml of isopropanol to dissolve 1 ml vegetable oil in an Erlenmeyer flask.
2. Add couple drops of Phenolphthalein to the solution.
3. Prepare 1 liter NaOH solution (1g/L).
4. Add the NaOH solution to the vegetable oil drop by drop until the solution turns deep purple.
5. Record the amount of NaOH that is used.
6. Repeat the test 2 more time and calculate the average amount of NaOH that is used.
7. According to the data, calculate the amount of NaOH is needed to react with 1 liter of vegetable oil.

Calculation: 5.5g NaOH per liter of oil + the amount needed to remove the fatty acid.

Step 2: Biodiesel Reaction

1. Dissolve 1 L vegetable oil in 0.2 L methanol in a 2-liter beaker.
2. Heat the solution up to 38 – 49℃.
3. Add the heated oil solution to a 2-liter bottle.
4. Add the calculated amount of NaOH solution into the bottle.
5. Shake it vigorously.
6. Let it stand overnight.

Step 3: 327 test (5 mins)

1. Measure 3 ml biodiesel.
2. Dissolve it in 27 ml methanol in a small vial.
3. Shake it for few mins and let it stand.
4. Check if there is anything that is not dissolved on the bottom.

If there is more than ¼'' on the bottom is not dissolved, add 30% more NaOH to the bottle and stand overnight.

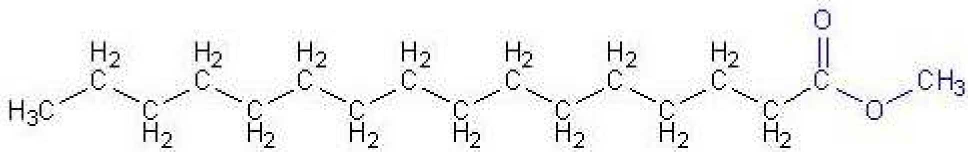
Step 4: wash and soap test

1. Add water to it and let it stand for 1 hour.

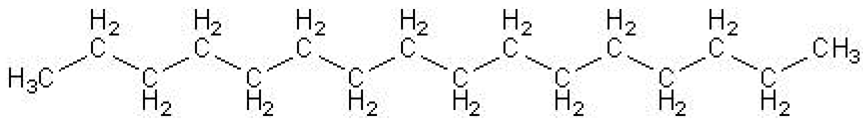
Step 5: Test Biodiesel using purification tests.

Molecular formulas

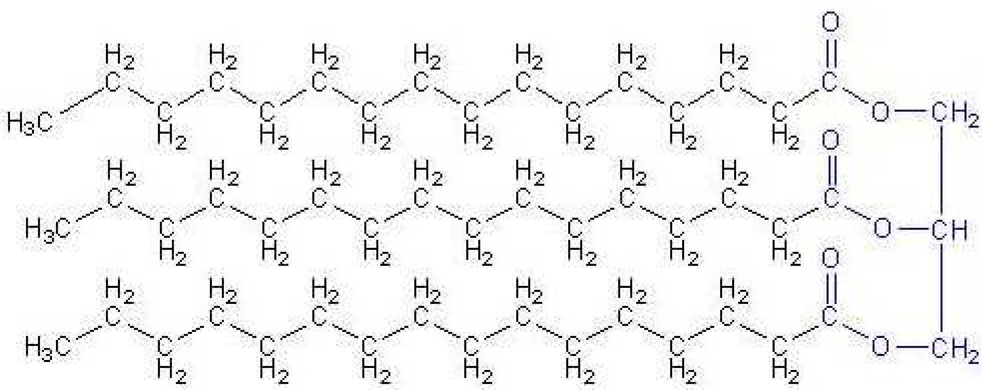
Biodiesel:



