Biodiesel Process Analysis for EPOCA

An Interactive Qualifying Project Report

Submitted to the Faculty

Of the

WORCESTER POLYTECHNIC INSTITUTE

In partial requirements for the

Degree of Bachelor of Science

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Submitted: 3/5/2009

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Abstract

This report, commissioned by the non-profit company EPOCA, investigates biodiesel production processes for a start-up enterprise. Different processes were analyzed based on outside research conducted. The processes were then rated using criteria given by EPOCA. Based on that rating, a recommended process was then selected for EPOCA to pursue and implement in their Empower initiative in order to meet their production needs and create a successful green company.

Acknowledgements

We would like to thank our sponsors EPOCA for giving use the opportunity to assist in their efforts at bettering the city of Worcester. We would especially like to thank Sarah Assefa and Juan Otero for the guidance they provided us during this project.

We would like to thank Mr. Bruce Fiene of WPI for helping us get an understanding of the collection, transport and filtering of WVO. We also want to thank the men at Steve's Auto Body for providing great real world information and examples, Mark Triano for going above and beyond in the helping of EPOCA, and all the other EPOCA members who have given us their help.

We also want to acknowledge the Marketing team and their advisor Prof. Miller for all the great work they did and for helping both us and EPOCA.

Finally, we want to give thanks to our advisor Rob Krueger for the assistance, guidance and friendship that we received from him over the course of the entire IQP project.

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1.0 Introduction

1.1 Problem Statement

Global climate change has become a major problem in the last 50 years. Harmful chemicals damage the ozone layer and create an insulating layer in the atmosphere that causes a rise in temperature and more aggressive weather patterns. Most of these harmful chemicals are the result of burning fossil fuels. Therefore, it is crucial that we take immediate steps to control the use of fossil fuel until a better, cleaner alternative is available.

1.2 Goals and Objectives

EPOCA began the EMPOWER initiative to create jobs for ex-prisoners, while helping the environment. EMPOWER is a cooperative business that will convert used cooking oil into biodiesel. EMPOWER will help both the community and the environment by creating more “green collar” jobs for the Worcester community. By creating new environmentally friendly jobs, EMPOWER can employ regular people and introduce them to a more high-tech industry. Green technology is a rapidly growing area and has much potential for steady growth in the future. These jobs will help ensure that Massachusetts remains an environmentally friendly technology leader while working to create a cleaner tomorrow for future generations.

The goal of this project was to design and construct a pilot plant for EPOCA capable of producing approximately 320 gallons of biodiesel per day and be able to support 2 full-time employees. Our research shows that EPOCA can meet these goals and more. While EPOCA had some understanding of the biodiesel conversion process, we provided them a greater knowledge of the system dynamics than they could have attained on their own. After our research was completed it was up to EPOCA to decide what suited them best. Though, with little alterations, EPOCA’s final system design will be similar to that which we analyzed and suggested. In the end, our project has accomplished what it was set out to do. The final system will be able to produce in excess of 320 gallons per day and sustain 2 full-time employees.

1.3 Summary

The following chapters include a detailed description of the project. These chapters include the background, methodology, analysis and conclusion. First the background will describe the company EPOCA and research done towards the project, starting with environmental impacts, history on biodiesel, and ending with processes and logistics to produce biodiesel. Following the background is the methodology chapter. In this chapter the steps for accomplishing the goals of this project are outlined, from determining the criteria for the project to how to select an optimal system for EPOCA. The next chapter is the analysis includes the results of the project. In the analysis, each process for producing biodiesel is evaluated as well as the evaluation matrix. The last chapter, the conclusion, will give a short summary of the results gathered and the suggestions made to EPOCA.

2.0 Background

In this chapter we will discuss how recent changes in our environment have sparked a worldwide search for alternative energy sources. First, we will introduce EPOCA and how their cooperative biodiesel initiative, Empower, will help them achieve their long-term objectives. Next, we will discuss the environmental impacts associated with the use of fossil fuels and how biofuels can help minimize those effects. Finally, we will explore the alternative of biodiesel; from the collection of WVO, to the storage of materials, and then to the safe production processes.

2.1 E.P.O.C.A

EPOCA stands for Ex-prisoners and Prisoners Organizing for Community Advancement. This is a group that believes they cannot wait around for the world to change, so they are mobilizing to change it themselves. Their mission statement is: "Working together to create resources and opportunities for those who have paid their debt to society." EPOCA is involved in many things. One of their main projects is CORI (*Criminal Offender Record Information*) reform, trying to change state law so that a CORI is not too restrictive when getting a job. Another program is the new leaf program; they work with job councilors and employers to help ex-prisoners find employment.

Empower, EPOCA's new initiative, is a cooperative business. In a cooperative business each employee holds a share of the business and has a say in the decision-making. The goal of the Empower project is to make a fully operational biodiesel manufacturing pilot plant that is able to produce approximately 320 gallons per 8-hour shift. Hopefully the plant will be able to employ several full time employees. Empower will be a pilot project, it will be an experiment. If it becomes successful, it will stand as a mold for more biodiesel plants with larger outputs to be built in the future. The long-term goals of Empower are to increase production to a commercial level while enhancing product quality and to create a new market of green jobs.

2.2 Environmental Impacts

The earth has gone through many climate changes throughout its history. Climate change is defined by the U.S. Environmental Protection Agency as, "significant changes in measures of climate (such as temperature, precipitation, or wind lasting for an extended period (decades or longer))." (http://www.epa.gov) The recent rise in temperature and more aggressive weather patterns have been attributed to the increasing use of fossil fuels. In 1880, the average temperature of the earth was 56.676 °F while in 2005 this temperature increased to 58.062°. (http://math.ucr.edu/home/baez/temperature) Greenhouse gases, gaseous constituents of the atmosphere that absorb and emit radiation that are produced as a result of the burning of fossil fuels have clogged the earth's atmosphere, preventing heat from escaping. There has been a widespread call for an increased awareness of this problem, with the hope that more people will consider alternative, more environmentally friendly fuels.

There are varying arguments for the cause of global climate change. Some believe that the recent changes are solely attributed to the earth's natural cycles, while others believe the human interference is to blame. It is likely that the source of the problem is a combination of the two. The earth's natural climate change is caused by many factors including solar activity, volcanic activity and Milankovitch cycles (http://www.skepticalscience.com). A direct correlation between solar activity and average global temperature has been discovered. Ironically, this correlation seems to have ended around 1970, which some believe is a strong argument that shows the impact of CO2 emissions had on our recent climate changes. Volcanic eruptions, or lack thereof, are also believed to be a major contributor to the recent variation of climate. Volcanoes emit CO2, which leads to warming, but they also emit sulfate aerosols, which cools the earth. Because volcanoes only account for less than 1% of the earth's carbon dioxide, it is often considered negligible when compared to other sources. The sulfate aerosols have a more profound influence on the atmosphere because it has a longer lasting effect. Periods of high volcanic activity can cause up to a 1° F decrease in temperature. When these effects wear off and the earth begins to warm again, it can be misconstrued as warming from other factors. Lastly, the earth undergoes cyclical periods of warming and cooling known as Milankovitch cycles. These cycles consist of about 120,000 years of ice ages, separated by short cycles of warmth known as interglacial periods. We are currently in an interglacial period, which accounts for the warming that we have been experiencing (http://www.koshlandscience.org).

Despite all of the arguments for natural changes, there is overwhelming evidence that human activity has a great affect on the atmosphere. Even though we are presently in an interglacial period, and warming should be expected, the past 100 years have shown a dramatic increase in the rate of warming. This dramatic increase is attributed to an increase of CO2 production from the burning of fossil fuels. "Beginning with the industrial revolution in the 1880's, the human consumption of fossil fuels has elevated CO2 levels from a concentration of about 280 ppm to about 387 ppm" (Adam, 2008). This has caused a temperature elevation of about 1.3° F, with an expected increase of another 2-10° F by the end of this century.

The main contributor of greenhouse gases is carbon dioxide. When CO2 becomes trapped in the atmosphere is creates something known as the greenhouse effect, the formation of a layer in the atmosphere preventing heat from escaping. This causes a substantial increase in average global temperature. Also, the increase in average temperature has a major effect on the earth's weather patterns. The frequency and severity of natural weather disasters, such as hurricanes and tornadoes, has gone up greatly because of the CO2 in the atmosphere.

