Experiential Learning Activities for K-12 Outreach and Undergraduate Students involving Production and Utilization of Biodiesel

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Abstract

A multidisciplinary team of students and faculty at University of Maryland Eastern Shore have been involved with making biodiesel from virgin and used cooking oils on campus. Biodiesel made with used cooking oil from campus dining services has been used for running farm equipment and a diesel generator to power a campus green-house and ongoing projects related to development of an Integrated Multi-trophic Aquaculture (IMTA) system. The multidisciplinary team at UMES also partnered with Cornell and member universities of the National Bioenergy and Bioproducts Education Program (NBBEP) with support from the United States Department of Agriculture (USDA). As part of the NBBEP, the UMES team developed a kit that could be used in K-12 settings without access to elaborate chemistry laboratories to make biodiesel from virgin cooking oil. The school teachers who have used the biodiesel kits in the K-12 settings have indicated that integrating the biodiesel production activity with its utilization in a transportation related activity will make the activity even more appealing to the students and provide richer learning outcomes.

This paper outlines the biodiesel kit development efforts, its utilization in K-16 outreach activities integrated with NBBEP and other ongoing K-12 outreach efforts at UMES. The recent efforts in utilizing a biodiesel blend (with heptane and castor oil) that have been reported to work with glow engines, to fly on a model remote controlled fixed wing airplane is also highlighted. The assessment framework and lesson plan for the biodiesel kit were suitably adapted based on the success of the trials, and incorporated in the K-12 outreach efforts at UMES in 2016 summer.

1.0 Introduction

The need for less expensive and cleaner alternatives to petroleum-based fuels has been the principal driver for much of today's energy research. While the price of oil has been at historically low levels over the last two years (2014-2016), predictions of production limits by The Organization of Petroleum Exporting Countries (OPEC) have contributed to the most recent bout of price instability [1]. In addition to economic concerns, the environmental impacts of traditional fossil fuels (FF) cannot be ignored. Significant changes to global ecosystems through both the acquisition and use of FF have been witnessed within the last seven years [2-3]. The catastrophic explosion of the Deep Water Horizon oil rig in 2010 has left an indelible mark on sensitive coastal ecosystems along the US Gulf Coast, with impacts likely to be felt for decades to come [4]. Even more recently, the crossing of the 400 ppm threshold for atmospheric carbon dioxide in 2013 signals that urgent and significant actions will be required to ward off the most dramatic effects of a changing climate [5]. The desire for job creation, economic prosperity, and perceived uncertainty with regard to climate science among some policy makers in the US may result in increased coal mining, and support the development of infrastructure for refining crude oil in the near future. An increased FF utilization in the United States will have negative environmental outcomes and global climate change [6].

Recognizing the significant challenges associated with the current energy scenario, a collaborative effort was undertaken to support the current campus operations and research at the UMES to reduce its carbon footprint. The first phase, led by a multidisciplinary team of university faculty, career scientists, staff, and supported by students, saw the implementation of a year-round biodiesel generation capability [7]. The project's rationale stemmed from the institution's sizeable agricultural operations (UMES is an 1890 land grant institution) which were undertaken by heavy machinery operating on copious amounts of traditional diesel fuel (Figure 1). Biodiesel, on the other hand, is a renewable alternative which can be produced by virgin oils extracted from oil seeds, or used oils, such as the waste oils from the university's cafeteria. Through the process of transesterification, the oil is converted to fatty acid methyl esters (FAMES), which can then be utilized by diesel-capable machines such as the tractors and combines employed on the farm (Figure 2). To support these efforts, a BioPro 190 from UTAH biodiesel was purchased. Additionally, some of the farm machinery also required retrofitting to make them fully compatible with the new fuel source, so the appropriate hardware were acquired. Much of this work was accomplished by the students. Participating student feedback indicates the experiences enriched their learning and broadened their perspectives. (Figure 3) [5].

Figure 1. An example of farm equipment, a combine, that could utilize biodiesel.

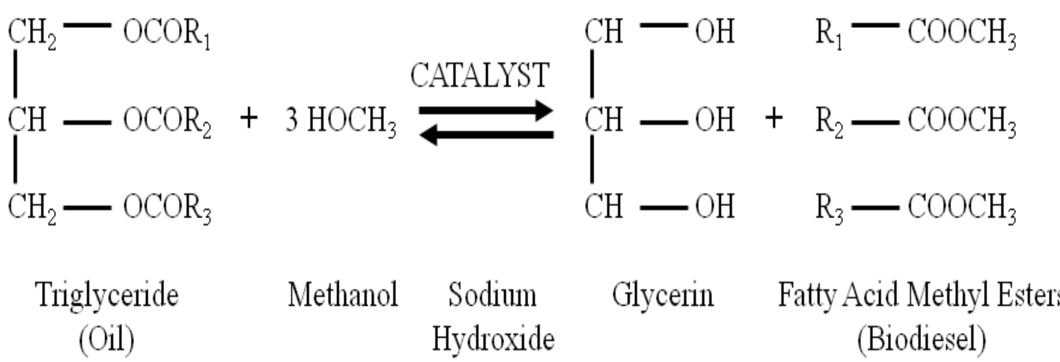

Figure 2. Reaction pathway for synthesis of biodiesel from oil.

Figure 3. Students preparing the BioPro 190 for a new biodiesel production run.