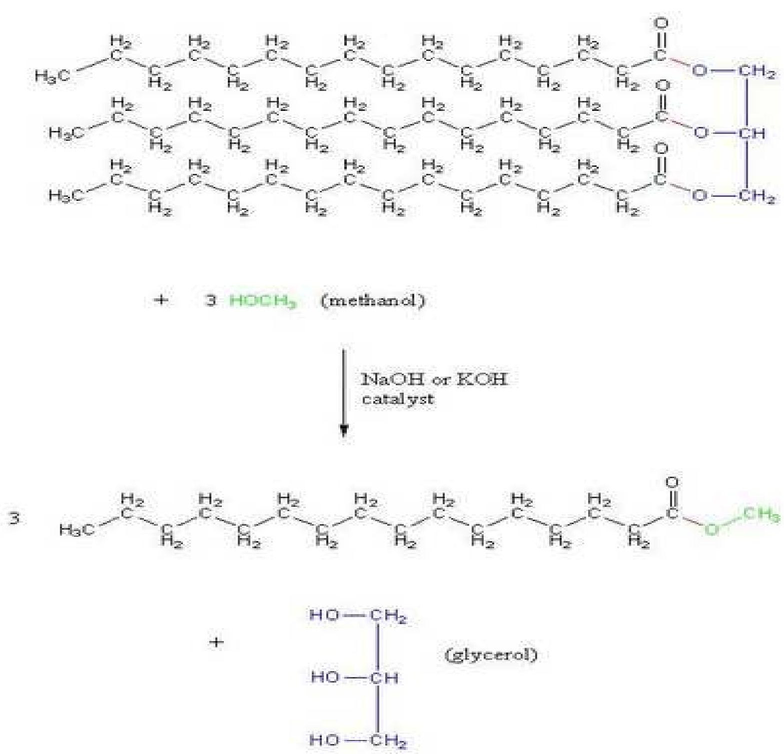
Regular diesel:



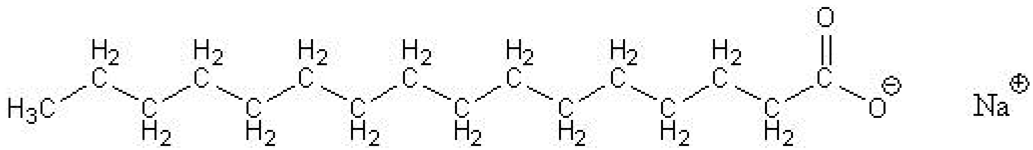
Vegetable oil:



Chemical Reaction (transesterification reaction):



If water exists, saponification will occur and soap will form:



3. Biodiesel Car Project

ESW-RPI Biodiesel's next step after producing a biodiesel production plant is to obtain a vehicle that will be able to run on biodiesel. The vehicle will be used as an academic tool as well as a promotional tool that will help to raise awareness of sustainability on campus and will be used as tool to help future other ESW projects as well.

How will this project impact Rensselaer or the greater community?

ESW-RPI's Biodiesel Project will impact Rensselaer by setting an example of how to use alternative energy to build a more sustainable world. With this project, we plan on using different types of energy to fuel the car, and transform the car into a mobile solar panel charging station for outdoor events, etc.

Afterwards, ESW-RPI Biodiesel plans on acquiring a facility to design and build a biofuel production plant with the help of faculty from the Chemical and Biological Engineering Department. Professor Mattheos Koffas is working on a project with biofuel, so we may be able to collaborate with him as well. With the vehicle we obtain, we plan on using it to test and measure efficiency of our biofuel. ESW-RPI then plans on using food wastes and other materials to produce biofuel to sell to RPI to fuel the shuttles and maintenance vehicles. With the money we obtain, it will be put back into the ESW-RPI fund to keep the biofuel project running, as well as fund additional RPI-ESW projects, such as the Haiti Project.

Project Timeline in 2012-2013

1. Send out letter asking for donated used-diesel car OR buy cheap diesel car. 2. Identify engine and plan out modification. Figure out if biodiesel/biofuel conversion. 3. Research modification and purchase modifications OR buy a conversion kit OR make a biofuel processing plant. 4. Obtain used vegetable oil or fuel source. 5. Run and get working. 6. Obtain removable solar panels and modify car to run on solar panels with solar conversion battery (Able to power generators, etc.) 7. Obtain difference sources of energy and experiment with car (hydrogen/water/chemical) energy.