Carbon dioxide is produced from a variety of sources. CO2 is a byproduct that comes from the production of metals, such as titanium and aluminum. Deforestation is also a huge concern is certain parts of the world. It is often overlooked as a contributor to global warming, because plants and trees absorb CO2, cutting them down greatly reduces the capability to remove CO2 from the atmosphere. Finally, the most relevant factor is the CO2 that is produced when fossil fuels are burned. Fossil fuels are very widely used in modern society, from manufacturing plants to gasoline in our cars. The burning of fossil fuels has contributed the most of the human damage to the earth with deforestation and urbanization also dealing significant damage (http://www.epa.gov). The most common way that most people burn fossil fuels is through driving their cars, which accounts for about 20% of global carbon dioxide emissions. Those who live in a harsh winter environment, like Worcester, also use significant amounts of oil to heat their home in the winter.

Carbon dioxide is the highest contributor of greenhouse gases, but other gases such as water vapor, methane and nitrous oxide also contribute harm to the atmosphere. Methane absorbs 25 times more heat than CO2, but it is present in much smaller amounts. It is produced from wetlands, energy production and livestock, which accounts for more than 50% of total methane production. Water vapor accounts for nearly 36%-66% of total harmful products in our atmosphere, but human activity does not contribute to the production of water vapor, so it is usually ignored when it comes to prevention.

The United States, as a whole, is dependent upon the automobile more than any other country. About 48% of global greenhouse gas emissions from automobiles come from the United States despite the US making up only 5% of the world's population and only 30% of the entire vehicle population (http://www.edf.org). The US government has set up a policy to try and slow the ever-increasing rate of carbon dioxide emissions by "strengthening science, technology and institutions and enhancing international cooperation" (http://www.epa.gov). Rising gas prices are also a major concern with the current state of the economy, and this is magnified because of the reliance on the automobile. This leads to both financial and environmental incentives to develop a cleaner and economical alternative to the fossil fuels.

While extensive research is currently being conducted to develop an alternative to fossil fuels, there is still much time before they are efficient enough to become a capable solution to our environmental problem, particularly in the case of automobiles. The American Solar Energy Society recently put together a report that covers, "energy efficiency in buildings, transportation, and industry, as well as six renewable energy technologies: concentrating solar power, photovoltaics, wind power, biomass, biofuels, and geothermal power. The results indicate that these technologies can displace approximately 1.2 billion tons of carbon emissions annually by the year 2030." (http://www.ases.org). Until these technologies can be implemented efficiently we must look for other sources of energy that have the potential to make a difference immediately.

2.3 Biodiesel from Waste Vegetable Oil: A possible solution?

Biodiesel is a very good compromise until new technologies can be implemented because it can be converted relatively easily from waste vegetable oil. The resulting fuel can be used in an unmodified diesel engine in a pure form, although it is normally mixed with petroleum diesel. Biodiesel can also be used in boilers to heat your home or business with little or no modification.

Because waste vegetable oil is readily available it is a possible very cost friendly solution, and the fact that it is made from renewable resources lowers our dependence on foreign oil and helps our own economy. Biodiesel has also been shown to help reduce carbon dioxide emissions, which can help the global warming crisis. "Biodiesel reduces net CO2 emissions by 78 percent compared to petroleum diesel. This is due to biodiesel's closed carbon cycle. The CO2 released into the atmosphere when biodiesel is burned is recycled by growing plants, which are later processed into fuel" (http://www.biodisel.org). The effects of replacing petroleum diesel with biodiesel could have a drastic change on the environment and is a step towards our goal of reducing global warming.

There are two different types of waste vegetable oil. The first type of waste vegetable oil is brown grease. Brown grease is the grease trap grease from stovetops and deep fryers. It is very thick, dark, and filled with impurities. There are about 4 to 48 lbs/person and 3,000 to 24,000 lbs/restaurant of brown grease produced in one year. In terms of the biodiesel market and production, brown grease has little to no value. The second type of waste vegetable oil is Yellow grease. Yellow grease is made up of the oils and animal fats that are used and produced during cooking and deep-frying. (Morea, Sept-12) Its production range is 3 to 21 lbs/person and 2,000 to 13,000 lbs/restaurant in a given year. This vegetable oil waste can be used for rendering and has been established as a valuable commodity in the biodiesel market. (http://www.nrel.gov/vehiclesandfuels)

Biodiesel has many various sources. It can be made from virgin oil, produced mainly from soybeans and rapeseed, waste vegetable oil, used in the cooking process, animal fats, like lard and tallow, biodiesel can even be made from algae grown to produce vegetable oils. Waste vegetable oil (WVO) is a good source as it is readily available at low cost (Biodiesel, 2008).

The first internal combustion engine to run on vegetable oil was designed by Rudolf Diesel in 1900. Diesel believed that engines that run on a biomass product were the future of his invention, in 1911; he said "The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it". The actual patent to the process in which biodiesel is made today, called transesterification, was given to G. Chavanne in 1937 for his design of the transesterification process (Biodiesel, 2008).

As a fuel biodiesel is very versatile, it can be applied to several different areas. An engine that is designed to burn diesel fuel can be modified to burn pure biodiesel, known as B100. Or that same diesel engine can burn an 80% diesel 20% biodiesel mixture with no modification at all, known as B20. This is advantageous as it will help to keep emissions down and slightly increase mileage. Pure Biodiesel, B100, can also be used as a replacement for home heating oil (Biodiesel, 2008).

Biodiesel has properties that are very different than other fuels on the market today. One of the major differences between biodiesel and diesel is that biodiesel contains less energy per gallon, but it burns more completely, making up for some of the loss due to smaller energy density. Another advantage to biodiesel is it has a much greater lubricating property than other fuels. This can reduce wear and prolong the life for engine parts that require the fuel as a lubricant, such as fuel injectors. Biodiesel also burns cleaner; tests have shown a reduction in unburned hydrocarbons, carbon monoxide and sulfur emissions, but a very slight increase in nitrogen oxides. The flash point of biodiesel, the temperature at which the vapors above the fuel become flammable, is about 100^{o} C higher than that of diesel fuel. The higher flashpoint makes biodiesel safer to handle and transport. A negative attribute of biodiesel is its high cloud point. The cloud point is the temperature when a liquid starts to thicken and gel, this makes it difficult to use in a regular internal combustion engine (Advantages of using Biodiesel, 2008). In addition, biodiesel is also an effective solvent (Storing Biodiesel Fuels, 2007).

2.4 Collection

In the United States there is approximately 2.9 billion gallons of waste vegetable oil produced in one year (epa.gov). Most of this oil is produced by industrial deep fryers owned by potato chip and snack food companies. This waste oil is classified as a hazardous material by the DEP and therefore forces business owners to deal with not only the storage, but the disposal of this waste. The average cost for disposal of this waste is about 150 dollars/tonne which, when factored into the generation of waste per year, equals 16 billion dollars for waste disposal (http://www.mass.dep.gov/).

2.5 Storage

Containers are the most fundamental means of storing and transporting materials. Containers come in various shapes and sizes and can be manufactured out of a variety of different materials. These containers have a wide range of applications including the storage of materials both above and below ground. Due to the limited budget, it would be more cost effective to consider above ground storage, and to avoid the added costs of zoning and excavation for large underground tanks. Not only are smaller tanks cheaper, but they are also readily transportable and easily cleaned.

Biodiesel is registered with the Environmental Protection Agency and is classified as an alternative fuel or fuel additive (Engleman, 2002). Biodiesel is not considered a hazardous material by the Department of Transportation, and does not require special permits to transport (Engleman, 2002). Biodiesel and Diesel itself possess similar properties, which mean each must be stored in similar conditions. They must be stored away from sunlight, moisture, oxygen, as well as any extremes in temperature. Subjection to any of the above will lead to degradation in the fuel properties and could render them useless. One might think that in order to store biodiesel, special permits must be acquired. In fact, the majority of the regulations for storage of ordinary petroleum diesel fuel pertain to those of biodiesel as well. Recommended materials for storage include steel, fluorinated plastics, and high density polyethylene.