With the normalization of biodiesel generation on campus, it became apparent that a full assessment of the production cycle would be necessary to ensure the project's viability. Approximately 50 gallons of biodiesel were produced at every run which quickly outpaced the farm's utilization rate. The initial solution was to stockpile the unused fuel, however, this proved problematic due to space constraints and the propensity of unadulterated biodiesel to gel under prolonged exposure to cold temperatures. An alternative solution was to utilize the fuel to support other energy-intensive research efforts on campus. Coincidentally, there were parallel and tangentially related efforts geared towards the design and implementation of an Integrated Multi-Trophic Aquaculture (IMTA) system based upon the culture of white-leg shrimp and a red seaweed, *Gracilaria* (Figure 4). These efforts formed the basis of a doctoral dissertation and were being undertaken on campus in a large greenhouse without a functioning environmental control system.

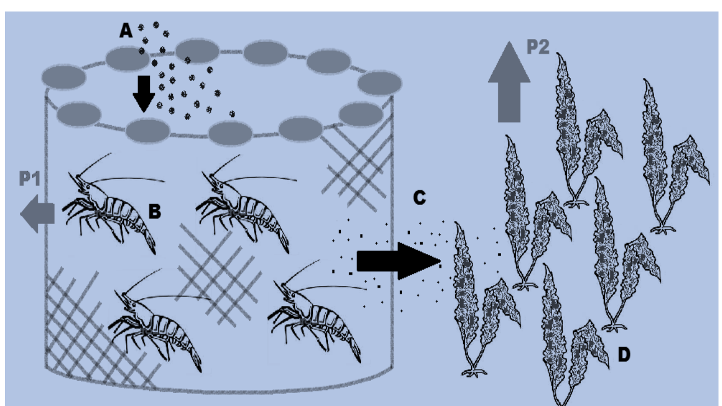

Figure 4. IMTA based upon shrimp and *Gracilaria*: (A) Artificial feed, (B) Fed shrimp culture (C) Nutrients from uneaten feed & excrement, (D) Extractive seaweed culture, (P1) Product 1, & (P2) Potential new product

Since the research was being undertaken in a location with no direct connection to any marine or estuarine systems, all system dynamics had to be maintained artificially. As such, significant amounts of energy (from the traditional grid) were needed to aerate, heat, and circulate the water contained in the large tanks housing the shrimp and the seaweed. While the use of biodiesel did not significantly change the energy requirements of the IMTA system, it reduced the associated environmental footprint. At the same time, the IMTA made use of the excess biodiesel currently stored in the biodiesel facility. The students were again enlisted to identify a diesel generator capable of servicing all the energy requirements for the IMTA related equipment. Eventually, a six kilowatt GT-Power generator was purchased (Figure 5). The students first tested the generator with various biodiesel blends (B20, B50, and B80) to ensure that it was indeed capable of running on biodiesel without any adverse effects before switching to B100 (100% biodiesel). Subsequent to completion of these tests, the generator was installed in the greenhouse as the major source of power for the IMTA system.

Figure 5. The 6 KW diesel generator prior to installation in the greenhouse.

2.0 Biodiesel Kit Development and Usage in NBBEP

Given the successes at both the implementation and integration of biodiesel processes with existing campus infrastructure, the team looked for avenues to expand the visibility of biodiesel as a viable alternative to existing energy sources. The lead researchers overseeing the aforementioned projects got involved with a K-16 education program in the areas of bioenergy and bioproducts around this time. The USDA-NIFA funded program, known as the National Bioenergy and Bioproducts Education Program (NBBEP), brought together a group of eight universities, colleges, and labs that provided professional development opportunities for educators in the areas of bioenergy and bioproducts, sustainability, and systems thinking [8]. According to the program's mission, "the ultimate goal of the program is to inspire student interest in STEM and Agriculture related courses and career paths through the use of the program-related content and teaching tools" [8]. A key component of the program was the dissemination of instructional materials and kits to participating educators for use in their respective classrooms. The NBBEP provided a unique opportunity to develop teaching materials geared towards the small-scale production of biodiesel and pathways for its integration at the participating schoolteacher's institution.

Under the supervision of the project leaders of some of the UMES students involved with the projects experimented and developed a protocol for the safe production of small quantities of biodiesel. The constraints outlined included that the protocol would likely have to be carried out in classrooms without access to ventilation hoods, appropriate glass-ware, or even access to the required chemicals. In other words, they would have to engineer their way to a safe and suitable outcome through the use of household or easily accessible chemicals and components. The team, having experienced the production process at varying scales (lab bench to 50 gallon production runs) identified the most important aspects of the process; the chemicals, required glassware, and the finishing process (Table 1). The household alternatives for the required chemicals were quickly identified in the form of sink and drain cleaner for Lye and gas-line antifreeze or Heet, in the place of methanol. Since the items would be made available in the form of kits assembled at the university, the required quantities would be appropriately premeasured and packaged.

Table 1. List of most critical materials and steps to develop new small-batch biodiesel protocol

Required Reactants	Required Glassware	Finishing process
NaOH (Lye)	500 ml beaker	Heating of reactants
CH_3OH (Methanol)	1,000 ml beaker	Agitation of reactants
H_2O	2,000 ml beaker	Washing of crude biodiesel
Vegetable Oil	Separation funnel	

The reaction vessel, on the other hand, posed a more significant challenge. On the lab bench, the transesterification reaction was contained within 1liter glass beaker and the biodiesel and glycerin were separated using a glass separation funnel. Both of these are often not readily available in middle and high school labs and as such, alternatives were needed. Some of the students from the group, having worked extensively with aquaria and aquarium fittings on another project, suggested the development of a combined plastic reaction vessel and separation funnel utilizing a 1 liter plastic bottle and aquarium valves (Figure 6). The plastic for the vessel would be inert to the chemicals being used and the valves could be used to vent the gases produced by the extremely exothermic reaction. A few prototyping and preliminary tests were conducted; some of the early iterations suffered from leaks where valves had been secured to the bottle. These issues were later addressed by replacing the original glue-stick adhesive with a fuel resistant sealant.