Project Presentations in 2012-2013

ESW-RPI Biodiesel Project Summary Presentation
http://prezi.com/z8bgfzykcohp/?utm_campaign=share&utm_medium=copy&rc=ex0share

ESW-RPI Biodiesel Project RPI Business Plan Competition Presentation
http://prezi.com/c6wotncb8ogk/?utm_campaign=share&utm_medium=copy&rc=ex0share

Engineers for a Sustainable World

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FACULTY/PROJECT ADVISORS
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Michael Jensen
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Jean Purtell

September 30th, 2012

To whom it may concern,

Engineers for a Sustainable World at Rensselaer Polytechnic Institute is a student non-profit organization currently seeking a corporate sponsor for a used diesel car. Today, over 18 million gallons of oil are going to be used. ESW-Rensselaer is trying to set an example of using alternative methods of energy to improve and sustain the world in which we live.

At ESW-Rensselaer, we are trying to reduce your dependence on oil, thus using alternative fuel sources to power our needs of transportation. We plan on converting a used diesel car to run on waste vegetable oil, with a possible solar-powered mechanism as well. We also plan on using the car to store, move and mount solar panels donated from GE to use to generate electricity for outdoor events and possibly use as a power generator to power buildings and lights. We also plan on experimenting with biodiesel and possibly even hydrogen fuel cells to power our vehicles. ESW-Rensselaer is trying to explore different methods of obtaining energy in order to revolutionize the way we think about energy.

ESW-Rensselaer has a proven track record. An ESW team of seven undergraduate engineering students converted a 20-foot shipping container into a medical ward and installed it in Haiti this past summer. ESW-Rensselaer conducted two other projects in Haiti, as well as in Mexico, Peru, Ghana, and the United States. ESW-Rensselaer has been featured on several local and regional television networks, newspapers, and publications, as well as the front page of RPI's website and student newspaper.

With this, we are asking for any kind of functioning diesel car that we can use to help get ourselves better acquainted with the process of converting diesel cars to run on vegetable oil and experimenting with alternative sources of energy, to help us develop a more sustainable world.

Please contact me at parker5@rpi.edu to discuss the project further. ESW-Rensselaer faculty and project advisor, Dr. Michael Jensen, can be reached at jensem@rpi.edu.

Sincerely,
Ray Parker
(425) 210-5827

III. Similar Projects and Feasibility Studies

As most people know, biodiesel is not a new technology. It has been around for many decades and many companies and projects have been completed using biodiesel. Carleton College has proposed a similar project to the one that we are starting now. Currently, Engineers Without Borders - Carleton College is prepared to construct a biodiesel reactor for the Carleton College and they have completed a funding application and have thoroughly researched all aspects of construction and production. In addition, they are in contact with other chapters of Engineers Without Borders across the United States who have completed other/similar biodiesel projects.

Clarkson's Chapter of Engineers Without Borders has also completed something similar. St. Regis Mohawk Tribe - This project entailed the conversion of vegetable oil into biodiesel for the St. Regis Mohawk Tribe and was completed in 2007. One approach utilized to achieve self-sufficiency is the reuse of waste cooking oil from local restaurants as biodiesel, which counteracts the high cost of diesel fuel. Students performed a feasibility study on the production of biodiesel from waste cooking oil. The students found an approach that was feasible for the community- the use of 100% biodiesel generators and waste collection vehicles for the warmer months, supplemented with 20% biodiesel in the waste collection vehicles in colder months. Assuming 95% efficiency inherent to the biodiesel production system, 6,400 gallons of waste oil will be converted into 6000 gallons of biodiesel fuel. By incorporating the heating value of each fuel, 4,500 gallons of B100 will be necessary to produce the needed 210 kW of energy per month. This is taken from the Clarkson EWB website.

Klean Industries has released a feasibility case study report has been produced so as to provide relevant information to anyone who is exploring the potential to develop a commercially viable biodiesel business. In addition to analyzing biodiesel's potential feedstock characteristics, output volumes and environmental impacts, this report examines:

- The existing diesel fuel industry, and its environmental impact
- Current biodiesel activity in North America and around the world
- Biodiesel standards and regulatory issues
- An environmental comparison between biodiesel and regular diesel
- Biodiesel production technologies and processing options
- Potential markets and distribution channels
- Critical success factors for the development of a biodiesel business plan
- Recommendations to project developers and governments that will accelerate the development of the biodiesel market in B.C.

