Enhanced 3-D Printing for Energy Harvesting Project Implementation into Green Energy Manufacturing Laboratory

Dr. Richard Chiou, Drexel University (Eng. & Eng. Tech.)

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 P.E., 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.

Mr. Sanjay Jayadev, Drexel University (Eng. & Eng. Tech.)
Mr. carlos michael ruiz, Drexel University (Eng. & Eng. Tech.)

©American Society for Engineering Education, 2018

Enhanced 3-D Printing for Energy Harvesting Project Implementation into Green Energy Manufacturing Laboratory

Abstract

The paper presents a laboratory course in renewable energy systems that engages project-based activities in clean energy and energy efficiency. The objective of the project is to improve student-learning outcome by incorporating green energy manufacturing with 3-D printing technology. Renewable energy courses offer in-depth information of renewable energy resources. Such information includes the manufacturing of photovoltaics, fuel cells, wind turbines, etc. Simple laboratory experimental modules are often available on the market for purchase. Current modules feature complete system assemblies that require student interface for measurements. Although these educational modules are completed exceptionally well for student learning, the modules often lack involvement of student interdisciplinary challenges to encourage creativity and problem-solving skills. Information and educational modules of renewable energy technology are focused based. Learning the 3-D printing technology offers students a greater ingenuity of information and promotes students' interdisciplinary skills in integration of 3-D printing with renewable energy systems. The students were given multiple projects within the green energy manufacturing course. Projects included circuit schematics of battery charging, direct power to LEDs/motors, and cost-effective systems to implement energy storage and usage from renewable energy sources. The course contains laboratory experiments that help students to determine wind turbine and solar cell energy efficiency using 3-D printing in the projects. The results of the mechanical, electrical, and energy efficiency tests for the 3D printed specimens are presented for comparison. The interactive project-based learning gives students an incentive to seek creative solutions to accomplishing project goals.

1. Introduction

This paper presents the project learning result of a laboratory course on green energy manufacturing integrated with 3-D printing technology in the Department of Engineering Technology at Drexel University. The course was jointly developed with the Industrial, Manufacturing and Systems Engineering at the University of Texas at El Paso. Since green energy manufacturing is defined as "a system that integrates product and process design issues with issues of manufacturing planning and control in such a manner as to identify, quantify, assess, and manage the flow of environmental waste in materials and energy with the goal of reducing and ultimately minimizing environmental impact while maximizing resource efficiency," increased environmental consciousness among manufacturing industries helps to foster new techniques for streamlining processes and increased reusability[1-6]. Connecting manufacturing devices and aggregating the data created is enabling manufacturers to reduce overhead, conserve resources, increase profits and optimize operational efficiencies. For consumers, the 3-D printing technology has the potential to deliver solutions that dramatically improve energy efficiency, security, health, education and many other aspects of daily life. For enterprises, 3-D printing technology can underpin solutions that improve decision-making and productivity in manufacturing, retail, agriculture and other sectors[7-8]. There are many ways the 3-D printing technology helps in optimizing manufacturing: inventory control and supply chain management help companies become more efficient. But one of the greatest advancements made possibly by the 3-D printing technology is energy management. Energy is often one of the largest expenses for manufacturers; and, unfortunately, it is also one of the most ambiguous[9-10].

Increased global adoption of green energy and green manufacturing technologies presents a reformation of engineering education geared toward renewable energy and green manufacturing practices. According to a research brief titled "Investment in renewable energy generates jobs. Supply of skilled workforce needs to catch up" from the digest "Skills and Occupational needs in Renewable Energy[11-14], it is estimated that by 2030 up to 12 million people could be employed in clean energy sectors. It is mentioned that there is a widespread skill shortage of engineers and technicians with knowledge in the field of renewable energy technologies. Based upon the need for increased skills in renewable energy and green manufacturing technologies, this paper discusses a project based learning approach taken, along with a series of projects held in the field of green energy manufacturing, to enhance student professional success.

