

IPRO-337

## Zero Energy Lab

Advisor: Nancy Hamill Governale

Final Report

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## 1. Abstract

Most of the energy we consume today is produced from non-renewable sources which take million years to form such as fossil fuels. IPRO 337, Zero Energy Lab is a project addressing this issue and devising unique solutions for generation of power on the 4<sup>th</sup> floor Machinery Hall. The main purpose of this project is to design a universal format for occupying laboratories that utilize minimal amount of energy. Previous semesters have done extensive research on alternative energy and energy storage. This semester we focused on a new topic, which is designing a biofuel system to supply additional energy to the lab for future use. We also focused on designing a lighting system to illuminate the Zero Energy Lab during non-daylight hours.

## 2. Background

Our professor, Nancy Hamill Governale, is supporting this IPRO and brings in outside companies who support the Zero Energy Lab with product samples and technical expertise. Her company, Facilities Persaeas Inc., provides the lab manager for the Zero Energy Lab, maintaining the PV array and battery bank, and develops new technologies that can benefit the ZEL and the general population.

The Zero Energy Lab is a project, which addresses the issue of the consumption of varying forms of non-renewable resources. It is an effort to strike a balance between energy consumption and energy generation. IPRO 337 is focused towards the development of a Zero Energy Lab station situated on the 4th Floor of Machinery Hall. The station would function independently from the energy supplied by the main grid, which dictates the energy supply of the campus. The main goal of IPRO 337 is to devise solutions for power generation that could be implemented in the workspace of Machinery Hall. The Zero Energy Lab would be dependent on the sources of energy but not on the forms of energy. In the past, many teams have been working towards this goal through the use of various technologies such as solar thermal heating, a mobile energy cart, a mechanical window ventilation system, wind turbines and a hydrogen fuel cell hybrid system.

Previous semesters of IPRO 337 researched three types of lighting technologies for the design process. There were conventional fluorescent, incandescent lights, and

light emitting diodes (LED). Due to the inefficiency of incandescent lights, previous teams decided to use both fluorescent and LED lights. Their proposal included the testing of light scooping in a small section of the workspace in Machinery Hall. The scoop was used for the reflecting sunlight from the upper windows onto the floor, therefore maximizing the useable light.

This summer, the team was divided into two sub teams; one sub team designed approaches for power generation through biomass, while the other sub team designed an efficient lighting system for an existing 6000 sq ft space. Extensive research was conducted and a working model of a biomass generator was designed to minimize the consumption of fossil fuels and shift the focus towards eco-friendly materials. The use of daylight sensors and motion sensors was also explored in order to minimize the energy consumption of the space, while also taking into account the use of reflective materials like: photo-luminescent paint and glass beads.

### 3. Objectives

#### Lighting

The main focus of the lighting sub-team was to install a lighting system in the Zero Energy Lab to illuminate the lab in the non-daylight hours. During the daylight hours, the lab is properly illuminated by natural light.

The team wanted to test different materials and determine which material scatters light most efficiently. We then tested different types of light fixtures so the fixture that produces the highest intensity and the lowest wattage could be used. Finally, determine which light fixture worked best with the angle of the Zero Energy Lab ceiling and the applied material to create the most amount of intensity.

#### Biofuel

The main focus of the biofuel sub-team was to figure out another way to be more self sufficient with the space in the Zero Energy Lab. The sub-team looked into what the previous years have completed and one of the main topics that were not investigated yet was biofuel. The team's objective was to design and propose a biofuel system that would supply additional energy needed to the existing battery bank.

## 4. Methodology

### Lighting

The Lighting Sub-Team researched and brainstormed an assortment of lighting types and materials. Examples include various halogen, fluorescent, and LED lamps and light fixtures, as well as white paint, photoluminescent paint, glass beads, and projector screen materials. In addition, lighting techniques, such as diffusing, reflecting, and directing light were looked into. It was concluded that using a combination of LED lights and a white painted surface coated with glass beads would be the best option for the Zero Energy Lab.

The first task for the lighting team was to find the constraints of the Zero Energy Lab space. Based on the limitations, the team concluded that the best option would be to find a material that can diffuse the light produced by an LED or DC fluorescent source.

