Design of Biofuel Production Facility for Renewable Energy Generation

…Lets not be cruel, use alternative fuel!

Final Report

IPRO 316
SPRING 2009
Illinois Institute of Technology
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1. Abstract

The aim of IPRO 316 was to design a biofuel process that generates biodiesel or bioethanol. To achieve this task, the team decided to work on producing biodiesel based on the needs of the sponsor, Testa Produce, Chicago, IL. The team was then split into two groups: a biodiesel production group and an economics/transportation group. Peter Testa, President of Testa Produce, is interested in producing biodiesel from waste vegetable oil that Testa Produce drivers could collect from restaurants and hotels when they deliver their shipment of produce. The goal of IPRO 316 was to look at every step of that process, from waste oil collection and transportation to biodiesel production and waste disposal.

2. Background

The sponsor for this IPRO, Testa Produce, is a Chicago-based wholesale distributor of fresh and frozen fruits and vegetables to restaurants and hotels in the Chicago area and Midwest. Testa Produce contacted the IPRO office with the idea of producing biodiesel for use in their delivery trucks, and when paired with IPRO 316, Mr. Testa shared with the team his interest in the entire process of collecting waste vegetable oil and converting it to biodiesel.

Testa Produce currently has roughly 1500 customers including restaurants, hospitals and hotels. Since the delivery trucks are already making the trips out to these customers, no additional fuel or energy will need to be spent to collect the waste vegetable oil as the truck drivers can pick it up at the time they deliver produce. Determining how to transport waste vegetable oil in the same truck trailer as fresh produce was one of the challenges of this IPRO. The other challenges included designing a biodiesel production process with the correct capacity and reasonable price and proper waste treatment and disposal.

Currently, biodiesel processing kits are available for purchase on the internet, and the biodiesel production process is well defined. These processors can generate biodiesel in batches of 1 to 500 gallons in a 48 hour period. For a higher level production, the reactors and tanks that make up the process need to be designed, but either way, one must determine where to house the reactor, how to store hazardous chemicals, how to dispose of wastes, and how to transport used vegetable oils in order to make the whole process come together.

This is the first offering of this IPRO, which means that no previous work on this IPRO is available. Ethical issues involved in designing a biodiesel production process include development of a safe process so that employees and the community are not threatened, respect for coworkers within the IPRO and our external contacts, compliance with federal, state, and local laws and production of high quality biodiesel.

3. Objectives

- Conduct literature search on renewable biofuels, with emphasis on:
  - Sustainability of their basic components
  - Economic feasibility
  - Resulting environmental impact
- Develop a process for production of a biofuel meeting our objectives, improving upon current methods of production, by using homogenous and heterogeneous catalysis under extreme or supercritical conditions in order to improve the following:
  - Fuel quality
  - Reaction time
  - Economic feasibility
- Design a reactor for biofuel production using software such as Matlab and Hysys for the process and scale-up the reaction process to three different capacities. Design should be:
  - Safe
  - Reliable
  - Feasible
- Perform an economic analysis of the process and determine the following:
  - The most cost efficient design
  - Payback period

4. Methodology

4.1 Definition of Problem

The overall goals of IPRO 316 have been to research biofuels, such as ethanol and biodiesel, design a viable small scale biofuel production facility for Testa Produce, and perform an economic analysis of the process. The first stage of the project involved gathering crucial information about different biofuels in order to eventually decide on which biofuel type to focus. Once the sponsor was identified, the team was given a more specific task to turn waste vegetable oil into biodiesel. Extensive research was therefore needed for biodiesel production and to overcome obstacles of collecting and transporting the waste oil to the production facility. The team had initially planned on performing an extensive economic analysis of the process. However, since contacts with the sponsor occurred few weeks after the start of the semester and were limited through the semester, there was not enough time to achieve this goal.

4.2 Work Breakdown Structure

In order to solve the problem, the members of this IPRO team must develop a better understanding of the problem and biofuel production technologies currently being used, apply this knowledge to develop various process models for biodiesel, solve the problem of transporting the waste oil and perform a limited economic analysis.

Stage 1: Research

During this stage, the team members focused on gaining a deeper understanding of the current biofuel production technologies. The research was conducted mainly using research articles from the internet, but team members were encouraged to contact companies that were involved in producing biofuels.

Stage 2: Waste Oil Transportation and Biodiesel Production Process Design

At this stage of the semester, there were two problems that had to be solved: (1) the problem of transporting the waste vegetable oil from Testa Produce clients to the Testa Produce warehouse where the small scale biodiesel production facility will be located, and (2) to determine an efficient and viable process to produce biodiesel, including determining design parameters of necessary physical components, such as reactors, using Matlab and Hysys. Throughout the semester, the majority of the time was devoted in this stage. Due to the limited contact we had with our sponsor throughout the semester, it was difficult to finalize much of this work, and therefore, the team came up with strong recommendations for the next IPRO team to look into.

Stage 3: Design Optimization and Economic Analysis

Since so much time was invested into stage 2, it was not possible to perform an extensive economic analysis on the process. However, based on the results achieved, we were able to draw basic economic conclusions. This was the most significant change in the breakdown of the original work structure created at the start of the semester.

Stage 4: Generation of IPRO Deliverables

The final two weeks of the class were spent in preparing the deliverables, such as the brochure, poster, final presentation, website, and final report.