The report identifies four critical strategic factors that will drive the success or failure of a commercial biodiesel project. These are:

- The ability to balance feedstock supplies, processing technology, and market penetration in an integrated system that that is both reliable and efficient;
- The ability to form stable strategic alliances with feedstock suppliers, distributors, end users, and other stakeholders;
- The ability to anticipate and deal effectively with competitive pressures; and
- The ability to generate a business plan that will allow a project to attract financing, and maintain its financial health.

Using this information from Klean's and Clarkson's project websites, ESW-RPI will be able to develop a better understanding of what we need to do to get our project accomplished.

IV. Recommendations, Lessons Learned and Future Plans

As we start to begin to start testing and refining our experimental biodiesel production procedure, we have not had too many barriers to overcome. One in particular that we are struggling with now is being able to order chemicals from the School of Engineering. The School of Engineering has particular vendors that they go through and a certain policy on what can be ordered and what can't be ordered. In particular, alcohol, chemicals, gases and syringes are restricted. We are now working with our advisor, Michael Jensen, to overcome this problem. Another problem that we have had problems with is being able to keep the interest fueled within our team and slowly people are starting to disband. The failure is in managing distributed actions. Structure in goals and roles do not lead to a loss of interest within a team, but a team leader that is able to fuel other members' interests would help them to develop a more excited environment for our team to work within.

A future goal of this project is to create a process that, once started, will produce biodiesel and remove waste independent of human interaction. Such a process would have the capability to produce a large volume of biodiesel at a high efficiency. Large-scale biodiesel plants run continuous processes in order to achieve high volume production efficiently. Developing a continuous biodiesel process is dependent on a number of factors.

The first concern in any continuous process is automation. The design needs to run automatically without human intervention. Automation would need to be implemented with flow metering, valve control, and temperature control, and must be able to handle a malfunction. For this process design, one major improvement would be the addition of a pre-mixer device to prepare the methoxide. This would extend the longevity of the circulation pump by avoiding extended periods of pumping pure methanol. This would avoid the possibility of localized cavitation and therefore extend the longevity of the pump-rotor blades. As a separately controlled element to the system from the reaction tanks, the pre-mixer would aid in maintaining accuracy during automation.

The major factor specific to a continuous biodiesel process is the settling time required to separate the glycerol. Since the settling time is significantly longer than the mixing and reacting times it is difficult to create a biodiesel process that runs continuously. One possible solution that has been examined is the use of a centrifuge to accelerate the settling process. Centrifuge enhanced separation could be tested using bench-scale batch experiments and, eventually, a continuous flow centrifuge could be implemented.

Due to the early stages of this project, there are not very many lessons to be learned that can be passed down to future students but funding is one of the aspects of this project that ESW-RPI is very familiar with. As we have progressed through our proposals, we have found that applying to grant opportunities within RPI and the region around RPI is the best way to go. For example, ESW-RPI Biodiesel originally started as a way to start experimentation of chemical engineering facilities, but as new opportunities opened up, such as the RPI Business Plan Competition, we have adapted our project to fit likewise and thus ESW-RPI came up with a business model to sell biodiesel to RPI and then make profit (of which failed). We then had opportunities to apply for grants through the School of Engineering and other non-profit organizations that required us to become a non-profit organization, so again, we became a non-profit organization.

V. Acknowledgments

Research for the ESW-RPI Biodiesel Project is funded by Rensselaer Polytechnic Institutes' School of Engineering along with WeR and their WeR Gold Funding Opportunity. Thanks to the Center of Future Energy Systems, Chemical and Biological Engineering Department at Rensselaer, Sodexo, Facilities of Engineering at Rensselaer, and Rensselaer's STS and Sustainability Department. Also thanks goes out to Ned Woodhouse, Marty Byrne, Jerry Faiola, Alexandre da Silva and Wayne Bequette, for all of their help during the period of the Biodiesel Project.

