Development of a Green Energy Manufacturing Laboratory Course on Clean Energy and Energy Efficiency

Dr. Richard Y. Chiou, Drexel University

Dr. Richard Chiou is Associate Professor within the Engineering Technology Department at Drexel University, Philadelphia, USA. He received his Ph.D. degree in the G.W. Woodruff School of Mechanical Engineering at Georgia Institute of Technology. His educational background is in manufacturing with an emphasis on mechatronics. In addition to his many years of industrial experience, he has taught many different engineering and technology courses at undergraduate and graduate levels. His tremendous research experience in manufacturing includes environmentally conscious manufacturing, Internet based robotics, and Web based quality. In the past years, he has been involved in sustainable manufacturing for maximizing energy and material recovery while minimizing environmental impact.

Dr. Michael G. Mauk, Drexel University

Michael Mauk is Assistant Professor in Drexel University's Engineering Technology program.

Prof. Tzu-Liang Bill Tseng, University of Texas, El Paso

Dr. Tseng is a Professor and Chair of Industrial, Manufacturing and Systems Engineering at UTEP. His research focuses on the computational intelligence, data mining, bio- informatics and advanced manufacturing. Dr. Tseng published in many refereed journals such as IEEE Transactions, IIE Transaction, Journal of Manufacturing Systems and others. He has been serving as a principle investigator of many research projects, funded by NSF, NASA, DoEd, KSEF and LMC. He is currently serving as an editor of Journal of Computer Standards & Interfaces.

Dr. Regina Ruane Ph.d., Drexel University

Regina Ruane, Ph.D. is the Director of the Exploratory Program for the Goodwin College at Drexel University. Additionally, Dr. Ruane teaches for the online Bachelor of Science in Education and at Drexel and serves as a consultant for the US Department of Education DHSIP project– Fusing Green Energy into Manufacturing Engineering Education to Cultivate a Technical Success and Leadership Excellence Among Hispanic Engineering Students. In particular, she aids in the development and organization of a secure, web-based forum for student engagement for this project. Dr. Ruane's pedagogical and research interests include online learning, computer-mediated communication, computer supported collaborative learning, information exchange in online learning environments, online communities, communities of practice and practice fields, social network analysis, collaboration, peer mentoring, situated learning, curriculum theory and development. Dr. Ruane earned her doctorate from Drexel University in Educational Leadership and Learning Technologies in 2012. She completed her Master of Arts degree in Curriculum and Teaching at Teachers College, Columbia University and her baccalaureate degree at Villanova University, where she studied education and philosophy. Dr. Ruane presents nationally and internationally on blended and online education, particularly online peer mentoring. This past April, Dr. Ruane presented her research at the American Educational Research Association's Annual Meeting.

Ms. Chetana R. Bayas
Mr. Abhishek Raja, Drexel University
Mr. Carlos Michael Ruiz, Drexel University

Development of a Green Energy Manufacturing Laboratory Course on Clean Energy and Energy Efficiency

Abstract

This paper describes the development of a new undergraduate green energy manufacturing laboratory course on clean energy and energy efficiency. The course is intended to provide an in-depth student leaning of clean energy technology and energy efficiency issues in manufacturing and industrial resources to reduce the environmental impact of their produced products and services. The course presents the various sources of renewable energy including wind, solar, and fuel cells as potential sources of energy and investigates the contribution they can make to the energy profile of the nation. The students calculate energy savings and environmental impacts through life cycle assessment for most energy efficiency methods in order to identify and assess energy conservation opportunities. In addition, the students demonstrate the appropriate usage of energy monitoring and measuring equipment commonly used by energy specialists and energy auditors. The course is taught as a lecture-practicum with an emphasis on clean energy and energy efficiency both in class and in laboratory. In particular, the key energy efficiency topics are discussed how they can be integrated into manufacturing coursework to include sustainability principles.

1. Introduction

Fusing U.S. innovation on green science and clean manufacturing is an environmental necessity. There is a need to instill sustainability awareness and concepts among undergraduate students, in order to ensure that sustainable production will be achieved in the near future. Clean energy manufacturing is considered a new worldwide industry. Clean energy manufacturing is referred to as the process of converting one form of energy from a clean energy source, such as sunlight, wind, and fuel cells, into another form of energy that consumers can use directly (for example, electricity or transportation fuel). Countries that make and sell more renewable energy will have a competitive advantage. Many countries are competing for leadership in clean energy manufacturing. To enhance the global competitiveness of the U.S. in clean energy manufacturing, there is a dramatic need for a workforce trained with clean energy and energy efficiency skills[1-2].

