A Sustainable Waste Oil Solution

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***Abstract* – The growing concern for the environment and human quality of life by the government and special interest groups is urging industrial organizations to implement sustainable practices. A cracker manufacturing process produces a consistent volume of waste oil per unit time. A senior project team analyzed the waste oil for potential uses and determined biodiesel to be the most beneficial solution for the waste oil. Tests were conducted to establish that the waste oil can be converted to ASTM D6751 standard biodiesel; therefore, the oil can be blended to offset the organization's diesel fuel demand. A bench-scale proof-of-concept biodiesel processing system was designed and constructed. The design is highly automated to meet the industry sponsor's food and human safety specifications. A business case for full-scale implementation of the system was conducted for social acceptability, environmental responsibility, and economic profitability.**

Index Terms – Biodiesel, biofuel, capstone design, green manufacturing, sustainability

SITUATIONAL BACKGROUND

The sustainability effort is attempting to resolve many interrelated issues. In order for it to succeed, a culture of sustainability must be achieved. This culture will require education on the need for sustainability, applied research on potential solutions, the implementation of sustainable practices in industry, and government involvement through policy and funding programs. This paper discusses a capstone design project that responded to the growing awareness by both industry and education of the need to support sustainable solutions. The following discussion will address the trends which identify the current U.S. culture, the need for sustainability, sustainable engineering, the government's role, and a framework for a cultural shift.

I. Current U.S. Trends

According to the U.S. Energy Information Administration (EIA), the U.S. energy consumption portfolio for 2008 consisted of 84.02% fossil fuels, 8.50% nuclear electric generation, and 7.73% renewable energy [1]. Figure 1 displays the U.S. energy portfolio from 1988 to 2008. Based on the 1988 to 2008 consumption records, the U.S. energy demand has increased by 20.1%. During this time period, renewable energy has increased from 6.73% to 7.37% of the total energy consumption mix, representing a 9.5% increase in the renewable portion of the energy demand.

The U.S. population has grown by 25.9% over the same twenty years [2]. Total energy demand and the population are growing at a rate faster than renewable energy production and consumption are increasing. It is safe to say that the U.S. economy and standard of life have become increasingly dependent on fossil fuels since 1988.

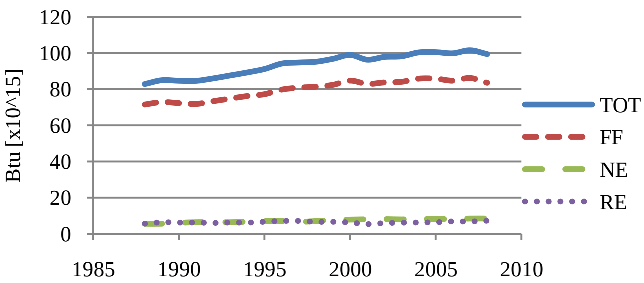

FIGURE 1
U.S. ENERGY CONSUMPTION BY SOURCE [Btu x 10^{15}][1]

**TOT=Total, FF=Fossil Fuels, NE=Nuclear Electric, RE=Renewable Energy*

Since the introduction of the internal combustion engine (ICE), we have changed the fashion in which we travel, choose residences, entertain, and perform work, all in ways that consume more energy [3]. Therefore, the carbon footprint per person is growing. With population growth comes urban sprawl which is blurring the boundary between rural and urban & sub-urban areas [4]. Social issues such as odor from farming and land fill operations are on the rise.

II. Need for Sustainability

The interconnection between the growing population, industrialization of developing countries, agricultural commodity shortages, urban sprawl, landfill locations, global warming, and recent fuel price fluctuations have sparked concern that the human race may not be able to sustain the rate of growth, development, and standards of living currently experienced. A concern is that limited resources will eventually extinguish, causing the standard of living and quality of life to diminish. Military defense depends heavily upon high density fuel sources such as petroleum fuel. A threat to a nation's standard of living and military capacity can lead to political instability. Another concern is that the byproducts from our existence (trash and fossil carbon sources) will saturate our capacity to handle them. Trash will lead to sanitation issues while atmospheric carbon dioxide content is the source of the global warming debate. Sustainable engineering and practices are the potential solutions to these concerns.

III. Sustainable Engineering

Sustainable engineering expands on the traditional three 'R's: reduce, recycle, and reuse. The *reduce* tenant emphasizes being conscious of how much resource is needed for a given activity and to not over consume. The *recycle* tenant focuses on the collection of materials which can be re-fabricated into useful products so that they are not lost to landfills. *Reuse* is the idea that traditional one-time-use products can be replaced with a multiple-use product. Sustainable engineering involves manipulation of processing systems or the chemical makeup of a substance so that it may be used to offset demand for other resources.