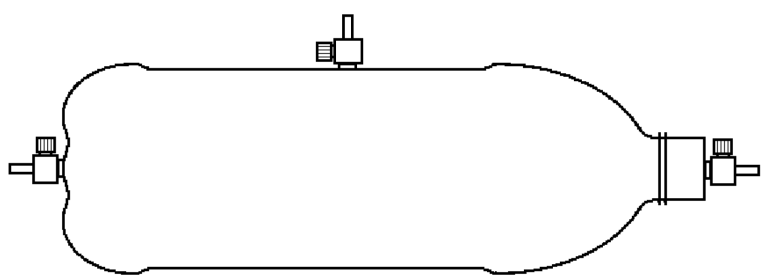

Figure 6. Diagram depicting student design for biodiesel reaction vessel, showing approximate locations of aquarium air valves around the liter sized plastic bottle.

After adapting the final procedure that was acceptable to all members of the team, a few test kits were assembled to be used in the upcoming summer NBBEP workshop. At the workshop, twelve participants had the opportunity to work with the updated kits and gave their feedback (Appendix A). Furthermore, the participants also had the opportunity to request and receive kits to take back with them to their respective classrooms... The feedback received for the biodiesel activity was generally positive and the activity was implemented by at least two of the participants at the K-12 setting. One of the participant also initiated a project at his school to produce biodiesel using machines similar to BioPro 190 to run the school buses (http://biodiesel.org/docs/ffs-basics/better-choice-for-children-and-buses.pdf?sfvrsn=6) .

3.0 Outline – BioEnergy Academy for Teachers (BEAT) the energy crisis through Bioenergy Literacy for Teachers (BLT)

The Bioenergy Academy for Teachers (BEAT) draws from the experience the project team at UMES developed through participation with the NBBEP. BEAT program independently supported at UMES by National Institute of Food and Agriculture (NIFA) through their Capacity Building Grant Program has allowed the team to fine-tune, adapt, and enhance some of the efforts undertaken at UMES during the NBBEP for additional participants. After NBBEP project was completed, BEAT workshop was conducted independently at UMES in 2016 summer. For the final year of the BEAT project in 2017 summer instead of conducting the activities on UMES campus the project team plans to hold a workshop during the 2017 conference and exposition of the American Society for Engineering Education in Columbus in the month of June.

Although the focus of this document is around the biodiesel related activities on UMES campus that have been undertaken in concert with the NBBEP and BEAT projects, for ready reference an overview of all of the BEAT/NBBEP activities (see APPENDIX B for the 2016 BEAT schedule), assessment and impact are outlined below:

Figure 7. Some of participants using the Biodiesel Kit during BEAT workshop in 2016 summer

Biodiesel: In the biodiesel activity, participants are introduced to the environmentally-friendly alternative to petro-diesel that is capable of being used in many of today’s vehicles with diesel engines. The concepts of carbon neutrality are also introduced since it is an integral reason for the adoption of biodiesel as an alternative in today’s carbon-heavy economies. Using products that are readily available from many “big-box” and automotive stores (HEET, a source of methanol and Drain opener, a source of sodium hydroxide), and vegetable oils that were pressed from grains produced at the UMES research fields, small amounts of biodiesel were created in the lab. The synthesis of the fuel also led to discussions concerning the market penetration of the fuel in the US versus other global markets as well as the viability of the byproduct, glycerin, which was used in the glycerin soap making. This activity culminated in a brief tour of the university's biodiesel facilities where the fuel is regularly made from waste cooking oil for the use in farm equipment as well as for the diesel power generator powering the Integrated Multi-trophic Aquaculture (IMTA) facility where both shrimp and *Gracilaria* are produced in an attempt to address food, energy, and environment concerns in the future bioeconomy in a sustainable way (Figure 8).

Gracilaria to Bioethanol: Another biofuel to which participants were exposed to was bioethanol. Macroalgae grown in the IMTA system is used to demonstrate the synthesis of ethanol which can be used as an additive to traditional gasoline or as its own alternative fuel in newer technology vehicles. The *Gracilaria* grown in the IMTA tank is commonly referred to as a nuisance alga since it readily forms pervasive blooms around the Mid-Atlantic region. .Fortunately, from a biofuels perspective, the seaweed is comprised of quantities of easily fermentable sugars. It is this sugar that the participants made use of in this lab, by simply macerating the alga and then treating it with basic baker's yeast and allowing the medium to culture over a 24- hour period. Thereafter, the medium was filtered of solids and distilled to reveal the small amount of crude ethanol liberated by the process. In a retrospective discussion, participants were given the opportunity to reflect on the viability of such techniques and products in the current market place and to how the process may be improved in the future (Figure 8).

Algal PBR: In this activity, participants were taught the concepts of algal bioenergy and algal production systems. The activity began with a brief lecture on algal ecology, algal morphology, eutrophication, algal storage compounds, and other applications for algae. It was then culminated in the participants constructing their own algal photobioreactors (PBR's) complete with *Arthospira platensis* inocula and growth media using two 500ml plastic water bottles, aquarium air hoses, and an aquarium air-pump (Fig 9a). After constructing their PBRs, participants were also exposed to the implications of using PBRs in research and were allowed to tour current investigations using various scales of PBRs for the bioenergy and bioremediation efforts being undertaken at the university.