This paper describes the development of a laboratory course on clean energy and energy efficiency at Drexel University. The goal of the new course is to develop advanced knowledge to meet evolving workforce demands, expanding opportunities for professional advancement, or pursuing a managerial position in green energy manufacturing[3]. To support this goal, the new course is intended to enable students to make green decisions when selecting and implementing a sustainable design plan for a particular industrial application through an in-depth understanding of newly emerging green energy manufacturing. One of the key challenges in developing the laboratory course is an emphasis on hands-on experience for enhancing student learning on green energy manufacturing. To provide life cycle experience, simulations with an industry-standard modeling tool GaBi software is used. Hence the teaching of green and sustainable manufacturing is an excellent opportunity to teach about research innovations and industrial setting[4-5].

INDE t280 Clean Energy and Energy Efficiency is an undergraduate engineering special-topic course taken by pre-junior level students in the Engineering Technology Department at Drexel

University. It is a 3-credit laboratory course held each fall quarter. The students learn the basis of energy engineering, science and technology involves the relationship between the clean energy and the energy efficiency in manufacturing. It is necessary that the students learn and succeed in a multi-disciplinary environmentally conscious manufacturing that necessitates a sustainable system approach. Additionally, many colleges and universities are not providing all of their graduates with the critical thinking, problem-solving, and sustainable practices required to meet the needs of employers. In order for companies to compete in the global marketplace, employers in the 21st century will require that their engineers couple traditional engineering design skills with newer, modern skills in sustainability, and eco-design as well as the ability to function in multi-disciplinary teams[6-10].

2. Overview of the Course Development

This course INDE t280 was offered at Drexel University for the first time as a special-topic course during the Fall quarter of 2015-2016. The INDE t280 Clean Energy and Energy Efficiency course provides the students with the various sources of renewable energy including wind, solar, and fuel cells as potential sources of energy and investigates the energy efficiency they can make to the energy profile of the nation. The INDE t280 laboratory includes industrial testing procedures and experiments. In order to provide an enhanced hands-on laboratory experience, the students work with experimental studies associated with green energy manufacturing. Table 1 provides an overview of lecture and laboratory series in INDE t280 Clean Energy and Energy Efficiency.

Table 1: Overview of lecture and laboratory series

Week	Topic	Labs
1	Introduction to energy systems and resource Energy, sustainability & the industry	
2	Solar - PV and Solar – thermal	Solar Cell Lab
3	Wind power	Wind power Lab
4	Fuel cells	Fuel Cells Lab
5	Hybrid PV-fuel cell-wind	Hybrid Energy Lab
6	Midterm Exam	
7	Green energy manufacturing project A: LCA Simulation (Paper clip)	LCA simulation 1
8	Green energy manufacturing project B: LCA Simulation (solar cell, fuel cell, wind)	LCA simulation 2
9	Industrial energy efficiency	Energy Efficiency Lab
10	Thermal energy imagining Energy audit	Energy Management Lab
11	Final Exam	

The Accreditation Board for Engineering and Technology (ABET) is charged with the task of "Quality assurance in higher education" for programs in applied science, computing, engineering, and technology. Institutions pursuing accreditation must demonstrate that the program meets a set of general criteria. Of particular interest are the requirements of Criteria #2, #3, and #5, which are focused on Program Educational Objectives, Program Outcomes and Assessment, and Faculty[11-12]. These requirements include:

1. A process based on the needs of the program's various constituencies in which the objectives are determined and periodically evaluated (Criterion #2);
2. The students in the program must attain "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" (Criterion #3); and
3. The overall competence of the faculty may be judged by such factors as education, diversity of backgrounds, engineering experience, teaching experience, ability to communicate, enthusiasm for developing more effective programs, level of scholarship, participation in professional societies, and licensure as professional engineers (Criterion #5).

In these programs, renewable energy lab exercises have become an essential part. Several educators have highlighted the importance of lab activities in teaching renewable energy manufacturing. According to their observations, the students can better comprehend complex concepts and theories through a series of lab experiments and projects in other universities[13-18]. Teaching Clean Energy and Energy Efficiency in the project presents the general challenges of teaching an application rather than a discipline. The class was taught for 10 weekly lectures of 3-hour each which represent 11 weeks on a regular quarter. The course learning outcomes are: 1. Understand the main sources of energy, energy efficiency, and their primary applications in the US and the world, 2. Describe the challenges and problems associated with the use of various energy sources, including fossil fuels, with regard to future supply and the industry, 3. Evaluate economic efficiency and compare small scale energy projects using major economic measures of pay-back period, simple rate of return, net present value, internal rate of return, 4. Evaluate manufacturing energy consumption and determine methods to increase energy efficiency, and 5. Relate properly their hands-on laboratory experiences to solving real world clean energy and energy efficiency engineering problems. This allows the students to understand how these products are made so they can understand further on how they are manufactured. The class is evaluated thru two exams in order to assess the level of the student understanding of the course materials. The course is broken down into ten modules. Brief details of these modules are described below.