Methanol, on the other hand, is a Class 3 Flammable Material, and considered a hazardous material by the Environmental Protection Agency and OSHA. Methanol is volatile and will readily react, thus its Class 3 rating, and can only be transported in loads smaller than 755 gallons at a time. When being stored, the site must be inspected to ensure precautionary fire protection and ventilation systems are in place to meet safety codes. The inspector will also set a capacity as to how much methanol can be kept on site. Methanol must be stored in completely enclosed containers. It cannot be allowed to oxidize with the air or come into contact with an ignition source. Stainless steel, High Density Polyethylene, and vulcanized natural rubber are the recommended materials for storage of methanol as they show the greatest resistance to methanol's corrosive properties.

Metal is an ideal means of storage due to its ability to cancel out sunlight. Metal is also non-permeable so there will be no exchange of moisture or air when being stored for extended periods of time. If using a new drum, a drum with interior linings must be resistant to biodiesel's and methanols solvent properties. When using a used drum, knowledge of its previous application and contents is important as well, as biodiesel may react with any remnants. Any subsequent reactions with interior linings or remnants from previous usages leads to fuel degradation and may negatively affect whichever system the fuel is added to (Engleman, 2008). Metal containers are cost effective, they're cheap to manufacture and can be created in large quantities. The only drawback to metal containers is that they are considerably heavier than other storage devices.

Fluorinated and other high density plastics are also effective means of storing biodiesel. Plastics that have been fluorinated reduce the permeability of the container and also serve as a barrier against biodiesel's solvent nature. When it comes to high density plastics, they act very much like the fluorinated plastics in that they offer increased resistance to any reactivity with biodiesel. Plastics are much lighter than their metal counterparts, but have an increased manufacturing cost. The higher price of these containers is attributed to their slow production rate and required tooling. Despite the drawback of their higher price, plastics are recommended over metal containers due to their resistance to reaction with the numerous forms of Biofuels (Storing Biodiesel Fuels, 2007).

Figure 1: Small Storage tanks and pumps to move WVO, Hubbardston, MA

2.6 Transportation

Transportation is the means by which you deliver your materials to the required destination. When choosing a means of transportation with an integrated storage tank, all the above mentioned must be taken into consideration. Materials are transported everyday by rail, air, and ground. The only means of transportation that this operation will rely on is that of transportation by means of ground. While there are few regulations on the transportation of waste vegetable oil and biodiesel that is not the case with methanol. Only 755 gallons of methanol can be transported at a time. The vehicle containing methanol must display proper flammable tags and identification in accordance with the Department of Transportation.

Small pickup trucks are more mobile and more fuel efficient, but do not offer the load capacity that a larger oil truck could offer. Thus, multiple trips would have to be taken to collect all of your raw materials or dispose of your wastes. On the other hand large oil tankers have an increased payload capacity, which means ideally all of your waste vegetable oil can be collected in one single trip. Repairs for light duty pickup trucks are cheaper than that for larger trucks, but under constant load, one can expect more frequent visits to the local mechanic. Larger trucks are built to take punishment and while any repair would cost more than usual, one wouldn't expect to frequent the mechanic too often. Each option has its own advantages and disadvantages. The best choice for a vehicle would be a septic truck. Septic trucks do not sacrifice mobility for capacity. They remain efficient and at the same time can haul anywhere from 1, 000 – 4,000 gallons of material. Also the truck would be diesel so it can use the produced biodiesel.

2.7 Production of Biodiesel

2.7.1 Batch Process

There are several ways to produce biodiesel from WVO. The most widely used way is the batch process. The incoming oil must be filtered to remove any solids while the levels of free fatty acids and water are being monitored, too much of either can cause problems later in the production process. The catalyst, lye (NaOH), is mixed with the alcohol, methanol, then the alcohol/catalyst mix is charged into a closed reaction vessel. Then the oil is added. The system from here on is totally closed to the atmosphere to prevent the loss of alcohol through evaporation. The vessel is then heated to between 55^{o} – 70^{o} C in order to speed the reaction up. After 1 -8 hours of mixing/reacting the reacted liquid is separated, the heavier glycerin byproducts will sink, either by gravity or by centrifuge. After separation, the excess alcohol is distilled away or flash evaporated and recycled. The unused catalyst is recovered from the glycerin byproduct and is recycled (Blair, 2005). The glycerin is stored as it is a valuable commodity. Then the biodiesel is washed with warm water to remove any residual impurities. (See figure 1.)

Figure 2: Batch Process Components, Hubbardston, MA Site

Clockwise from top right: Methanol Recovery Tank, Filter for WVO,
Heat Source for Process, Mixing and Settling Tanks.

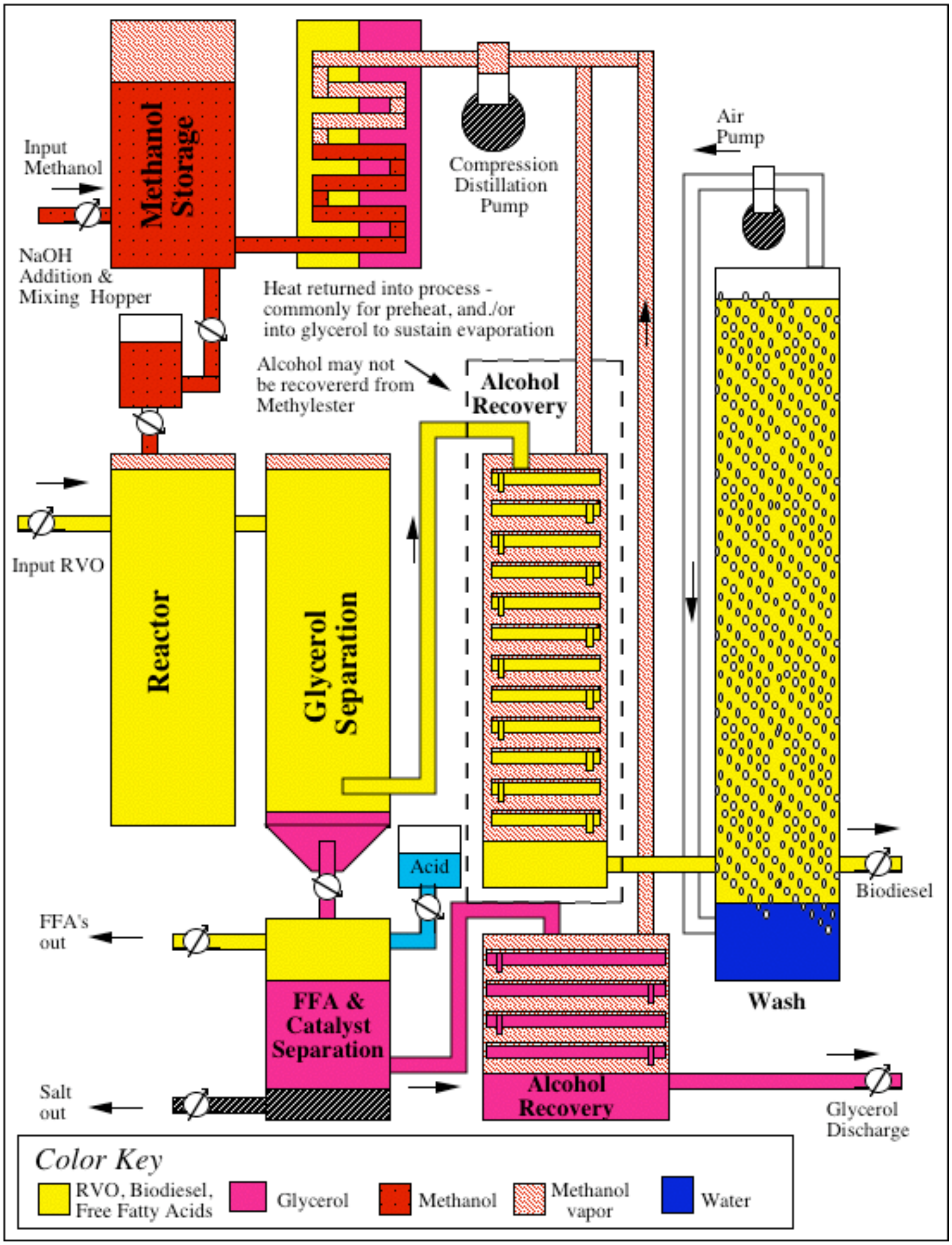

Figure 3: Schematic of a batch process. Courtesy of biofuelsservices.com

2.7.2 Ultrasonication

Ultrasonication is a newer way to produce biodiesel. The methanol and catalyst are pre-mixed like in the batch process; this mixture is combined with the oil. The mixture is usually heated to 50^{o} – $60^{o}C$, while being hit with ultrasonic sound waves. The sound waves cause a phenomenon called cavitation, where bubbles are randomly created and imploded with incredible frequency. These cavitations provide both enough mixing and the needed activation energy for the transesterification to take place in a much shorter time than the batch process. Then the reacted mixture is phase separated, washed and stored as before (Hielscher,). This process has several advantages: it is much more energy efficient than the batch process, it takes much less time to create an equivalent amount of biodiesel, and it is run as a continuous process (Gogate, Kelkar, Pandit, 2005). (See figure 2.)

