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Integrating Freshmen into Exploring the Multi-faceted World of Engineering and Sustainability through Biofuels Synthesis from Waste Cooking Oil

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A Malaysian native, Laura-Ann Chin attended the University of Arizona where she completed her B.Sc. in Chemical Engineering. Throughout her undergraduate career, Laura has worked with numerous cutting edge projects including studying endocrine disrupting compounds in wastewater, researching genetic stability of E.Coli in a novel COSBIOS reactor (RWTH, Aachen Germany) and designing an automated zebrafish tracking system using MATLAB (STUBA, Bratislava, Slovakia). Laura performed her graduate studies at Villanova University where she obtained her M.Sc also in Chemical Engineering. Her graduate thesis work involves the characterization & upgrading of biocrude-oil from waste lignocellulosic biomass at Villanova's Chemical Engineering Biomass Conversion & Research Technologies Laboratory under Dr. Justinus Satrio. Currently, Laura is a process engineer for Jacobs Engineering where she is involved in the design of biopharmaceutical facilities.

____ Dr. Justinus Satrio's Biography

Dr. Justinus A. Satrio is an Assistant Professor of Chemical Engineering at Villanova University, Pennsylvania. He earned his B.S., M.S. and Ph.D. from Iowa State University. He also has several years of industrial experience as a chemical processing engineer. Originally from Indonesia, a country blessed with biomass resources, Dr. Satrio's research passion focuses on developing technologies for utilizing biorenewable materials to produce energy, fuels, and chemicals that decrease society's dependence on non-renewable resources. His research area specializes on non-catalytic and catalytic thermochemical processes, such as fast pyrolysis and gasification to convert lignocellulosic biomass into chemicals and liquid fuels. Past and present research projects that Dr. Satrio have been involved include biomass pretreatment and characterization, fundamental studies on fast pyrolysis, characterization of fast-pyrolysis products, catalytic upgrading of fast pyrolysis oil to produce hydrogen, conversion of syngas to liquid fuels via Fischer-Tropsch-type synthesis, engineering bio-char for soil quality enhancement, and technoeconomic evaluation on fast pyrolysis and gasification-based biorefineries. From his work, Dr. Satrio has authored over 20 publications. Through Dr. Satrio's work and research in chemical engineering education, he has made contributions in the development of innovative laboratory experiments and curricular materials related to biorenewables, biofuel synthesis and sustainable engineering.

____ Dr. Kenneth A. Kroos

Dr. Kenneth A. Kroos is an Associate Professor of Mechanical Engineering at Villanova University. He has a B.S., M.S., and PhD in Mechanical Engineering from the University of Toledo. He taught for five years at Christian Brothers College in Memphis, Tennessee, served as Student Section Advisor and Chair of the Memphis-Mid-south Section of ASME. Dr. Kroos joined Villanova University in 1982, teaching courses thermodynamics, fluid mechanics and several others. He serves as Assistant Department Chair for the Mechanical Engineering Department, has authored more than fifteen publications in the fields of fluid mechanics, heat transfer, engineering education and computer graphics for flow visualization, performed research in computer graphics for the U. S. Army Ballistics Research Lab, and consulted for a number of companies in the Memphis and Philadelphia areas. Dr. Kroos is a Fellow of the American Society of Mechanical Engineers (ASME) and a member of the American Society for Engineering Education (ASEE). He served as Vice President of ASME in 2001 and served a three year term on the Council for Member Affairs. Dr. Kroos is the co-author a new engineering textbook on thermodynamics, titled Thermodynamics for Engineers, published by Cengage Learning. The book becomes available in February 2014.

Dr. Justinus Agus Budi Satrio, Villanova University

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Dr. Kenneth A. Kroos, Villanova University

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Abstract

Solid first year courses are building blocks in helping a freshman navigate through and discover a new major. It is imperative for a freshman to be exposed to different engineering disciplines to experience first-hand the expectations and variations among them. Villanova University's College of Engineering has strategized this teaching opportunity through a series of 7-week-long freshman mini projects, designed to introduce different engineering majors in the first two-semesters of mandatory freshman engineering courses.

This paper focuses on the Biofuels Process and Sustainability mini project, which started in the Fall 2011 semester. This project was developed with the idea of exposing these young engineers to the latest advancements and technological developments in our society. In response to the need for decreased dependence on fossil fuels and other non-renewable energy sources, the concept of bioeconomy is introduced and emphasized. Through bioeconomy, vital sources of carbon and energy are obtained from biorenewable materials such as biomass. The need to embrace this transformation from non-renewables to an era of bioeconomy should be more important than ever if a significant change is to happen. Through this Biofuels Process and Sustainability mini project, freshmen are exposed to two fundamentals evolving around bioeconomy: the production process of liquid transportation fuels from biorenewables and the sustainability issues surrounding biofuel production and utilization. Specifically, the goals of this mini-project are to challenge freshmen to utilize basic engineering and chemistry principles in synthesizing and characterizing biodiesel made from a renewable resource such as waste cooking oil, to interpret and analyze experimental data in scaling up to a biodiesel processing facility and finally to assess the overall sustainability of the biodiesel production process.

Overall, the freshman mini projects come together to better prepare young engineering students to have an appreciation for engineering design and development in the world around us. This course not only introduces the fundamentals of basic engineering principles, but also proactively engages students to perform design experiments while challenging them to come up with a conclusion of their own. Through this multi-disciplinary introductory course, these mini projects will seek to provide a platform for a successful undergraduate engineering career.

Background

Well-designed first year experience courses are mainstays in the curriculum for freshman engineering students, as well as for freshmen in other fields. Solid first year courses are building blocks in helping a freshman navigate through and discover a new major. It is imperative for a freshman to be exposed to different engineering disciplines in order to experience first-hand the expectations and variations among them.

Many high school students considering engineering as a major have been equipped with experience in robotics and various software packages. Previously, students transition right into the classroom and are grinded with mathematics and engineering fundamentals at a university. However, newer students do not work that way. They need a reason and motivation to buy into an engineering education, thus an inviting and creative approach is needed early on. For a course to be successful, students need to see the relation of course material to things that interest them or to the careers they are preparing themselves for[1]. While passive learning is often a method used to impart knowledge on a student, active project based learning has consistently demonstrated the most effective way for a student to retain information. In an active learning during a class session, all students are invited to do other than simply listening, watching and taking notes[2].

Villanova University's College of Engineering has strategized this inductive teaching and learning opportunity through a series of freshman multidisciplinary engineering projects and mini-courses. In inductive teaching and learning, students are the center of the learning process. In other words, the students are given more responsibility for their learning process[3]. The freshman mini project is structured as part of a two-semester program that gives all Villanova University's freshman engineering students a multidisciplinary experience in engineering analysis, design and research.

Figure 1 shows the timeline of a typical freshman engineering program at Villanova University's College of Engineering. In the first semester, this freshman engineering course begins with a seven-week core lesson plan incorporating engineering fundamentals alongside dynamic hands-on group micro-projects that bring classroom lessons to life. Following the core lesson plan, students are presented with the opportunity to select two of six interdisciplinary, 7-week hands-on mini projects. These mini projects that span the second half of the first semester and the first half of the second semester have been designed to expose students to a minimum of two different engineering disciplines. By mid second semester, students select their preferred engineering discipline and spend the remaining seven weeks in the chosen disciplinary field. With the knowledge and experience gained from the core lesson plan and two mini-projects, students should be better equipped to make a more informed decision on their engineering major of choice.

The freshman multidisciplinary projects are constantly updated to include the latest research and studies in the engineering world. The general categories of these projects evolve around: 1) Sustainability/Energy/Environment, 2) Infrastructure and Systems, 3) Robotics 4)

Interfaces 5) Materials 6) Engineering and Business. Every academic year, six distinct mini courses are selected from a pool of engineering projects in which they are rotated biennially. Figure 2 depicts the six projects offered in the academic year of 2011/12 and 2012/13. Each of these freshman mini projects was designed to incorporate a multidisciplinary engineering aspect.

Biofuels Process and Sustainability Mini Project Course

One of the six multidisciplinary freshman engineering projects is the Biofuels Process and Sustainability mini project, which started in the Fall 2011 semester. This mini project was developed with the idea of exposing young engineering freshmen to the latest changes in society. In response to the need for decreased dependence on fossil fuels and other non-renewable energy sources, society is slowly transitioning into an era of bioeconomy. Through bioeconomy, vital sources of carbon and energy are obtained from biorenewable materials such as biomass[4]. The need to embrace this transformation from non-renewables to an era of bioeconomy should be more important than ever if a significant change is to happen. Until our transportation systems are no longer energized by liquid fuels, we will continue to be dependent on carbon-based resources. Thus, it is crucial that the future generation, namely students embrace this transformation. For this to happen, students first need to learn about the various aspects of bioeconomy.