4.3 Organization of Files and Data

In order to ensure that the team's work is properly recorded and documented, the team ensured that the iGroups online system is used to its full potential. All files containing the work done were uploaded and organized into easy-to-access folders. This will allow all members of our team, 24 in total and therefore larger than most IPRO teams, to find relevant information quickly. It will also minimize the overlap of work being done and ensure that everyone is working on tasks that will further the project. Additionally, this method of archiving the team's work will make it easier for members in future offerings of this IPRO to access the information and therefore allow them to move forward on the project without repeating the tasks.

4.4 Gantt Chart

A detailed visual representation of the team's work through the semester is provided below.

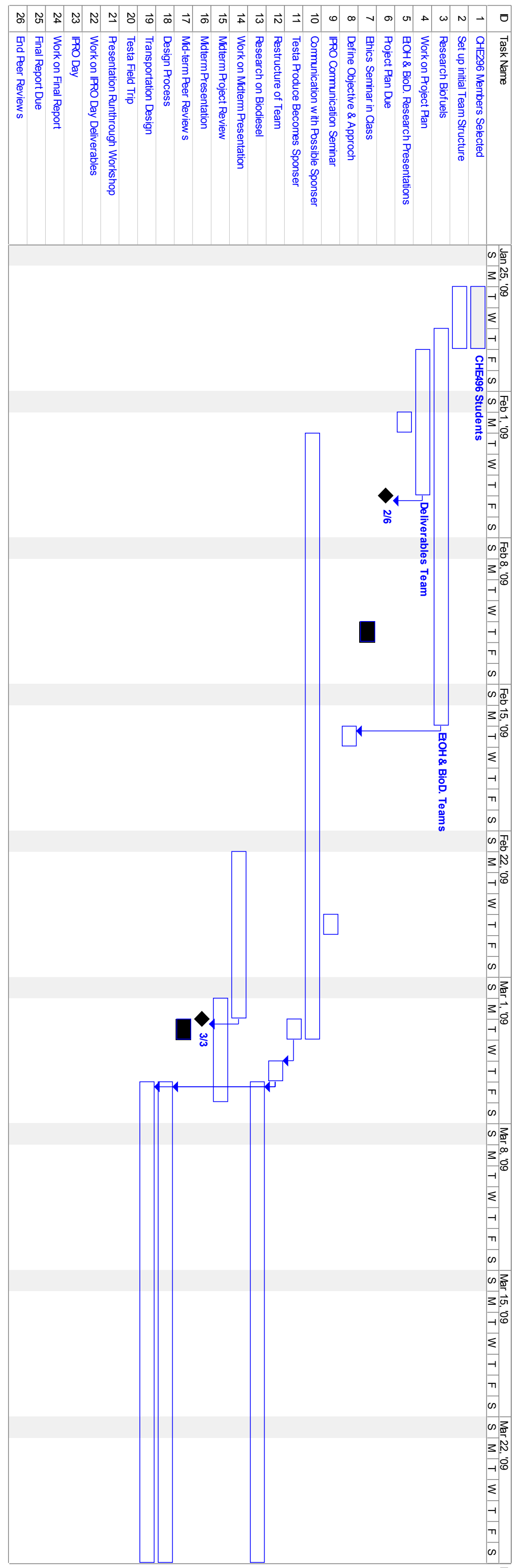

Figure 1: Gantt chart for the first half of the spring 2009 semester.

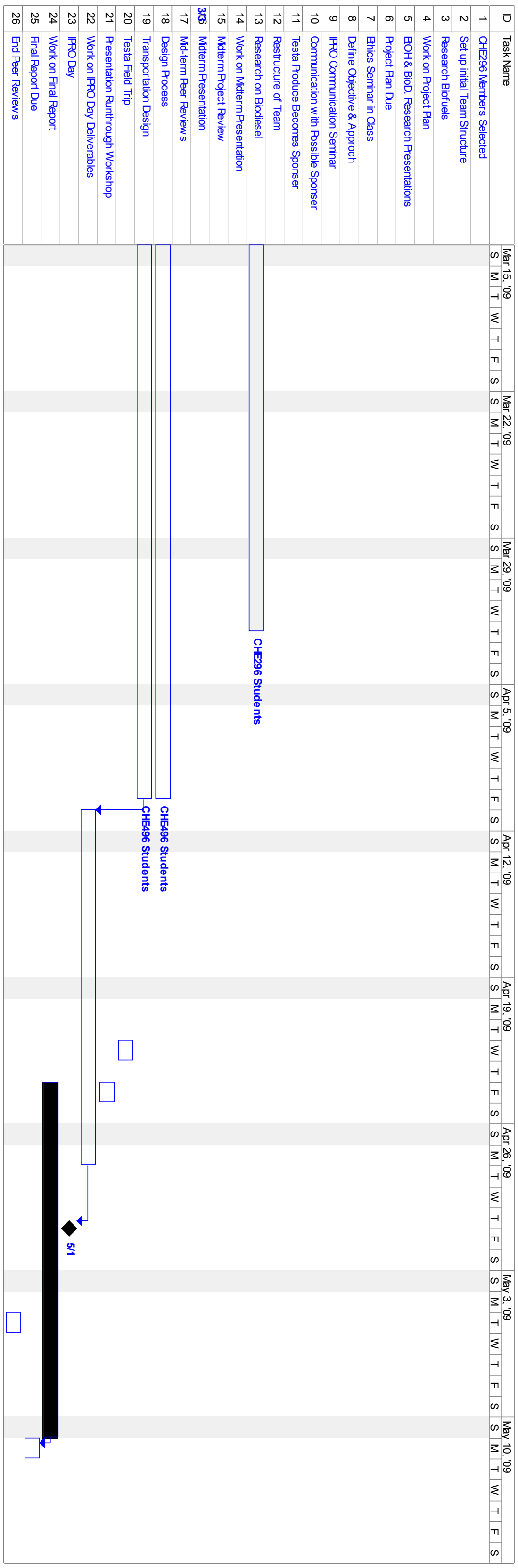

Figure 2: Gantt chart for the second half of the spring 2009 semester.