IV. Government's Role

Sustainable practices tend to be overlooked in industry because they are not perceived to be as cost-effective as traditional methods. Government policies such as cap-&-trade or restrictions such as CAFÉ fleet fuel economy standards help mold the culture of industry decision-makers to be more favorable of sustainable practices. Assigning a dollar amount to reducing waste or greenhouse gas (GHG) emissions is far more likely to get a manager's attention than any other sustainability issue.

V. Sustainable Culture Development

Education establishes knowledge at an impressionable age which determines one's perception on given topics. Current skepticism about sustainability can be partly attributed to a lack of education or understanding. Including concerns and facts about sustainability in K-12 and higher education will help future generations develop a culture of sustainability when making decisions throughout their respective careers.

A three 'R' culture and applied engineering research can help identify profitable methods of converting waste streams into resources. This is the development of waste-to-resources technologies, which harness potential energy or resources not available in the substance's current state. Anaerobic digestion (AD) is a perfect example of waste-to-resource technology. AD is a method of converting carbon-rich bio-waste (cow/pig manure, corn silage, milk fat, etc.) into hydrocarbons such as methane gas through biological conversion (microbial activity). Processes like AD can serve as models for future sustainable engineering practices.

Lean production, design for maintenance or recyclability, energy efficient design (less energy to operate component), and product end-life return/recycling/ refurbishing programs are growing sustainable industrial practices. These practices are only adopted if they are economically profitable for the organization. Organizations usually require a two-year or less payback period for investments. In a sustainable culture, organizations may be willing to adopt sustainable practices due to their life-cycle impact instead of their short-term return. Even though the short-term profitability will not be present, sustainable projects have the potential to yield large economic profits and a large positive environmental impact. Furthermore, organizations will consider the life-cycle of their products when making decisions, from raw material acquisition to the end of the product lifecycle. This will help sustainable programs handle the products at the product's end life [5].

For this project, education teamed up with industry to meet the needs of both parties. The students gained experience solving an industrial problem. The organization provided a practical learning situation for the students and had a problem investigated. The following sections discuss the project in detail.

PROJECT BACKGROUND

This senior design project produced a waste-to-resource technology as a solution to a waste oil stream for an industry leading food processor. A high volume cracker line generates an average volume of 352 gallons of waste oil per week (18,300 Gal/yr) through a sheeting process. The cracker dough is compressed by a series of rollers from three inches thick to one-sixteenth of an inch thick during the sheeting process. Each set of rollers compresses the dough, forcing some of the non trans-fat oil in the dough to extract and drip onto a collection gutter. The collection gutter guides the waste oil into a collection tote at the end of the cracker sheeting process (Figure 1). The cracker processing line is also sprayed with a thin layer of non trans-fat oil for flavor and texture. The waste oil collected is a mix between the non trans-fat oil that is extracted from the dough and the non trans-fat oil spray.

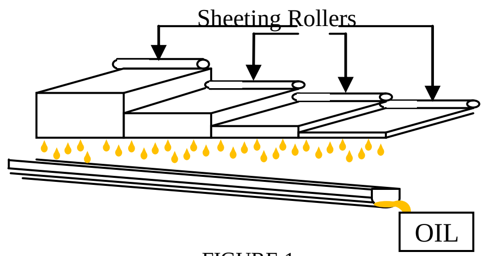

FIGURE 1
SHEETING PROCESS AND WASTE OIL COLLECTION

The waste oil is currently sold to an oil collection service for an average value of seventy-six cents per gallon (the average was calculated based upon the past two years of transactions). This equates to sales revenue of approximately $14,000 per year. The industry sponsor tasked the team with generating an economically profitable, sustainable solution for this waste oil stream. The economically profitable tenant of the solution has two requirements: a payback period of less than three years and a minimum of 20% return on investments. The sustainable tenant of the solution requires that the solution either has a positive or neutral impact on the environment.

METHODOLOGY

This project carefully followed the engineering design process throughout. Having defined the problem and initial constraints, the team proceeded with extensive research and development of potential solutions. The following section outlines the sequential steps in determining the waste-to-resource method that best fit our sponsor's needs, starting with feedstock analysis, feasibility of alternatives, and the chosen alternative with justification.