Through this Biofuels Process and Sustainability mini project, freshmen are exposed to two fundamentals evolving around bioeconomy: the production process of liquid transportation fuels from biorenewables and the sustainability issues surrounding biofuel production and utilization. Specifically, the goals of this mini-project are to challenge freshmen to utilize basic engineering and chemistry principles in synthesizing and characterizing biodiesel made from a renewable resource such as waste cooking oil, to interpret and analyze experimental data in scaling up to a biodiesel processing facility and finally to assess the overall sustainability of the biodiesel production process. In the past several years, the concept of sustainability has become an important issue, driven by societal attention to environmental concerns. As a result, sustainability principles have been incorporated into engineering research and education in many universities, motivated by the increased funding for research in sustainable engineering[5].

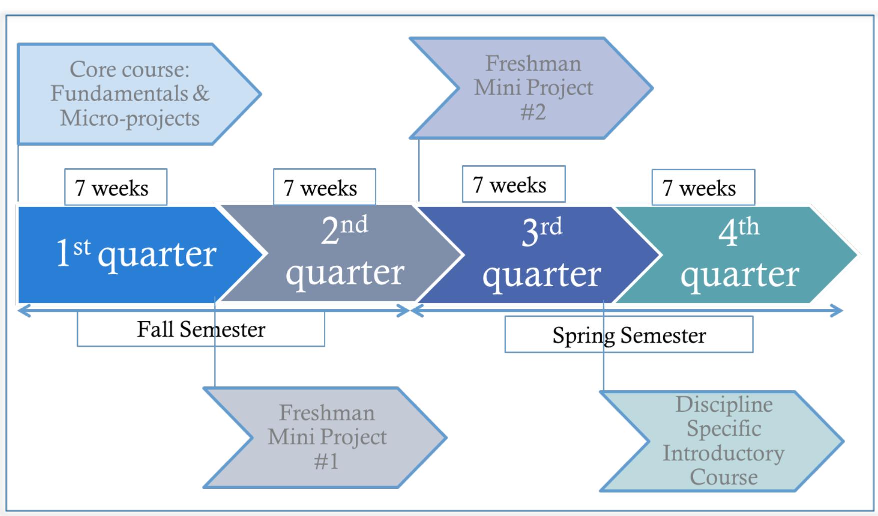

Figure 1. Timeline of a typical freshman introductory engineering course at Villanova University's College of Engineering. The entire course spans two semesters with the first quarter's focus on core fundamentals, the following two quarters on mini-projects and the last quarter on discipline-specific introductory course.

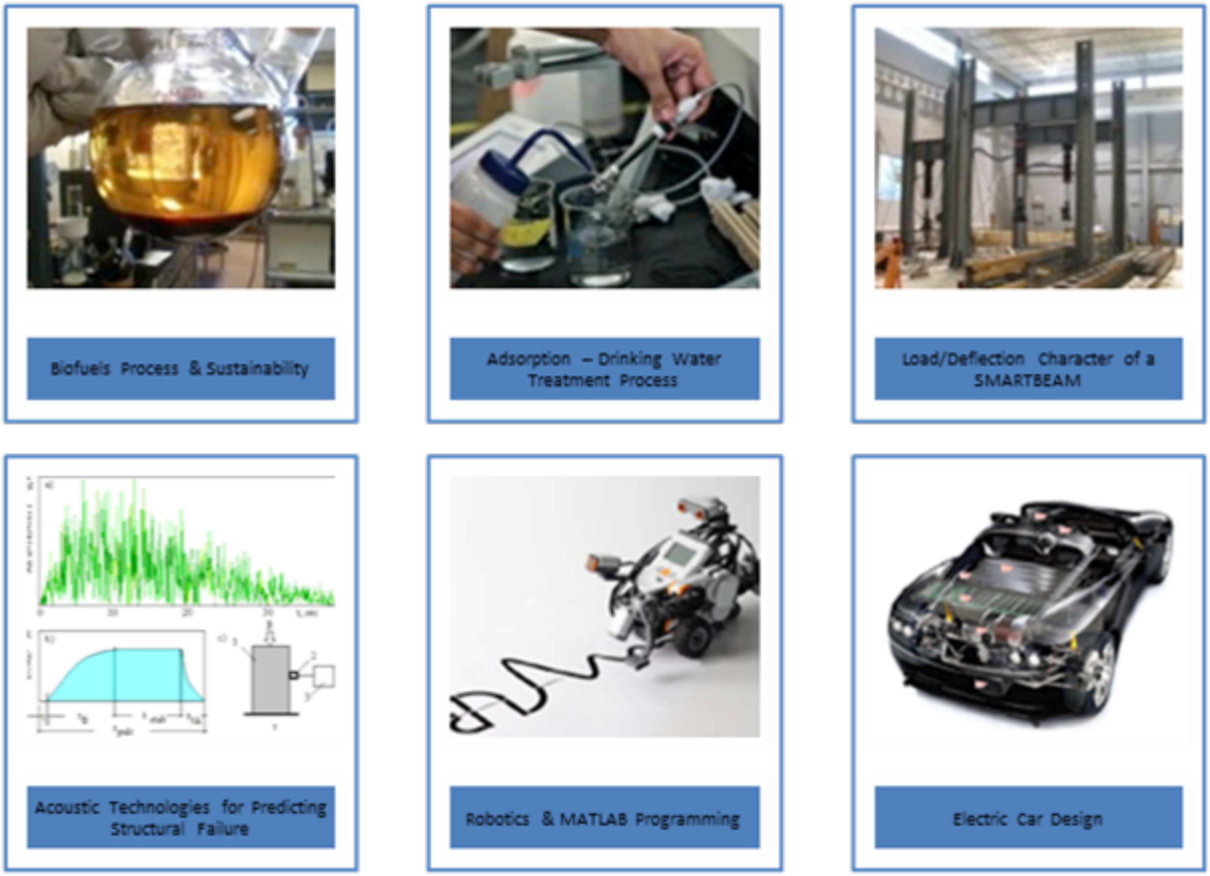

Figure 2. Six multidisciplinary freshman engineering projects offered in academic year 2011/12 and 2012/13 at Villanova University's College of Engineering. Freshmen select two of the six multidisciplinary projects offered to help them make more informed decisions on choosing their engineering major.

The Biofuels Process and Sustainability mini project was also developed to foster the growth and interest in the on-going student-run Villanova University's Biodiesel program within the College of Engineering. In the 4-year-old biodiesel production program, which was established in 2009, students operate a biodiesel production facility located in the department of chemical engineering's unit operations laboratory to convert waste cooking oil into biodiesel.

The production facility has the capacity to process 50% of approximately 6,000 gallons of waste cooking oil produced by the dining services center yearly. Currently, only about 10-15% of the waste cooking oil is processed for biodiesel production. In order to increase the capability of the facility to produce more biodiesel, more student participation is needed. The proposed mini project can serve as a recruiting tool by introducing new freshman engineering students to various aspects involved in the production of biofuels, thus making them more prepared should they decide to participate in Villanova University's Biodiesel program.

Course Structure

The seven-week freshman mini project begins as a combination of lectures and in-class group exercises on various aspects on biofuel production and sustainability. At Villanova University, each freshman introductory class for a mini project typically averages around 35-40 students. The class meets regularly twice a week, typically on Tuesday and Thursday, for 75 minutes each. In order to ensure that each student receives quality level of coaching and attention, the student to faculty ratio is decreased by splitting the class size into half. The first half of the class would attend an in-class lecture session on Tuesday with the course instructor while the second half of the class would perform laboratory experiments with a graduate assistant. Then, on Thursday, the order is switched whereby the first half of the class would attend the laboratory session while the second half of the class would attend the in-class lecture session.

A third class meeting session (regularly 50 minutes, typically on Friday) can also be scheduled as deemed necessary should students wish to consult for additional help on the project or class materials. Inside the classroom, students learn about the concepts of sustainability, technical aspects of biodiesel production and how to assess the sustainability of a biofuel production system. In order to bring classroom concepts to life, hands-on laboratory experiments are performed in the weeks following the lectures. The laboratory experiments involve biodiesel synthesis and characterization, analysis on energy usage and heat transfer of the synthesis process, and the synthesis of soap from glycerin by-product. The course structure and schedule of activities alongside learned skills are presented in Table 1 below.