Glycerin Soap Synthesis: In this activity, participants were introduced to a potentially valuable byproduct of biodiesel production using biodiesel glycerin (also known as glycerol). The glycerin that was previously obtained from the synthesis of biodiesel on campus was used to make environmentally-friendly soaps (Figure 9b). Kits, produced at the university, contained all the necessary materials to allow for the saponification reaction to be conducted safely. The basic reaction, an acid plus base, utilizes the fatty acids present in the triglycerides within the biodiesel glycerin and react with sodium hydroxide (Lye), to produce the soap (a salt) and glycerin, which serves as a moisturizer. Essential oils from a variety of sources were also added based upon the individual's preference to add another dimension of originality to the soap making process. After completing the reaction in the classroom, the participants were exposed to several methods which they could employ to test the quality and safety of their soaps. Once the soaps were allowed to set and dry after 24 hours; they were also given the opportunity to create decorative bars as gifts and mementos.

Sustainable Bioproducts : Given the common misconceptions surrounding “green” and organic products, the bioproducts activity was designed to expose participants to the many facets of these up–and-coming products. First, a discussion of what it means to be “green” and organic was held to arrive at a consensus. Several product demos and trials were convened to put these products through their paces. Some of the activities included a tasting of algal food products such as chips with seasonings, and the synthesis of a biopolymer packaging peanut to protect an egg during an egg drop activity. There was also a comparative assessment of various traditional versus green cleaning products against common day-to-day stain causing compounds. The participants concluded that many of the green alternatives met or in some cases exceeded their expectations in comparison to the performance of the traditional products.

Mudwatt Microbial Fuel Cell: The Mudwatt Microbial fuel cell (MFC) activity was centered on the potential for harnessing energy from living microorganisms. The MFC is a bioelectrical device that takes advantage of the natural metabolic activities of microbes to produce electrical power directly from organic material. In this activity, the participants collected mud from the banks of a river located on the campus, and prepared it for use in the MFC. The MFC chamber was then filled with the mud and allowed to sit until a steady pulse of light was emitted from the diode indicating peak productivity. The participants were also able to check the voltage obtained from their cells and compared it with different mud preparations (Figure 9c). The resistance of the MFC was also varied and its effect on the system was also recorded.

Biolite: Using the BioLite stove, the participants were exposed to the concept of thermodynamics, thermoelectric materials, the Seebeck effect, and the practical applications of their use in today’s society in addition to how the varied energy densities of feedstock may impact the energy production regime. The participants were given an opportunity to collect various materials from outside and then test their suitability for combustion within the stove. Thereafter, the stove was used to charge several mobile devices and also to roast marshmallows and make green tea for the participants to enjoy (Figure 9d).

BITES: Buildings, Industry, Transportation, and Electricity Scenarios (BITES) tool can be accessed from the URL:https://bites.nrel.gov/education.php. It has been developed by National Renewable Energy Laboratories (NREL) and allows users to create ‘what if’ scenarios to explore and compare outcomes related to baseline reference cases of the carbon footprint by adjusting energy inputs to buildings, industry, transportation, and electricity generation sectors in the United States. An activity developed in consultation with developers of the tool at NREL was integrated in the institute in the third year. The educators participating expressed that the tool allowed them to better comprehend the broader dimensions of the overall picture that provides relevance for the emphases on bioenergy and bioproducts during the institute. In particular, they could readily see the carbon implications of using more biofuels in the transportation sector, as well as increased use of biomass for heat and power generation for buildings, industry, and electricity generation sectors.

Figure 8. Schematic of IMTA System depicting the production of oil from oil seeds for biodiesel synthesis, the use of the biodiesel to meet the IMTA's electrical needs, and the production of *Gracilaria* biomass for bioethanol production.

Figure 9. **(a**) Participants receiving a brief lecture on algae ecology and putting the final touches on their water bottle PBR systems; (**b**) Bioproduct soap making with biodiesel glycerin **(c)** Demonstration of the Mudwatt microbial fuel cell; **(d)** Participants using the Biolite to prepare roasted marshmallows and charge their cell phones.

4. RESULTS: PROGRAM IMPACT

4.1 Content Knowledge and Perception Surveys

The educators were administered a multiple-choice test consisting of 20 questions. Teaching partners took this test twice: once before the institute and the second time after the institute to measure the impact on the content knowledge in the areas of sustainability and renewable energy with a particular emphasis on bioenergy, and bioproducts. The pre-test scores before attending the institute were much lower than the post-test scores. The data indicated that there was an improvement in the scores of the post-tests for all the four years of the institute. Figure 10a shows that the average pre-institute score on this test was 42% while the average post-institute test score among educators was 77%. The online perception survey was also a pre and post-assessments comprised of eleven questions in which the educators rated their comfort level teaching the topics within the following areas: Agriculture, Sustainability, Forestry, Systems Thinking, Biomass, Biodiesel, Ethanol, BioHeat, BioPower, BioProducts, and Environmental Policy. The chart below shows the pre-test to post-test scores of 2011-2014 participants. The two different columns in the light blue and dark blue show the pre vs post-test percentages of educators who selected the criteria designations ‘somewhat comfortable’ or ‘very comfortable’ to describe their comfort-level with each of the listed topics. Comparing these two columns and the overall results of the pre-institute to post-institute perception survey scores, it can be inferred that there was an increase in the content knowledge and comfort level of teaching topics such as sustainability, bioenergy, and bioproducts for the participants. This change is indicated by a shift toward increased levels of comfort through a self-assessed rating, where each participant indicated his/her perceived comfort level with a given topic on a 5 point scale ranging from ‘very uncomfortable’,’ somewhat uncomfortable’,’ neutral ‘, to somewhat comfortable and very comfortable. Specifically, this change evidences a percentage shift and increase with respect to the above-neutral scale designations ‘somewhat comfortable’ and very comfortable’. Prior to the institute, an average of 25% of the participants selected the rating designations ‘somewhat comfortable’ and or ‘very comfortable’ in describing their level of comfort in teaching the given workshop topics: Environmental Policy, Bioproducts, Biopower, Bioheat, Ethanol, Biodiesel, Biomass, Systems Thinking, Sustainability, Agriculture and Forestry. However, at the conclusion of the institute almost 76% of the participants selected the higher comfort level ratings of ‘somewhat comfortable’ and or ‘very comfortable’ to describe their familiarity and competencies with these topics (Figure 10b).