Sustainable Issues with Clean Energy and Energy Efficiency

Students learned the introduction of the sustainable issues to clean energy and energy efficiency in the first week. Specially designed experiments have been developed for the course as a part of this practicum, and are necessary to complete many of the exercises in the course. Generally speaking, manufacturing is to convert materials and energy into products. The manufacturing processes provide the job opportunities for people. The products made by manufacturing are to improve our standard of living. To increase the value and quality of the products, supply chain and services have to be involved with the manufacturing processes. One of the outputs must include waste from manufacturing processes. The shadow side of manufacturing needs to be addressed first, such as environmental issues and excess of energy used in industry. The fundamental issue in green energy manufacturing is to align manufacturing needs with environmental issues and energy. In addition to the relationship of energy efficiency to manufacturing, there is a particularly important role for energy use for environmentally conscious manufacturing.

Solar Cell Energy

One important topic covered in INDE T280 Clean Energy and Energy Efficiency is solar cell energy. Solar panels can be installed at different locations with different configurations. There are various factors that affect the efficiency of the solar panels. Factors like radiant heat, tilt angle, shade and maximum power point were studied by simulating the environment on DL Green Kit Aggregator Board. DL Green Kit, solar panel module and the software help the students to understand the concepts better. Figure 1 shows the DeLorenzo workstation, which was used for teaching the students laboratory experiments. Different experiments such as effect of heat, tilt and shade on solar panels were performed. A live demonstration of these effects can be shown by plotting the real time voltage, current and power on the DL Greenkit software that runs on the computer. Observing these real time changes in the values of voltage, current and power helped students understand this concept to greater depth.

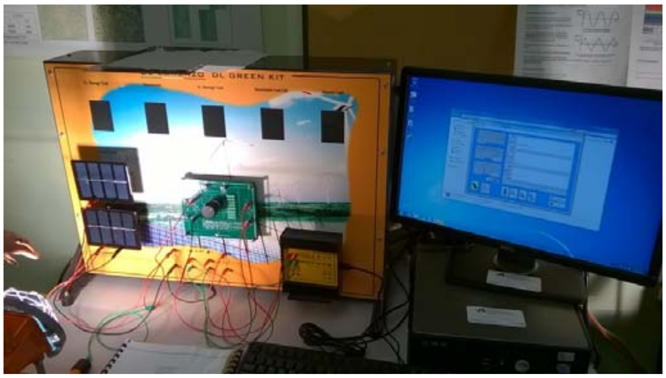

Figure 1: DeLorenzo renewable workstation and DL Greenkit software

The students understood the importance effect of panel temperature and how radiant heat can greatly affect the performance of solar panel. Students simulated various conditions to understand that it directly effects the voltage and current. Too much radiant heat can also damage a solar panel, shortening its lifespan.

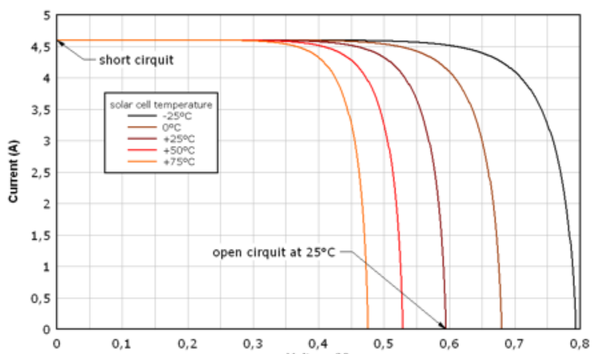

Figure 2: Temperature-related Efficiency[19]

The students also took into account about the issues of tilt angle of solar panel and how panel installation should be with respect to sun. Fundamentally, the best angle is the one that points directly in line with the light source. Most of the time, this is not possible. Since the sun appears to be moving in the sky during the day, a solar panel can only gather a portion of the light depending on its fixed tilt angle. So there is a compromise to make here; what angle is best for the given solar panel application. Shade is major factor involved in reducing the efficiency of a solar panel as shown in Figure 3. A small part of the panel covered in shade causes a large decrease in power output and can even cause physical damage to solar panel. The physical damage can be avoided by using internal protection. This can be done by using diodes.

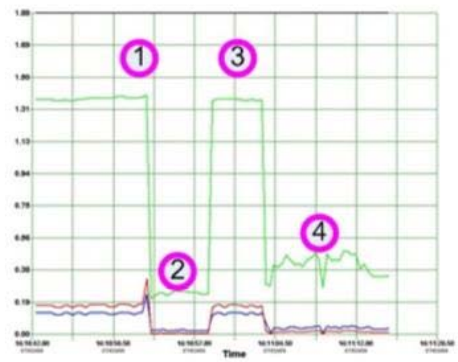

Figure 3: Efficiency related to shading: 1 – No shade, 2 – Overcast Sky, 3 – No shade, and 4 – Partial and full shade of bottom solar panel

The concepts about maximum power point (MPP) in solar panels are made clear using experimental setup. MPP is not just maximum voltage or maximum current by itself but it is the maximum power that is produced when voltage and current are multiplied. The resistance of the solar panel should match the load resistance in order to produce the maximum power.