Table 1: Schedule of learning activities coupled with gained skills from each lesson week.

Week	Learning Activities	Learned Skills
1	• Introduction to biofuels production process and concept of sustainability • Sustainability and carbon footprint: how much CO_2 does my household emit per year? Develop carbon footprint calculator	Concepts on biofuels production and sustainability, carbon footprint, programming using MATLAB, ethics, basic organic chemistry
2	Introduction to the concept of mass and energy balance and heat transfer phenomena	Concepts of mass and energy balances and heat transfer phenomena, mathematics
3	Laboratory experiment #1: Biofuel synthesis and experimental data collection	Laboratory skills, data collection, team work, time management
4	Laboratory experiment #2: Biofuel characterization and experimental data collection	Laboratory skills, data collection, team work, time management
5	• Analyze data collected and use data to prepare a report on energy and heat transfer • Utilizing byproduct: soap making from glycerin by-product	Data analysis, mathematics, team work, computation skills, time management, laboratory skills, report writing

Week	Learning Activities	Learned Skills
6	• Analyze data and use data to prepare report on chemistry and mass balance • Lecture and in-class activity: Concept of entrepreneurship	Data analysis, mathematics, team work, computation skills, time management, report writing, concept of entrepreneurship, brain storming, oral presentation skills
7	Final presentations: poster and final report	Oral presentation skills, team work, time management, poster preparation, executive summary writing

Before all experiments and laboratory activities are conducted, safety is highly emphasized among the students. The students are made aware of an emergency egress routes, safety showers, eye wash stations, and emergency spill protocols should an accident were to happen. Dress code among which involve closed-toed shoes and long pants besides laboratory goggles should be worn at all times. Other good laboratory practices that are highly encouraged include labeling all chemicals since most chemicals look alike and maintaining a clear and neat workstation at all times.

Students perform the elementary transesterification of waste cooking oil (WCO) into biodiesel while producing a by-product of glycerin. After the experiments, students prepare two laboratory reports: one on the chemistry and mass balance aspects of biofuel synthesis and the other on the energy and heat transfer aspects of the biofuel synthesis. The report preparation involves conducting technical literature searches, executing data collection, and using spreadsheets to analyze data and perform numerical analysis. In addition to the chemistry and heat transfer aspects of biodiesel production, the element of entrepreneurship is also incorporated in the soap production via glycerol by-product. One of the in-class activities is an introductory workshop on entrepreneurship in collaboration with the Villanova University's Engineering Entrepreneurship program (http://www1.villanova.edu/villanova/business/centers/ice.html).

In addition, students are also exposed to the scale up of a bench laboratory setting to a commercial level biodiesel production facility. As their final assignment, students are assigned in groups of 3-4 to develop a poster on a topic of their choice based on the materials learned throughout the mini project course. At the end of the course, the College of Engineering also hosts a poster competition where the posters developed are presented to a group of audience and judges. Alongside this poster presentation, students certainly garner the ability for improving public speaking and professional skills a good engineer should practice.

Identification of Multidisciplinary Engineering Components

This freshman mini project focuses on many fundamental skillsets any engineer should have regardless of their engineering discipline. These important skillsets which any engineer should master includes understanding the use of mathematical equations in explaining engineering concepts, collecting, analyzing and reporting experimental data and performing scholarly research, including preparing technical reports. Sustainability, not only in engineering, is a new interdisciplinary concept that every future engineer should understand, have an appreciation for and apply in his/her area of expertise. The design process of biofuel production from renewable materials involves engineers from multiple disciplines including but not limited to chemical, mechanical, civil/environmental, and electrical/computer. In addition, this mini project also challenges the student to consider a whole systems thinking on optimizing process design while minimizing material intensity alongside maximizing the use of renewables.

Fundamental Concepts in Biodiesel Synthesis from Waste Cooking Oil

The overall structure of the Biofuels Process and Sustainability mini-course revolves around five basic concepts. These concepts include:

Concept #	Concept Description
1	Sustainability and biofuels production
2	Chemistry behind biodiesel synthesis from vegetable oil/waste cooking oil
3	Mass and energy balance of biodiesel synthesis
4	Heat transfer phenomena: conduction and convection heat transfer during transient and steady state conditions
5	Sustainability and entrepreneurship: optimizing use of glycerin by-product and design of marketing strategy for soap production (aesthetics, public appeal and consumer preference)

Concept #1: Sustainability and biofuels production

In the first two weeks of the mini course, lectures, in-class activities and homework assignments are given to students on various aspects of sustainability and biofuels. The class starts with the introduction of the definition of sustainability, i.e. "meeting the needs of the present generation without compromising the ability of future generations to meet their needs" (United Nations – Brundtland Commision – 1987)[5]. Students learn about the Triple Bottom Line (TBL) concept on sustainability, coined by John Elkington, which considers social, economical, and environmental aspects as three key parameters for measuring sustainability development[2]. According to the TBL concept, a sustainable society can only be achieved with the support of a sustainable economy, which in turn supports a sustainable environment[6].

The concept of sustainability on the environment is also related to the issue of climate change. On this, students are assigned to read the article "Climate Change 101, Overview"[7] and write an opinion about the article as a whole. Moreover, students are asked to discuss one specific aspect about climate change that they feel is important from the many aspects discussed in the article.

Another assignment that students are asked to do is to evaluate the impacts of their daily activities on the environment by calculating the amount of carbon dioxide release from those activities. For this assignment, students perform the CO_2 emission calculations using the online Household Carbon Footprint Calculator available on the EPA website[8]. After knowing their current carbon footprint, students are challenged to think of lifestyle changes to mitigate and reduce their carbon footprint by 10, 30, 50 and 75% of their current CO_2 emissions. The overall goal of this exercise is to help the students foster self-awareness of their personal impact on the environment. Furthermore, from this exercise, students are made aware that although the impact may seem small individually, but on a larger scale through communities, the impact can be significant.

On the concept of biofuels production, students get to explore the various plant based potential feedstock's for producing biofuels and the conversion technologies that are currently commercially available or still in the developing stages. These potential feedstocks include oil/fat producing plants such as soybean, palm oil, algae, and jatropha. Furthermore, students study how bioethanol and biodiesel are not only made from carbohydrate/sugar producing sources but also come from lignocellulosic biomass. An emphasis is placed on biodiesel production technology to encourage students to have a better appreciation for the biodiesel production experiment to come in the week following the lecture series.

In learning about assessing the sustainability of biofuel production, students are first introduced to the concept of mass and energy balance and how the concept applies to the biofuels production processes. The mass and energy balance background is very useful in performing a life cycle analysis (LCA), which is a cradle-to-grave analysis for the energy and environmental impacts of making a product. In learning to become familiar with the concept of LCA, students were presented with several technical papers on life cycle assessment of biodiesel production [3, 11,12] and are assigned to select one paper to read and summarize what they learn from the paper.

The technical reading assignment also serves as an exercise in training these young engineers on how to perform a literature review. In assessing the energy balance biofuels production process, students first learn about the steps that involved in biofuels production, i.e. from biomass production to biofuel distribution as shown in Figure 3. Next, students are presented with the evaluation of energy balance based on the "point of view "of a plant engineer vs. an environmentalist, as shown in Figure 4. The information obtained from the energy balance analysis typically is expressed as the net energy ratio (NER), which is the total energy produced by the process system divided by the total energy consumed by the system balance.

Overall, higher NER values indicate better process efficiencies. Students are made aware that they must be careful in using NER values for assessing the sustainability of biofuels production processes, especially when they are going to use NER values found in literature when comparing different biofuel production processes. NER values can be arbitrarily different depending on the scope/battery of limit of the biofuel production systems analyzed. Therefore, in analyzing the sustainability of a biofuel production system, it is imperative to know the details of all the process steps alongside the mass and energy input and output streams involved within the system's battery limits. Figure 4 shows that according to a plant engineer in a biofuel processing facility, the energy balance of interest only involves the energy inputs and outputs within the processing plant battery limit. On the other hand, for the environmentalist, in assessing the energy balance for biofuel production, one must include the energy that is used in acquiring the biomass feedstock, i.e. the energy utilized from its production to the energy utilized to transport the biomass to the processing plant. In the case of plant engineer vs. environmentalist energy balances, the NER values will be very different. Such awareness is important for students to compare studies on a common playing field especially when technical versus non-technical articles report different assessment results that can be conflicting.