The next step was to create a facsimile of a section of the Zero Energy Lab (Figure 1). There were 5 different roofs on the model, and each was coated with white paint, white paint with glass beads, photoluminescent paint, projector screen material, or the opposite side of the projector screen material. The team tested each roof section with a fluorescent lamp and a HOBO rendering device mounted inside the model. Every 30 seconds, the HOBO device recorded the light intensity inside the model. Each roof was tested for 10 minutes. Furthermore, a DC fluorescent and LED light fixture was tested with white paint and white paint with glass beads using the HOBO device to measure light intensity.



**Figure 1: The roof model**

Since the white paint and white paint with glass beads with LED light turned out to be the best options, the team began to paint a section of ceiling in the lab with a few coats of primer and white paint. The team also purchased, painted, and coated insulating boards with glass beads and white paint. The team tried to mount three boards of glass beads coated in white paint to the ceiling, but only one board was successfully mounted due to the height. Using various LED light fixtures donated from IO Lighting, the team tested the white coated ceiling and the insulating boards coated with glass beads at night. An optimal position and placement of each fixture was achieved.

### Biofuel

The Biofuel Sub-Team researched several biofuel technologies, including biomass conversion, biodiesel production, and using vegetable oil directly in a diesel generator. After assessing the needs of the lab, it was decided that using vegetable oil directly in a diesel generator was the most feasible option. The building of a biodiesel production lab further down the road is also recommended, and the information for both systems is laid out in the team's project notebook.

At the beginning of the semester, the team took a trip to Loyola University to better understand biodiesel production by observing their existing system. Shortly thereafter, the concept of using vegetable oil directly in a diesel generator to obtain power was brought to the team's attention. The system requires fewer components, has no by-products, and doesn't require harmful chemicals to produce. Thus, it was chosen over biodiesel production.

Since both biodiesel production and the vegetable oil system need to be heated significantly, the idea of incorporating solar thermal arose. This particular technology has been researched by previous installments of this IPRO, and there is an existing flat panel solar thermal collector available. Unfortunately, this particular design of collector doesn't provide quite enough heat for the system, so evacuated tube collectors were researched. The system was designed using the evacuated tube solar thermal collectors to heat the oil, which will be discussed later in the Results section.

One of the possible locations for the system is in the Co-Generation (Co-Gen) Facility. The team has received permission from the parent company, so long as safety concerns are addressed before further action. After a visit to the site, the idea of using

waste heat from the boilers arose. A second design of the system using steam from boilers was drawn up. Another idea was to use the condensed steam once it reaches the condensate tank. This particular idea will need to be researched more in-depth if this project is continued.

## 5. Team structure and Assignments

The IPRO team was broken into two smaller teams throughout the semester, and each team member was given various tasks to accomplish within that sub-team. Furthermore, certain individuals were responsible for other tasks that were not part of any specific sub-team.

### Biofuel

Sub team leader, Nicole Karns, MBB

Vaibhav Gupta, EE

Neha Padwal, BME

Priyanka Patel, ARCH

Michael Yee, AE

### Lighting

Sub team leader, Lidens Cheng, PHYS

Lauren Gillmeister, BME

Mayra Vega, ARCH

Jason Walker, ARCH

Rachel Walker, CS

Certain tasks were given in the beginning of this semester:

Minute Taker, Rachel Walker

Agenda Maker, Priyanka Patel

Time Keeper, Priyanka Patel

Summarizers, Lidens Cheng and Nicole Karns

Master Schedule Maker, Lidens Cheng

iGroup Manager, Neha Padwal

As a whole we worked excellent as a team. When research needed to be done, we all worked together to find what we needed. When we had to build or paint we all worked together to get the job done. We also went on field trips as a team to learn from our precedents.