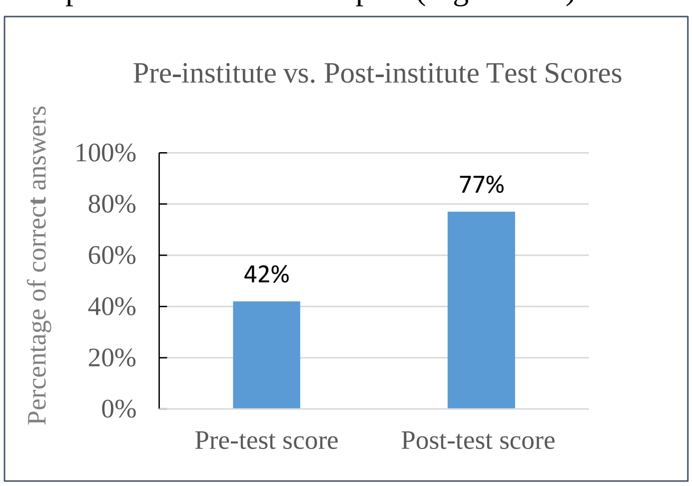

Figure 10a. Pre vs. Post Institute Test Scores

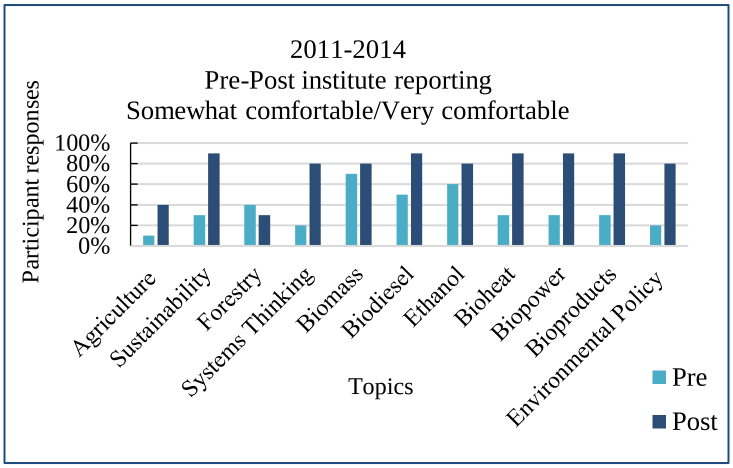

Figure 10b. Pre vs. Post Institute Perception Survey

4.2 Ratings for Program Labs/Activities

The program has also developed another survey related to educator perception of the quality of the institute. This survey was completed on the final day of the institute. It provided educators with statements related to BEAT program curricula, to which they responded on a five-point Likert scale where 1 represents poor/low, 2 fair, 3 good/medium, 4, very good/medium high and 5 excellent/high. Each of the BEAT program lectures, labs and activities were included in this survey. A total of eleven labs and hands-on activities and six lectures were rated. Each of the categorized lab exercises/activities and or lectures had some variation of the following criteria (depending on whether they referenced a lecture or lab):

1. Knowledge of the subject by presenter (*same for both)
2. Clarity of presentation or clarity of presentation and lab activity
3. Time management (*same for both)
4. Application to classroom (*same for both)
5. Quality of power point lecture or quality of lab activity

The surveys were completed by all the forty one participants for the four institutes. Figure 11 depicts an example of the survey for individual lab/activity/lecture.

BIOENERGY ACADEMY FOR TEACHERS EVALUATION OF ACTIVITIES *Please rate from 5 to 1, with 5 as Excellent and 1 as Poor.*					
EXAMPLE					
LAB/ACTIVITY/ LECTURE 1:					
Knowledge of the subject by presenter	5	4	3	2	1
Clarity of presentation and or activity	5	4	3	2	1
Time management	5	4	3	2	1
Application to classroom	5	4	3	2	1
Quality of power point presentation	5	4	3	2	1
Comments:					

Figure 11. Example of survey for individual lab/activity/ lecture component

4.3 BEAT Interdisciplinary Impacts

The following table (Table 2) summarizes the activities which were implemented in various courses in middle and high schools as well as undergraduate classrooms.