VI. References and Works Cited

Photographs Sources

Rensselaer_Polytechnic_Institute_logo.gif. 2013. Photograph. http://www.rpi.edu/. 03 Dec 2013. < http://topnews.in/usa/files/Rensselaer_Polytechnic_Institute_logo.gif />.

Piping and Instrumentation Diagram Excerpt. 2013. Photograph. http://www.rpi.edu/. 05 Dec 2013.

Research Sources

Authors: Lynn Bresnahan, Matt Burnham, David Camerota, Chris Czec, Nathan Korey, Jeff Marquis, Fred Moore, Mark Roberts. *Rensselaer Polytechnic Institute Campus Biodiesel Project: Design Report*. 01 Sep 2006: 1-48. Print.

This site contains information biodiesel projects that have been started before and gives facts and lessons on what to do differently next time.

http://www.kleanindustries.com/s/tire_plastic_recycling_feasibility_studies.asp?ReportID=138596
http://legacy.ewb.ca/en/whoweare/accountable/failure.html

This site contains information to Carleton College's EWB Biodiesel Project.

https://apps.carleton.edu/student/orgs/ewb/projects/biodiesel/

This site contains information about common vegetable oil viscosities and equations with which the values can be extrapolated.

Noureddini, Houssein. Teoh, B C. Clements, L Davis. *Viscosities of Vegetable Oils and Fatty Acids.* http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1012&context=chemeng_biomaterials

This site contains information about common vegetable oil densities and equations with which the values can be extrapolated.

Noureddini, Houssein. Teoh, B C. Clements, L Davis. *Densities of Vegetable Oils and Fatty Acids.* http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1016&context=chemeng_biomaterials

This file is a comprehensive source for many aspects of biodiesel production. Useful information and background is included on the chemical reaction, ASTM standards, production and processing techniques, process components, patent information, and safety protocols.

J. Van Gerpen, B. Shanks, R. Pruszko, D. Clements, G. Knothe. *Biodiesel Production Technologies.* http://www.nrel.gov/docs/fy04osti/36244.pdf

Aleks Kac outlines the technique used to perform a two stage transesterification; resulting in increasing yield and lower reliance on titration. This also includes a link to an updated version of the system.

Kac, Aleks. *The Two Stage Adaptation of Mike Pelly's Biodiesel Recipe*
http://journeytoforever.org/biodiesel_aleks.html

Oscillatory flow mixing is a promising technology for expansion into a continuous flow process. This site gives a full outline of the technology.

Professor Malcolm R Mackley, Bob Skelton, Dr Trond E Bustnes, Mingzhi Zheng. *Oscillatory Flow Mixing.* University of Cambridge Department of Chemical Engineering
http://www.cheng.cam.ac.uk/research/groups/polymer/OFM/

A comprehensive economic analysis of several processes of biodiesel production from waste oil and one virgin oil process, this report takes tax incentives, plant capacity, and overhead costs into consideration.

Y. Zhang, M.A. Dube, D.D. McLean, M. Kates. *Biodiesel Production from Waste Cooking Oil: 2. Economic Assessment and Sensitivity Analysis.*
Available online at www.sciencedirect.com

This report gives a fairly brief, but well-rounded overview of biodiesel. Information includes history and background, physical and chemical descriptions, production processes, advantages and disadvantages, and logistics of implementation.