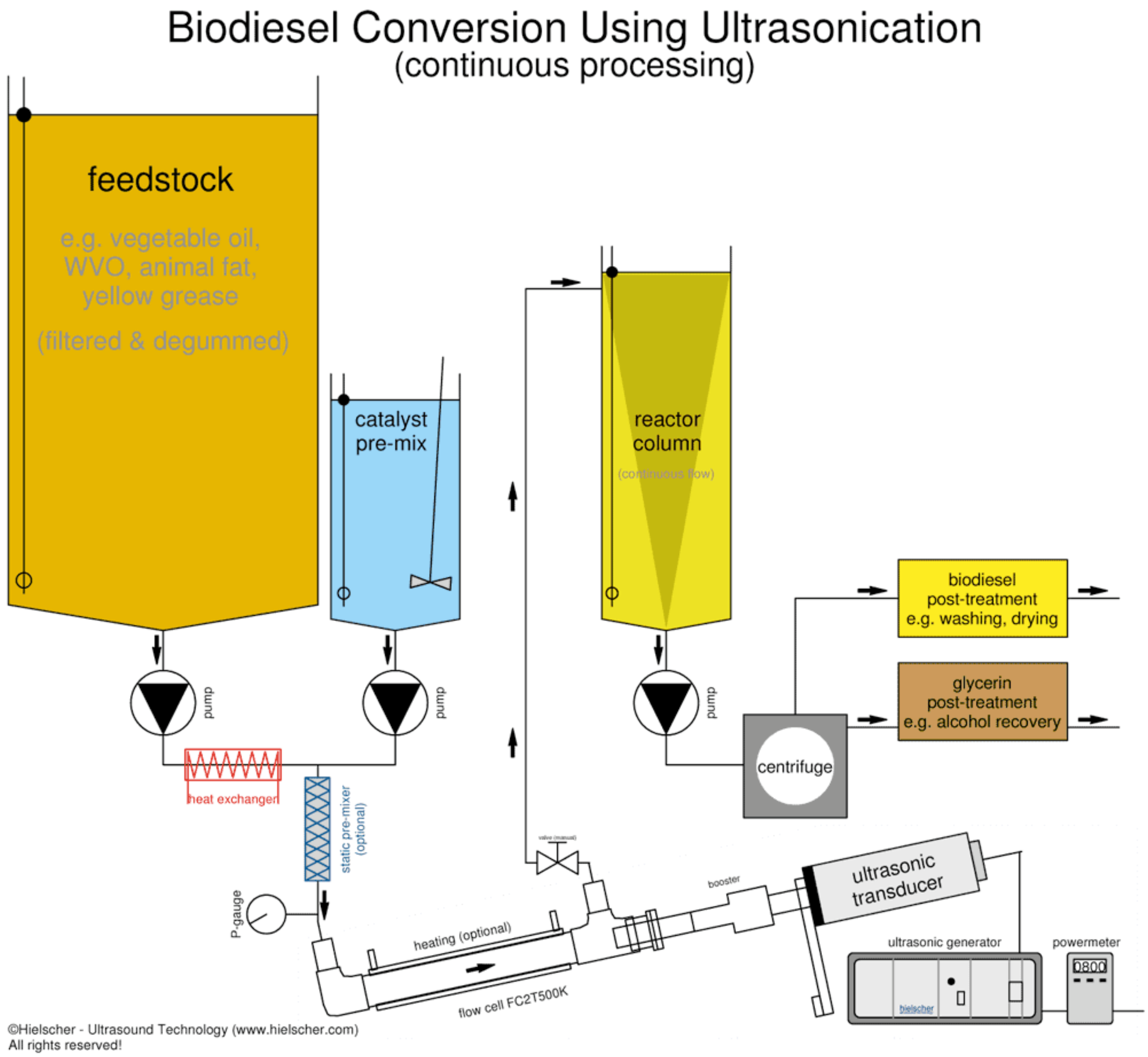

Figure 2: Schematic of an ultrasonic process. Heilscher Technologies.

2.7.3 Supercritical MeOH

One of the newest ways to produce biodiesel uses methanol in a supercritical state. A substance in a supercritical state is neither a liquid nor a gas, but still retains properties of both. In order to reach a supercritical state, the substance must be at a super high temperature and pressure. For methanol, it must be over 650^{o} F and 5000 psi. One of the main advantages is that this process is incredibly fast. It is able to react similar amounts of oil as the batch process in as little as 6 minutes. Another advantage to using supercritical methanol is that the reaction is completely spontaneous, meaning no catalyst is needed. The third advantage may be the greatest; this process is much more tolerable of excess water and free fatty acids in the feedstock. That means that it can accept and successfully react a much wider range of feedstocks as the quality doesn't need to be as high (Hegel, Mabe, Pereda, Brignole, 2007). There are negative attributes to this process. Start up costs would be huge as the equipment needs to be able to handle huge temperatures and pressures.

2.8 Safety

2.8.1 NFPA Safety rating system

Safety is a large concern when dealing with any type of process, especially chemical. The National Fire Prevention Association (NFPA) has a four color category rating system for all materials to be used in the production process. (See figure 3.) The four categories are health, fire, reactivity and specific hazards. Each category has its own number rating from 0 to 4 with 4 being the greatest risk. Health (blue) defines the risk if exposed to the substance for any period of time. Flammability (red) deals with the flashpoint of a material or under what circumstances the material will ignite. Reactivity (yellow) is the likelihood and conditions that a material will detonate or explode. Finally, the Special Hazard (white) category indicates special characteristics that a material may have, e.g. oxidizer, acid, biological hazard, etc.