Table 2.Activities, disciplines, and level implemented and impacted

Activity	Disciplines Impacted	Level
Algal PBR	Plant Science, Technology, Biology, Marine Botany, Materials Science, AP Chemistry, General Integrated Science	Middle School, High School, Post-Secondary
Soap Lab	Marine Botany, Biology and Earth Science, Biology and Environmental Sciences, Chemistry, Transdisciplinary Class, AP Chemistry, Materials Science	Middle School, High School, Post-Secondary
VO to Biodiesel	Biology, Chemistry, Technology, General and Analytical Chemistry, General Integrated Science, Biology and Environmental Sciences, AP Chemistry	Middle School, High School, Post-Secondary
Bioethanol lab from feedstock and algae	Ag. Science, Plant Science, Marine Botany, Chemistry, Biology, and Environmental Sciences	High School, Post-Secondary
Sustainability activity-design of homes, office	General Integrated Sciences & Human Ecology, Transdisciplinary Class	Middle School, Post-Secondary
Earth as an Apple	Earth Science & Biology	High School
Sustainable Bioproducts	Chemistry, General Integrated Science, Materials Science, Transdisciplinary Class	Middle School, High School, Post-Secondary
BITES	Pre-Algebra, Biology and Environmental Science, Environmental Science, AP Chemistry	Middle School, High School,
Biolite	Engineering, Transdisciplinary class	Post-Secondary
Microbial Fuel Cell	Physics, Transdisciplinary class	Post-Secondary

4.0 Biodiesel Blend, Glow Engine Trials, and demonstration during 2016 Summer Program

Having subsequently facilitated several workshops with successful classroom implementations of the biodiesel process, a consistent participant's comment had been their lack of ability to showcase the biodiesel produced in a transportation related activity. While attending the workshops at the UMES campus, educators had the ability to visit the farm shop to see the diesel-powered vehicles as well as the IMTA activities in the greenhouse. At their respective school districts, student's exposure to this final step of the life cycle would require resource intensive field trips or the acquisition of compatible infrastructure. With UMES having an Aviation Science program, whose students regularly attend and participate in many of these projects, the suggestion was made about utilizing the biodiesel to power a small remote -controlled aircraft.

Seven students (two from computer science, three from engineering, and one from aviation science) took responsibility for seeing this project to completion. First, the students researched small format engines and fuel blending techniques to develop a biofuel blend that could be successfully run in a model aircraft engine. Eventually, a Glow-type engine (http://www.rc-airplane-world.com/glow-plugs-for-rc.html) was decided as the most promising format due to its ability to run on oily fuels. This eventually led to the purchase of a NGH GT9 9cc Gas Engine. After engine selection, an Avistar Elite .46 RTF trainer model RC aircraft was purchased as it was compatible with the engine. The team constructed a temporary test bed out of wood to allow for the testing of various fuel blends. Upon completing the structure, the engine was initially tested with the stock fuel to ensure it was functional.

With the test mount complete, the team moved on to identifying the appropriate fuel blend. Through a thorough review, the students had identified that B100 would not burn continuously in Glow engines, and in fact, needed an additive, such as heptane, to make it more volatile. In addition to the heptane, castor oil was added to help lubricate the engine's internal components. The fuel blending process began with the synthesis of fresh biodiesel from soybean oil, which had been pressed from beans grown on campus. With this biodiesel, a series of trials with varying mixtures of the required additives were undertaken (Table 2). After these trials, it was inferred that a mixture of 40/40/20 (biodiesel/heptane/castor oil) was most optimal for continuous and safe engine operations.

Table 3. The range of fuel blends tested with the NGH GT9 engine.

Fuel Blend	Biodiesel (%)	Heptane (%)	Castor Oil (%)	Test Result
A	60	20	20	Non-start
B	50	30	20	Intermittent
C	40	40	20	Continuous
D	30	50	20	Detonation

Subsequent to the testing, the engine, fuel tank, and other components were installed in the aircraft fuselage. Once installed, several static engine test-runs were completed to ensure everything had been correctly installed. Thereafter, the aircraft was taken to the unmanned aerial systems (UAS) test runway on campus for further ground testing. Ground handling and high speed taxi tests were conducted, and both were found to be favorable. Coincidentally, the completion of the airframe coincided with the BEAT summer Program of 2016 and it was decided that a test flight could be conducted at that time. Unfortunately, on the day of the flight, the winds were considered unfavorable, and the flight was cancelled. In its place however, the participants were given an opportunity to watch the aircraft being fueled, have its engine started, and then they were allowed to take control of the aircraft for a series of high speed taxi runs (Figure 12).

Figure12. BEAT participants observe as biodiesel powered aircraft is prepped.

The 2016 BEAT summer workshop participants had positive responses towards the model airplane activity. The thread of continuity among pressing seeds to get oil; processing the virgin oil to make biodiesel; and finally using a biodiesel blend for the motion of the model airplane in a user-friendly framework was enriching for the BEAT participants, and they felt that these activities could be adapted effectively in their in K-12 and/or college settings.

5.0 Conclusions

Synergy of the BEAT and NBBEP project activities facilitated the two endeavors to be conducted in concert with one another on campus during the first few years. In the 2016 summer, the BEAT workshop was conducted independently at UMES since NBBEP project was completed in 2016 February. The final workshop for K-12 and college educators for the BEAT project will be held during the 2017 ASEE conference and exposition in summer in Columbus, Ohio.