Wind power

In this course, in addition to solar cell, students learned the technology of wind power and its energy efficiency issues. The experimental setup consists of a wind turbine with 6 removable blades and a 3-speed air blower. The system is connected to the data acquisition board via the voltmeter and ammeter ports on the workstation and the load is connected through the multi-decade resistor. The DL Greenkit software is interfaced with the DAQ board via USB and can be used to obtain real-time data from the system and save/export data for further analysis. Modern wind turbines are very powerful in generating electricity; however, their power output is defined by more than just wind speed. This experiment demonstrates some fundamental principles behind wind turbine design and performance criteria using established formulaic equations that define the limits of wind power generation. The wind equation includes:

$$\text{Power}=\tfrac{1}{2}*C*\rho*A*V^3 \quad (1)$$

Where ρ = Air density, C = Coefficient of performance, A = Frontal area, and V = Velocity of wind.

Wind velocity is the most important factor in determining power output. Power varies as the cube of the wind velocity (V^3). This means is that if the wind speed doubles, the power will theoretically increase by a factor of eight (8). However, if the wind speed is reduced by one-half, the power output will be reduced to 1/8 of the original power. Small changes in wind speed make big changes in power. Along with blade pitch, or angle, using the right number of blades for a given wind condition is important in extracting the maximum electrical power from a wind turbine. In this experiment students would gain an understanding of the choices between the numbers of blades and blade pitch that are necessary to produce the most power.

In real turbines, the pitch is not constant, the pitch can be varied depending on the wind speed in order to extract maximum power; this is called blade pitch control. Blade pitch control is a feature of nearly all large modern horizontal-axis wind turbines. While operating, a wind turbine's control system adjusts the blade pitch to keep the rotor speed within operating limits as the wind speed changes. Feathering the blades stops the rotor during emergency shutdowns, or whenever the wind speed exceeds the maximum rated speed. During construction and maintenance of wind turbines, the blades are usually feathered to reduce unwanted rotational torque in the event of wind gusts. This experiment demonstrates how to find a MPP where the wind turbine generates the most electrical power at a given wind speed. The goal of this experiment is to find the MPP at the fastest fan speed setting using multiple resistor loads as shown in Figure 4.

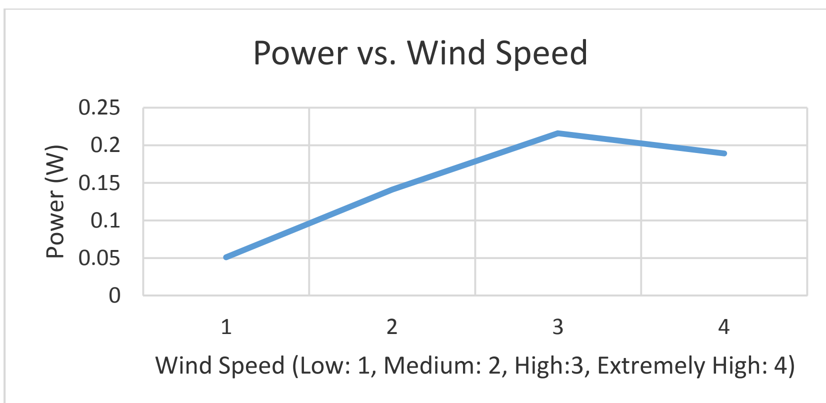

Figure 4: Maximum Power Point

This experiment uses a multi-decade resistor board to adjust the voltage and current to determine the Maximum Power Point (MPP). Students understood: 1. The power source for a wind turbine is the wind from the fan, 2. Maximum power from a wind turbine depends on the ability of the blades to spin the electrical generator and for the generator to deliver power into a specific load value for a given wind speed, and 3. There is a narrow range of resistance values that will produce maximum power for the model wind turbine at a given wind speed.

Fuel Cells

Water electrolysis requires energy to break or release the oxygen-hydrogen bond. This reaction is driven by the voltage applied across the electrodes. The electrochemical decomposition of water cannot occur unless the voltage is high enough to overcome the strength of the hydrogen-oxygen bonds. The concepts of minimum voltage required can be measured using DeLorenzo kit with fuel cell module and the software as shown in Figure 5.