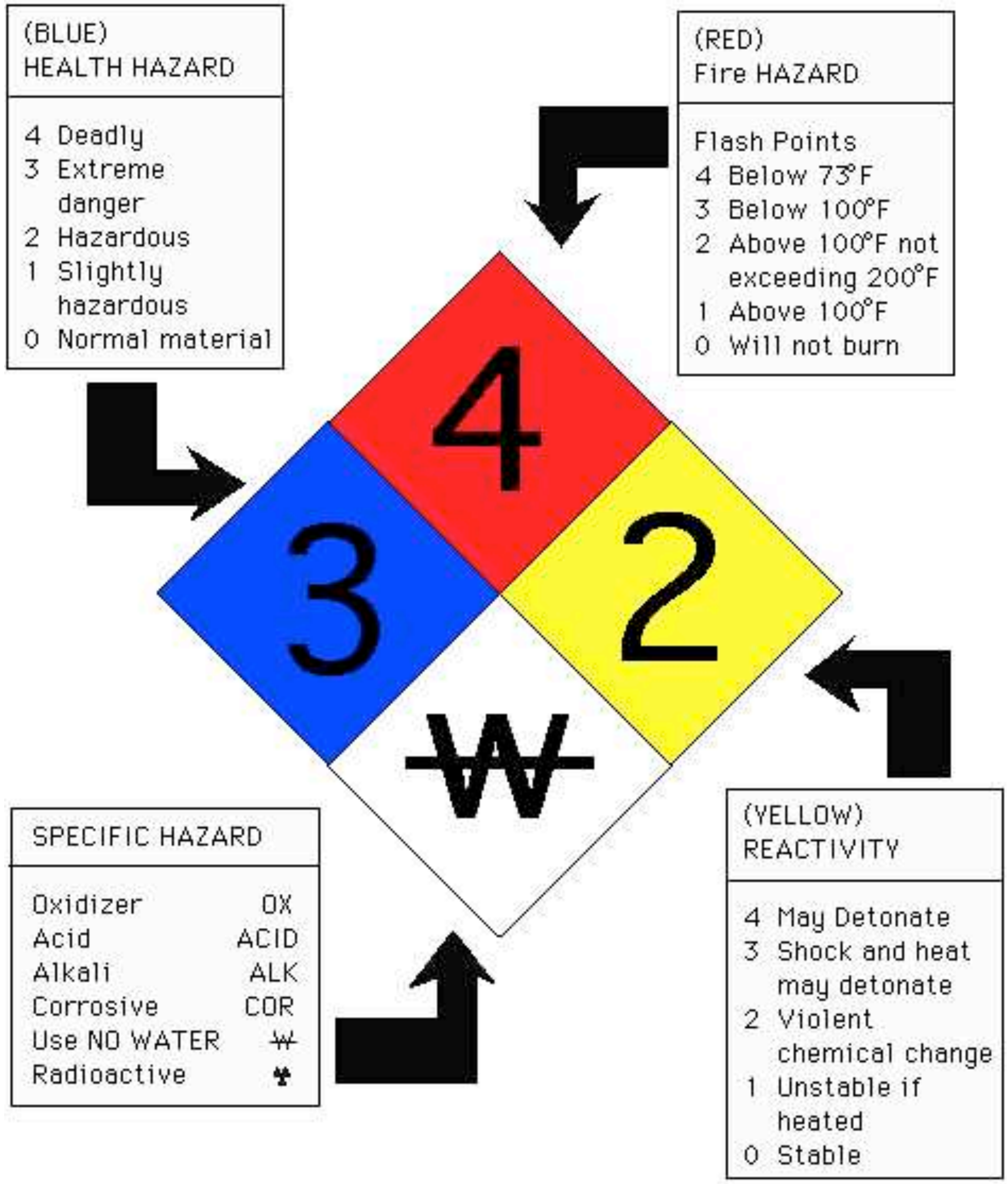

Figure 3: Example of a NFPA rating system

2.8.2 Rating of the Chemicals Used

The production processes by which biodiesel is produced requires certain chemicals and compounds that must be identified and acknowledged. These chemicals include methanol, waste vegetable oil, lye, phenolphthalein, isopropanol, glycerol, and the final product of biodiesel. Each substance has its own NFPA rating and its own handling requirements.

Methanol is a highly flammable substance necessary for the transesterification process. According to the NFPA "fire diamond", methanol is categorized as Health: 2, Flammability: 3 and Reactivity: 0. It is toxic if inhaled, digested or absorbed through the skin, as well as being highly flammable. Methanol should be stored in a cool dry place away from heat and sparks in tightly closed containers not made from aluminum or lead. When handling methanol an operator should wear chemical protective clothing (gloves and goggles) and if in poorly ventilated area, a self-contained breathing apparatus (SCBA).

Lye (NaOH) is a corrosive white solid that is the catalyst in the reaction. Its NFPA rating is Health: 3, Flammability: 0, and Reactivity: 1. Lye can cause severe burns to the eyes, skin, and respiratory tract as well as being harmful or fatal if inhaled or swallowed. Lye is not flammable but reacts with most metals and water. Lye is to be stored in a cool, well ventilated area in tightly closed non-metal containers. Protective clothing, gloves, and goggles are required when handling lye.

The raw waste vegetable oil is a clear light yellow oily liquid with a fatty odor. It has a Health 0, Flammability: 1, and Reactivity: 0 on the NFPA rating scale. Waste vegetable oil is non-toxic and has a very low flammability. It should be stored in a cool, dry, well ventilated place. Only gloves and goggles are suggested when handling this material.

Phenolphthalein is a clear, colorless liquid used as an acid/base indicator. It has a NFPA rating of Health: 2, Flammability: 1, and Reactivity: 0. Phenolphthalein may cause cancer due to overexposure and should be kept away from heat, sparks, flame, halogens and strong oxidizers. It should be stored in adequately ventilated areas and handled while wearing safety goggles and gloves.

Isoproanol is a colorless liquid with an alcohol odor and is used as an organic solvent in the titration process. Isopropanol has a NFPA rating of Health: 2, Flammability: 3, and Reactivity: 0. It is a highly flammable liquid and is a severe eye irritant. Gloves and goggles should be worn when handling isopropanol.

Glycerol, the by-product of the biodiesel process, is a clear and odorless oily liquid. The safety rating of glycerol is Health: 2, Flammability: 1, and Reactivity: 0. Glycerol has a low flammability and toxicity, it is a mild irritant to the skin and eyes, and if ingested can cause damage to the kidneys. It should be stored in a cool, well ventilated place and protected against physical damage. Gloves and goggles should be worn when handling Glycerol.

The final product, Biodiesel, is a light green or yellow liquid with a mild fuel odor. Biodiesel is a flammable material that should be kept away from heat, flames, static electricity, and strong oxidizers. Goggles, gloves and/or face shield should be worn when handling biodiesel.

Understanding what is necessary for handling these materials is important when setting up a successful process. When handling these materials every worker needs to have access to protective goggles and gloves. The areas where the chemicals are stored and the area in which the process occurs need to be properly ventilated to prevent fire and respiratory hazards. Eye wash stations, emergency showers, and fire extinguishers need to be accessible to employees at all times.

3.0 Methodology

The goal of this project was to design and build a functioning biodiesel plant for EPOCA. In order to attain this goal, we needed to first research available technologies for transforming waste vegetable oil into beneficial biodiesel. Given this knowledge, we then had to determine a vital set of criteria that must be kept in mind during the project. Given these criteria and the available technologies, we then had to determine which method of biodiesel production would benefit EPOCA the best. Our next task would be to compile all research and information and present them to EPOCA so as to make our proposal. The following presents our methodology for accomplishing these objectives.

3.1 Determine Criteria

To determine how to approach the problem of setting up a manufacturing process for biodiesel, weekly meetings were held with EPOCA. Representatives from EPOCA, specifically those involved with the project group Empower, met once a week with both the marketing and production teams from WPI. The Empower group consisted of Juan Otero (Manufacturing head), Sarah Assefa (Treasurer), as well as other assistants and volunteers, most notably Lonnie. Meetings ran in a semi-formal fashion, EPOCA would give status reports on what they have been working on the past week, budget, and goals they had for the future; then the marketing and production teams gave their reports. After reports, both WPI teams would ask EPOCA pre-prepared questions that came up during their week's work, focusing on criteria, and what they wanted each team to accomplish for the next meeting.

3.2 Determine an Optimal System

In order to determine just how the batch process works, the system dynamics, vital components, as well as learning more about biodiesel, we needed to contact various people and organizations. By viewing other people's systems first hand, we can use them as a template and add or subtract wherever we see fit. One of the first people we were put in contact with was Steve, of Steve's Auto body located on Chandler Street in Worcester. There we learned the cost of converting diesel vehicles to run on biodiesel. Steve then showed us his Ford truck which he converted, started it up, and was running it on filtered waste vegetable oil. Another beneficial contact was Bruce Fiene. He showed us how to refine WVO. He told us that filtered WVO can be blended with regular gasoline and be run in a diesel engine. He runs a 95-5 percent mixture of WVO to gas in the summer and an 85-15 percent mixture in the winter to prevent the oil from thickening. Unfortunately we were unable to make contact with what would have proved to be two very important sources: “Ready, Willing, and Able,” and “Wachusett Biomass.” Ready, Willing, and Able is an organization very much like EPOCA. They employ ex-prisoners and the homeless to run their own biodiesel production process. Their experience would have proved beneficial and would have helped EPOCA with any questions or solve common problems. Wachusett Biomass is a local company that collects oil and produces biodiesel. It would have been helpful to have been able to see a fully functioning biodiesel plant and document their system as a template. A big break came when EPOCA learned of a building complex in Hubbardston, Massachusetts that had a biodiesel system on site. We made arrangements and one afternoon, members of our group and EPOCA drove out to Hubbardston and viewed the system. We took pictures and noted the setup and used this as the basis for the system which we built for EPOCA.