I. Oil Characteristics

Samples of the waste oil were tested using mass spectrometry and titration to determine the oil's makeup. Some of the most relevant characteristics are displayed below:

- Acid #: 2.17 mg-KOH to neutralize 1g-oil
- Water content: 0.05% by weight
- Contaminants: Wheat, flour, & salt

Due to the contamination of wheat, flour, and salt, the waste oil cannot be reused as an ingredient in any of our sponsor's food processing operations. Outside of the food processing industry, this waste oil is relatively pure. The dietetic content and chemical makeup of non trans-fat soybean oil will determine the potential uses for the waste oil. The following section analyzes three potential solutions for the soybean-based oil.

II. Waste-to-Resource Options

Post-harvest, soybeans are dehulled (seed case removed), crushed to separate the fatty material from the protein meal, and then further processed to extract the oil. About 95% of the protein meal is used for animal feed while the rest is used for human food products. The non trans-fat soybean oil is refined further for food grade or for industrial uses. Approximately 75% of the fats and oils consumed by humans are extracted from soybeans [6]. Animal feed and synthetic gas were considered as potential uses for the waste oil while biodiesel was the our sponsor's preferred option.

Soybean oil can be used to as animal feed. Livestock are provided a mixed diet with specified caloric, vitamin, protein, starch, and fat requirements. Some livestock owners will mix vegetable oil in their animals' diet in order to meet fat requirements. The waste oil could be sold to a livestock farming operation with no alterations to the waste oil itself and with no investment cost.

For horse feeding, two cups of vegetable oil are mixed into the feed per thousand-weight of horse per day [7]. A typical 2,000 lb horse requires four cups (0.25 Gal/day) of oil per day. This equates to 1.75 gallons per week. It would require a stable of approximately 200 horses to consume the volume of waste oil generated in our sponsor's process. Since the cracker line waste oil is classified as food processing waste, the market value of the oil is low. No more than $40 dollars can be charged per fifty-five gallon drum of waste oil, which would result at a revenue rate of $0.73 per gallon, or four to five cents less per gallon than the current revenues per unit. Switching to animal feed would require no investment cost; however, this option can be discarded because it would not result in increased revenues.

Syngas generation is the chemical breakdown by thermal treatment or gasification of biomass into hydrogen and pure carbon monoxide. The high quality hydrogen and carbon monoxide mixture can be further processed into useful hydrocarbon energy sources such as diesel fuel or methane, ethane, and butane. Typically, syngas generation for energy sources uses coal as a feedstock. Other feedstocks are reduced to simple compounds, purified, and used in industrial applications.

Synthetic gas generation is a very developed process and would require capital investments of millions of dollars to obtain and install all the necessary equipment [8]. Syngas generation relies on economies of scale to make the output gas profitable. Therefore, the volume of waste oil produced from the cracker line would not be large enough to support the investment into synthetic gas generation equipment.

Our sponsor preferred biodiesel production as a method of converting the waste oil into a resource because it is a simple technology, has a relatively low investment cost, and has future potential to increase in profitability. Oil sources are triacylglyceride molecules which consist of three long chain fatty acids esterfied to a single glycol molecule [9]. There are four ways to make biodiesel: blend for direct use, microemulsions, thermal cracking, and transesterification. Triacylglycerides have a high viscosity, low volatility, and can lead to damaging engine deposits [10]. Therefore, blending for direct use would not be sustainable to our sponsor's logistics fleet which is used too frequently to use an impure form of fuel. The American Society of Testing Materials (ASTM) also has restrictions against blending oil for direct use [10]. Microemulsions and thermal cracking are not as common and require more equipment, and thus more capital investment, than transesterification. Transesterification consists of the conversion of oils to alkyl esters with light alcohols such as methanol. The process is aided by a catalyst such as potassium hydroxide (KOH) or sodium hydroxide (NaOH). See Figure 2 for a diagram of the transesterification process.

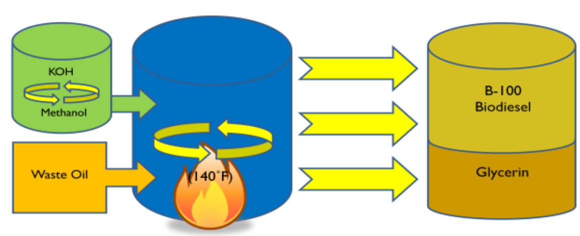

FIGURE 2
TRANSESTERIFICATION PROCESS DIAGRAM

Basic biodiesel processing units are commercially available, starting around $3,000 for the forty gallons per batch size. These basic processors can convert a batch in approximately two days. If biodiesel is used to offset diesel fuel purchases for our sponsor's over-the-road fleet, potential savings could result. The current price of diesel fuel is $2.78 per gallon [11]. However, in June 2008, diesel rates were just under $5.00 per gallon; at some point in the future, diesel rates may approach that point again.

