



## Motivating Student Learning Using Biofuel-based Activities

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## Abstract

Student learning is greatly enhanced when students are intrinsically motivated by the subject matter. For many students the topic of biofuels appeals to their intrinsic desire “to make a difference” with respect to the environment. At Kettering University an interdisciplinary group of engineers and scientists have found success in motivating students by introducing biofuel topics into the classroom and by offering undergraduate research and project experiences. Through these experiences students are learning both the fundamentals of their disciplines and developing an understanding of the opportunities and challenges associated with producing and utilizing biofuels. This paper provides a summary how biofuel learning activities have been integrated into the educational program.

## Introduction

Learning experiences are greatly improved when students are intrinsically motivated by the subject matter. An intrinsically motivated student will undertake an activity "for its own sake, for the enjoyment it provides, the learning it permits, or the feelings of accomplishment it evokes."<sup>1</sup> An extrinsically motivated student performs "in order to obtain some reward or avoid some punishment external to the activity itself."<sup>1</sup> Studies show that intrinsically motivated students tend to employ strategies that demand more effort and that enable them to process information more deeply. These students tend to prefer tasks that are moderately challenging. Extrinsically oriented students are inclined to put forth minimal effort.<sup>2</sup>

It is important for instructors to find educational activities that appeal to the intrinsic interest of their students. In a recent Harris Interactive survey commissioned by Microsoft Corporation<sup>3</sup>, 39% of the college students surveyed reported that one reason they chose a STEM degree was that they wanted “to make a difference.” It should be noted that this percentage was much higher for women (49%) than for men (34%). One concern that is on the mind of many college students is the impact of fossil fuels on the environment and on society. For many students, activities that are centered on biofuels appeal to their intrinsic interest help society address the problems associated with fossil fuels.

Studying biofuels allows instructors to cover both the fundamental principles of their discipline and broader issues such as understanding the impact of technology in a global, economic, environmental, and societal context. Meeting the energy needs of the nation and the world is becoming increasingly difficult in the face of escalating demand and dwindling supply of conventional fuel resources. Developing renewal sources of energy is critical to keep economic engines turning and to allow standards of living of people around the world to increase.

Biofuel is a renewable energy source produced from natural (biobased) materials, which can be used as a substitute for petroleum fuels<sup>4</sup>. Common biofuels include biodiesel, bioethanol and biogas (or more specifically biomethane). Biofuels have many benefits over traditional non-renewable fuels; including reduced environmental impacts and greater national energy security. Bioethanol is produced by fermentation of feedstocks such as corn, wheat, or sugar beets. Biodiesel is produced by chemically extracting the oil from algae or oil seeds. Biogas is produced by anaerobic digestion from most any organic material. The benefits and production costs for these biofuels will vary widely by feedstock, conversion process, scale of production and region of the country.

Developing the technology to produce and utilize biofuels is truly a multidisciplinary project, involving chemists to understand the fundamental chemical processes, chemical engineers to efficiently produce the biofuel, mechanical engineers to understand the effects of using biofuel in conventional engines, and mathematicians to aide with developing predictive models.

At Kettering University an interdisciplinary group of faculty have been using biofuel education activities to motivate their students and develop student understanding of the opportunities and challenges associated with producing and utilizing biofuels. Ongoing activities include projects for the classroom, undergraduate research, co-operative learning projects, and student competition projects. While there are many ongoing projects, this paper will summarize the following examples:

- Biogas production project for an undergraduate chemical engineering course
- Biogas production modeling project for an undergraduate mathematics course
- Biogas research projects for undergraduate and co-operative learning students
- Bioethanol usage in student competition projects
- Bioethanol research projects for undergraduate and co-operative learning students