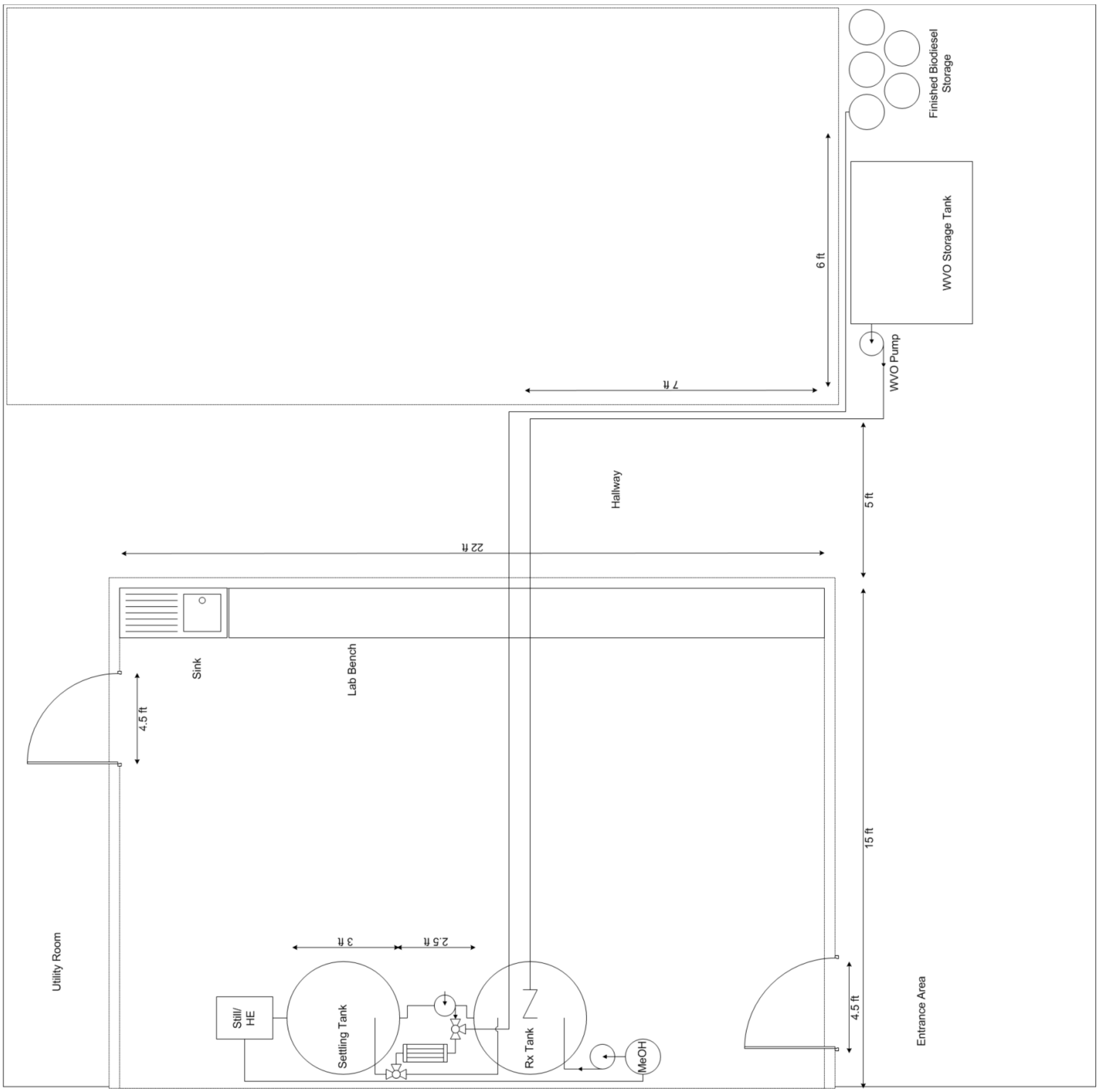
Leon G. Schumacher, Jon Van Gerpen, Brian Adams. *Biodiesel Fuels.*
Encyclopedia of Energy, Volume 1. 2004, Elsevier Inc.