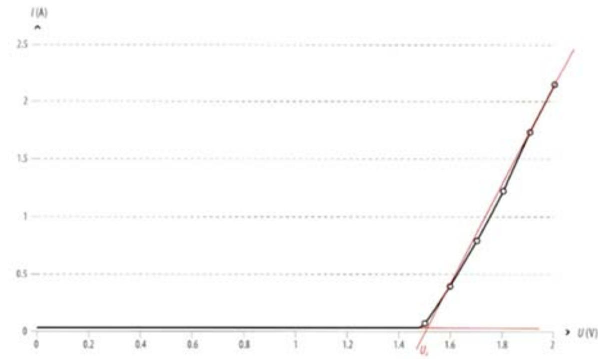

Figure 5: Minimum voltage required for electrolysis

Students learned the principles of electrolysis using DC voltage source and electrolyzer using the above setup. Students understood how pure (distilled) water can be proportionally decomposed into two parts hydrogen and one part oxygen using an electrolyzer and a DC voltage source. Because hydrogen is not a free element on earth, electrolysis is a necessary procedure to separate water into its two elements, hydrogen and oxygen. Modern electrolysis methods can be used to produce large quantities of hydrogen that can be used to power cars and other electrical appliances. Fuel cells can be used for many different modern applications. Regardless of the application there are three fundamental states of a fuel cell that deliver the voltage and current into a load. This includes the activation region, ohmic region and mass transport region. Also known as the polarization states, each region affects the fuel cell's ability to deliver usable power to an external load. The students also performed the two types of efficiencies – Energy efficiency and Faraday efficiency. When correctly constructed and maintained, a fuel cell is a very efficient energy converter. The energy efficiency is calculated as the ratio of power output divided by the power input, times 100. The faraday efficiency is calculated as the ability of hydrogen gas to deliver power versus its actual measured ability to deliver power.

Hybrid Energy

With the accumulated knowledge from renewable energy sources, the students then learned to apply them into a hybrid system. The hybrid system contains more than one source of energy production and can change the efficiency based on the specific environmental constraints. The students were required to compare different hybrid systems using electrolyzers, reversible fuel cells, and photovoltaics within various experimental setups through calculated efficiencies with energy transfer.

Figure 6 shows the hybrid system experiment demonstrating the ability to use various energy sources and apply them into one collaborative system. The comparisons of each system allow students to determine the application of the system within a larger scale model within manufacturing and industrial facilities. The established principle is to reduce costs as to maintain high standards of reducing emissions output. The electrolyzer and reversible fuel cell are tested to maintain this principle within a hybrid system. The final hybrid experiment is a simulated hybrid car system. The system involves the collection of energy through photovoltaics and energy storage through an electrolyzer to fuel cell. The load is applied after hydrogen collection by the hybrid car. The design enables students to interact and understand the sophistication of hydrogen transport and storage when applied to vehicles within societal parameters. The students were then given critical thinking questions following completion of experiments using their results to justify their answers.

Figure 6: The hybrid system experiment

Life Cycle Assessment

From the outline of the lecture, students learned what LCA is, Why use LCA, and what it can be used for business benefits. LCA is a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). In this section of the course students learn how the LCAs can help avoid a narrow outlook on environmental concerns by: 1. Compiling an inventory of relevant energy and material inputs and environmental releases, 2. Evaluating the potential impacts associated with identified inputs and releases, and 3. Interpreting the results to help make a more informed decision.

The LCA simulation allows them as engineers of the future to optimize the processes, use of materials, selecting energy resources, minimize waste, increase recyclability and overall design not only for manufacturing and assembly but also to design for environment. For the purpose of analysis, students also learned how to use LCA tools and softwares such as GaBi 6 from PE International. Softwares such as GaBi® 6 provide students with the means of processing all the data and visualizing it in the form of a flowchart containing production processes and material flows. GaBi® 6 also contains an extensive database of all materials and processes and their parameters such as material and energy inputs and outputs.

LCAs in GaBi are conducted in compliance with the ISO 14040 and ISO 14044 standards. The software supports large data management for modeling product life cycle. It helps students calculate different types of balances and to analyze/interpret the results. GaBi automatically tracks all material, energy, and emissions flows, as well as defined monetary values, working time and social issues, giving instant performance accounting and facilitates the students with modular individual life cycle phases such as manufacturing, use and disposal that can be grouped into categories and individually processed.

Life Cycle Assessment Project: Hand Dryer

The first GaBi tutorial given to the students was the modelling of a simple, single component, paper clip. The next phase of life cycle analysis challenged students with a more complex model. They were given a project of creating the plan for a hand dryer based on the lessons they learnt in the previous model. The hand dryer consists of numerous parts, each requiring various materials and processes. Students learned the modelling of more complex products requiring about 14 materials, 18 processes, assembly, use, disassembly and disposal which gave them a hands on of real life problems. The experience was complete with all requirements of the ISO standards such as the goal and scope definition, inventory analysis and impact analysis.