5. Team Organization

5.1 Team Structure

IPRO 316 is a very large group consisting of 24 members, 15 of whom are chemical engineering sophomores, and five are chemical engineering seniors. The other four members are students majoring in computer science, mechanical engineering, biology, and biochemistry. The project team was organized in three different ways through the semester according to the following diagrams.

The initial structure of IPRO 316 before the project was well defined and the sponsor's needs were known is presented below.

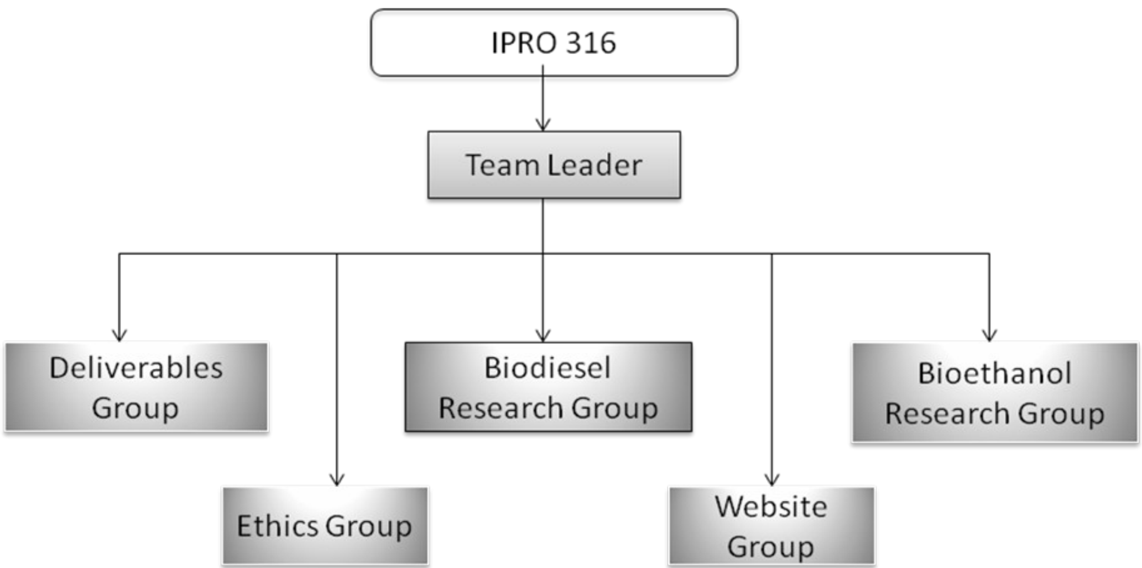

Figure 3: IPRO 316 initial structure.

Following initial communication with the sponsor, the team was reorganized into two subgroups as shown below.

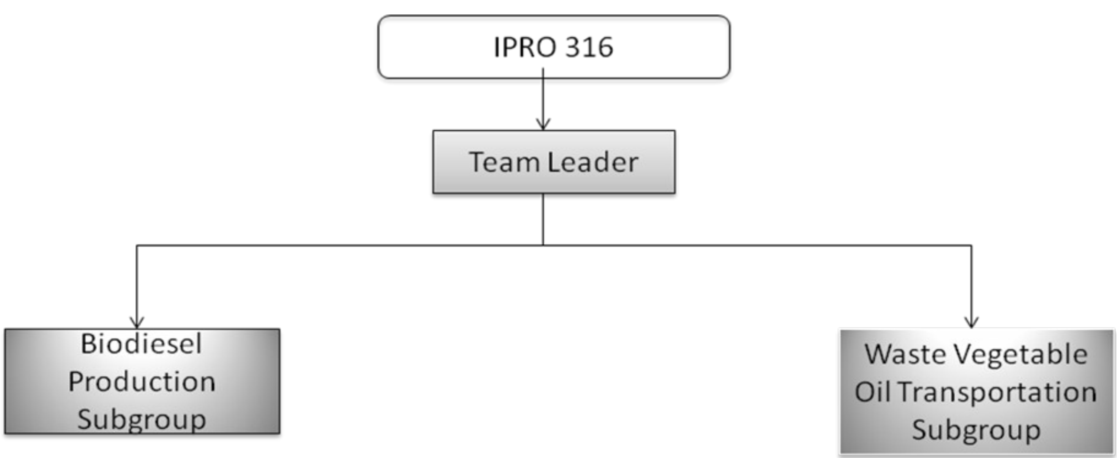

Figure 4: IPRO 316 structure at midterm.

The final structure of IPRO 316 is presented below. While students continued to work in their respective production and transportation subgroups, they also worked in the three deliverables subgroups.