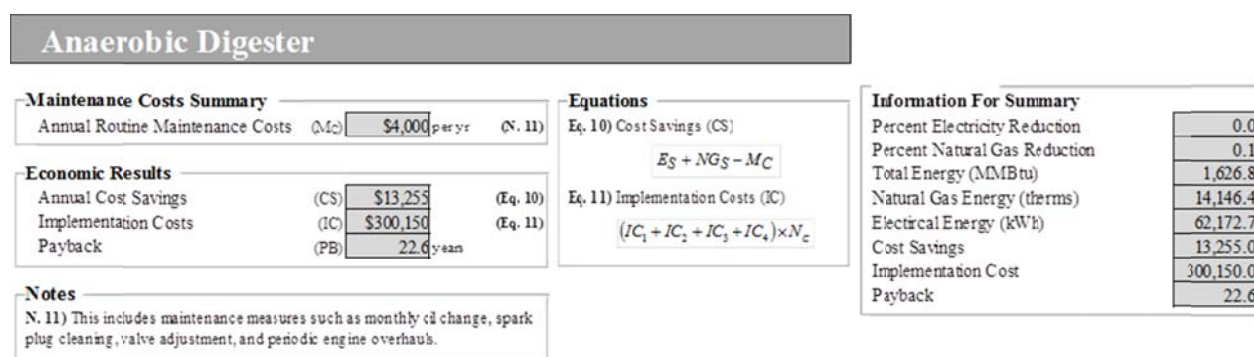
### **A Biogas Production Project in Chemical Engineering**

CHME-200 is the first exposure to chemical engineering for undergraduate students. The course combines material and energy balances. For a term project students are asked to perform calculations for a simulated dairy farm that uses anaerobic digestion to produce biogas. The model for the digester includes calculations for mass balance, energy balance, and basic economic analysis. The combined calculations become large and tedious to solve by hand, so software (Microsoft Excel) is used to facilitate the calculations.

Anaerobic digesters use microorganisms to convert waste into useful products and energy. Biodegradable organic matter such as food, paper, yard clippings and human/animal waste is used as feedstock. The output from the reactor is widely used as a renewable energy source since the digestion process produces biogas, which is composed mainly of methane and carbon dioxide. The other output stream is a nutrient rich digestate, which can be used as a fertilizer

which can impact the local community. One of the challenges for researchers is to determine the most efficient utilization of the anaerobic digesters to produce valuable products for the local community and to analyze the true impacts of reducing waste streams and energy stream production.

The goals of the term project are to familiarize students with alternative fuels technology, teach them how to incorporate software with problem solving and to understand the impact of a larger problem. The students are allowed some freedom in their choices for sizes and efficiencies of the parts involved in the process, which allows for creativity. The project is assessed using a simple rubric, making certain the students address all areas of the problem and the description and overall understanding of the problem is weighted slightly higher. A sample output for the analysis is shown in Figure 1.



**Figure 1 Sample output for biogas digester model**

Course evaluation Student surveys indicate that the students enjoy this term project since it involves aspects of biochemistry, chemical engineering, mechanical engineering, economics and business. The nature of this project is based on alternative fuel and Green principles which are interesting for many students, and since it involves using the computer, it does not seem as dreary as hand calculations. The problem allows students to connect science and engineering to community involvement and can be extended to involve societal impact. The following are statements from the course evaluations submitted by the students:

1. "The project forces you to think and combines multiple problems from multiple classes"
2. "The biogas spreadsheet design problem was challenging yet rewarding"
3. "I learned a lot from the biogas problem, though it was tough at times"
4. "The biogas spreadsheet helped pull everything together"

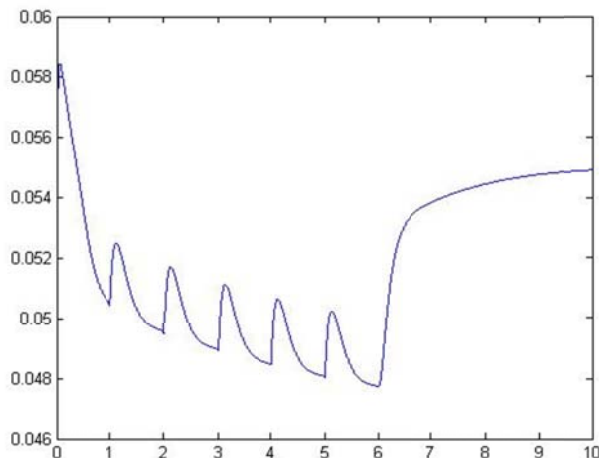
### **A Biogas Production Modeling Project in Mathematics**

A project is under development which would introduce biogas production modeling into the mathematics curriculum. The target courses are either MATH-305 Numerical Methods or MATH-420 Mathematical Modeling. The biogas production model used is based on the

International Water Association's (IWA) Anaerobic Digestion Model No. 1 (ADM1)<sup>5</sup>, which provides many avenues for teaching in the fields of mathematics, engineering, and computer science. The simulation of biogas production using a model involves many steps. The broad themes in the process are 1) model derivation, 2) model implementation, and 3) simulation. The study of any combination of these steps will provide many opportunities for student involvement and learning.