## 6. Budget

<u>Item</u>	<u>Unit Price</u>	<u>Quantity</u>	<u>Price</u>
White Paint	\$25	1	\$25
LED Light Fixture	\$300	1	\$300
Photo Luminescent Paint (1/2 pint)	15.00	1	15.00
Projection Screen	\$40	1	\$40
Paint Brushes (3 piece set)	\$9.97	1	\$9.97
Paint Roller/Roller Frame/Tray (6 piece)	\$ 17.97	1	\$17.97
Tarp	\$13.98	1	\$13.98
Tray	\$0.64	3	\$1.92
Screws (box)	\$10	1	\$10
Nails (box)	\$6	1	\$6
Insulating foam and other materials	\$23	1	\$23
Spray Adhesive	\$7	1	\$7
Loyola Trip	-	-	\$15
Smart House Trip	\$10	8	\$80
		Total:	\$564.84

## 7. Code of Ethics

The overarching standard that governed IPRO 337 was the safety of the members involved this semester and the semesters to come. In addition, the team expected all members to attend the meetings, complete designated tasks, be punctual with meetings and tasks, abide by IIT's code of conduct concerning research and experimentation, credit

external sources, respect other members of the team, and communicate with the rest of the team when problems arise.

Since the Zero Energy Lab will be made readily available to IIT when it is completed, the team made sure to keep the IIT community in mind when installing new additions to the space. The biofuel sub-team met with the Loyola University Biofuels Lab Director and discussed ways in which we can develop a biofuel system for the Zero Energy Lab. We were informed of problems that we may encounter and ways to handle such problems. We also visited the CoGen Facility and discussed possible locations since the development of a biofuel system would require multiple inputs from different departments of the IIT community.

The lighting sub-team communicated often with our advisor, Nancy Hamill-Governale, and received great recommendations on the different kinds of lights and materials to test out. Nancy also helped them attain samples and materials. The relations among the sub-teams and the relation between the two sub-teams, and our advisor were always civil and respectful. The lighting sub-team had to deal with the fact that one of its team members, Rachel Walker, was not available for the last week. The sub-team handled the situation well since Rachel informed the team ahead of time and the sub-team worked around this. Communication was kept open throughout the entire semester and this helped keep the team on task and on schedule.

Since safety is our paramount standard, both sub-teams kept it as their number one priority. The biofuel sub-team made sure that the biofuel system that they developed was as safe as possible and addressed different safety precautions. In addition, the lighting sub-team strongly recommended that future teams find a way to organize LED fixture wiring in order to keep the space safe.