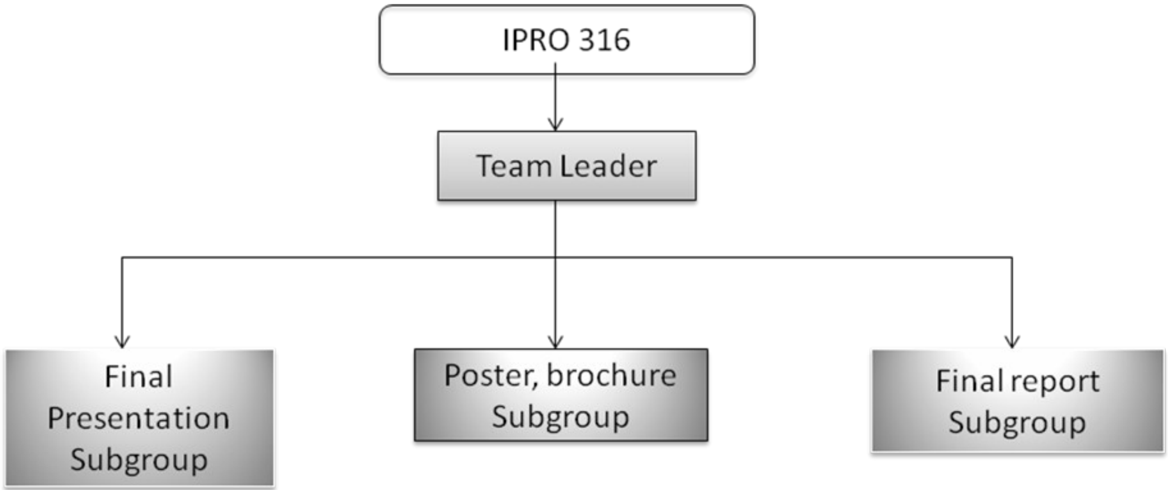

Figure 5: IPRO 316 final structure.

Every subgroup shown above had a group leader in order to help the IPRO team leader monitor progress of individual subgroups. This allowed the work to be done more efficiently and ensured that all deliverables were completed, reviewed and submitted by their deadlines.

5.2 Team Members

- Abdalmohsen Alhassan
- Pierre-Paul Amegasse
- Ryan Attard
- Kelsey Camp
- Don Dornbusch
- Hector Garza Rodriguez
- Corey Hawker
- Omaditya Khanna
- Daniel Kim
- Calvin Kirtley
- Richard Lewis
- Joel Meno
- Babajide Oke
- Nicole Parks
- Mehul Patel
- Nicole Reigle
- Kirsten Reimann
- Jesse Reinhardt
- Ricardo Rodriguez
- Piotr Sajdak
- Emmanuel Sakla
- JongHwa Song
- Deepthi Veliyathuparambil
- Christopher Wiseman

6. Budget

Event	Cost	Description
Teambuilding/Ethics Discussion Pizza Party	$150	Cost covers pizza, pop and paper products for 25 people.

Table 1: Budget for IPRO 316 for spring 2009.

7. Code of Ethics

Overarching Standard:

We will work together in a professional manner, adhering to ethical standards and existent regulations in coming up with a socially, economically and environmentally sound design.

1st Layer - The Law:

- **Canon:** The process design to produce biofuels will comply with all Federal, State and Local laws regarding proper disposal of any waste by-product from the chemical plant, keep stringent records that can be produced on demand, and have citations of all references with regards to the project.
- **Pressure:** In order to decrease the costs associated with the process, a company may decide to not properly dispose of waste and conceal records that do not comply with the law.
- **Risk:** A company may continue violating these laws, which will lead to government involvement and consequently putting their employees' jobs in jeopardy.
- **Pressure:** As an attempt to avoid higher taxes for emitting more pollution into the atmosphere, as per government regulations, the company may not be entirely honest about the level of waste being produced by their process plant.
- **Risk:** Waste products that are improperly disposed could seep into air, soil and/or rivers, causing pollution, which would be in violation of environmental laws.
- **Pressure:** Members may be required to constantly come up with quick solutions to problems that arise during the development of the project. Members may thus look up multiple sources.
- **Risk:** Members may forget to quote sources or give credit where needed, causing them to unknowingly infringe on copyright laws.
- **Measure:** In order to ensure transparency in recording of levels of waste produced in the plant and to follow all rules and regulations, the company should set strict ethics guidelines and make employees adhere to these to ensure that each individual is aware of what information needs to be disclosed and how he/she will do that.

2nd Layer - Contracts & Agreements:

- **Canon:** The employees of the company that work on the biofuel production process will abide by all contracts and agreements in regard to the chemical engineering industry.
- **Pressure:** In a cost-cutting effort, the company may hire employees, who are not licensed engineers, at lower wages.
- **Risk:** If strong ethical guidelines are not provided in the written contracts to be signed at the start of employment, employees will not perform their tasks in a proper and stringent manner.
- **Risk:** If the engineers are not fully competent to work in a process plant, other employees may be endangered due to technical difficulties that serve as a safety risk.
- **Measure:** All guidelines should be stated clearly in the written contracts that employees are required to sign upon employment. This will allow them to work in a safe environment with tasks being performed in a proper manner.

3rd Layer - Professional Code of Ethics:

- **Canon:** We shall handle the project in a responsible manner, parallel with the ethical standards of being students as stated in IIT's Academic Integrity guidelines.
- **Pressure:** Members are required to produce sizeable deliverables on a weekly basis.
- **Risk:** Violations of IIT Academic Integrity guidelines.
- **Risk:** Team members claim credit for the work of others.
- **Risk:** Reduce the quantity/quality of testing in order to achieve minimal expected results.
- **Measure:** Work will be assigned fairly and evenly among group members so that the utmost level of professionalism is maintained.