EPOCA’s main concern is what system they’ll be able to afford with their allotted budget. An outline of the various biodiesel production systems available was created. The outline categorized each individual process into 3 different price ranges. The price ranges were determined by using the average cost of the system and sustainability, as supplied by Internet biodiesel production system manufacturers. Internet research was done to reverse engineer each process in order to make a detailed parts list of each system. Individual prices of the main components of each system were found through Internet biodiesel production system manufacturers to present to EPOCA the cost benefits of purchasing each component separately and building a custom-made biodiesel system.

3.3 Make Presentation to EPOCA

After the cost and benefit data was collected, it was organized and presented to EPOCA. The data was presented to EPOCA at one of the weekly meetings with Sarah, Juan and others from EPOCA as well as the production and marketing teams. A spreadsheet outlining the information to asses and analyze our data was presented to the EPOCA team.

Each of the different processes was described in detail, from the actual science behind it to what each part in the process did. The pros and cons of the different methods were weighed carefully against each other; criteria like energy efficiency, personnel needs and training, product quality, final yield, etc. Much time was spent on this discussion as it would be a major factor when selecting the final method of production.

4.0 Analysis

4.1 Explanation of rating system used

The next task, as well as the most important, was to determine the optimal system for EPOCA. First, all possible criteria had to be considered. These criteria are as follows: efficiency, upgradability, personnel requirements, safety, and cost effectiveness. In order to analyze these, a "quality cube" was created to give a value to each criterion, for each of the three methods of biodiesel production. Each value was given either a numerical value on a scale from 1 to 5.

One of EPOCA's main concerns for its pilot project is efficiency. EPOCA needs a system that is time efficient and will produce biodiesel at maximum capacity. To maximize productivity, EPOCA would need a system to minimize the time it takes to react, settle, and wash their biodiesel. First let us consider production capacity. Capacity was determined by the total time it takes to produce a single batch of biodiesel. A value of 1 means that it takes greater than 8 hours to yield a product, and a value of 5 means that it takes less than or equal to 1 hour for a yield. Also contained under efficiency is Yield. Yield is the percentage of material that can be recovered from the process. More specifically, how much product is created and how much of the raw materials, such as methanol, can be recycled. Yield was ranked from 80% efficiency to 100% efficiency with increments of 5%. To determine a final value for efficiency, the average of these two values was taken.

Upgradability is important so EPOCA's system can expand along with their customer base. Parts need to be chosen in such a way that they can easily be swapped out or added on in place of parts with greater quality that can increase capacity and efficiency. Upgradability was given a qualitative rank. This rank ranged from 1, not being able to accept upgrades at all, to 5, where all parts have the potential to be upgraded.

Understanding that training is neither cost nor time effective, EPOCA wants their pilot plant to be as easy to operate as possible. Workload/ Stress load is considered when designing a processing plant. Ideally, the system steps would be linear; meaning that the next step is located next to the previous. Workload was also given a qualitative set of values. A value of 5 indicates that no human interaction is needed for the process, meaning that the system is completely autonomous, and a value of 1 indicates that the human workload is extremely intense and demanding, meaning workers need to be present in every stage of the process. Also under personnel requirements is complexity of parts. The system cannot be overly complex. Arrays of buttons, lights, and switches are not what EPOCA is looking for. The same qualitative ranking system that is used for workload is also used for complexity of parts. A value of 5 means that parts are not complex and are easy to replace and a value of 1 means that parts are overly complex and complete knowledge of the system is critical. To attain a final value for Personnel Requirements, the average of the two categories was taken.

This project is attempting to help expand green jobs. If the system were not safe for both the environment and its workers, then it defeats the purpose. The ideal system would be one that produces as little waste as possible, waste that would hurt the environment, as well as be a safe environment for its workers, free of toxic fumes and contact with harsh chemicals. Safety was determined by the protective equipment that must be worn. A number 5 denotes the basic safety equipment like goggles and gloves. The number 1 denotes safety equipment such as HAZMAT suits and self-contained breathing apparatus'.

The final criterion, as well as the limiting one, was that of cost. Cost encompasses three sub-categories: Startup Cost, Production/Operating Cost, and Maintenance Cost. Startup cost denotes the money expected to pay for all components that make up the system as well as any legal fees, permits, or licensing needed to begin the operation. Production/Operating cost is the expected cost of raw materials, energy consumption, and insurance and legal fees that are required to keep the system running from year to year. Maintenance cost is the expected cost of all replacement parts that may be needed to maintain and sustain operations throughout the year. A numerical ranking system was used for these three systems. A rank of 5 denoted that the expected cost would be less than $5,000 and a rank of 1 meant that the expected cost would be greater than $25,000. To determine the final value placed on cost, the average of these three categories was taken.

4.2 Batch Process

The batch process is the most widely known biodiesel conversion process because a rudimentary system is relatively inexpensive, and easy to operate. This makes the batch process ideal for the people who only wish to produce enough fuel for their own use. However, the versatility of the "batch process" easily allows for a production increase, making it the perfect biodiesel conversion process for small companies like EMPOWER.

4.2.1 Cost – Avg. Score: 5

The main benefit of the batch system is the extremely low start-up cost compared to other, more complex systems. A pilot plant consisting of 3 tanks, 2 pumps and the respective hoses and fittings can cost well under $2000. Larger tanks and more powerful pumps can be used to increase the production capacity while still keeping the price well under $5000.

Production costs are also more inexpensive than other biodiesel systems. Prices for legal permits and insurance are the same or lower than other processes that require higher temperatures and/or pressures. Raw material prices are generally fixed, but companies usually give a discount when buying in large quantities. This is beneficial to EMPOWER because the production costs associated with raw materials will actually decrease as more biodiesel is being produced.

Maintenance for the batch system is minimal. It requires replacing parts that malfunction, which are inexpensive to purchase and replace.

4.2.2 Upgradability – Avg. Score: 5

Another main benefit of the batch process is the high upgradability of the system. Upgrading the system to increase the production capacity is as simple as increasing the tank size and/or adding more tanks. However, as more and more tanks are added, space does become a concern.

4.2.3 Efficiency – Avg. Score: 3

A downside of the batch process is the low efficiency compared to other, more expensive systems. One can expect efficiency between 85% and 90% for the typical batch process. A methanol recovery system can also be implemented to recover almost 85% of the methanol used in the process.

4.2.4 Personnel Requirements – Avg. Score: 2

Because of the volatility of the chemicals used and the temperature required for transesterification, personnel must be present at all times. An employee is expected to use the pumps to transfer the WVO/Biodiesel between tanks, add specific amount of chemicals, and control the temperature of the heating element. Training for personnel is relatively straightforward, as most of the work being done is simple. Personal responsibility is more essential to the job than any unique skill set.

Table 2 : Batch Process Rating Chart

COST				Avg. Value:	5		Efficiency			Avg. Value:	3		
1 >$25,000	2≤$20,000	3≤$15,000	4≤$10,000	5<$5000			1<80%	2≤85%	3≤90%	4≤95%	5≤100%		
Startup Cost:	Denotes the money expected to pay for components an all other materials needed to start process						Yield:	It is the percentage of materials we can recover from the process					
				Value:	5					Value	2		
							1 > 8hours	2>6hours	3>4hours	4>2hours	5 ≤ 1 hour		
Production/ Operating Cost:			Expected costs of raw materials and energy use				Time/ Capacity:	It is the time it takes to produce a single batch of biodiesel					
				Value:	5					Value:	4		
Maintainance Cost:			Expected cost of replacement parts				Personel Requirements					Avg. Value	2
									1=very	2=strong	3=somewhat	4= little	5=none
				Value:	5		Workload/ Stress Load:		The work and stress levels a worker will encounter during a single day of work				
Safety				Value:	5								
1=HAZMAT, breathing aid	2=Suits, faceshield etc	3=Suits etc	4=Aprons, gloves, goggles	5=Gloves, goggles								Value:	2
UPGRADEABILITY			Value: 5				Complexity of Parts:		How easy is it to replace parts? Can repairs be done in-house?				
1=Not at all	2=Min.	3=Partially	4=Majority	5=Totally									
												Value:	2

4.3 Continuous Batch Process

The second process that we analyzed was the continuous batch process (CBP). This process is very similar to the batch process, but has a few major differences. These differences include a methanol recovery system and more tanks for mixing and settling. When this system was put into the quality qube it scored an average value of 3.5.