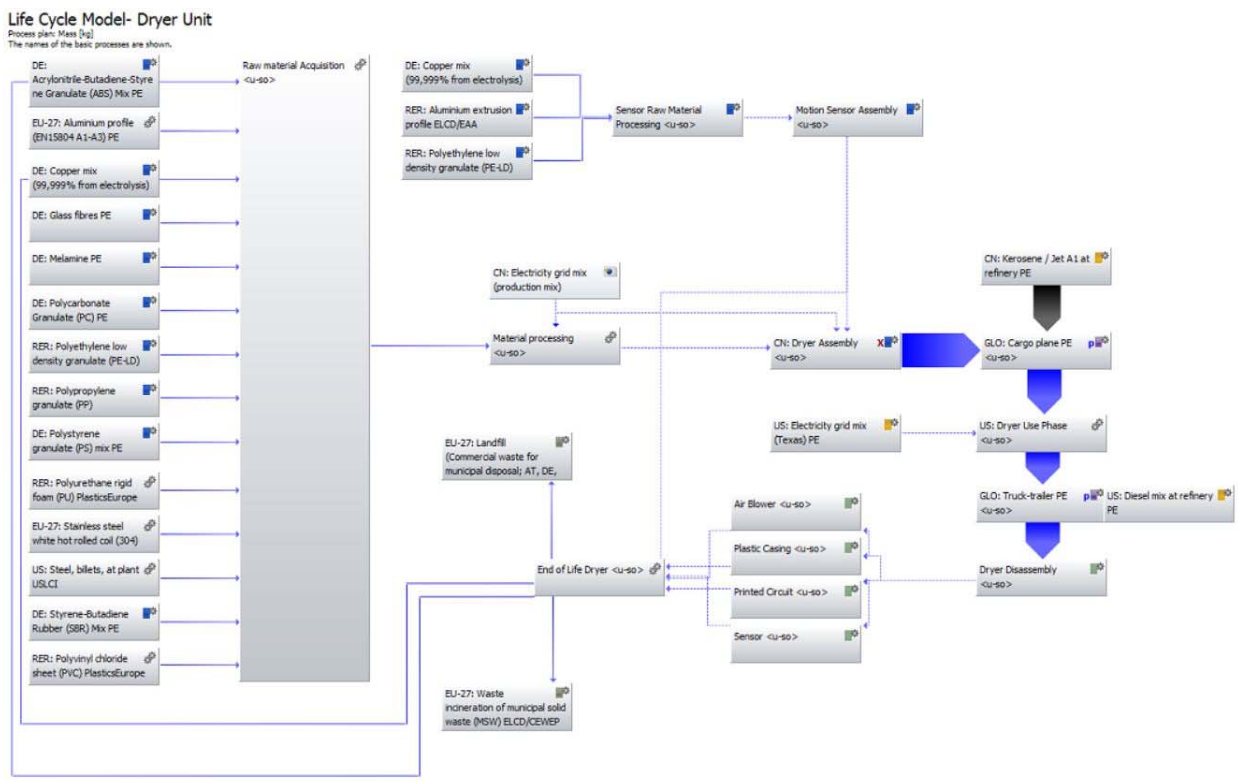

Figure 7: Life cycle assessment of a hand dryer

The students were then given the task of creating a similar model where the material is not recycled and compare the impacts of the plans with and without recycling. This not only helped students understand the importance of recycling but mainly what process or material contributes the most to the impact on the environment. Students came up with ideas on how to optimize the processes based on the interpreted data and hence were able to understand the significance of the life cycle of the product.

Waste Heat Recovery by Thermoelectric Ceramics for Energy Harvesting

In addition to piezo-electrics, the students evaluated thermoelectric properties. The experiments show basic operation of thermoelectrics and establish a foundation for alternative renewable energy sources. The students evaluated energy efficiency and properties with established power supplies and heat sources. The power supply and heat sources are adjusted to discover through direct application dependencies and characteristics of the thermoelectric. The application of thermoelectric shows similarities to thermocouple circuits and their implementation. The students determined energy efficiency by measuring the ratio of output power to input power.

The experimental setup can be seen in Figure 8 involving efficiency using a thermal camera, power supplies, and the De Lorenzo kit's ammeter and voltmeter. The experiment shows students that the temperature dependent thermoelectric directly affects the efficiency. The direct correlation allows students to determine the field of application and to determine systems that currently exist that could benefit from the thermoelectric effect with regards to massive heat loss. This experiment promotes the sophistication of a system that can apply specifically to thermoelectric applications and think reasonably as engineers the parameters that must be satisfied with justification for implementation within standard regulation.