4th Layer - Industry Standards:

- **Canon:** The employees of the biodiesel company will abide to the rules of industrial standards.
- **Pressure:** Heavy deadlines may result in disregard of safety procedures.
- **Risk:** Improper techniques used may result in danger to the company.
- **Risk:** Failing to follow rules may result in risking the lives of the employees.
- **Measure:** In order to produce a safe environment, the company will set strict rules and guidelines and ensure that the employees fully abide by them.

5th Layer - Social, Civic & Geographic Communities:

- **Canon:** The biofuel produced must be safe, economical and environmentally friendly, exceeding current standards for fuels.
- **Pressure:** The biofuel production may lead to environmentally unfriendly byproducts.
- **Risk:** Overlooking the potential impact of biofuel production facility on the surrounding communities and the environment as a whole.
- **Pressure:** The biofuel produced may be of inferior quality.

- **Risk:** The company that produces the biofuel may be liable for damage to any engine or mechanical equipment that consumes it.
- **Measure:** The biofuel produced will meet or exceed a thoroughly tested high standard.

6th Layer - Personal Relationships:

- **Canon:** Members shall work in a professional and objective manner, avoiding all forms of interpersonal conflicts and resolving them if and when they occur.
- **Pressure:** To create a transparent research system that clearly acknowledges all sources.
- **Risk:** Breaking the confidentiality of information from contacts that wish to remain anonymous.
- **Pressure:** Contributing ideas and opinions openly to improve project design.

- **Risk:** Conflict of ideas among members that leads to misunderstanding.
- **Measure:** Group leaders and members will work to ensure that everyone is on the same level in regards to respecting all IPRO contacts and members.

7th Layer - Moral and Spiritual Values:

- **Canon:** Members are allowed to candidly express their concerns and beliefs so that a common understanding is reached during conduct of the project.
- **Pressure:** To treat all members with respect, so that the project may be completed in an efficient and timely manner.
- **Risk:** Creating conflicts between members because of personal beliefs.
- **Measure:** If a conflict occurs, the members involved or others knowing about it will inform a group leader or the teacher to help settle it.

8. Results

8.1 Overall Process

The team gained a deeper understanding of the task at hand after being approached by the sponsor for IPRO 316, Testa Produce. Peter Testa, President of Testa Produce, currently uses biodiesel to run his delivery trucks, and he wanted the team to look into the entire process of collecting waste vegetable oil and producing biodiesel from it. The major task of the IPRO team was to look at the overall process and every step that must be taken to turn waste vegetable oil (WVO) into biodiesel. The steps in this process are: waste oil collection, transportation, storage, biodiesel production, and waste disposal. Each step in the process is explained in the following sections.

8.1.1 Waste Oil Collection

Testa Produce delivers fresh produce and other assorted goods to many customers in the Chicago area and the Midwest, including restaurants, hospitals and hotels. When a truck reaches a customer's establishment to drop off Testa products, the truck driver will pick up waste vegetable oil from the customer to bring it back to the Testa Produce warehouse. This step makes the biodiesel production scheme economical because there are no extra trips made to collect waste oil. The truck is already there delivering goods, so no extra time and money are wasted in collecting used oil.

To make the waste oil collection step easy for the driver, the IPRO team suggests that the customer, a restaurant for example, cool its waste oil when done with it and put it into the original container it came in. This was decided to be the best option for many reasons. First, this is the easiest way to ensure that different kinds of oils are not mixed. The effects of mixing different types of oils on the resulting biodiesel quality has not been well documented yet, so in order to ensure a quality product, the oils should be kept separated until further testing can be done. It may be possible to mix oils that have similar properties and therefore will not affect the quality of the biodiesel, but mixing oils with different properties and creating biodiesel may lead to a fuel with a higher gel point than just using one kind of waste oil, which is undesirable. Studying the biodiesel quality from different combinations of mixed oils has been left as a recommendation for future IPROs (see Section 10). Another reason for requesting that the oil be put back into the container it came in is that the containers can be recycled, and waste can be reduced. Also, by using the smaller containers which are usually three to five gallons, the WVO can easily be collected and moved into the truck by one person. With the use of a two-wheel cart, one person can move several oil containers at one time.

Another possibility for Testa Produce is providing customers with color-coded containers. Containers with different colors or labels can be used to store different types of waste vegetable oil. Since English may not be the first language for many kitchen workers, such containers will make it easier for the restaurants, hotels, and hospitals to collect and organize their WVO for a later pickup by Testa Produce. Again, these containers would be reused to minimize waste.

8.1.2 Transportation

Once the delivery truck driver collects the WVO from the customers, he or she must be able to haul the smaller containers in the back of the truck without damaging any other products or allowing the oil to leak onto the floor which would cause the floor to become extremely slippery. The team's solution to this issue was the use of a large container made out of very durable plastic that has the length and width of a pallet and is roughly three to four feet tall. The top would be open so that the driver could pick up each three to five gallon container of WVO and place it into this 'tub'. The plastic tub would be securely attached to the pallet, and the plastic would need to be durable enough to withstand the impact from a two-wheel cart that may be rolling around in the back of the truck. This provides secondary containment in case one of the smaller oil containers leaks or spills. Since the tub is attached to a pallet, it can be unloaded easily with a forklift and then the smaller containers inside the tub could be sorted out by oil type. This is discussed in the next section.