6.0 Acknowledgement

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Bibliography

1. US Energy Information Administration (EIA). 2016. Short-Term Energy Outlook. Retrieved from http://www.eia.gov/forecasts/steo/realprices/
2. Amin, S. 2009. Review on biofuel oil and gas production processes from microalgae. Energy Conversion and Management, 50: 1834-1840.
3. Demirbas, A. 2009. Political, economic and environmental impacts of biofuels: A review. Applied Energy, 86: S108-S117.
4. Van der Ham, J., Mutsert, K. 2014. Abundance and Size of Gulf Shrimp in Louisiana's Coastal Estuaries following the Deepwater Horizon Oil Spill. PLoS One, 9(10): e108884. doi:10.1371/journal.pone.0108884
5. Leung, D., Caramanna, G., Maroto-Valer,M. (2014). An overview of current status of carbon dioxide capture and storage technologies, Renewable and Sustainable Energy Reviews, 39: 426-443.
6. Nitta, Y. and Yoda, S. 1995. Challenging the human crisis: “The trilemma”, Technological Forecasting and Social Change, 49: 175-194.
7. Nagchaudhuri, A., Mitra, M., Teays, T., Daughtry, C., Schwarz, J., Marsh, L. 2012. UMES STEM Faculty, Students, and Staff Collaborate to Address Contemporary Issues Related to Energy, Environment, and Sustainable Agriculture. ASEE Proceedings, June, 2013, San Antonio, TX.
8. Bioenergy & Bioproducts Education Programs (BBEP). 2016. Program Overview. Retrieved from http://www.wingsofeagles.com/education/bioenergy-bioproducts-education-programs-bbep/

APPENDIX A

Procedure for making biodiesel using the UMES Biodiesel Kit

Introduction: Biodiesel is an environmentally friendly fuel for vehicles that work using today's diesel engines. By reducing the amount of petroleum needed to run everyday vehicles, emissions are also limited. Today you are going to create a small amount of the liquid fuel that a diesel engine can run on. By thinning the feedstock (or oil), with the use of easily obtained, household chemicals, you will have a batch ready to use within a day.

Materials:

1 L Plastic Reaction Chamber
Funnel
Mason Jar
2000mL Beaker (or other sufficient size)
Stove (hotplate)
Thermometer
Hot pads

Ingredients:

500mL Feedstock (vegetable oil)
2 grams Lye (Drain Cleaner/NaOH)
125 mL Heet (Methanol)

Safety: Use safety gloves, eye protection, and work in a ventilated area if possible. If any clothing gets chemicals on it, remove and wash. If there is any skin contact, wash skin with warm water and soap. If there is eye contact, flush for 10 minutes. It is best not to wear contacts during this lab.

Procedure: Making Biodiesel

Open your kit and verify that all materials are present and ask Lab Instructor for any other materials.

1. Begin heating oil to 140F/60C in the beaker. If in groups, one person may also move to step 2.
2. Find your 2 grams of Lye and carefully pour into the Mason Jar containing the Heet and close it tightly. This step should be conducted near a ventilation source. Shake the mixture until the Lye is no longer visible. You should notice a heating or warmth in your hands, this is normal as the reaction is exothermic, meaning it gives off heat. The temperature will reduce within 10 minutes. Slowly and carefully loosen the lid and release the pressure built up in the jar. This solution is known as Methoxide.
3. When the oil reaches 140F/60C, carefully pour the beaker of oil into the reaction chamber using the funnel and add the Methoxide.
4. Once the reaction chamber is resealed and all are valves shut, you may begin shaking the mixture for 5 minutes. If shaking the chamber is tiring switch with someone else in the group. Be sure to shake with force.
5. Send someone in the group to wash out the beaker and add 1000mL of water. Place the beaker on the hot plate and heat to 140F/60C.
6. Once you have finished shaking the chamber and heated the water, place the chamber in the beaker, making sure not to overflow.
7. Invert the chamber in the specified beaker upside down before you leave the lab for the different layers to settle down. Make sure you put the beaker with the chamber sitting over it in a dark place (lights out), out of the way.

You have made biodiesel! You will be able to see the separation in layers of biodiesel and glycerin next day when you come back to do the washing.

Procedure: *Washing and Drying Biodiesel*

Bring out the chamber sitting over the beaker from the day before where you processed the biodiesel. Also obtain a 500mL beaker for glycerin collection.

1. Begin heating ~1200mL of water in the beaker that was used for heating the biodiesel in a hot water bath. Pick up the chamber with the biodiesel and glycerin, and observe the layers that are present. Which layer is the biodiesel and which is the glycerin? Which is heavier the biodiesel or the glycerin? Make sure not to invert the bottle while these layers are present as they may take some time to settle down.
2. Open the top valve and then carefully open your bottom valve of the chamber, and remove the bottom layer into the smaller beaker (500mL). Please note that the glycerin does not drain out if you do not have the top valve open. Why? It is alright to lose some of the top layer to guarantee that the entire bottom layer is removed.
3. Now your layers are separated and you can begin washing what remains in the chamber. It is mostly biodiesel, water, and unreacted chemicals. It is very important to note that gentle movement of the chamber is necessary to properly wash the biodiesel. As you progress through the stages you should increase the energy applied to shaking the chamber.
4. Wash one: Add 250mL of hot water and make sure to use the funnel. Reseal the chamber and VERY gently rotate the bottle, end over end, for 30 seconds. Please have your instructor demonstrate this to you if you are not clear. Allow for the biodiesel and the water to separate before repeating this process.
5. Wash two: again add 250mL of hot water and reseal the chamber. Shake very lightly this time for 30 seconds and allow for the layers to separate. Pour out the water and hopefully noticed a less cloudy appearance. This means that the washing is working. As you progress the cloudiness of the oil should decrease as well as the water in later stages.
6. Wash three: add 250mL of hot water and shake more forcefully than last time. Allow for separation and dispose.
7. Wash four: add 250mL of hot water and shake more forcefully than last time. By this time you should be shaking fairly hard.
8. Wash five: add 250mL of hot water and shake more forcefully than last time. Hopefully you have noticed the changes mentioned above. If not repeat this step once more. If there is still an issue ask your Lab Instructor.
9. Now to finish the job, empty the larger beaker (used for the hot water bath) and place it on the hotplate and add the washed biodiesel to the beaker. You may see some cloudiness or small bubbles on the bottom. This is the remaining wash water that didn’t separate. Don’t worry this is typical.
10. Heat the biodiesel to ~140F/60C, and aim for below rather than above. This should remove the water through evaporation until the biodiesel is very clear. (Should not take more than half hour! If it does you may need to come back later and check…but it should eventually become very clear)