ADM1 is a system of first-order, linear, differential equations and algebraic equations. Among the phenomena these equations describe are the chemical reactions that occur during biogas production, mass balances of chemicals within the system, flow of materials into and out of the system, and levels of inhibitory quantities (pH, nitrogen, hydrogen sulfide, etc.). Some major questions of interest for the students would be: what variables and other factors are important to the process of biogas production? What simplifying assumptions have been made in ADM1 and why are they valid? How are the physical phenomena translated into mathematical equations?

The conversion of the mathematical equations of ADM1 into a working code offers an approachable yet stimulating challenge. Students would be able to attempt to write their own implementations of the code (or pieces of the code). Also, an existing MATLAB/Simulink code which simulates biogas production via ADM1 is available upon request of the authors. A sample of output from the code is shown in Figure 2.



**Figure 2 Methane production from an anaerobic digester as predicted by ADM1 model**

Using their own code or this available implementation, students may run the ADM1 model and observe the predicted outputs. They can study the effects on biogas production of varying the inputs and parameters, and suggest ways in which biogas production could be optimized. Combined with a lab that contains an anaerobic digester, these predicted optimal conditions could then be tested. Currently, an undergraduate co-operative learning student is working in the lab to describe the make-up of alternative feedstock (or substrate) in terms of the ADM1

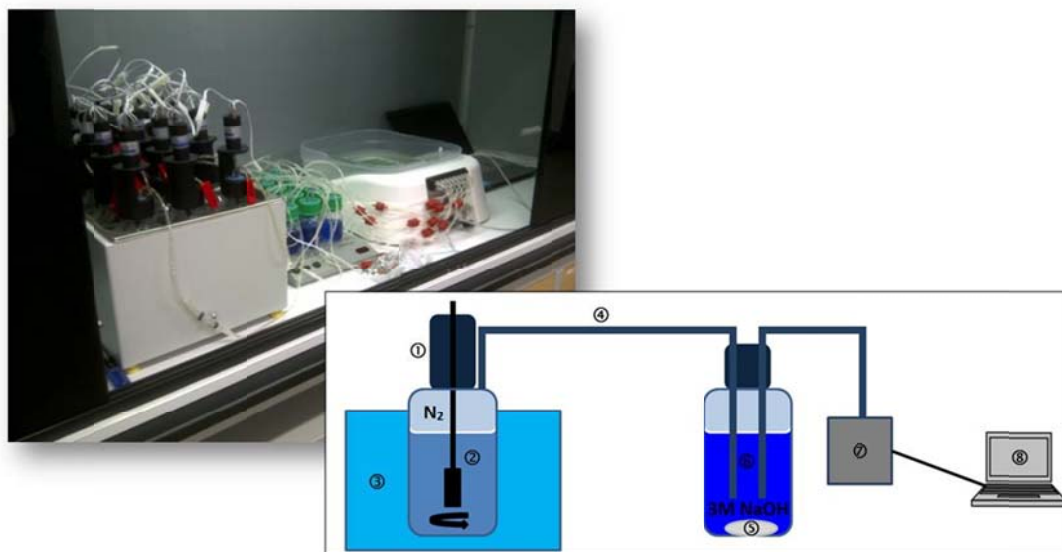
parameters. Once these values are estimated, the code will be run using these inputs to determine the viability of these substrates.

In conclusion, the study of biogas production using ADM1 provides a framework where students can be exposed to concepts in theoretical modeling, numerical implementation, and the use of model outputs to optimize physical processes.

### **Biogas Research Projects for Undergraduate and Co-operative Learning Students**

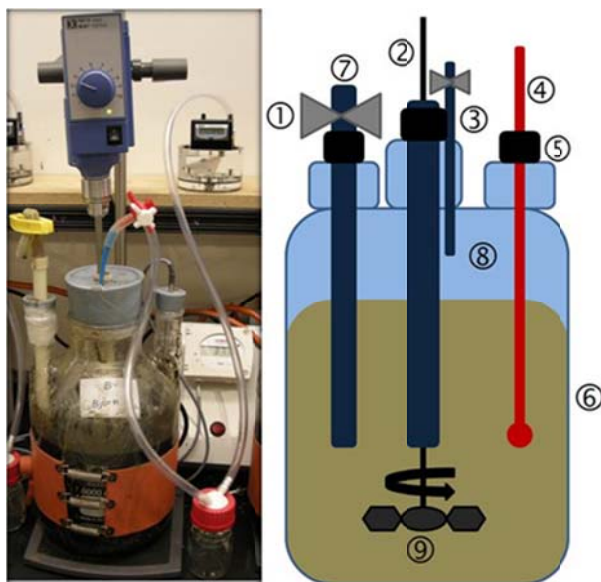
Funding from the Department of Energy was employed to develop an Anaerobic Digestion and Verification Laboratory (ADV L). The lab evaluates substrates for implementation in anaerobic digestion systems, by performing Biological Methane Potential (BMP) testing, small scale reactor operation, biogas analysis and analytical testing. Undergraduate students are involved in all phases of laboratory development and operation.