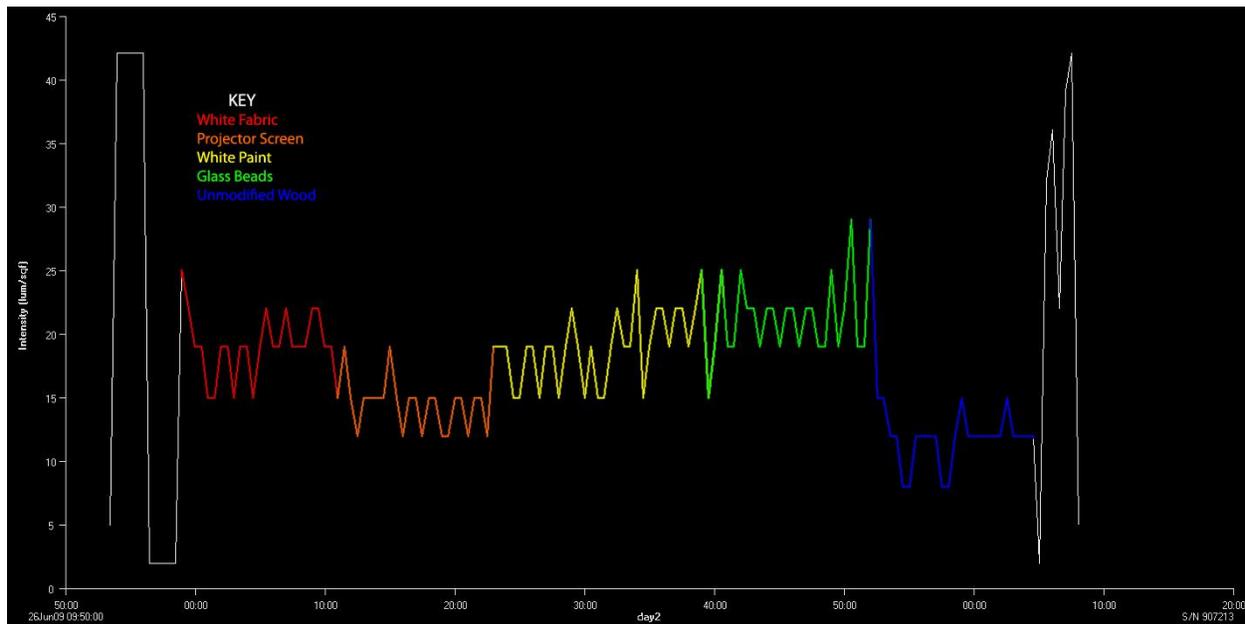
## **8. Results**

### Lighting

After becoming familiar with all of the current energy technologies utilized in the space, the team decided that the lighting system would have to maximize the amount of

lumens per square foot per watt. Thus, the team concluded that the best technique would be to diffuse the light so that one fixture could be used to light a larger area of the lab.

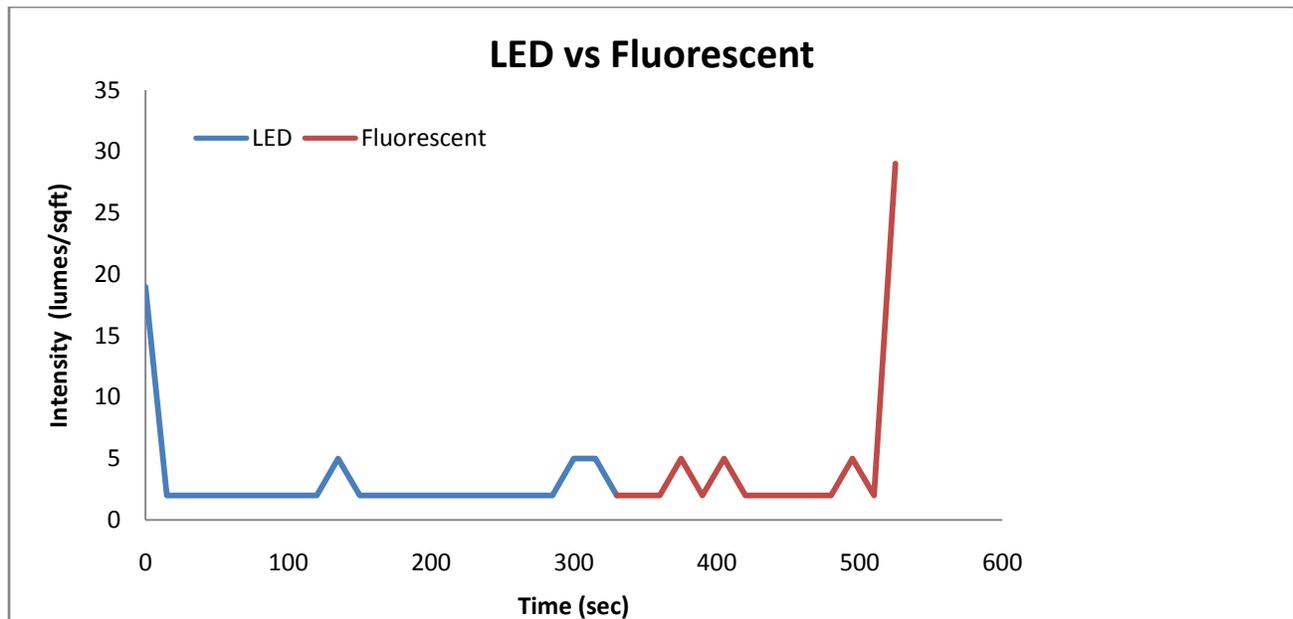
The results show that the intensity of the white paint and the white paint with glass beads are close (Figure 2). There is only a slight difference between the two materials. Although said spikes can be interpreted as negligible, it must be noted that the differences might be more noticeable on a larger scale, thus the team chose to use the glass beads.