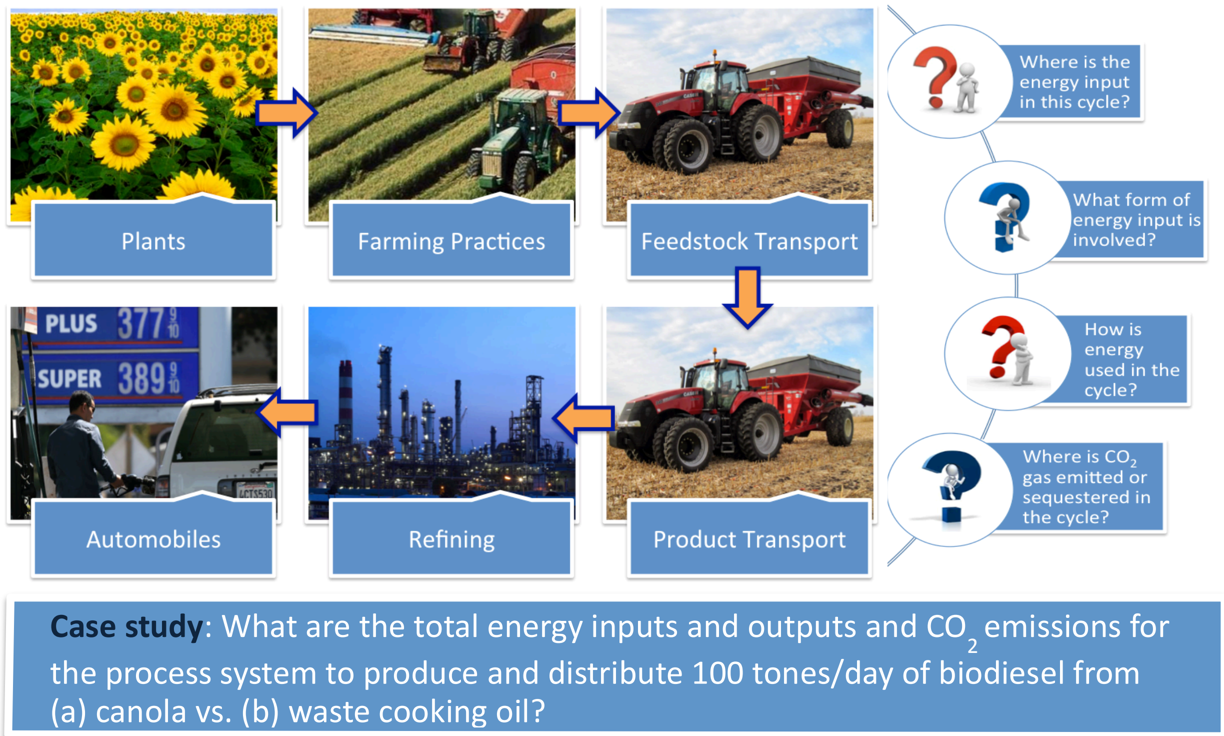

Figure 3. Process chain of a biofuel production from feedstock procurement to the distribution of the biofuel finished product. The column on the right describes the list of questions related to the life cycle analysis of the biofuel production system (Figure adapted from Great Lakes Bioenergy Research Center webpage[15])

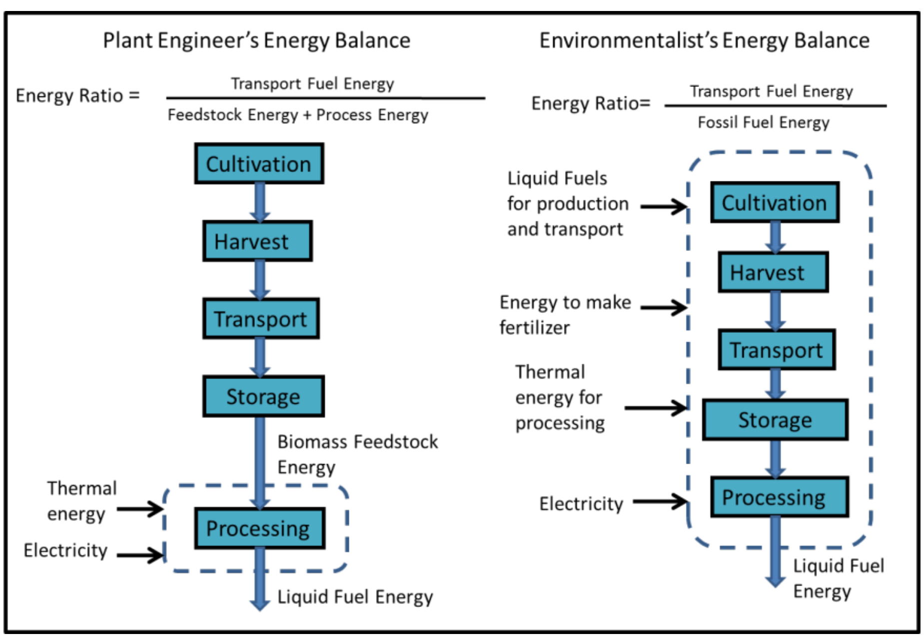

Figure 4. Energy balance of Biofuel Production from two different perspectives: process plant engineer versus environmentalist. Clearly, the scope and battery limits of a process have direct effect on the energy ratio produced and must be clearly defined if results are to be compared across the board.

Concept #2: Chemistry behind Biodiesel Synthesis from Waste Cooking Oil (WCO)

One important concept introduced in this mini course is the chemistry of biodiesel synthesis. The goal of this experiment is to convert waste cooking oil (WCO) obtained from Villanova University's dining services into biodiesel (also known as fatty acid methyl esters – FAME) by a transesterification reaction with methanol in the presence of a catalyst, namely sodium hydroxide (NaOH). In transesterification, NaOH and methanol are mixed to create sodium methoxide (Na+ CH3O-). When mixed in with the WCO, this strong polar-bonded chemical breaks the trans-fatty acid into glycerin and also ester chains (biodiesel), along with some soap if one is not too careful. The esters become methyl esters, which is the biodiesel produced. Depending on the type of alcohol used, the biodiesel (esters) produced can be different. For instance, if ethanol is to be used as the alcohol, then ethyl esters would be produced versus methyl esters with methanol. Figures 5 and 6 depict the transesterification reaction waste cooking oil undergoes to produce biodiesel and its by-product, glycerin. Figure 7 on the other hand depicts a side reaction, which also occurs during the transesterification due to the free fatty acid content in waste cooking oil.

In performing biodiesel synthesis experiment in the laboratory, students work in groups of two in the laboratory. Some groups use waste cooking oil, which contain free fatty acids, while others use pure canola oil. The two different vegetable oils were incorporated as part of this laboratory experiment to foster discussion among the students on the observation differences in color, layers of separation, heating value, quality of biodiesel, and etc. The reaction takes place in a reactor in the form of an Erlenmeyer flask at 65°C. The setup of the reactor apparatus can be seen in Figure 8.

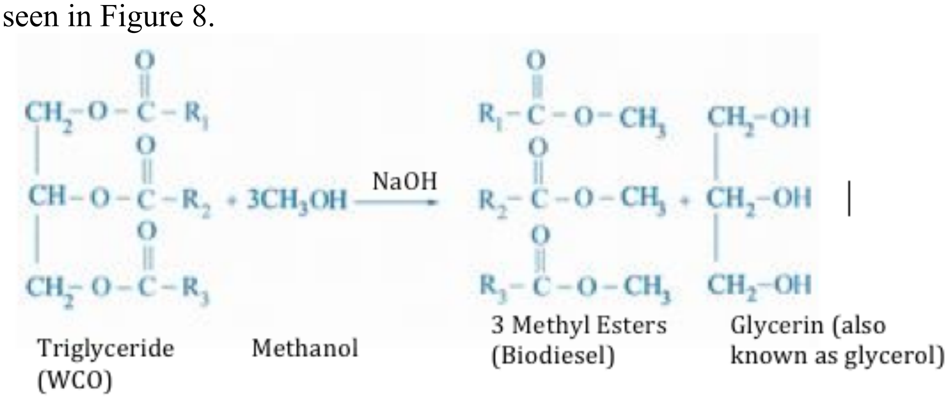

Figure 5. Transesterification of Waste Cooking Oil into Biodiesel: Reaction of triglycerides (3 fatty acids & a glycerol molecule) with methanol to form methyl esters (biodiesel) and glycerin by-product.