The team was tasked to develop a proof-of-concept biodiesel reactor that met the following specifications:

- *ASTM D6751standard biodiesel* – This would allow the fuel to be used on over-the-road vehicles.
- *Process can be conducted by current employees* – The process needs to be conducted with minimal training.
- *Minimal operator interface* – This is process automation to reduce labor cost associated with biodiesel generation
- *Minimal methanol & KOH handling* – To reduce human interaction with the chemicals because they are harmful to humans. This is also to ensure food safety since the employees work on the food processing lines.
- *Process completes within one 8-hour shift* – This is so that only one employee need oversee a single batch.

DEVELOPMENT OF SOLUTION

The chosen solution consisted of two pilot conversions using other biodiesel processing facilities, the purchase of a basic biodiesel processing unit, and the alteration of the purchased unit to meet our sponsor's above specifications.

I. Pilot Conversions

Two pilot conversions were conducted, as well as the observation of another biodiesel processor in action. The first pilot conversion was conducted at Western Michigan University's Bronco Biodiesel with one liter of waste oil. This pilot conversion resulted in an incomplete reaction. As the waste oil temperature rises, the reaction time decreases (assuming adequate mixing of the solution). We did not preheat the waste oil, therefore, the reaction duration was not long enough. The next event was the observation of the Michigan State University Chemical Engineering Department's biodiesel processor in action. The second pilot conversion, using laboratory equipment in the WMU Chemical Engineering Department, successfully converted a gallon of waste oil. This biodiesel was tested and passed the American Society of Testing and Materials (ASTM) D6751 biodiesel quality tests. This was a critical step, as it determined that the waste oil was capable of meeting our sponsor's initial hurdle for moving forward with the project.

Once the pilot conversions were complete, a pilot scale processor was designed using a commercially available processor as a starting point. The changes in the design were made in order to meet our sponsor's criteria. See Figure 3 for fluid flow diagram and Figure 4 for a CAD drawing of the processor design.

In Figure 3, T_1 (Tank 1) holds the raw waste oil from the sponsor's cracker line in its original form. T_2 is a 55 gallon drum with a 40 micron filter for pre-filtering the raw waste oil. While the raw waste oil is pumped from T_1 to T_2, T_5 is being filled with KOH from the VF (volumetric feeder) and methanol from T_4. Once 40 gallons are filled into T_2, the oil is looped into T_3 through the heater (H_1) until the oil is pre-heated to 150˚F. The KOH and methanol mixture is looped through P_4 (Pump 4) while the oil is heating to ensure the KOH is completely dissolved. Once the oil is preheated, the KOH/methanol mixture is pumped into T_3 with P_4. The mixture is then looped through H_1 to maintain temperature during the reaction. The reaction runs for one hour and is then let sit for biodiesel/glycerin separation. Separation takes approximately two hours. The glycerin is drained into T_6 once separation is completed. This process completes in approximately four hours.

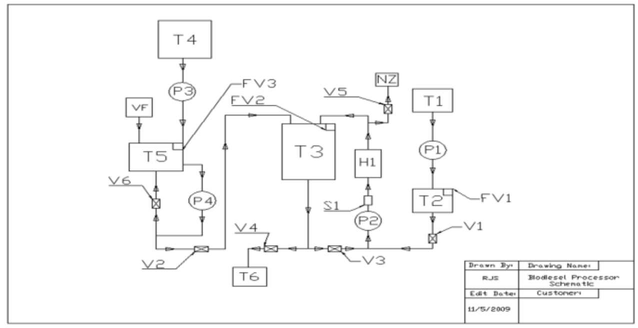

FIGURE 3
FLUID FLOW DIAGRAM

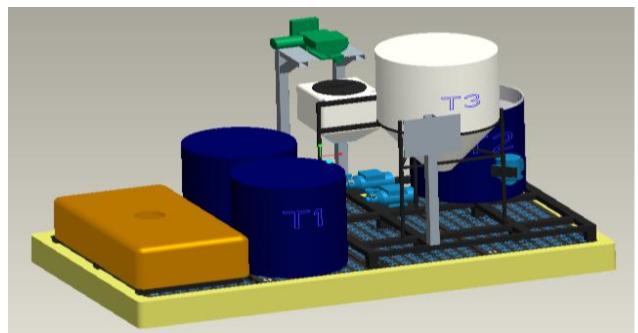

FIGURE 4
3-D MODEL OF PROCESSOR LAYOUT

II. Basic Biodiesel Processing Unit

In order to simplify the process of designing and purchasing, a manual biodiesel processing unit was purchased from Evolution Biodiesel. The unit purchased is called the Mega Ester – a manually operated, forty-gallon processor with a processing time of about 14 hours. This processor is equipped with a reaction tank, a methanol mixing tank, an inline heating element, an oil filtration drum, a methanol/KOH mixing pump ($1/25^{th}$ Hp), and a multipurpose pump (0.5 Hp), all mounted on a steel frame.