The tub solution explained above is a very basic solution to the problem, but it takes up space on the truck that could be used for one additional pallet of produce since it must be transported from the beginning to the end of the route. Another idea suggested by a team member was a collapsible container that would not take up as much space when the truck is first leaving the warehouse full of produce. This collapsible container would probably have the dimensions of a pallet, but when collapsed, it would be shorter, so when the truck is full of produce, the collapsed container could possible fit above another pallet just until the first pallet of produce is unloaded. At that time, the container can be brought down to the floor of the truck and expanded so that it would be ready to hold the waste oil. This design may require the help of a materials expert to determine how this container could be durable and leak-proof, while still having the ability to collapse and expand.

The solution described above was the team's recommendation. However, team members came up with multiple ideas on how to transfer the waste oil, each with its own advantages and disadvantages. One idea is to carry large containers in the truck, for example 55 gallon drums. The driver would dump the oil from the smaller containers into the large ones, either by mixing all types together or keeping them separate. One major disadvantage of this solution is that the driver might spill the oil when transferring it from the smaller container to the larger one. The smaller container would then have to be thrown away or taken back to the Testa Produce facility. Another idea involved attaching some sort of shelving unit or cabinet to the inside wall of the truck trailer, but upon visiting the Testa Produce facility, the team learned that the side walls of the truck are not very supportive. The idea of using trucks with separated containers was also not pursued further because Mr. Testa currently has 52 trucks, and buying new trucks with separated containers is not economical. One possibility is building a separated section in the back of a few or several of his trucks. This could be done if Mr. Testa's biodiesel production becomes large or if he needs a more permanent way to transport the waste oil.

8.1.3 Storage

In order to run a biodiesel production process, Testa Produce will have to provide storage for waste vegetable oil; other reactants including methanol and potassium hydroxide; and the products which are biodiesel and glycerol. As mentioned earlier, the waste vegetable oil collected from the customers is to be separated by type and put into larger containers, either 55 gallon drums or 375 gallon intermediate bulk containers (IBC) and labeled. Both containers can be stacked, but the larger bulk containers may be a better option since they can be moved easily by forklift, and they have a larger volume than the drums.

Methanol, a reactant, and potassium hydroxide, a catalyst, are both used in the biodiesel reaction and will have to be stored on-site to avoid down time between batches. Potassium hydroxide will be used in relatively small amounts, so it will likely be stored in the containers it is shipped in, which could be smaller plastic containers or possibly 55 gallon drums. Storing methanol is more complicated. There are strict OSHA regulations that deal with storing methanol since it is flammable. For example, methanol must be stored in a grounded container, and there must be no other electrical equipment in the same room. The EPA also regulates the storage of chemicals, but their main concern is to ensure proper storage to prevent leaks that could contaminate the ground and groundwater.

The main product of the reaction process, which is discussed in the following section, is biodiesel. Mr. Testa has already planned where to put the tanks that will store the blended fuel in his new facility, so unless production exceeds the demand for the Testa Produce trucks, no additional storage will be necessary. In the future, as production of biodiesel increases and Testa Produce fleet increases, more or larger tanks would have to be installed. Glycerol, which is the main byproduct of the biodiesel process, will have to be stored on-site until it can be properly disposed of. Since the amount of glycerol made is nearly 200 gallons per week for the basis used in this IRPO, the storage of the glycerol will depend on how it will be disposed of. This will be discussed in a later section. Because hauling of the waste will impact overall process economics, glycerol should be stored on-site for as long as possible to accumulate enough to fill up a waste hauling truck. This may require a large tank for glycerol storage that could be emptied by a waste hauling company. If the chemical plant next to the future Testa facility is willing to accept the waste glycerol, it may be best to keep the glycerol in smaller containers that are easier for Testa employees to move. Once the glycerol is emptied, these containers could be reused for additional glycerol collection.

8.1.4 Biodiesel Production

To understand the production of biodiesel, the following kinetics are included. There are three main reactions that take place, and the methyl ester is the biodiesel product while glycerol is the byproduct. The reaction kinetics is well understood for many oils but not for mixtures of WVOs. For each type of oil, there are different reaction rate constants, k, which effect the time it takes to produce biodiesel.

$$Triglyceride(TG) + Methanol(M) \xleftrightarrow{k1,k2} Diglyceride(DG) + Methyl\ Ester(E)$$

$$Diglyceride + Methanol \xleftrightarrow{k3,k4} Monoglyceride(MG) + Methyl\ Ester$$

$$Monoglyceride + Methanol \xleftrightarrow{k5,k6} Glycerol(GL) + Methyl\ Ester$$

$$\frac{d[TG]}{dt} = -k_1[TG][M] + k_2[DG][E]$$
$$\frac{d[DG]}{dt} = k_1[TG][M] - k_2[DG][E] - k_3[DG][M] + k_4[MG][E]$$
$$\frac{d[MG]}{dt} = k_3[DG][M] - k_4[MG][E] - k_5[MG][M] + k_6[GL][E]$$
$$\frac{d[GL]}{dt} = k_5[MG][M] - k_6[GL][E]$$
$$\frac{d[E]}{dt} = k_1[TG][M] - k_2[DG][E] + k_3[DG][M] - k_4[MG][E] + k_5[MG][M] - k_6[GL][E]$$
$$\frac{d[M]}{dt} = -\frac{d[E]}{dt}$$

*[] = molar concentration and Methyl Ester is the Biodiesel product

Currently, Testa Produce uses 1000 gallons of mixed petro/biodiesel fuel every day. During the summer, which provides the highest temperatures, biodiesel can be mixed with petro diesel in a 20/80 ratio. This means that currently, Testa Produce uses at maximum 200 gallons of biodiesel per day. The team is recommending that Testa Produce use Murphy's Machines for the design of their processor. There were three main reasons for the choice of this company. The first reason being the fact that they have great customer service, including technical support when the processor is up and running and support for any modifications to the process. Murphy's also provides the parts kit that can be purchased with the plans. This would provide all of the sensitive instruments needed to run the processor along with pumps, valves, etc. Murphy's Machines sells plans and equipment for a 500 gallon biodiesel processor. The purchase and construction of this processor will be an initial investment to around $5000 plus cost of storage units for products and reactants. With such a small initial investment, the payback period will be very short, and since the initial capital investment of the processor and containers is relatively low, the dominant economical factor in this process is labor.