Material Sources

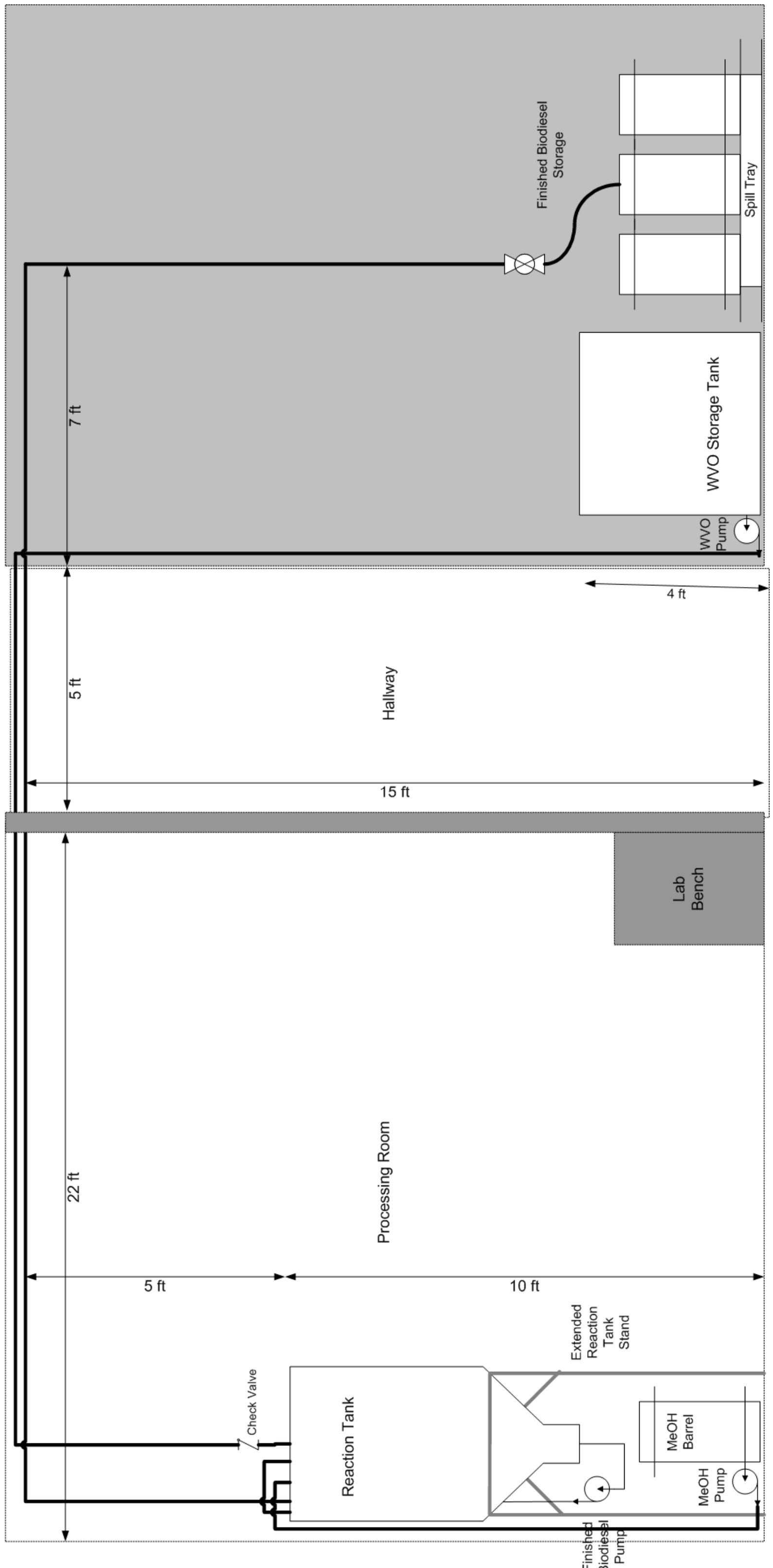
1) 300 gallon Conical Bottom Bulk Storage Tanks With Support Stands 2x ~~~ $2,000
http://www.usplastic.com/catalog/item.aspx?itemid=23153&catid=513
2) Pumps ~~ $1,000
http://www.grainger.com/Grainger/pumps/ecatalog/N-bir
3) Filter Bag Housing for Waste Vegetable Oil and Product Biodiesel ~~ $200
http://www.grainger.com/Grainger/PENTEK-Bag-Filter-Housing-4BA80?Pid=search
4) Bag Filter 100microns ~~ $200
http://www.grainger.com/Grainger/PENTEK-Filter-Bag-4BE18
5) Bag Filter 10microns ~~ $200
http://www.grainger.com/Grainger/PENTEK-Filter-Bag-4BE12
6) 450 gal. Polyethylene Waste Vegetable Oil Storage Tank ~~ $500
http://www.usplastic.com/catalog/item.aspx?itemid=22852
7) Piping - check on materials to ensure pipes won't corrode.
8) Product storage tanks, glycerol and biodiesel.
9) Lab equipment to characterize product (hydrometer, titration equipment to determine FFA content, etc.)