The stock heater was estimated to preheat the oil in one to two hours depending on ambient temperature. The Mega Ester's heating element was upgraded to the 3500W inline heater (power specifications for the stock heater were not provided) in order to ensure preheating would occur closer to one hour instead of two. The 3500W heater provides a heat transfer rate of 199.15 Btu's of heat per minute. Assuming the ambient temperature is 60˚F, 9,970 Btu retention is required to heat the 40 gallons of waste oil to the 150˚F (ΔT=90˚F) required for the reaction. The specific heat (c) of soybean oil is 0.285 [Btu/lb-F]. The weight (W) of 40 gallons of oil is 310.94 lbs. The assumed electrical to heat conversion efficiency (η_e) is 80%. See (1) below for the heat requirements calculation.

$$Q_{req} = \frac{c * W * \Delta T}{\eta_e}. \qquad (1)$$

The above calculation does not consider heat loss; the heat loss will require additional heating time. The heat loss coefficient (α) for the reaction tank is 1.4 [Btu/hr-ft^2-F]. The surface area of the reaction tank is 25 [ft^2]. See (2) below for the heat loss rate (R_L=50.54 Btu/min) calculation.

$$R_L = \alpha * SA * \Delta T. \qquad (2)$$

The total heat transfer rate (R_T=148.78 Btu/min) is the difference between the heat transfer rate and the heat loss rate. The heat retention rate (R_R=133.9 Btu/min) is the heat transfer rate multiplied by an assumed transfer efficiency (η_t) of 90%. See (3) below for the heat retention rate calculation.

$$R_R = R_T * \eta_t. \qquad (3)$$

Therefore, the estimated heating time for the waste oil is 74.46 minutes.

III. Automation of Purchased Processor

Automating the processor consisted of:

- Altering the plumbing
- Frame additions
- Swapping the manual valves with pneumatic valves actuated by pilot solenoid valves
- Oil feedstock loading with a pump
- Methanol loading with a pump
- KOH metering and loading with a screw auger
- Float switches to indicate volumes
- A temperature probe
- Wiring of all electronics to a central control panel
- Program coding to control all electrical components

The purchased processor utilized fluid flow lines for multiple purposes during the reaction process; the operations manual required that a valve be closed just enough to 'hear the pump change pitch.' However, the change in pitch indicated added stress on the pump, which could lead to breakdown of the equipment. The plumbing was altered so that all functions can be conducted simultaneously and independently of each other, and that the pumps can be run without restricted fluid flow lines.

The frame was expanded to accommodate the KOH metering auger, the control panel, electric junctions, and for stability. For scale up of full-scale processors (larger batch size), thicker steel was included in the design to account for the increased weight of the oil. Furthermore, higher capacity pumps, feeders, piping, and valves were required. Therefore, the cost for the scaled up processors increased linearly. This information was useful in the economic analysis portion of the business case. See Figure 6 in the business case for the scaled capital cost diagram.

Two types of valves can be controlled and automated by a logic controller: pneumatic and solenoid. Pneumatic valves are actuated by compressed air, while solenoid valves are actuated by electrical signal. Methanol is highly volatile and can be ignited by electrical spark, so pneumatic valves were chosen to eliminate the risk of igniting the methanol. In order to be controlled by a logic controller, pneumatic valves must be controlled by pilot solenoid valves. The pilot solenoid valves control the introduction and release of compressed air to the pneumatic valves.

Waste oil and methanol loading from bulk storage containers reduces the need for manual loading of the oil and methanol. The waste oil is pumped from the bulk storage container, through the 40 micron filter and into the filtered oil drum. A float switch was located in the filtered oil drum to send a signal to the logic controller that just over 40 gallons of oil had been filtered. Another float switch was located in the reaction tank to indicate that 40 forty gallons were loaded into the reaction tank. Methanol is pumped from a fifty-five gallon drum of methanol directly into the methanol/KOH mixing tank. A third float switch was located in the methanol/KOH mixing tank to indicate that eight gallons of methanol were loaded.