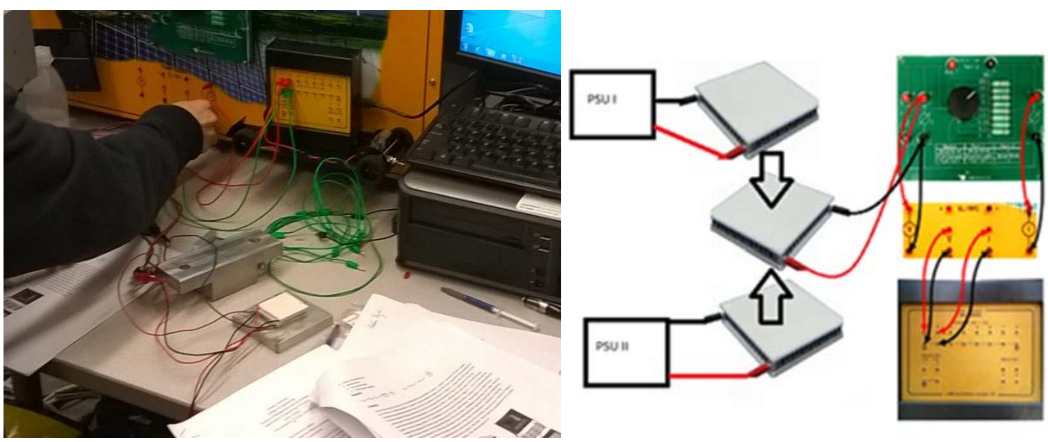

Figure 8: Waste heat recovery by thermoelectric ceramics

Energy Efficiency

In the final week of the course, students performed experimental studies of the lighting efficiency, and quantify the performance of light bulbs in terms of efficiency as shown in Figure 9. Students placed a lumen sensor in direct lights or under artificial light sources. They record electrical data at selected times in order to determine the energy efficiency at which the light bulb has its ability to generate light energy intensity. The students used a watt meter to compare each type of bulb to the given specifications. The bulbs were LED, fluorescent, and incandescent. The students then used a lumen meter to determine the luminous flux for each bulb at a given distance of 1 meter, as shown in Figure 9. The result was then converted to lumens using the area multiplied by the luminous flux. The luminous flux was then divided the luminous efficacy to determine a constant for comparison to other bulbs. This experiment shows students how to evaluate lighting efficiencies through a lumen per watt ratio and compare results to the specifications given. Currently 30% of building costs are directed towards lighting facilities to luminosity under United Facilities Criteria (UFC) for personnel operations. Students were also given required standards of luminosity of various facilities to understand guidelines and to determine methods of energy reduction.

Figure 9: Lighting energy efficiency experimental setup

Upon completion of this experiment, students were able to determine which bulbs, through direct measurements, were more efficient through lumen efficacy. The students also were able to understand excessive energy losses and explain why they would impact other systems within a facility such as equipment and cooling units. Measurements can be instantly produced to determine additional steps to costs and energy effectiveness. The addition of the watt meter provided comparable results towards energy management and determined initial power inputs.

During the course development, an online discussion component was added to the Clean Energy and Energy Efficiency course to allow engineering technology undergraduate students who are separated geographically the opportunity to interact with other students in their major regarding specific topics in Green Energy Manufacturing in Blackboard. Such interaction provides participant engagement and enhancement among students through meaningful discussions regarding academic experiences and opportunities to share learning and wisdom with peers at their institution and with those at a partnering institution. Computer-supported collaborative learning allows for the monitoring of student understanding and achievement in collaborative learning activities. Instructors can analyze the discourse using semiautomatic data analysis procedures for facilitation, moderation, grading purposes, and research. Analysis of the discussion board participation shows who turns to whom for support, how frequently, and how information travels among the participants. Social network analysis provides a way to describe the nuances of online interactions and connectivity as it considers social structure to be the patterned organization of network members and their relationships, social network analysts work to explain both the impact of changes in social structure, and account for these changes. The online course discussion component enhances the student experience in that it provides a new way for traditional undergraduate students to interact with their peers. The Social Network Analysis provides important data regarding the student interactions and relational patterns.

3. Conclusions

This paper describes the incorporation of clean energy and energy efficiency practices for student learning in green energy manufacturing. Towards this, weekly lectures and experiments are assigned within the course INDE t280 Clean Energy and Energy Efficiency so that students complete at the end of each week session. It provides laboratories, experiments, demonstrations, and classroom-ready resources appropriate for instruction in the areas of sustainability and manufacturing energy. INDE t280 Clean Energy and Energy Efficiency Course reviews by students were very positive. Student evaluations were conducted at the last week of the class. According to the results, the course received a 4.2 on 5.0 point ratings, compared with an average rating of 3.4 for the all courses at our engineering technology program. Many commented positively about their knowledge gained related to their current jobs in their own companies. Students commented that they enjoyed working in the clean energy and energy efficiency laboratory. The results show the highly supportive evidence towards the intended course outcomes.