The processor can produce 315 gallons of biodiesel per batch, with each batch being completed in about 32 hours. In a week, this processor can produce 1654 gallons of biofuel which will overshoot the current biodiesel demand of Testa Produce. This will allow for downtime to do maintenance and/or the use of poor quality WVO. Poor quality WVO, which may contain impurities or significantly more free fatty acids, has a lower yield of biodiesel than higher quality WVO.

A material balance of the process provides the following amounts of reactants and products. The initial reaction mixture must be fine-tuned based on available WVO. For calculations, a mixture containing 22 % (vol) methanol, 78 % (vol) waste vegetable oil and 36 g KOH/gallon of oil was used.

Reactants		
Waste Vegetable Oil	1470	gal/week
Methanol	367.5	gal/week
KOH (90% Pure)	52	kg/week
Products		
Glycerol	184	gal/week
Biodiesel	1654	gal/week

Table 2: Amount of reactants needed and products produced for Testa Produce's current basis.

The whole process of producing biodiesel from waste oil occurs in four main steps shown in the following figure.

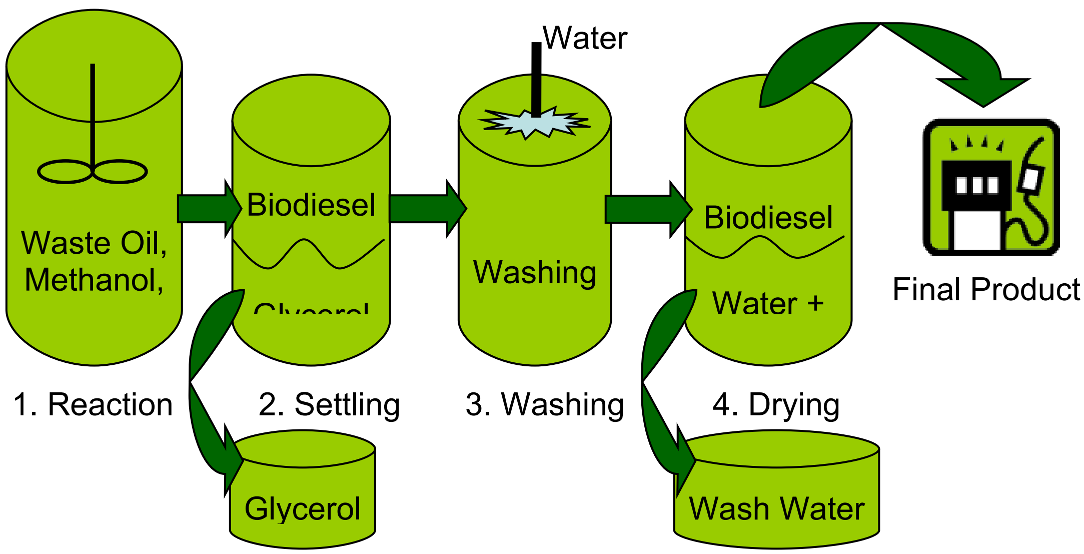

Figure 6: Overall process of making biodiesel.

The first step is the reaction. Waste vegetable oil is loaded into the reactor with methanol and KOH. The mixture is stirred and allowed to react. The reaction is promoted in the direction of the biodiesel product by the catalyst, KOH. Once the process has reached steady state, meaning no reaction is taking place any more, the product is allowed to settle. The byproduct, glycerol, must be removed from the biodiesel. A difference in densities allows the glycerol to settle to the bottom of the tank from where it then can be drained off the bottom. The biodiesel product on the top must then be washed to remove any left-over impurities, which could include glycerol, methanol and any particulate matter contained in WVO. This product must be dried to remove water and impurities. Once the drying is complete, the biodiesel can be mixed with diesel for use in the Testa Produce trucks.

8.1.5 Waste Disposal

The two primary waste materials of the production process described above are wastewater and glycerol. The wastewater, resulting from the washing stage of the process, may contain hazardous chemicals, such as methanol. Pretreatment of the wastewater will most likely be required, but since the exact composition of the wastewater is unknown, further exploration of this topic has been left as a recommendation for a future IPRO. If the concentration of methanol is negligible, the wastewater may be released into a drain and into the sewer system. Since Mr. Testa already has plans to have a lagoon on his property near the new facility, it may be possible to release the wastewater into the lagoon for natural treatment.

The team looked into two main options for glycerol disposal. Since glycerol is abundant, it would be difficult to sell glycerol created from the biodiesel process because it will be contaminated with methanol and lye. The first option the team considered was hiring a waste hauling company to pick up glycerol bi-weekly or monthly, depending on the quantity of glycerol produced, and haul it to the local wastewater treatment plant. One of the team members spoke with some employees at the wastewater plant, and they agreed that they would be able to accept glycerol, which they would use as substrate in their biological reactors. The second option was suggested by Mr. Testa, and is a more profitable option if an agreement can be reached with the chemical company next to the future site of the Testa Produce warehouse. A chemical company is currently located next to the site that Mr. Testa plans to build his new facility. This company has expertise in producing and selling glycerol. If arrangements could be made for the chemical company to accept Testa Produce's waste glycerol to purify and sell, Mr. Testa would save money on its hauling.