KOH is a powder and can be metered into the methanol/KOH mixing tank by turning screw augers. The device loads the KOH at a consistent rate as long as sufficient powder is held in the powder reservoir. KOH loading is controlled by the logic controller to turn on for a specific amount of time in order to load an accurate and consistent volume of KOH. Powder metering has the potential to generate static buildup of powder during use. Static buildup could result in under- or over-loading of KOH which can hinder the reaction process. An electrically grounded chute was used to guide the KOH into the methanol tank and to eliminate the threat of static buildup.

A temperature probe was attached to read the temperature inside the reaction tank for two reasons: to indicate that oil has been preheated so that methanol/KOH can be loaded into the reaction tank and to keep the temperature of the solution between a given temperature range during the reaction loop. The temperature probe's output is used by the logic controller to indicate when the inline heater should be engaged or disengaged.

Due to the size of the heater, the processor had 220V power requirements. The majority of the electrical lines ran off 120V, so the addition of all of the electrical components required to automate the reaction process added electrical risk. All wiring was conducted to safety standards with conduit, junction boxes, and wire color coding. The logic controller's wiring was labeled for maintenance and troubleshooting purposes. Figure 5 displays the processor after all alterations were applied.

Water tests were conducted to test the plumbing junctions for leaks and to ensure that the program was functioning correctly. Once the design was assembled and the program and wiring were troubleshot, two trial batches were conducted with the sponsor's waste oil using the automated processor. Both batches finished in approximately four hours. The biodiesel generated was tested and met ASTM D6751 standards. The biodiesel is intended for use at a B20 blend. Measures are currently in progress to ensure donor vehicles are biodiesel ready.

FIGURE 5
AUTOMATED BIODIESEL CONVERSION SYSTEM

100% biodiesel is corrosive to rubber fuel lines. Vehicles equipped with synthetic or aluminum fuel lines are biodiesel ready, and rubber lines can be swapped for synthetic lines. Biodiesel is a solvent which will clean out any diesel fuel deposits in the lines. These deposits will clog the fuel filter and can cause the engine to seize. Anyone planning on switching to biodiesel from diesel should purchase an extra fuel filter and change it after a couple hours of driving on biodiesel. If the engine does seize, the operator can replace the filter and the engine should start. No permanent damage will result from switching to biodiesel as long as the fuel filter is maintained and the fuel lines are not rubber.

BUSINESS CASE

The current business environment required that this industrial project meet three criteria: social acceptability, environmental responsibility, and economic profitability. The following discussion addresses this project in relation to each of these criteria.

I. Social Acceptability

A socially acceptable project would have no adverse impact on the industry that the project is involved with and a neutral or positive impact on the surrounding community. The biodiesel processor could be located in the same location that the waste oil is produced or near the use point. Food safety precaution should be the primary concern when choosing the placement of the biodiesel processor. The biodiesel could then be pumped directly into the diesel motor vehicle on the same site where the oil is produced as well. Therefore, there is no or neutral interaction between the function of this project and the surrounding community.

Biodiesel or biofuels in general could be a concern for the food processing industry. As food is used for fuel, added demand causes agricultural commodity price increases. This could affect the profitability of a food processing organization. However, the food-for-fuel debate does not apply to this project because the waste oil used is no longer considered a food grade material.

II. *Environmental Analysis*

Biodiesel is considered carbon neutral while diesel fuel is carbon emitting. With the federal carbon cap-and-trade program set to be implemented in 2012, this project has the potential to earn carbon credits once the program is in place [12]. One carbon credit represents one metric tonne of carbon dioxide or greenhouse gas (GHG) equivalent.

The 350 gallons of waste oil per week translate to 270 tonnes of carbon avoided per year. These credits would be worth $5,870 per year on the European Union Emission Trading Service (EU ETS) and $40.60 on the Chicago Climate Exchange (CCX) [13]. This potential for revenues was not included in the economic analysis portion of the business case because there is currently no effective cap-and-trade policy in the United States.

III. Economic Analysis

The two major variables in the profitability of biodiesel production are the batch size of the processor and the market price of diesel fuel. The batch size determines the capital cost and operational cost. See Figure 6 and Figure 7 for diagrams of how capital cost and operational cost change with batch size.