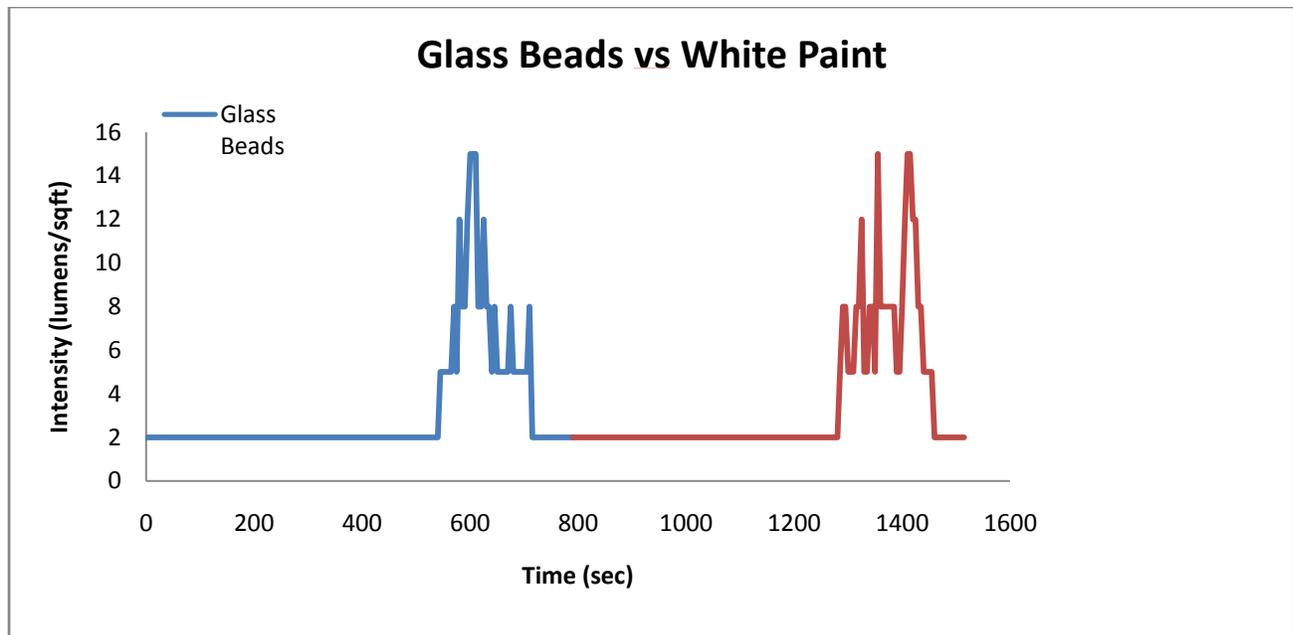
**Figure 2: Light Intensity Test for Roofs**

The Zero Energy Lab's main source of electricity is through the photovoltaic (PV) panels mounted on the roof. In order to convert the DC power from the PV panels to AC power used by most technologies, an inverter is necessary. Unfortunately, a lot of power is wasted in the inverting process. Since lighting, especially in winter months, will need to last longer, it was decided to use DC light fixtures. In order to power DC fixtures, electricity can be taken directly from the battery bank, thus saving the energy lost through the inverting process. Using a HOBO device, the comparison between a DC fluorescent fixture and a DC LED fixture are similar (Figure 3). However, the fluorescent fixture was 4W and the LED fixture was 3W. In addition, the LED light fixture visually outperformed the fluorescent fixture since the light from the LED fixture was more

uniform, appearing much brighter to the eye. Testing the LED fixture with white paint and white paint with glass beads yielded similar results (Figure 4). The white paint coupled with the LED light showed a higher number of peaks of greater intensity. However, since only one out of three insulating boards was successfully installed, the light intensity of the LED upon the glass beads was similar to that of LED upon white paint with a much smaller area. Therefore, the team chose to use LED lights with glass beads on a white painted surface.