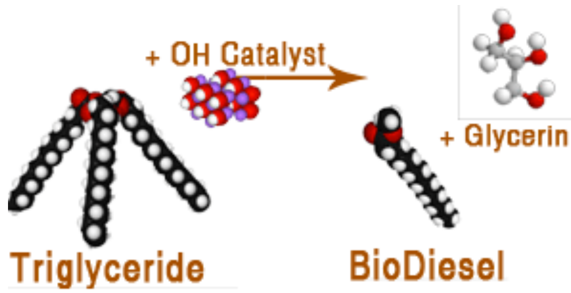

Figure 6. Pictorial representation of transesterification reaction of WCO (triglyceride) into biodiesel while producing by-product, glycerin.

$$\underset{\text{Free fatty acid}}{HO\text{-}\overset{\overset{O}{\|}}{C}\text{-}R} + \underset{\text{alkali catalyst}}{Na^{+}\ OH^{-}} \rightarrow \underset{\text{water}}{H^{+}\ OH^{-}} + \underset{\text{soap}}{NaO\text{-}\overset{\overset{O}{\|}}{C}\text{-}R}$$

Figure 7. Saponification reaction: Side reaction of free fatty acid with alkali (NaOH) to form soap. Catalyst (NaOH) is provided in excess to compensate for loss due to soap formation, which competes with transesterification reaction.

Concept #3: Mass and Energy Balance of Biodiesel Synthesis

Mass Balance

Mass balances (also known as material balances) are based on the fundamental Law of Conservation of Mass. This law states that the mass of an isolated system will remain constant over time. In other words the mass of the reactants must equal the mass of the products. The setup for the mass balance looks like the following in Figure 9. All vegetable oils are not created equal in which physical and chemical properties are dependent on the fatty acid constituents in the oil. By knowing the percentage of fatty acid in the oil and the molecular weight of triglycerides formed from each type of fatty acid, the average molecular weight of the oil can then be estimated. Then, based on reaction stoichiometry, students can determine the amount of alcohol, in this case methanol, and catalyst (NaOH) needed for converting WCO into biodiesel (methyl ester).

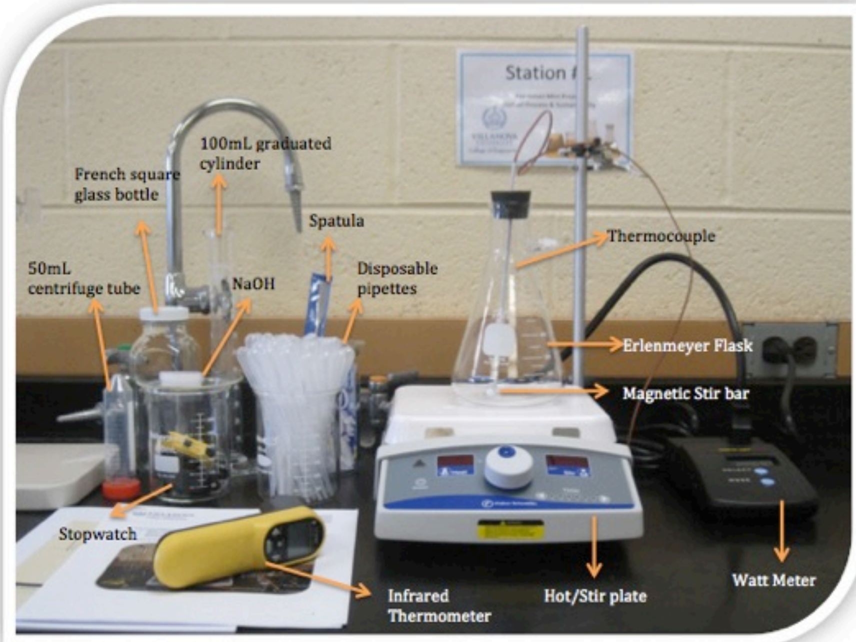

Figure 8. Reaction setup of biodiesel synthesis experiment from waste cooking oil (WCO). In the figure above, NaOH, which is the catalyst in the experiment, functions to speed up the transesterifcation reaction to an hour versus a few days without its presence.

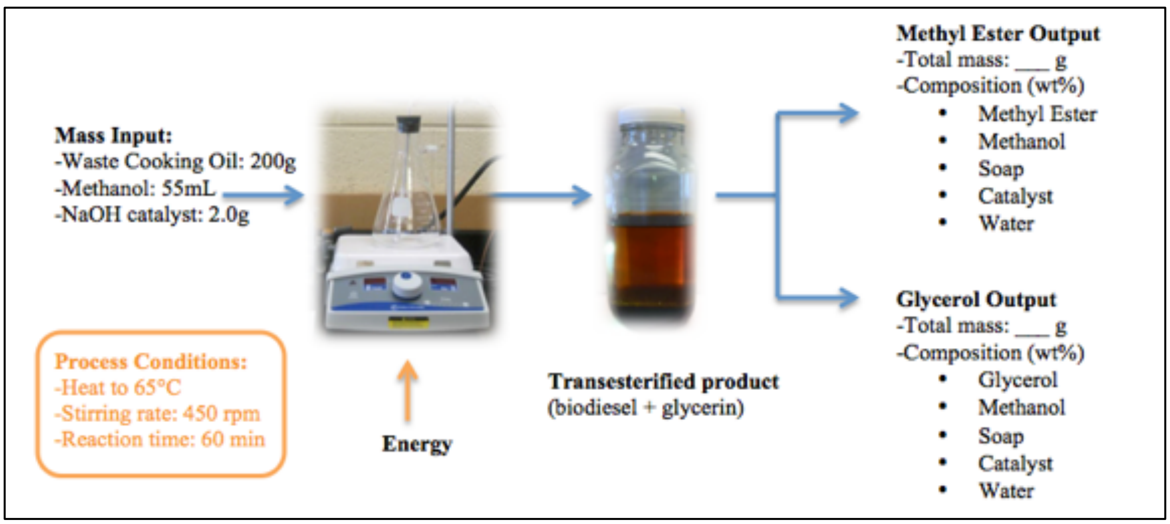

Figure 9. Theoretical mass balance setup depicting process input (energy + material) versus process output (biodiesel production + by-product, glycerin, also known as glycerol).

Energy Balance

Synonymous to the first law of thermodynamics is the Law of Conservation of Energy. This law states that energy can neither be created nor destroyed. Therefore, the sum of all the energies in a system is a constant.

During the biodiesel synthesis process, the electrical power usage and reaction temperature will be recorded manually using a watt meter and infrared thermometer. The data collected will be used to determine the efficiency of the process, both during transient and steady state periods. Figure 10 depicts the schematic setup of the transesterifcation reaction for energy balance considerations.

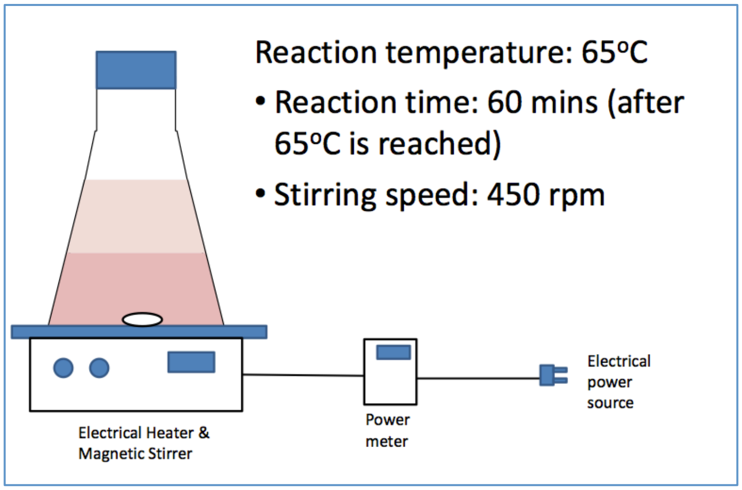

Figure 10. Schematic diagram of reaction setup for energy balance considerations.

Students are asked to examine the energy requirement of the system throughout the one hour reaction and compare the value to the total actual energy supplied to the system. By taking into account these two calculated values of energy (J), the efficiency of the process can be calculated using (Eq. 1) below:

$$\text{Energy efficiency (\%)}: \eta = \frac{Energy\ required\ by\ process}{Total\ energy\ supplied\ for\ process} \times 100\% \qquad \text{(Eq. 1)}$$

In other words, the energy conversion efficiency is defined by the ratio between useful output of the process (energy used to heat and perform the transesterification reaction) versus the total energy supplied for the process (based on what was obtained from the watt meter).