More than fifty substrates have been evaluated by the lab to date for their Biological Methane Potential. The BMP is determined using the Automated Methane Potential Testing System from Bioprocess Control (Figure 3). The laboratory follows the International Water Association method.<sup>6</sup>



**Figure 3 Automated Methane Potential Testing System (AMPTS).**

If the substrates show promise in the Biological Methane Potential test they are then fed to a small scale anaerobic digester to determine the process stability. An example of the small scale reactors are shown in Figure 4. The reactors are fed with the substrate and biogas production recorded at the same time daily, including weekends. The reactors are tested once a week for process parameters such as pH and degradation in addition to biogas sampling for the components present in biogas.



**Figure 4 A Continuously Stirred Tank Reactor (CSTR) is a small scale anaerobic digester used to determine the process stability.**

All Kettering students work in a co-operative learning job throughout their degree program. The ADV Laboratory hires many freshmen – seniors to work in the lab. As freshman and sophomores the students are responsible for simple operations such as feeding of the digesters. As they progress in their degree programs the student’s responsibilities grow. As seniors, students are expected to complete a comprehensive thesis projects. In addition to senior thesis work, senior Chemistry students are expected to complete “senior research” projects. The following are examples of senior thesis and research projects:

- “The Use of Gas Chromatography to Analyze Biogas with a Focus on Process Management and Forensic Analysis”: In this thesis this student worked collaboratively with our collaborators at Swedish Biogas International (SBI) in Sweden to improve the analysis of the components in biogas. The methods that were developed were superior to the methods in SBI and many were adopted by them. This student is now attending graduate school at Georgia Tech.
- “The Identification and Quantification of Trace Components in Biogas”: In this project the quantification of trace components in biogas were undertaken. Siloxanes and hydrogen sulfide were the focus of this thesis. The result of this thesis brought in external research dollars for sample testing to the laboratory. This student is now employed is the laboratory technician for Swedish Biogas International (SBI) and Kettering University.
- “Evaluation of Post-consumer Food Waste for Mono-Substrate Anaerobic Digestion”: This funded thesis project was to evaluate post-consumer food waste from a local hospital in mono-substrate anaerobic digestion. This project has led to numerous

publications and presentations. The student responsible for this project is now attending Notre Dame graduate school.

- “Evaluation of Trace metals in Anaerobic Digestion”: This project worked to analyze trace metals in the Anaerobic Digestion process. The student was able to develop standard curves for two metals and concentrate samples in order to identify one metal. This student will graduate and has been accepted to medical school at Michigan State University.

The students that are flourishing in this environment are not necessarily the students with the highest GPAs, but the students that are willing to work the hardest. It was found that including the students early in the process, during the grant writing phase, led to the best results because the students fully understood the expectations of the funding agency. It was also found that it was important to have a lab technician available to work with the students on a daily basis.

Experience has also taught that it is important to push the students; give them projects that are above what they think they can do. They will go through a period of frustration. Let them get frustrated and be patient with them. Help them to come to a conclusion by giving them the resources and they will complete the project. Ultimately they will not have anyone to walk them through the process when they go to graduate school or industry. They will learn how to design experiments and how research works. They will be better scientists for it.

Finally, it should be noted that the Anaerobic Digestion and Verification Laboratory is maintained in collaboration with a company Swedish Biogas International. Consequently, the students are exposed to the expectations of industry while they work in the lab. The students participate in hosting corporate collaborators, the students learn much more than the laboratory techniques.

### **Bioethanol Usage in Student Competition Projects**

Kettering University students participate several of the Society of Automotive Engineers (SAE) Collegiate Design Series (CDS) competitions.<sup>7</sup> Two of the competition vehicles, the Clean Snowmobile Challenge sled and the FormulaSAE racecar, have been converted to run on bioethanol fuel.