**Figure 3: LED vs Fluorescent**



**Figure 4: LED on Glass Beads vs. White Paint**

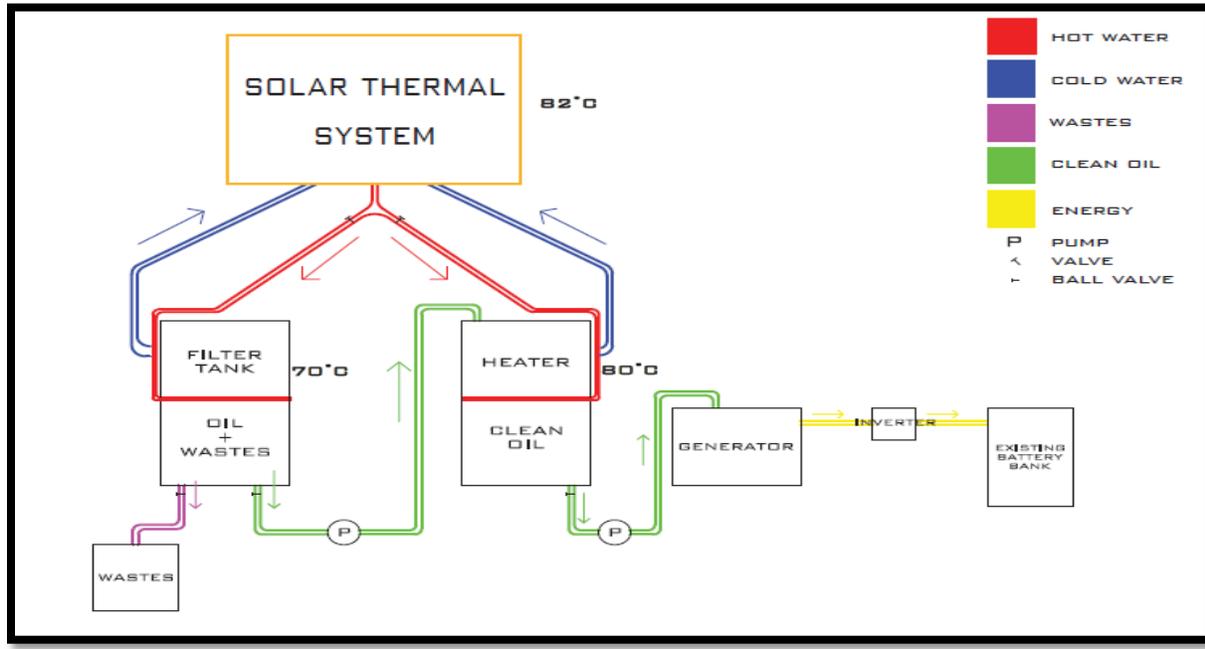
After coating the ceiling of the Zero Energy Lab with white paint, the team visually tested the light intensity of several different LED light fixtures in several different positions. It was concluded that the optimal position was underneath the window, and the preferred angle was based on the individual light fixture.

### Biofuel

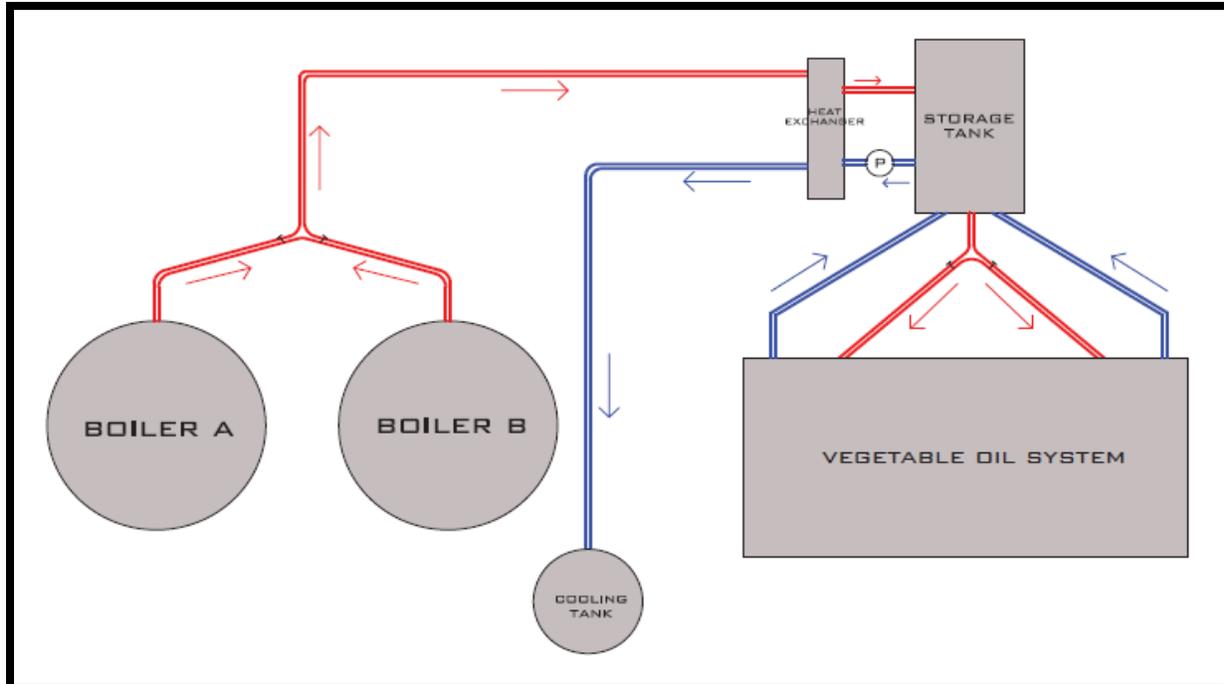
Research shows that using vegetable oil directly in a diesel engine is plausible. The only requirements are that the engine start and finish on diesel, and that the oil is heated to at least 80°C. There are plenty of sources verifying this for car engines, and even a few for diesel generators.