4.3.1 Cost – Avg. Score: 3.5

The first thing analyzed in this process was the cost. The CBP scored a 3 for start-up cost. Though no single part of the process is overly expensive, purchasing the quantity of tanks to set-up a proper process can get costly. The next things to consider in the cost category are production/operating costs as well as maintenance cost, on which the CBP scored a 4. Although the start-up costs are higher in this process, the cost of operation is rather low. The methanol recovery system featured in this process will save on the purchase of raw methanol and therefore lower production. Maintenance costs are low due to the simplicity of the system and with most of the parts available at any local hardware store.

The next Criterion to be considered was safety. Using the quality cube, the safety of this system was given a value of 3. A value of 3 indicates that while this process is safe, proper ventilation and some protective equipment is required. The process uses corrosive materials; therefore protective gloves and possibly a face shield are required at some point during the process. Also, with the number of tanks being used in the CBP, proper ventilation is necessary for operation and the safety of the operator.

4.3.2 Upgradability – Avg. Score: 5

Third, the upgradability of the process was evaluated. The CBP had a very high upgradability, scoring a 5 on the scale. The CBP scored a 5 on this scale because every aspect of the system can be upgraded, since it is basically an upgraded batch process. More settling and mixing tanks can be added to increase the output of the system. Parts such as the mixing components, pipes, pumps, and filters can all be upgraded at any time when convenient to increase productivity.

4.3.3 Efficiency – Avg. Score: 3

Efficiency was the fourth criteria looked at when analyzing the process. The efficiency was split into two sub-categories; yield and time/capacity. For yield, the CBP scored a 2 which means that the process overall has a percent yield of around 85%. For the CBP, evaluation of time/capacity is complex which is why it was given a 3. This criterion is dependent on the number of tanks in the process. The time for a single batch will be equal to that of the regular batch process; however when multiple batches are in process much more can be produced than the original process in a day.

4.3.4 Personnel Requirements – Avg. Score: 2.5

The final criterion was the personnel requirements of the process. This category includes the workload stress on the operator and the complexity of the system and its parts. In the sub-category of workload stress the CBP had a value of 2. The CBP has a value of 2 because an operator will be in charge of run and checking on multiple tanks at a time. To keep up with process, the operator will need to be able to effectively transfer multiple batches at a time and orchestrate them in the proper sequence. A complexity value of 3 was given due to the simplicity of the system and its parts. This process does not require any prior knowledge of the system to operate and mostly involves the opening and closing of valves. Only simple process training would be required to educate one to effectively run the process.

Table 2: Continuous Batch Process Rating Chart

COST				Avg. Value:	3.5		**Efficiency**			Avg. Value:	3		
1 >$25,000	2≤$20,000	3≤$15,000	4≤$10,000	5<$5000			1<80%	2≤85%	3≤90%	4≤95%	5≤100%		
Startup Cost:	Denotes the money expected to pay for components an all other materials needed to start process						Yield:	It is the percentage of materials we can recover from the process					
				Value:	3					Value	2		
							1 > 8hours	2>6hours	3>4hours	4>2hours	5 ≤ 1 hour		
Production/ Operating Cost:			Expected costs of raw materials and energy use				Time/ Capacity:	It is the time it takes to produce a single batch of biodiesel					
				Value:	4					Value:	4		
Maintainance Cost:			Expected cost of replacement parts				**Personel Requirements**					Avg. Value	2.5
									1=very	2=strong	3=somewhat	4= little	5=none
				Value:	3		Workload/ Stress Load:		The work and stress levels a worker will encounter during a single day of work				
Safety				Value:	3								
1=HAZMAT, breathing aid	2=Suits, faceshield etc	3=Suits etc	4=Aprons, gloves, goggles	5=Gloves, goggles								Value:	2
UPGRADEABILITY			Value: 5				Complexity of Parts:		How easy is it to replace parts? Can repairs be done in-house?				
1=Not at all	2=Min.	3=Partially	4=Majority	5=Totally									
												Value:	3

4.4 Ultrasonication

4.4.1 Cost – Avg. score: 2

Ultrasonication is a very effective process for the production of biodiesel using sound waves to drive the reaction. Start up costs for an ultrasonic setup can be very large, as much as one hundred thousand dollars. That is why this process received a 1 for the score of start up costs. A combination of lots of expensive mechanical and electrical equipment drives the cost up.

The operating cost to run an ultrasonic process is much smaller than one would think at first. While being a very complicated process with lots of complex machinery, it is very energy efficient and the process requires very little from the outside. The ultrasonic process receives a better score for the operating costs, 4

Maintenance on an ultrasonic operation could be very great. There is a lot of complex equipment running at high temperatures and pressures that would require a certified technician to repair. Other processes that have more simple components require only basic skills to repair. Ultrasonication receives a 2 for the cost of maintenance.

4.4.2 Upgradability – Avg. Score: 1

The ultrasonic process is difficult to upgrade. Once the process is set in place it would need to be disassembled and put back together with new part and components. Some of the more important parts such as the ultrasonic transducer could be used for a greater capacity, if it was capable.

4.4.3 Efficiency – Avg. Score: 5

Ultrasonication, while being expensive, is very efficient. The percent yields from the process are often greater than 98%. Ultrasonication is also capable of accepting a greater variety of raw materials, meaning the WVO does not have to be filtered as extensively. This makes the process more efficient from start to finish. This process gets a 5 for yield.

The ultrasonic process is much faster and more energy efficient than most other processes available today. Due to the unique method of driving the transesterification process, ultrasonication uses half the energy of the average batch process. It is also much faster, the process can produce the same amount of biodiesel product in less than a quarter of the time. It gets a 5 for the time/capacity rating.

4.4.4 Personnel requirements – Avg. score: 2

The Stress level for the employees in an ultrasonic plant would be much lower than in other production plants. The system is mostly automated and does not require a major input from the operators. The overall stress level of the ultrasonic process would be a 2.

The complexity of the ultrasonic process would be much larger than most other processes. The employee would be required to know the process well, both the parts and the computers involved with the process. Unfortunately the ultrasonic equipment would probably not be able to repair in house, outside technicians would be required.

Table 3: Ultrasonication Rating Chart

COST				Avg. Value:	3.5		**Efficiency**			Avg. Value:	5		
1 >$25,000	2≤$20,000	3≤$15,000	4≤$10,000	5<$5000			1<80%	2≤85%	3≤90%	4≤95%	5≤100%		
Startup Cost:	Denotes the money expected to pay for components an all other materials needed to start process						Yield:	It is the percentage of materials we can recover from the process					
				Value:	1					Value	5		
							1 > 8hours	2>6hours	3>4hours	4>2hours	5 ≤ 1 hour		
Production/ Operating Cost:			Expected costs of raw materials and energy use				Time/ Capacity:	It is the time it takes to produce a single batch of biodiesel					
				Value:	4					Value:	5		
Maintainance Cost:			Expected cost of replacement parts				**Personel Requirements**					Avg. Value	2
									1=very	2=strong	3=somewhat	4= little	5=none
				Value:	2		Workload/ Stress Load:		The work and stress levels a worker will encounter during a single day of work				
Safety				Value:	5								
1=HAZMAT, breathing aid	2=Suits, faceshield etc	3=Suits etc	4=Aprons, gloves, goggles	5=Gloves, goggles								Value:	2
UPGRADEABILITY			Value: 1				Complexity of Parts:		How easy is it to replace parts? Can repairs be done in-house?				
1=Not at all	2=Min.	3=Partially	4=Majority	5=Totally									
												Value:	2

5.0 Conclusions and Recommendations

The goal of this project was to select an appropriate biodiesel production process for EPOCA. EPOCA is a cooperative business which employs prisoners and ex-prisoners who would normally not be able to find work. EPOCA, specifically their focus group Empower, is seeking to create new green jobs for its employees and produce a competitive product for sale in the fuel market.