10) Raw materials, mostly methanol and sodium hydroxide (possibly some acid for pretreatment).
11) Bases for the pumps
12) Containment area (concrete) beneath reactor (possible)
13) Valves

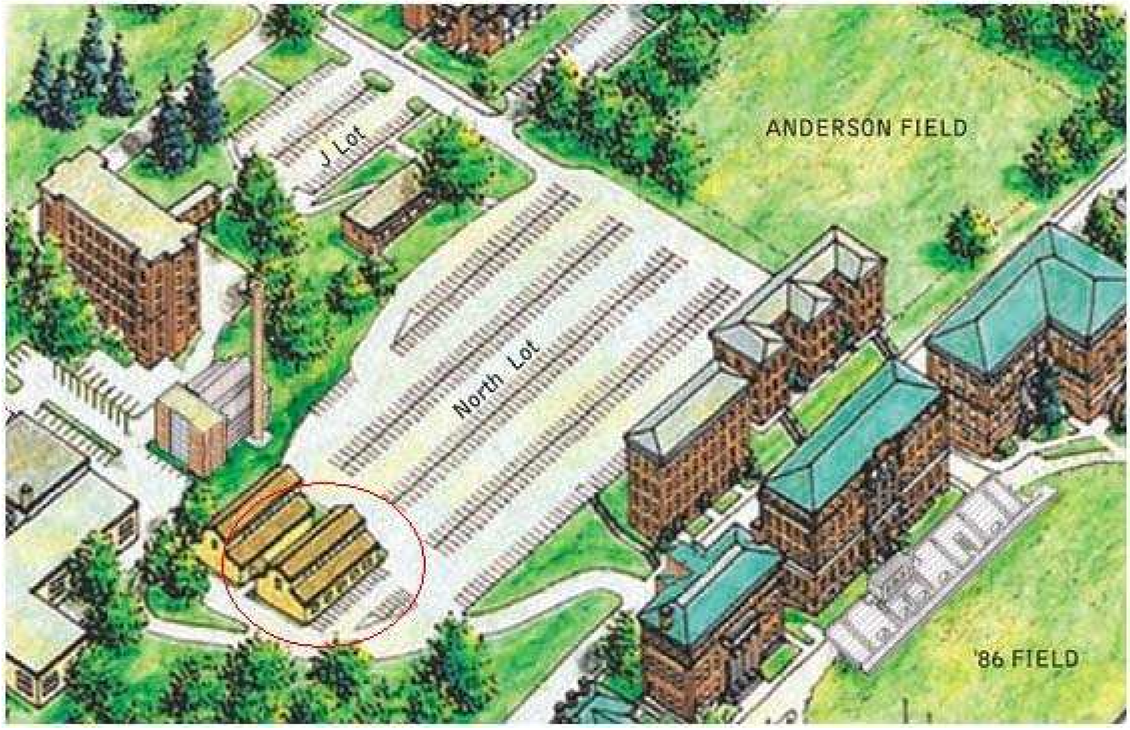
Appendix: Physical Layout Diagram – Top



Appendix: Physical Layout Diagram – Side


Finished Biodiesel Storage
Spill Tray
WVO Storage Tank
WVO Pump
7 ft
4 ft
Hallway
5 ft
15 ft
Lab Bench
Processing Room
22 ft
5 ft
10 ft
Extended Reaction Tank Stand
Check Valve
Reaction Tank
MeOH Barrel
MeOH Pump
Finished Biodiesel Pump

Appendix: Blaw Knox Location



Top: Campus map with Blaw Knox 1 circled in red.
Bottom: External photo of Blaw Knox 1

Appendix: Process Area

Top left: caged off area for waste vegetable oil storage tank. Top right/bottom: Blaw Knox process room (needing obvious housekeeping)