The team designed two systems. The first (Figure 5) uses a solar thermal system to heat the vegetable oil, and the second (Figure 6) uses waste heat from boilers at the Co-Gen Facility. The only difference between the two lies in the method of heating. The system itself remains the same. Basically, the waste vegetable oil is heated to at least 70°C, at which point the oil will become lighter, allowing waste particles left over from the cooking process to sink to the bottom. These are drained off and taken to the same rendering company that would have taken the waste oil initially. What's left is mostly clean oil, which is pumped through a filter to a second tank. Here, the clean oil can either

sit and wait until it's needed or be heated right away to be used in the generator. The generator needs to run for about ten minutes on diesel before the oil is added, but after the oil is added, it can run for however long it's needed. Once finished, the generator needs to finish with another 10-15 minutes of diesel to flush any remaining oil out.



**Figure 5, Diagram of the Vegetable Oil System using Solar Thermal Heat Collectors.**



**Figure 6, Diagram of the Vegetable Oil Biofuel System using waste heat from the boilers at the CoGen facility.**

The team succeeded in meeting most of its objectives. It was unfortunate there was not enough time to build the prototype, but the parts and design are laid out for the next team to work on if they so choose.

## 9. Obstacles

This IPRO was originally designed around the “sustainability of brick.” It was our advisor’s intention to hold hands-on sessions with brick experts, to learn how to tuckpoint and clean bricks. This was to have been done in addition to continuing the mission of the ZEL. Because of campus operation obstacles, we were not able to physically improve the ZEL space to a desired level. The team re-focused quickly to take full advantage of the semester’s time frame.

### Lighting

The main obstacle of the lighting sub-team was determining which combination of materials and type of lights dispersed light most efficiently. Other minor problems were: creating a scale model of the Zero Energy Lab and transporting it to the fourth floor

of Machinery Hall, determining how to paint the ceiling, and attaching boards to the full ceiling panel.

### Biofuel

The main obstacle of the biofuel sub-team was to develop an energy efficient method for heating along with it being efficient. With the design of the system liability issues became prevalent with its feasibility.

## **10. Recommendations**

### Lighting

Lighting is a necessity in the space, and so far one panel was placed on the ceiling. We suggest painting the rest of the space white and applying glass beads to maximize the amount of light penetrating the Zero Energy Lab. Also a decision needs to be made on which LED fixture is most energy efficient and is best suited for the space. We suggest that a light sensor and dimmer switch are put in place. This will help save even more energy by further controlling the amount of the light that enters the space. There will be a lot of wiring and not many areas to conceal it all, which brings another problem. We need to figure out a way to neatly organize the wiring of the LED system. And finally, one of the more important concerns is to figure out a way in which the LEDs used run on DC as opposed to AC. The conversion from DC to AC results in a loss of energy.