With the data collected throughout the one hour reaction (power usage and temperature), students are able to generate an energy and temperature profile graph as depicted in Figure 11.

Concept #4: Heat Transfer Phenomena: Conduction & Convection during Transient & Steady State

Heat is the amount of energy transferred between two objects or substances of varying temperature. Heat only flows if a temperature gradient is present in which one material is warmer than the other or vice versa. Generally, when heat is transferred to a material, the motion of the particles speed up and its temperature increases.

In this section, students are introduced to the three methods of heat transfer, namely, radiation, conduction and convection. Students are challenged to consider the heat transfer events taking place during the biodiesel synthesis period through the different methods of heat transfer. Heat transfer will be analyzed at two reaction time periods: (a) Transient state period (heating period) (b) Steady state period (period at constant reaction temperature). Using the temperature and energy usage vs. temperature plots that they are created using the experimental data, students are asked to analyze the behavior the synthesis process, e.g. identifying the length of the transient/heating period, etc.

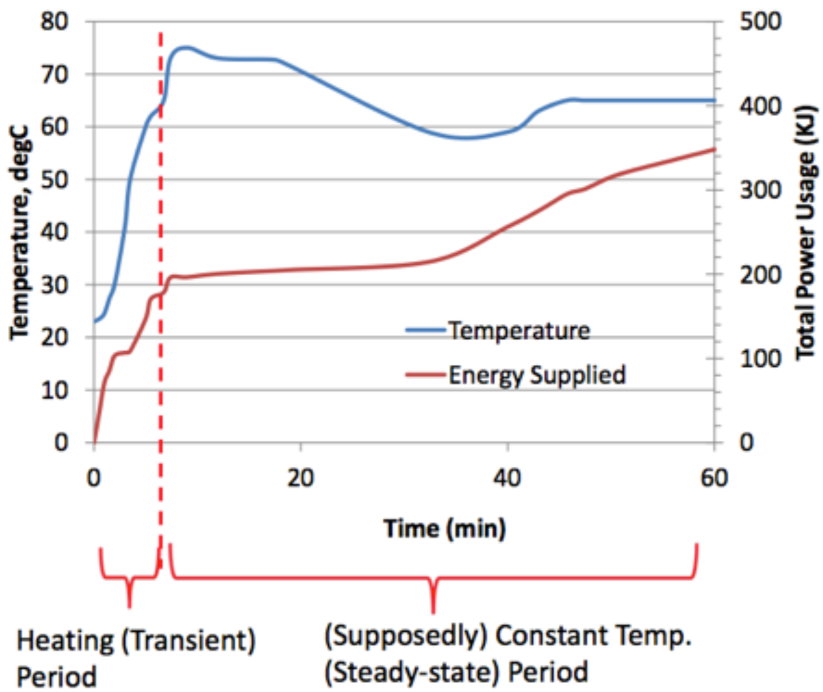

Figure 11. Temperature and energy usage as function of time profiles of biodiesel synthesis from waste cooking oil over a reaction time of 1 hour at 65ºC.

Transient State Analysis

This calculation involves the energy needed to bring the reactor to the desired reaction temperature of 65°C. The basic transient heat equation introduced can be seen in Equation 2 below.

$$Q = m \cdot C_p \cdot \Delta T \quad \text{(Eq. 2)}$$

where:

Q	**Heat required in Joules**
m	Mass in grams
C_p	Specific heat in Joules/gram°C
ΔT	Temperature difference = Final temperature – initial temperature in °C

During the biodiesel synthesis, at transient and steady state periods, heat is released via convection from the surfaces of the reactor and hot plate exposed to the environment (air surrounding the system). In order to maintain the system at desired temperature of 65°C, additional energy needs to be supplied to replace the energy loss. Students are asked to consider possible experiment/design modifications to eliminate or reduce energy losses (e.g. insulation).

Heat Losses by Convection

Calculations of heat losses via convection are introduced through Equation 3.

$$Q_{convection} = h \cdot A \cdot \Delta T \qquad \text{(Eq. 3)}$$

where:

Q	**Heat loss in Joules**
h	Heat transfer coefficient $\left(\frac{J}{s \cdot m^2 \cdot °C}\right)$ or $\left(\frac{W}{m^2 \cdot K}\right)$
A	Surface area of heat being transferred
ΔT	Surface temperature – environment temperature in °C

Again, students are asked to consider simplifying assumptions to reduce the complexity of the system and also calculations.

Concept #5: Sustainability & Entrepreneurship: Optimizing Glycerin By-product and Marketing Strategy for Soap Production

Every process that is sustainable strives to apply the different elements of eco-efficiency. Two among which include maximizing sustainable use of renewable resources and enhancing the recyclability of materials. In biodiesel production, waste minimization and management is a key issue to consider. Students will be exposed to alternative use of glycerin by-product in which soap can be made by the addition of more lye.

The process of making soap is called saponification[14]. In saponification, fatty acids are combined with alkali (NaOH) to make soap. Since glycerol that is 'freed' from the WCO when producing biodiesel contains a mixture of glycerol, soap, methanol, and some saponifiable elements (monoglycerides, diglycerides & free fatty acids), the glycerol by-product layer can be made into soap. This only happens after methanol, which is toxic, has been removed via evaporation at its boiling point of 65°C.

The resulting glycerol by-product soap will contain much more glycerol than soap produced with traditional methods. A normal soap contains 10-15% glycerol whereas a glycerol by-product soap can contain from 40-80% glycerol. This extra glycerol leads to a sweaty and somewhat soft bar of soap. In most cases, the bar soap formed will have little latherability. Therefore, the element of entrepreneurship is introduced to make the glycerin bar soap more appealing to a consumer. Among some steps that are implemented to perfect the bar of soap in terms of hardness and latherability include adding saturated fats such as cocoa butter, vegetable shortening and coconut oil. Aesthetics play an equal part in the marketability of a product. As a result, different scents/essential oils and coloring are added to mask the dark brownish colored, 'french-fry' smelling bar of soap.

The following figures 12-15 are some end products of bar soaps produced with the glycerin by-product with a consumer appeal in mind.

Figure 12: Different scented & colored glycerin by-product bar soaps made by students.

Figure 13: Lavender scented glycerin by-product bar soaps wrapped in organic soy paper and recycled paper ribbon.

Figure 14: Wrapped Orange Valencia & Moroccan Mint scented glycerin by-product bar soap.

Figure 15 Key lime pie scented glycerin by-product soap.

Recruiting Platform for Student Run Villanova University's Biodiesel Program

The freshman mini-project on biofuels synthesis and sustainability was also developed in conjunction with the on-going student-run Villanova University's Biodiesel program in the department of chemical engineering. In the 2-year-old biodiesel production program, students operate a biodiesel production facility located in the Villanova University's department of chemical engineering Unit Operations laboratory to convert waste cooking oil into biodiesel, which is now powering diesel-run lawn mowers on campus. The production facility has the capacity to process approximately 50% of the estimated 6000 gallons of waste cooking oil produced from dining services yearly. Currently, only about 10-15% of the waste cooking oil is processed for biodiesel production. The setup of the biodiesel production facility in Villanova University's Unit Operations Laboratory is depicted in Figures 16 and 17 below.

In order to increase the capability of the facility to produce more biodiesel, increased student participation is needed. The next phase of the project is to provide fuel for other diesel vehicles on campus. Villanova University also has received a permit from the state that will make biodiesel available for campus vehicles that use public roads. Thus, the proposed mini project can serve as a recruiting platform by introducing new freshman engineering students to various aspects involved in biodiesel production.

Figure 16: Nalgene hoppers used for biodiesel separation from glycerin by-product.

Figure 17: Batch reactors used for transesterification of waste cooking oil (WCO) into biodiesel.

Course Assessment

This Biofuels Process and Sustainability freshman mini project at Villanova University was developed to test two hypotheses in mind. The first hypothesis is that students would be introduced to the latest advancements and technological developments in renewable energy through the concept of bioeconomy, where vital sources of energy are obtained from renewable materials such as carbon based resource. The second hypothesis is that after undergoing this freshman mini project, a freshman would have been challenged to utilize basic engineering and chemistry principles in synthesizing biodiesel from waste cooking oil, interpret and analyze experimental data in scaling up to a biodiesel processing facility and finally to assess the overall sustainability of the biodiesel production process.