APPENDIX B (2016 BEAT SCHEDULE)

BEAT Day 1 (Monday August 15)				
TIME	**TOPIC**	**SPEAKER**	**LOCATION**	**NOTES**
8:00AM-8:30AM	Registration and Breakfast	All Participants	Lobby of EASC	
8:30AM-9:00AM	Pre-Test	All Participants	EACM 1064	
9:00AM-9:15 AM	Introductions	All Participants	EACM 1064	
9:15AM-10:00AM	Overview of the BEAT program; Goals and Expectations	Dr. Madhumi Mitra	EACM 1064	**PP Slides**
10:00AM-10:45 AM	Introduction to Renewable Energy and Sustainability	Dr. Xavier Henry	EACM 1064	**PP slides**
10:45AM-Noon	Systems Thinking and BITES	Dr. Abhijit Nagchaudhuri	EACM 1064	**PP Slides and Laptops required**
Noon-12:45PM	Lunch		Lobby of EASC	
12:45PM-1:00PM	Transportation to Hazel Hall	All Participants		**Transportation will be provided**
1:00PM-1:30PM	Safety Training	Drs. Henry and Das	Hazel Hall 3082	
1:00PM-5:30PM	Building your Organic Solar Cells	Dr. Das	Hazel Hall 3082	**PP slides and Lab Activity**

BEAT Day 2 Tuesday August 16				
TIME	**TOPIC**	**SPEAKER**	**LOCATION**	**NOTES**
8:00AM-8:30AM	Breakfast	All Participants	EASC Lobby	
8:30AM-10:00AM	Biomass and Biofuels	Dr. Henry	EACM 1064	**PP Slides**
10:00AM-Noon	Biodiesel Lab	Dr. Henry	EASC Patio/Ag Lab	**Lab Activity**
Noon-1:00PM	Lunch	All Participants	EASC Lobby	
1:00PM-3:00PM	Bioproducts: Biodiesel Glycerin Soap Lab	Dr. Henry	EASC Patio/Ag Lab	**Lab Activity**
3:00PM-4:00PM	Biodiesel Flight	Dr. Henry	UMES Field	**Field Demonstration**
4:00PM-5:30PM	Bioenergy Crops; Bioenergy Garden and Eco-friendly Aquaponics/Community Garden	Dr. Lurline Marsh and Dr. Henry	UMES Field	**Field Demonstration**
5:30PM-6:30PM	Dinner	All Participants	EASC Lobby	
6:30PM-8:00PM	Anaerobic Digestion: Building your own Digester	Guest Speaker: Dr. MingXin Guo	EACM 1064 and EASC Patio	**Lecture and Activity (Lab)**

BEAT Day 3, Wednesday August 17				
TIME	**TOPIC**	**SPEAKER**	**LOCATION**	**NOTES**
8:00AM-8:30AM	Breakfast	All Participants	EASC Lobby	
8:30AM-9:30AM	Microbial Fuel Cells	Dr. Das	EACM 1064 and EASC Patio/Ag Lab	**Lecture and Demonstration**
9:30AM-11:00AM	Algae and Algae Photobioreactor Lab	Dr. Henry	EACM 1064 and EASC Patio/Ag Lab	**Lecture and Lab**
11:00AM-Noon	Integrated MultiTrophic Aquaculture and Macroalgae	Dr. Henry	UMES Greenhouse	**Field Trip**
Noon	Board the van for trip to Assateague Island and Isle of Wight	Everyone		
1:00PM-1:30PM	Lunch at the beach	All Participants	Isle of Wight	
1:30PM-2:15PM	Macroalgae sampling	Dr. Henry	Isle of Wight	
2:15PM-3:45PM	ROV and KAP	Dr. Henry	Isle of Wight	**Demonstration**
3:45PM-4:45PM	Biolite Activity	Dr. Das	Isle of Wight	**Lab**
5:00PM-6:00PM	Drive back to UMES campus	All Participants		

BEAT Day 4, Thursday August 18				
TIME	**TOPIC**	**SPEAKER**	**LOCATION**	**NOTES**
8:00AM-8:30AM	Breakfast	All Participants	EASC Lobby	
8:30AM-9:30AM	Post-Test and Evaluations and Waivers	Dr. Mitra	EACM 1064	
9:30AM-9:45AM	Break			
9:45AM-Noon	Presentations of incorporation of your chosen activity in your course(s)	All Participants Moderators: Drs. Mitra and Henry	EACM 1064	**PP Slides**
Noon-1:30PM	Lunch	Dr. Craig Daughtry Research Agronomist, USDA-ARS	EASC Lobby/EACM 1064	
1:30PM-1:45PM	Certificates and Picture taking	All Participants	EASC Lobby	
2:00 PM	Wrap U	All Participants		