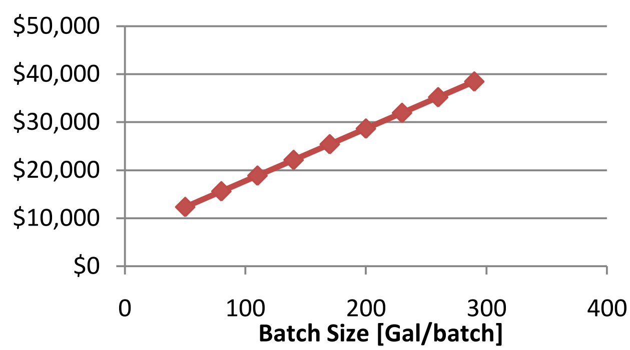

FIGURE 6
CAPITAL COST [$/unit]

The unit cost per gallon of biodiesel produced must be less than the difference between the market price of diesel fuel ($2.77/Gal) and the current revenues for the waste oil ($0.76/Gal), or approximately $2.00 per gallon. Figure 6 shows that it takes a minimum of 100 gallons per batch processor size to have a unit cost of below $2.00 per gallon. Also, the unit cost begins to level off when the batch size is larger than 230 gallons per batch.

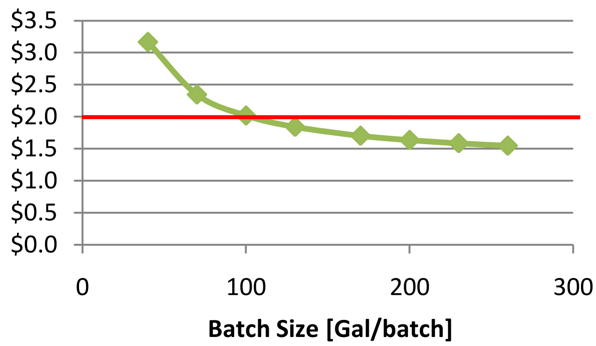

FIGURE 7
OPERATIONAL COST [$/batch]

With the current national average for the market price of diesel fuel being $2.77 per gallon, biodiesel production is not currently economically viable. With the 230 gallons per batch processor size and the current price of diesel, the processor has a seven year payback and an 8% return on investments. A financial analysis was conducted for a series of hypothetical scenarios ranging from 40 to 230 gallons per batch for the batch size and $2.77 to $4.95 per gallon for the market price of diesel.

The 20% return on investment criterion with a 3-year payback is viable when the market price of diesel fuel is $3.25 per gallon. Figure 7 shows how payback period is stable between 100 to 230 gallons per batch and starts to increase larger than 230 gallons per batch. Figure 8 displays the payback period in relation to batch size.

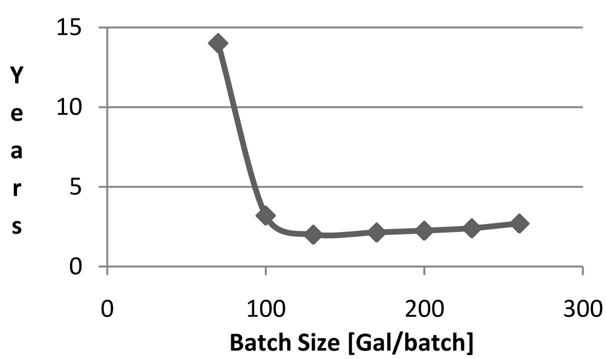

FIGURE 8
PAYBACK PERIOD [yrs]

RECOMMENDATIONS

Full-scale biodiesel production should be implemented when the market price of diesel fuel has stabilized above $3.25 per gallon. There are many production facilities and opportunities within our sponsor's organization that can utilize this biodiesel processing capability. These different facilities may have varying time, labor, and space constraints for the placement and operation of the processor. Therefore, we have identified a range of suitable batch sizes for the processing unit to be between 100 to 230 gallons per batch. It is suggested to choose the largest processor size within that range that can meet the site's labor and space constraints because of economies of scale. Even though payback period begins to creep up for the larger processor sizes, the unit cost of biodiesel is reduced. Once the unit is paid off, the larger processors will be more profitable due to the reduced unit cost of production.

BENEFITS OF PROJECT

I. For the Industrial Sponsor

Our sponsor was interested in determining if their waste oil could be utilized in a profitable and environmentally responsible manner. The carbon neutral biodiesel is an environmentally responsible solution for this waste oil as it can be used to offset carbon emitting diesel fuel. Unfortunately, the current design does not meet the sponsor's economic criteria with the current market conditions. However, historic trends indicate that the market price of diesel will, at some future point, likely exceed the $3.25 per gallon profitability threshold. This project provided the sponsor with the preliminary market research, a bench-scale biodiesel processor design and construction, and feasibility analysis. The sponsor can hold on to this concept and decide when to proceed with full-scale implementation based on the market conditions and the recommendations provided. Therefore, they can quickly implement the solution instead of beginning the research when the market is ready, thus maximizing the benefit from the solution.