Apart from the professional and technical skills introduced throughout the freshman mini project, the overall course success level of conveying the two main goals was summarized through an assessment survey. This assessment survey focused on how the students felt about sustainability and renewable energy prior to taking the Biofuels Process and Sustainability mini project and after taking the course. A list of 19 statements was carefully crafted to assess how the students felt about sustainability, biofuel synthesis process and the importance of renewable energy. Students are able to respond on a scale of 1 to 5 on their level of agreement for the listing of statements made through the survey. A scale of 5 indicated that the student strongly agreed with the statement while a scale of 1indicated that they strongly disagreed with the statement.

The list of 19 statements of the assessment survey presented at the beginning and end of this course can be seen in Figure 18. The same survey was presented at the beginning of the course and at the end of the course to study and understand how the freshmen felt about issues of sustainability before and after taking the freshman mini project course. The results from the assessment survey are presented in Figures 19-21 for all 19 statements made based on the surveys that were conducted in 2012 Fall and 2013 Spring semesters. The total number of students participated in the surveys is 75 students.

ENG 1200 FRESHMAN MINI PROJECT FALL 2012

Biofuel Process & Sustainability

ASSESSMENT SURVEY

Please indicate your level of agreement with each of the following statements:

5 = Strongly Agree 1 = Strongly Disagree

1	I believe sustainability is important to the future of the world I am living in today		5	4	3	2	1
2	The environmental impacts and sustainability of the products that I use/purchase are important to me personally		5	4	3	2	1
3	I can name at least three (3) activities that I HAVE DONE that are positive for sustainability and environment		5	4	3	2	1
4	I can name at least three (3) activities that I CAN DO DAILY that are positive for sustainability and environment		5	4	3	2	1
5	I believe that developing renewable source of energy is important in my life time		5	4	3	2	1
6	I believe that renewable energy is an important field in engineering theory, practice, and research		5	4	3	2	1
7	I believe learning about sustainability is an important part of my training to become a well-rounded engineer		5	4	3	2	1
8	I can describe well at least one job function of an engineer that relates to sustainability		5	4	3	2	1
9	I believe that as an engineer I need to know well other areas of engineering and science that are not necessarily my area of expertise.		5	4	3	2	1
10	I believe that as an engineer I need to learn about entrepreneurship		5	4	3	2	1
11	I am interested to learn how to become a good entrepreneur		5	4	3	2	1
12	I believe that biofuels are important for meeting our society's need of energy		5	4	3	2	1
13	Since biofuels are synthesized from plant materials, the production and utilization of biofuels will be carbon neutral*.		5	4	3	2	1
14	I can describe at least three (3) types of biofuels and the feedstock materials used to produce them.		5	4	3	2	1
15	I can describe well the process of making biodiesel from waste and fresh vegetable oil		5	4	3	2	1
16	Besides vegetable cooking oil, I can name at least three (3) sources of oil feedstock to produce biodiesel		5	4	3	2	1
17	I am familiar with the concept of energy and mass balances in biofuel synthesis process		5	4	3	2	1
18	I can describe well, at least in general, on how to assess the sustainability of biofuels synthesis.		5	4	3	2	1
19	I can name at least three (3) important factors that can affect the sustainability of biofuels synthesis		5	4	3	2	1

**Carbon-neutral implies that the amount of carbon dioxide released into the atmosphere equals the amount taken up by plants during photosynthesis.*

Figure 18. Assessment survey listing overall level of confidence on the topic of sustainability, renewable energy and biofuels synthesis before and after going through this 7 week freshman mini project. Two surveys were conducted: one at the beginning of the 7 week course, and another after the course was completed.

Figure 19 shows the student responses to the first group of 5 statements, where the central concept was on sustainability and its importance in daily life. It can be seen from Figure 18 that the survey shows increases within margins of errors in the level of agreement across the board for all 5 statements. Response to statement #1 concerning sustainability, indicates that students in general strongly agreed with the importance of sustainability in the world today, even before they took this Biofuels and Sustainability course. Similar response was observed for statement #5 concerning the importance of renewable energy. Student responses to statements #2, 3 and 4, students showed a rather significant increase in their agreement about the contributions of their individual actions to the environment and sustainability.

Statement #	Statement description
Statement #2	The environmental impacts and sustainability of the products that I use/purchase are important to me personally
Statement #3	I can name at least three (3) activities that I HAVE DONE that are positive for sustainability and environment
Statement #4	I can name at least three (3) activities that I CAN DO DAILY that are positive for sustainability and the environment
Statement #5	I believe that developing renewable source of energy is important in my life time

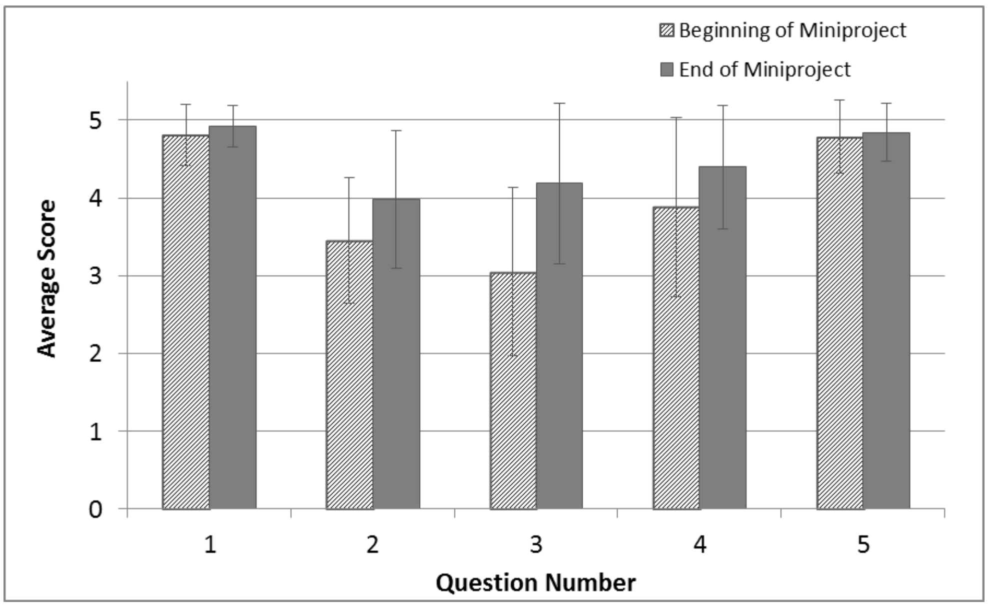

Figure 19. Comparison of assessment survey on questions 1-5 centering on the concept of sustainability and its importance in one's daily life. This group of statements also functions to gather information on how a student already incorporates sustainability practices in his/her daily life and how he/she can further develop habits to promote sustainability. The rating scale used was from 1 to 5 where a score of 5 indicated that the student strongly agreed with the statement while a scale of 1 indicated that the student strongly disagreed with the statement. Data are reported as the median ± the median absolute deviation of non-parametric statistical analysis by Mann-Whitney-Wilcoxon rank sum test.

The next set of 6 statements surround the idea of essential tools and skill sets of a well-rounded engineer. For this second set of statements a very slight change of agreement was shown prior to and after completing the Biofuels Process and Sustainability mini project. Through their response and level of agreement, as depicted in Figure 20, students already believed and acknowledged that renewable energy is an important field in engineering theory, practice and research. Responses show that a well-rounded engineer is inevitable to be a successful engineer. The responses also prove that after taking this biofuels mini project, they are able to better describe a job function of an engineer that closely ties to sustainability. Through this course, students are more likely to consider the feasibility of a project based on efficiency, life cycle analysis, scope of project, sustainable efforts to improve a process, and many more. In addition, it is also evident that through materials presented in this course, a student is challenged to consider the future of the environment and meeting the needs of the present generation without compromising the ability of future generations to meet their own needs.