### Biofuel

We wanted to design a system that would enable us to expand the already existing battery bank for the space. Though the design portion is complete, it is schematic and theoretical. Testing the system is critical to know the quantitative reality of each component. A few things to consider are how much diesel is required to run the generator, how hot the oil needs to be, and where the line exists between producing the maximum energy vs. wasting it. Though the generator is capable of running on heated vegetable oil, the diesel is needed to clean out the system before and after injecting the vegetable oil. We predict that about .5 oz is needed, but will not know until that is tested. Based on our research, we found that the oil needs to be heated to 80 degree Celsius, depending on what system is decided to use, it is important to calculate how hot the oil

can get before energy is wasted. Also heat is lost through the process, so the heated oil needs to account for that. Finally, we need to find out how much energy the proposed system is able to produce and determine whether it is feasible to add it on to the battery bank, in both energy and cost perspectives.

Location is a major obstacle with this system. We recommend looking more into the CoGen facility because there is plenty of space, roof access, and the potential to use the boiler system. Also the biodiesel production lab has the potential to be built there and we recommend building one. The technology already exists and there is plenty of information available. Either a kit can be bought or the individual parts can be purchased depending on the availability of time and funding. As mentioned, diesel is needed to start up the generator, so why not produce our own?

The need for biofuels at the Zero Energy Lab is the energy developed from vegetable oil or biofuel. Once the prototyping testing is done, a diesel generator can be placed on the first floor of Machinery Hall or on the roof. Fuel delivery to the first floor is easier since we have been working without an elevator for the past two years. Repair of the elevator has not been scheduled.

## 11. References

### Lighting

- "Energy-Efficient Lighting." *Eartheasy - Sustainable Living*.  
<[http://www.eartheasy.com/live\\_energyeff\\_lighting.htm](http://www.eartheasy.com/live_energyeff_lighting.htm)>.
- "HowStuffWorks "How Light Emitting Diodes Work"." *Howstuffworks "Electronics"* <<http://electronics.howstuffworks.com/led.htm>>.
- "Third generation Photoluminescent paint: Re-Light." *Metal Safe Sign Int*.  
<<http://www.mss-int.com/prod01.html>>.

### Biofuel

Most of our research were acquired from the following book:

- Schaeffer, John. *Real Goods Solar Living Source Book-Special 30th Anniversary Edition: Your Complete Guide to Renewable Energy Technologies and Sustainable Living*. New York: Gaiam Real Goods, 2007

Aside from that, we took a couple of trips to Loyola University to visit their Biofuels Lab and to obtain the parts list to their biodiesel system.

## 12. Resources

We did not keep a log of timesheets, but we created a “time availability” chart in which each team member provided the time whenever they are available additional to the regular class timings.

Both Biofuel and Lighting team had brainstorming sessions once a week. Each member of a biofuel team spent roughly around 2-3 hours each week outside the class. We assigned work among team members, which included extensive research on biodiesel and vegetable oil system. Lighting team put in a lot of effort and time in building create a model which is supposed to be a facsimile of the section of the roof at the Zero Energy Lab. They also painted the roof with different combinations of white paints, glass beads, photo luminescent paint, and projector screen material. They spent around 5-6 hours each week outside the class.

Additional time and effort had been put in for the deliverables produced by both the lighting and the biofuel sub-teams.

## 13. Acknowledgements

We would like to say thank you to the following people that provided some guidance to our IPRO Project:

- Nancy Hamill Governale - Faculty Advisor
  - We all like to thank our faculty advisor, Professor Nancy Hamill Governale, for her devotion to the mission of IPRO 337, Zero Energy Lab. Her expertise and enthusiasm inspires us all.
- Zack Waickman - Loyola University Biofuel Lab Director
  - We thank Zack Waickman for giving the entire team a tour of his biofuel lab and providing us guidance to help us design our own biofuel system.
- Geno Gargas and Loren Bo - Zero Energy Lab Technicians

- We thank Geno Gargas and Loren Bo for their support during this semester.
- Bridget Ford - IO Lighting
- Dave Perske - KSA Lighting
  - We like to thank both Bridget Ford and Dave Perske for donating a few LED lighting fixtures to aid the lighting team in their model experimentations.
- Chuck Bessler - CoGen Plant Manager
- John Bullo - CoGen Operator
  - We like to thank both Chuck Bessler and John Bullo for giving us a tour of the CoGen Facility and their efforts to help us find and reserve an area for our future biofuel systems assuming liability issues are resolved.