Acknowledgement

This work has been supported by the US Department of Education under the joint DHSIP Program with the University of Texas at El Paso, PR/Award No.: P031S120131. The authors wish to express sincere gratitude for their financial support.

Bibliography

1. Davidson, Cliff I.; Matthews, H. Scott; Hendrickson, Chris T.; Bridges, Michael W.; Allenby, Braden R.; Crittenden, John C.; Chen, Yongsheng; Williams, Eric; Allen David T.; Murphy, Cynthia F.; and Sharon Austin. "Adding Sustainability to the Engineer's Toolbox: A Challenge for Engineering Educators." *Environmental Science & Technology*, 2007, pp. 4847-4850.
2. Department of Energy - Clean Energy Manufacturing Initiative, http://energy.gov/eere/cemi/clean-energy-manufacturing-initiative.
3. Vest, Charles. "Context and Challenge for Twenty-First Century Engineering Education." *Journal of Engineering Education*, July 2008, pp. 235-236.
4. Heidi A. Taboada, Jose F. Espiritu, Olivia Moreno and Abril Vasquez. (2011). Experiences While Incorporating Sustainability Engineering into the Industrial Engineering Curricula. *Proceedings of the ASEE Annual Conference and Exposition*. Vancouver, B.C., Canada, June 26-29, 2011.
5. Connie Gomez, Heidi A. Taboada Jose F. Espiritu & Noe Vargas (2010). Increasing Sustainability Engineering in Education and Research. *In Proceedings of the 2010 ASEE Annual Conference and Exposition*. Louisville, Kentucky. June 20 - 23, 2010.
6. Wangping Sun, Bradley Kramer, Zhichao Li, and Joe Stuart, "A Review of the Commercial Trainers and Experiment Kits for Teaching Renewable Energy Manufacturing," *Proceedings of The 2014 IAJC/ISAM Joint International Conference.*
7. Pei, Z. J., Li, Z. & Sun, W. P. (2013). Collaborative Research: Development of a Sophomore-Level Course Introduction of Renewable Energy Manufacturing and Faculty Expertise. *National Science Foundation Grant* (Award Id: 1245132).
8. Thomassian, J.C., & Amani, Y. (2010). Renewable Energy: Senior Design Project Experience. *Proceedings of the 40th Annual Frontiers in Education Conference*, p. S3H1-S3H3.
9. Aung, K. (2011). Simulation Tools or Renewable Energy Projects. *Proceedings of the2011 ASEE Annual Conference and Exposition*.
10. Condoor, S., & Condoor, S. (2011). Renewable energy-Based Senior Design Experience for Undergraduate Students. *Proceedings of the 2011 ASEE Annual Conference*.
11. ABET, Criteria for Accrediting Engineering and Engineering Technology Programs, 2014-2015, http://www.abet.org/accreditation-criteria-policies-documents/

12. ABET, Inc., “Accreditation Standards and Program Criteria for Manufacturing Engineering and Similarly Named Programs”, Washington, D.C.:ABET, Inc., 2014-2015: http://www.abet.org/uploadedFiles/Accreditation/Accreditation_Step_by_Step/Accreditation_Documents/Current/2014_-_2015/E001%2014-15%20EAC%20Criteria%203-13-14(2).pdf
13. Pantchenko, O., Tate, D., & O’Leary, D. (2011). Enhancing Student Learning through Hands-On Laboratories on Renewable Energy Sources. *Proceedings of the 2011 ASEE Annual Conference*.
14. Madwar, H., Baltaci, K., & Pecen, R. (2011). Integration of Hydrogen Fuel Cell Technology to Undergraduate Education in EET Programs. *Proceedings of the 2011 ASEE Annual Conference*.
15. Mayer, A., & Powell, L. (2011). A Low-Cost Laboratory Experiment to Generate the IV Characteristic Curves of a Solar Cell. *Proceedings of the 2011 ASEE Annual Conference.*
16. Yildiz, F., Coogler, L, & Pecen, R. (2012). An Overview: Applied Interdisciplinary Renewable Energy Projects. *Proceedings of the 2012 ASEE Annual Conference.*
17. Bosma, B., & Kallio, G. (2009). Renewable Energy Labs for an Undergraduate Energy Systems Course. *Proceedings of the 2009 ASEE Annual Conference.* *Proceedings of The 2014 IAJC/ISAM Joint International Conference ISBN 978-1-60643-379-9.*
18. Chen, R., Goodman, D., & Izadian A. (2010). Teaching Renewable Energy through Hands-On Project-Based Learning for Engineering Technology Students. *Proceedings of the 2010 ASEE Annual Conference.*
19. DeLorenzo DL Greenkit manuals.