Statement #	Statement description
Statement #6	I believe that renewable energy is an important field in engineering theory, practice, and research
Statement #7	I believe learning about sustainability is an important part of my training to become a well-rounded engineer
Statement #8	I can describe well at least one job function of an engineer that relates to sustainability
Statement #9	I believe that as an engineer I need to know well other areas of engineering and science that are not necessarily my area of expertise
Statement #10	I believe that as an engineer I need to learn about entrepreneurship
Statement #11	I am interested to learn how to become a good entrepreneur

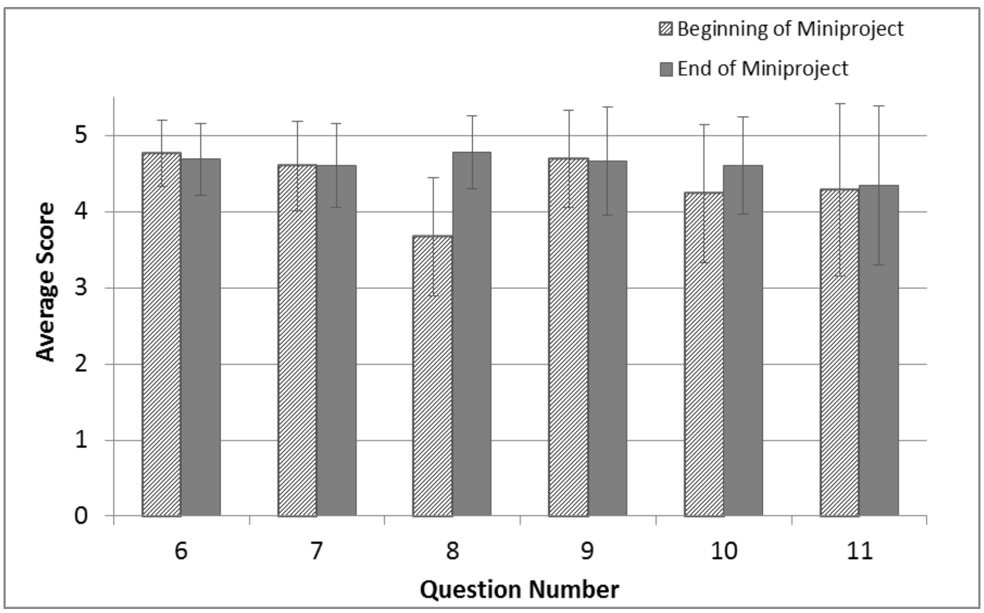

Figure 20. This second set of statements, ranging from statement 6 through 11 focuses on the essential tools and skillsets a well-rounded engineer should have in addition to his/her awareness of sustainability.

The third set of statements, statements 12-19, make a very powerful observation when it comes to conveying the significance and effectiveness of this specific Biofuels Process and Sustainability mini project. Just like all other statements, this survey was conducted at the beginning and end of the course. Results from the assessment survey show a dramatic increase in level of agreement among the students. This group of statements evolves around the theme specifically related to biofuel process from sourcing its feedstock, to understanding its synthesis process and to gauging the overall sustainability of biofuel production. From the results of this set of statements, as depicted in Figure 21, after completing the Biofuels and Sustainability course, students who initially felt uncomfortable with their knowledge in describing how biodiesel is synthesized and the different feedstock used were now able to confidently and actively discuss the sources of materials used to produce biodiesel, what makes a feedstock more desirable over others, the synthesis process, the mass and energy balance surrounding the biodiesel production to the sustainability of biofuel synthesis.

Statement #	Statement description
Statement #12	I believe that biofuels are important for meeting our society's need of energy
Statement #13	Since biofuels are synthesized from plant materials, the production and utilization of biofuels will be carbon neutral*.
Statement #14	I can describe at least three (3) types of biofuels and the feedstock materials used to produce them.
Statement #15	I can describe well the process of making biodiesel from waste and fresh vegetable oil
Statement #16	Besides vegetable cooking oil, I can name at least three (3) sources of oil feedstock to produce biodiesel
Statement #17	I am familiar with the concept of energy and mass balances in biofuel synthesis process
Statement #18	I can describe well, at least in general, on how to assess the sustainability of biofuels synthesis.
Statement #19	I can name at least three (3) important factors that can affect the sustainability of biofuels synthesis

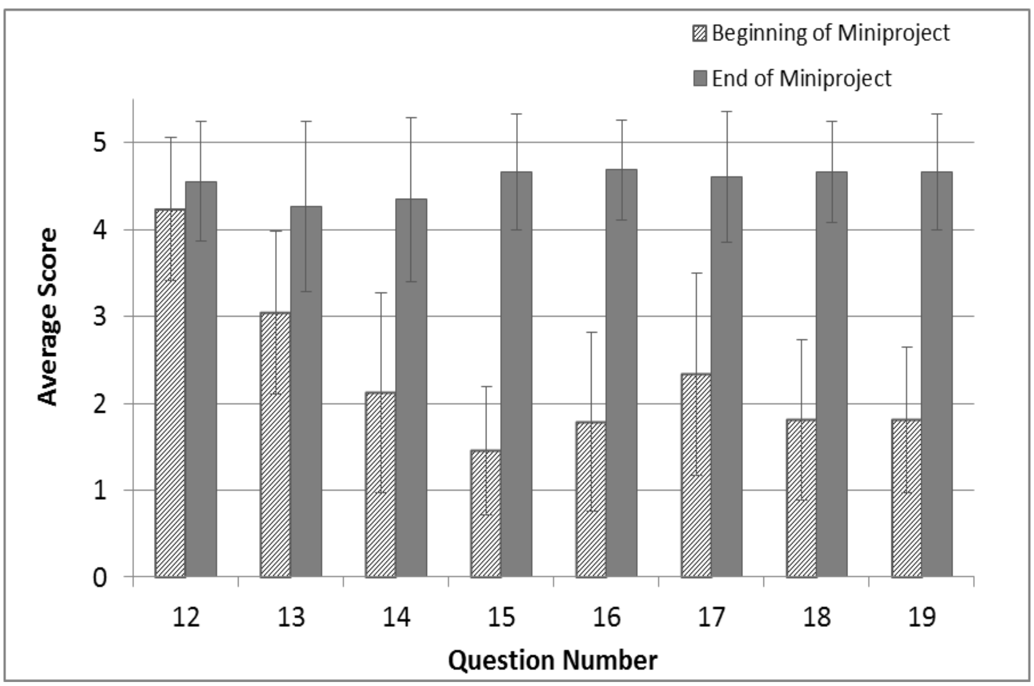

Figure 21. The third set of statements, namely statements 12-19, seeks to gauge the level of understanding and take away message after a freshman undergoes this Biofuels Process and Sustainability mini project. These statements target specifically to the knowledge of biodiesel synthesis process, the possible feedstock used, and the overall sustainability of the production process.

Conclusion and Future Directions

To recapitulate the overall goal of this Biofuels Process and Sustainability mini project offered at Villanova University's College of Engineering, the two hypotheses presented at the beginning of this discussion paper will be revisited. This mini project first seeks to confirm that after undergoing this course, students would be introduced to the latest advancements and technological developments in renewable energy through the concept of bioeconomy, where vital sources of energy are obtained from renewable materials such as carbon-based resource. The second hypothesis predicts that a freshman would have been challenged to utilize basic engineering and chemistry principles in synthesizing biodiesel from waste cooking oil, interpret and analyze experimental data in scaling up to a biodiesel processing facility and finally to assess the overall sustainability of the biodiesel production process.

From the results of the assessment survey, a dramatic overall increase in the level of agreement among the students after undergoing this biofuels process mini project reconfirms the two hypotheses that these young engineering students are now more aware of discussions of sustainability, feedstock used for biofuel production, biodiesel synthesis process, and the well-rounded aspects of being a successful engineer. It can also be said that through the activities and presentation assignments, students have developed a valuable skillset when it comes to analytical and critical thinking methods alongside professional skills to communicate data to an audience on his or her findings.

All activities related to biofuel production and process plant design are not only constrained to chemical engineering, but extend to other engineering disciplines as well. These other disciplines of engineering include but are not limited to mechanical, civil, environmental and electrical engineering. The development of a chemical processing facility is a highly interdisciplinary engineering effort, which requires the expertise of all major engineering disciplines.

In the near future, as the research in the biorenewable energy world progresses, these mini projects will seek to incorporate the latest advancements and methods to apply to classroom teaching. Students today are constantly seeking a reason and motivation to buy into an engineering education. By implementing creative and inviting subject matters and cutting edge techniques, students will more likely be convinced to see the relation between course material and the careers they are preparing themselves for.

Overall, the freshman mini projects, where Biofuels Process and Sustainability is part of the six rotational mini projects, come together to better prepare young engineering students to have an appreciation for engineering design and development in the world around us. This course not only introduces the fundamentals of basic engineering principles, but also proactively engages students to perform these design experiments and challenges these young minds to come up with a conclusion of their own. It is inevitable that through this multi-disciplinary course, these mini projects will certainly provide a platform for a successful undergraduate engineering career.

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