II. For the Capstone Design Project Team

The multidisciplinary project team included Engineering Management and Engineering Graphics & Design students. The project was a well-rounded engineering design process experience which exposed the students to a problem in an industrial setting with industrial goals. The project background research included potential uses for non trans-fat soybean oil given its characteristics, biodiesel conversion (specifically the transesterification process), government restrictions (ASTM standards), and the need for sustainability. The project required the team to become familiar with and use many of the skills required to design and create an industrial machine: functional design, mechanical design, design for maintenance, electrical wiring, logic control programming, performance tests, design adjustments, and scale modeling. The team also gained useful industrial engineering skills with the development of a food and human safety protocol along with a standard operating procedure (SOP). The SOP provides the instructions for set up, operation, breakdown, maintenance, and troubleshooting the reactor.

WMU has displayed advocacy in a sustainability movement with on-campus electric generation with biogas, a biofuel research center, a solar energy system, an on-site wind turbine used to charge the engineering building and a plug in hybrid Prius, a new Green Manufacturing Initiative with a consortium of industry members (www.wmich.edu/mfe/mrc/greenmanufacturing/index.php), and a developing energy-environment-economics program. It is imperative that educational institutions adopt a sustainable culture so that it can be passed on to the students. Design opportunities like this senior capstone project demonstrate the capabilities of WMU engineering programs and further coin WMU as a strong promoter for the development of a sustainable culture.

Finally, besides serving as a successful capstone design project, this study can serve as a model for industrial organizations that strive to implement sustainable practices. The only way to know if a sustainable concept is feasible is to conduct the research, collect the data, and do the calculations. If a concept is not profitable given current market conditions, the organization can further investigate the market conditions that will economically justify implementing the change. They can then set a policy on when the program will be launched. Industrial organizations can utilize academic resources through consortiums to investigate potential sustainable projects. When industry joins with education to further both of their own needs, educational opportunities and learning, and the future of sustainability, everyone is served.

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REFERENCES

[1] Energy Information Administration (2010). Monthly Energy Review January 2010. Retrieved February 1, 2010, from http://www.eia.doe.gov/emeu/mer/pdf/pages/sec1_3.pdf

[2] Census Bureau (2010). Current Population Reports. Retrieved February 1, 2010, from http://www.census.gov/statab/hist/HS-01.pdf

[4] Riley, R. (2004). *Alternative cars in the 21st century-a new personal transport paradigm (2nd Edition)* Warrendale: Society of Automotive Engineers.

[4] MI Public Act 451 (1994).

[5] Vezzoli, Carlo, and Ezio Manzini (2008). *Design for Environmental Sustainability.* London: Springer-Verlag.

[6] First Research (2009). Edible oils manufacturing: Quarterly update 11/09/2009. Retrieved from http://proquest.umi.com.proxy2.cl.msu.edu/pqdweb?index=22&did=1897539721&SrchMode=1&sid=6&Fmt=6&VInst=PROD&VType=PQD&RQT=309&VName=PQD&TS=1265207361&clientId=3552 on December 1, 2009.

[7] Valentine, Beth A. PhD (2003). Vegetable oils as a feed additive. Oregon State University Draft Resource Page retrieved from http://www.draftresource.com/EPSM/Draft_EPSM_FAQ.html, on November 8, 2009.

[8] Cobb, James T. (2007). Production of synthetic gas by biomass gasification. Proceedings of 2007 AIChE conference Retrieved from www.engr.pitt.edu/chemical/facstaff/Biomass_Energy_Project.doc. November 22, 2009.

[9] Wang, Lijun (2009). Energy efficiency and management in food processing facilities. Boca Raton: CRC Press.

[10] ASTM (2009). ASTM D6751-09 Standard specifications for biodiesel fuel blend stock (B100) for middle distillate fuels. Retrieved from www.astm.org/ on September 6, 2009.

[11] Department of Energy (2009). Gasoline and diesel fuel update. Retrieved from http://tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp, on December, 2009.

[12] Federal Budget Proposal FY 2010.

[13] CCX (2009). Chicago Climate Exchange Organizational Webpage. Retrieved from http://www.chicagoclimatex.com on November 7, 2009.

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