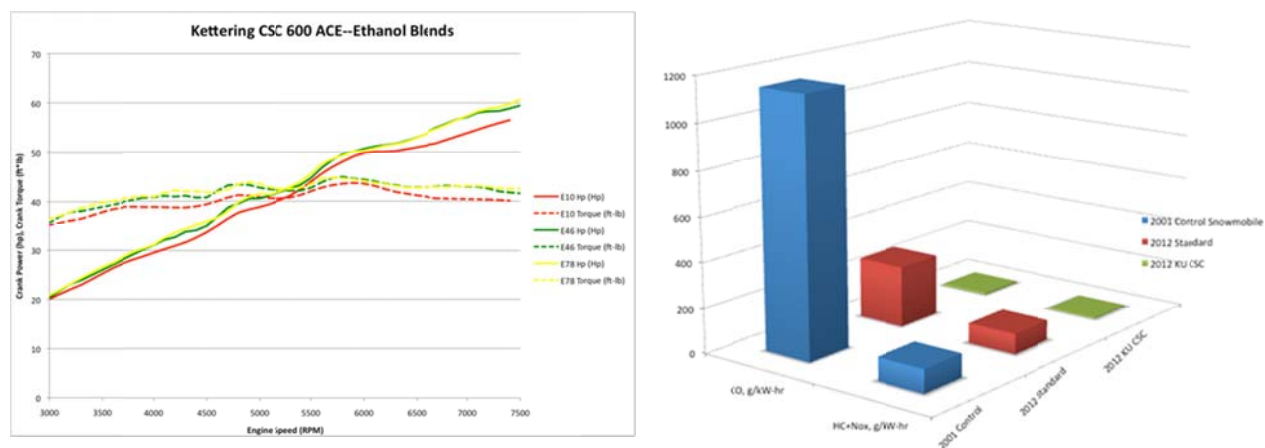
The SAE Clean Snowmobile Challenge (CSC) team competes in a yearly international collegiate design competition for the lowest chemical and noise emissions, the greatest fuel efficiency, and best performance from a modified production-based snowmobile. Combustion-powered snowmobiles can be fueled with blended biodiesel or a bioethanol blend, both mixed with unknown amounts of petroleum diesel or gasoline. Ethanol blended fuel was chosen to allow for an engine design with light weight and high power--important characteristics for a powersports application. The team has modified the engine with the addition of a turbocharger to take advantage of ethanol blend fuel's excellent knock resistance. Kettering has also implemented its



own engine controller and flex fuel sensor to allow the snowmobile to run ethanol blends from E0 to E85.

The Kettering Formula SAE (FSAE) team competes in a yearly International collegiate design competition for the best student designed, constructed, and driven autocross formula-style race car. To achieve excellent dynamic performance, the team must design the vehicle with the lowest possible mass. To achieve this goal for the engine system, a smaller-displacement, lightweight single-cylinder engine was chosen. High specific output was required from the small-displacement engine, thus the team chose E85 fuel instead of gasoline to increase torque and to provide knock resistance at an increased compression ratio of 14:1. The vehicle also achieves excellent performance in the Formula SAE fuel efficiency competition due to its small engine displacement and the E85 ethanol's lean limit which allows for lean running at more load points than gasoline.

Both competitions offer the students an opportunity to understand the differences between designing an engine to run on gasoline and designing an engine to run on bioethanol. Through their work students have discovered-on their own-the benefits of used bioethanol fuel; including the potential to increase power and to decrease overall emissions (see Figure 5).



**Figure 5** Examples of the differences between running an engine on gasoline and bioethanol. Left – wide-open throttle torque and power curves, Right – overall emissions performance.

But despite its many known benefits bioethanol has some significant challenges. There are ethical concerns over the use of food crops to make fuel and technical concerns (which may or may not be real) regarding the potential damage that ethanol can do to engines not specifically designed for ethanol fuel. So, in addition to learning about the technical differences between the fuels, the students on the teams are also learning about the societal issues that accompany the use of bioethanol. When team members are out in the community displaying their vehicle projects (e.g. at a local Corngrowers event as shown in Figure 6), they often hear differing opinions on the use of bioethanol from members of the community.