8.2 Objectives Met and Not Met

The team had initially planned on performing an extensive economic analysis of the process. Since the contact with the sponsor occurred during the semester and was limited throughout the semester, there was not enough time to reach this goal. Although the reactor design was started using the software Matlab, since biodiesel production kits are currently available, the team felt that providing Testa Produce with the information on the kits would be more useful as the building of the new Testa facility is likely to be completed within the next year. Based on the project assigned to the team, process optimization using lesser-known catalysts and unusual operating conditions was not the primary focus of this IPRO as thought at the beginning of the semester.

8.3 Ethical Issues

A complete code of ethics created by the team is found in section 7. A few ethical concerns encountered when conducting research included proper resource citation, no false representation, taking into account OSHA and EPA regulations and obtaining permission from companies to present their information and pictures. All sources are listed at the end of this document in section 11, and proper acknowledgements were given in the final project presentation on IPRO day. When contacting companies about biodiesel equipment or other related information, the team members did not represent themselves falsely. When speaking with any company or organization about the project, all members referred to themselves as students who are part of a research team. Safety and permits were studied throughout the semester for many of the project steps, and this included researching many OSHA and EPA regulations and guidelines. Regulations related to methanol storage and process safety are the most strict and most important. Lastly, when the presentation was given on IPRO day and the posters were displayed, proper credit was given to the sources used.

9. Obstacles

The initial obstacle for IPRO 316 was the ambiguity of the problem statement. The problem simply asked that an alternative fuel process be studied and refined from a chemical engineering and economics perspective. Due to the sheer variety of alternative fuels, even the subdivisions of bioethanol and biodiesel, the group did not know how to begin to tackle the gargantuan task. Eventually, the team split into two factions with one focusing on biodiesel and the other on bioethanol. Weekly presentations were held to keep the two groups informed, but it was not until the IPRO acquired a sponsor that a clear vision and united goals for the team became a reality.

With the acquisition of a sponsor came a whole new collection of problems. Initially the company was very helpful and had a clearly defined problem with obtainable goals. As the semester progressed, contact with the sponsor diminished and became an issue. The company was slow to respond to emails, and it became very difficult to extract meaningful information from representatives, hindering the progress of every team member. It was not until a week and a half before the IPRO day that a trip to the Testa Produce facility was scheduled. This meant that the group had only one week to incorporate new information and revise proposed solutions in order to have the deliverables in by the deadlines.

Another issue, especially in the latter half of the semester, surfaced when the team needed to contact third parties. When pricing reactors and materials, students needed to contact other companies for their information and policies. Team members could not represent themselves falsely as potential buyers, so acquiring pricing and information became a much more difficult task. Naturally, most of these companies did not have much time for undergraduates working on a school related project. Thankfully, Murphy’s Machines and Utah Biodiesel Supply answered the calls of frustration and helped guide the teams along with general biodiesel information, reactors, and pricing. These companies were very helpful to the students, and their generosity is greatly appreciated.

Perhaps the biggest obstacle of all came from the IPRO itself. The team consisted of 24 students, with varying backgrounds. The IPRO team consisted of computer science, mechanical engineering, biology, biochemistry, and chemical engineering majors. The different fields allowed for additional viewpoints, but it also hindered progress, since information specific to one field had to be explained to students in other fields. This issue swiftly became a major hindrance, since 15 of the team members were chemical engineering sophomores and greatly outnumbered the five chemical engineering seniors. Because the levels of experience varied wildly from person to person, careful planning was utilized to ensure that enough experienced students were in each subgroup. Overall, progress was slowed by the size of the IPRO, but thanks to exceptional management skills from group leaders, deadlines were met with quality deliverables every time.

10. Recommendations

During ensuing semesters, there are possibilities for furthering the goals of this IPRO, which could be achieved during a continuing IPRO. In order to better suit the goals of our sponsor, Testa Produce, we should first consider taking a survey of their restaurant/hotel customers, to see whether the possibility of producing the biodiesel on the scale that is desired is possible. This survey could also tell the IPRO team and Testa Produce what could be done differently to make it easier for the customers to prepare the waste oil for collection. Following the survey, the next step would be looking into prototyping the biodiesel process and the transportation system, and developing a prototype system that models Testa Produce's objective to produce high quality biodiesel simply and efficiently for use in their trucks. Another possibility for a future team would be to actually build and run a small-scale biodiesel process on the IIT campus. This way, production problems, methods and yields could be studied and reported to Testa Produce before the larger scale process is implemented. Another benefit of the pilot plant on the IIT campus would be to study the content of the wastewater produces from the washing process and determine what kind of pretreatment will be needed, if any.

The real system to be used to produce biodiesel on a large scale should include an adequate training manual for the drivers of Testa Produce trucks, but also for the producer of biodiesel on how to produce the fuel in sufficient quantity and troubleshoot problems in the process. That system should also contain a way to adequately mix diesel with biodiesel, which provides fuel which has a low enough gel point for the severe Chicago winters. In order to correctly plan the real system, the actual design and construction of the reactor and containers to be used will have to be an integral part of the IPRO. This will generate concise and accurate information to meet the goals of Testa Produce and the IPRO.

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