To determine what type of system would be best for EPOCA, they had certain criteria for their selected process. These criteria included the efficiency and upgradability of the system, personnel and training requirements, safety, and cost effectiveness. The criterion set by EPOCA were categorized and then sub-categorized and put into an analysis matrix to evaluate each production process. Each criterion was rated from 1 to 5 with 5 being the best possible on the scale. In all, three processes for producing biodiesel were analyzed; the batch process, continuous batch process, and ultrasonication.

When each process was put through the analysis matrix, the continuous batch process is the recommended process to produce biodiesel for EPOCA. The CBP scored on average a 3.5 when put into the analysis matrix. It particularly excelled in the areas of cost flexibility and upgradability. The CBP, being essentially an upgraded batch process, is able to have low preliminary costs, which are mainly dependent on the number and size of tanks used for the process allowing it to be configured to any budget. Also, to increase productivity, all components are able to be upgraded as funds become available.

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Appendix

ITEM	Quantity	Cost	Total	Sales Tax	Supplier Info
Methoxide Container Parts					
100 Gallor	1	$0.00	$0.00	$ -	U.S. Plastics, Graduated tank
Stand for	1		$0.00	$ -	
Pnematic	1		$0.00	$ -	Grainger
Propeller	1		$0.00	$ -	
Feed Stock Tank					
420 Gallor	1		$0.00	$ -	
Heating El	2	$18.99	$37.98	$ 1.90	240V Heating Element - BiodieselPlanet.net
Heating El	2	$14.99	$29.98	$ 1.50	240V Heating Element Thermostat - BiodieselPlanet.com
Thermoco	1	$17.65	$17.65	$ 0.88	Grainger TCP 10220
Reactor Tank Parts				$ -	
500 gallon	1		$0.00	$ -	
3hp chemical mixer 240V			$0.00	$ -	High velocity, adjustable
Heating El	2	$18.99	$37.98	$ 1.90	240V Heating Element - BiodieselPlanet.net
Heating El	2	$14.99	$29.98	$ 1.50	240V Heating Element Thermostat - BiodieselPlanet.com
Thermoco	2	$17.65	$35.30	$ 1.77	Grainger TCP 10220
Methanol Recovery				$ -	
Condenser			$0.00	$ -	
Water Tank			$0.00	$ -	
Pump			$0.00	$ -	
Heat Exchanger			$0.00	$ -	
Thermoco	2	$17.65	$35.30	$ 1.77	Grainger TCP 10220
Settling / Wash Tank Parts					
250 Gallor	2	$326.25	$652.50	$ 32.63	U.S. Plastics, discount with increase in quantity
Stand for	2		$0.00	$ -	
Chemical	1		$0.00	$ -	Low velocity
Mist Spray	2		$0.00	$ -	
Vent			$0.00	$ -	
Water Sof	1			$ -	
Water Heater 120 - 140 degrees				$ -	
				$ -	
Drying Tank				$ -	
500 gallon Drying tank, Conical			$0.00	$ -	
Heating El	2	$18.99	$37.98	$ 1.90	240V Heating Element - BiodieselPlanet.net
Heating El	2	$14.99	$29.98	$ 1.50	240V Heating Element Thermostat - BiodieselPlanet.com
Thermoco	3	$17.65	$52.95	$ 2.65	Grainger TCP 10220
General Plumbing Items				$ -	
90 degree	0	$0.00	$0.00	$ -	
45 degree 1" elbows			$0.00	$ -	
Steel Pipe (linear feet)			$0.00	$ -	
4 Way Fitting 1"			$0.00	$ -	
Tee 1"			$0.00	$ -	
Universal joints 1"			$0.00	$ -	
Polyethylene Tubing 1" I.D.(lin			$0.00	$ -	
2" HDPE Drum Adaptors			$0.00	$ -	
Pressure (	2		$0.00	$ -	
Female Nipple			$0.00	$ -	
Ball Valves 1"			$0.00	$ -	
Thermost	1		$0.00	$ -	
Relief Valve Coil			$0.00	$ -	
Male Nipple			$0.00	$ -	
male/male fitting			$0.00	$ -	
Hose Clamps			$0.00	$ -	
Water Hose			$0.00	$ -	
Viton Pipe Tape			$0.00	$ -	
Temperature Gauges			$0.00	$ -	

Pumps				$ -	
Transfer P	2	$384.89	$ 769.78	$ 38.49	Part #: 95025 5-MD-HC 1/8 HP, 115 Volt, Open Motor Little Giant® Seal-Less Magnetic Drive Pump 17.5 GPM
Transfer P	1	$215.53	$ 215.53	$ 10.78	Part#: 2-MD-HC 1/30 HP, 115 Volt, Open Motor Little Giant® Seal-Less Magnetic Drive Pump
Methanol	1	$ -	$ -	$ -	side winder pumps
Rotary Ha	2	$ 69.57	$ 139.14	$ 6.96	usplastic.com
Fuel Pump (finished product)				$ -	
				$ -	
Filtration				$ -	
Remote M	1	$ 104.99	$104.99	$ 5.25	jcwhitney.com
100 Micro	1	$ 41.58	$41.58	$ 2.08	builder depot
50 Micron	1	$ 19.00	$19.00	$ 0.95	bizrate.com
5 Micron F	1	$ 20.00	$20.00	$ 1.00	Ingramswaterandair.com
			$0.00	$ -	
			$0.00	$ -	
			$0.00	$ -	
Titration Equipment			$0.00	$ -	
500 ml Be	2	$10.00	$20.00	$ 1.00	HDPE Beakers
Paper Tow	4		$0.00	$ -	
Hydromet	1	$12.00	$12.00	$ 0.60	Sciencekit.com
Scale (sen	1	$182.00	$182.00	$ 9.10	Affordablescales.com
Petri dish	1	$90.00	$90.00	$ 4.50	Science Gear (case of 500)
1500 ml B	2	$20.00	$40.00	$ 2.00	
20 ml Bea	1	$10.00	$10.00	$ 0.50	
Graduated	2		$0.00	$ -	
Litmus Pa	1	$2.00	$2.00	$ 0.10	
Scientific	1	$20.00	$20.00	$ 1.00	Texas Intruments
			$0.00	$ -	
Tools			$0.00	$ -	
Slip Joint	1		$0.00	$ -	
5 Gallon C	20	$6.73	$134.60	$ 6.73	
Tubing Cu	1		$0.00	$ -	
Pipe Wren	2		$0.00	$ -	
Large Adju	1		$0.00	$ -	
Soap Ston	2		$0.00	$ -	
Measuring	1		$0.00	$ -	
Funnel	1	$28.68	$28.68	$ 1.43	919mL Nalgene Buckner Funnel - U.S. Plastics
			$0.00	$ -	
Chemicals			$0.00	$ -	
Methanol	1	$150.00	$150.00	$ 7.50	55 gallon drum, itsmc.com
Distilled V	2		$0.00	$ -	
Sodium H	1	$2.00	$2.00	$ 0.10	$2/lb, $1.50/lb for order over 100lbs; aaachemicals.com
Isopropyl	1	$20.00	$20.00	$ 1.00	$20/gal, $600 for 55 gallon; cqconcepts.com
Flow Improving Additive			$0.00	$ -	
Cutting Oil			$0.00	$ -	
			$0.00	$ -	
			$0.00	$ -	
			$0.00	$ -	
Personal Protective Equipment			$0.00	$ -	
High Corrosive Resistant Glove			$0.00	$ -	
Full Face Shield			$0.00	$ -	
Safety Gla	3		$0.00	$ -	
Safety Go	3	$10.00	$30.00	$ 1.50	
High Corr	2		$0.00	$ -	
			$0.00	$ -	
			$0.00	$ -	
			$0.00	$ -	
Miscellaneous Supplies			$0.00	$ -	
Masking T	1		$0.00	$ -	
Assorted	10	$0.50	$5.00	$ 0.25	

100 Gallor	3		$0.00	$ -								
55 Gallon	3		$0.00	$ -								
			$0.00	$ -								
			$0.00	$ -								
			$0.00	$ -								
Tool Rentals			$0.00	$ -								
Welding Equipment			$0.00	$ -								
Pipe Threader			$0.00	$ -								
			Sub Total	**Sales Tax**							**Grand Total**	
			$3,053.88	$152.69		3206.57						$3,206.57