**Figure 6 The Clean Snowmobile Challenge sled at a local Corn grower event**

### **Bioethanol Research Projects for Undergraduate and Co-operative Learning Students**

Undergraduate co-operative learning students are also employed by the Advanced Engine Research Laboratory. These students have participated in a number of bioethanol research projects in the laboratory. Most of these studies have been to understand the technical challenges associated with using bioethanol. In a project conducted for the Department of Energy, the effect of mid-level blend of ethanol (specifically E20) was studied to determine if the increased level of ethanol in the fuel would have negative effects on the vehicle fuel systems.<sup>8</sup> This project was particularly interesting for the students involved because at that time the U.S. Environmental Protection Agency was considering a waiver to allow E20 to be used in MY2006 cars and newer. (That waiver was approved, although there are currently court challenges that must be decided before E20 will be sold at the pump.)

More recently, a study was conducted to understand the problem of ethanol water phase separation in small engines. Many organizations and individuals have expressed concern about the possible ethanol-water phase separation when using ethanol-blended fuels. For example, the Environmental Protection Agency (EPA) issued a memorandum discussing possible detrimental effects that might be experienced by engines if they are fueled with a mixture that includes the separated phase layer.<sup>9</sup> As many know, water is not readily miscible with gasoline. This means that the addition of even very minute amounts of water to pure gasoline will cause water phase separation. Since water is denser than gasoline, this phase separation layer will be located at the bottom of the fuel tank, beneath the gasoline. If this layer is drawn into an engine, such as during a cold start, it will not combust, causing the engine not to start. The general consensus is that this will not lead to any engine damage.

Ethanol is readily miscible in water. This means that, if enough water is added to cause separation of an ethanol-blended fuel, the water will actually draw the ethanol out of solution; therefore, the separation layer will contain both water and ethanol. This layer is still denser than the base gasoline causing the phase to sink to the bottom of the fuel tank. The potential concern

is that this ethanol-water phase could be drawn into the engine during cold starts allowing the engine to run. If the engine does start on this mixture, the combustion will be lean, which could lead to damage due to the elevated temperatures. Further, the ethanol-water separation layer could compete with the lubrication oil and coat the metal components of the engine, leading to a loss in lubricity.

The phase separation issue is considered to be more of a concern in small engines because of their intermittent use and generally, unheated storage locations. This leads to longer fuel storage time, and might cause phase separation to occur.

Students conducted experiments to compare the effects of water in E10 fuel as compared with E0 fuel. Both fuel samples were acquired from commercial suppliers during the same time period to minimize differences in aging or formulation. Tests conducted included:

1. Long-term Storage Experiment – to determine the likelihood of the formation of water ethanol separated phase during storage (3-6 months).
2. Engine Performance Testing with Ethanol Water Phase Separation – a series of tests were conducted on a small engine by artificially creating water phase separation with a mixture of fuel and water.

The results of the testing indicated that the concerns that have been expressed regarding the water ethanol phase separation issue when using E10 seem to be unfounded. The example presented here shows just one example of a problem that is (rightfully or wrongfully) attributed to bioethanol fuel. There are many other such issues that need to be addressed before bioethanol is totally accepted as an alternative to conventional fuel.

Undergraduate students working on the competition and research projects have responded to the challenge of using bioethanol by producing impressive results. The students working on these projects have exceeded expectations. It is very rewarding to see how fiercely proud the students are of completing projects that other students would not even attempt to try.

## **Summary**

The topic of biofuels has been found to be effective in increasing student motivation to learn. Students have responded favorably to classroom projects at the sophomore level and have blossomed as student learners in project work at the junior and senior level. As described in this paper, the production of biofuels is a rich area for student research and an excellent opportunity to offer interesting multidisciplinary modeling projects for students. The use of biofuel involves challenges that are different than the use of conventional fuels, but these differences are not yet well understood. Understanding this difference is a rich area for student exploration and learning.

Biofuels provide a host of learning experiences, many of which match up well with ABET learning outcomes. In particular, biofuels offer excellent opportunities to develop:

- a. an ability to apply knowledge of mathematics, science and engineering (*in a very multidisciplinary manner*)
- b. an ability to design and conduct experiments, as well as to analyze and interpret data
- c. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- f. an understanding of professional and ethical responsibility
- h. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- j. a knowledge of contemporary issues

This paper has described a few of activities to develop student understanding of the opportunities and challenges of biofuels. There are many more projects that are possible. Next on the agenda for the group is to develop an understanding of the opportunities and challenges for using biogas in conventional engines.

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