Students used 3-D printing to create components used in different renewable technology devices. Design tasks were performed by teams of students in the mechatronics program after completing the same prerequisites. Each team was asked to select wind or solar energy generation technology based on their interest and experience. Students began their projects by identifying the main components of a given system and building CAD Models. Based on the loading type and the nature of the structure, they analyzed force and stress and determined the size of the structure. Students were asked to design with 3-D printing technology based on renewable energy type, operating environment, etc. and verify by hands-on experimental study[15-19]. For grading, a rubric was provided with an expected design content and steps to be followed. The evidence of learning included a final project report with description, analysis, experimental results, and power point presentation.

2. Design and 3-D Printing in Green Energy Manufacturing

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[20-21]. Design is a crucial component of engineering education. It is outlined in ABET's course outcomes criteria " c" that students should have "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."[4] The inclusion of a prototype in the design process helps to improve the final design. Witnessing the results and learning through failure in the earlier design phase minimizes loss in the later stages of product development. Creating a physical prototype can be an effective way to observe and assess ideas before implementing production.

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. Many institutions have integrated 3-D printing into their design courses. Lately, with open source, 3-D Printers are revolutionizing manufacturing. The application of this technology ranges from physical device prototypes to developing human organs and is growing exponentially. 3-D printing has witnessed significant improvements since its inception. The terms “3-D printing” and “additive manufacturing (AM)” are sometimes used interchangeably, as this process enables economical and rapid prototyping of various product designs within a very short time period. 3-D printing is a process of producing three dimensional (3-D) objects from digital models in which the solid objects are made by laying down successive layers of various types of materials: such as polymers, metals, ceramics, and composites. In contrast, traditional machining techniques are considered to be a “subtractive process” technique, which the products or parts are mostly machined out from stock materials.

Teaching clean energy and energy efficiency in the class projects integrated with 3-D printing represents the general challenges of teaching an application rather than a discipline. The class was taught for 10 weekly lectures of 3-hour each 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 with 3-D printing 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 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.

3. Course Description

EET 320 Renewable Energy Systems is an undergraduate engineering course for 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.

This course EET 320 Renewable Energy Systems 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 green energy manufacturing 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. The course provides an overview of lecture and laboratory series in clean energy and energy efficiency, including solar - PV and solar – thermal, wind power, fuel cells, hybrid PV-fuel cell-wind, waste heat reuse, energy management, lighting energy efficiency, and life energy cycle assessment.

The student are asked to have their final team project as required in the course. The project report essentially follows the format with final report and project presentation. The required section include the following: Cover sheet, project title, name, course number, submission date, introduction, description of project, significance and objectives of the project, data collection methods, literature review, analysis, conclusion, references, and appendices. The students chose their topic within the field of renewable energy systems involved 3-D printing technology (ie. Solar cell, fuel cell, wind turbine, area of research which we did not cover in class; new energy technology, 3-D printing, etc.). The time for presentation allotted to each team was 15 minutes followed by a five minute question and answer session.

4. Summary of Design Projects

Out of various renewable technologies suggested, students selected wind turbine and PV with 3-D printing[22-23]. The goals of the design of final projects include: 1. to use 3-D CAD modeling software to design small-scale renewable energy systems, 2. to manufacture the renewable energy systems using available manufacturing processes such as 3-D printing, and 3. to learn how to compare design and application of power output model and improve energy efficiency.

4.1. Wind turbine blade design and manufacturing

A wind turbine is a device/machine that is used commercially to harnesses wind energy and convert it into electrical energy. The electrical energy produced is then transmitted to a power grid. Wind turbines are often grouped together into a single wind power plant, also known as a wind farm, and generate bulk electrical power. The driving force of wind turbine is, lift force generated, when wind flows over such airfoils. The basic principle involved with creating lift is the Bernoulli Principle. Lift force will be perpendicular to apparent velocity. Generally lift force increases with angle of attack. Along with that undesirable drag force also increases. While tangential component of lift force supports blade rotation, drag force opposes it. A wind turbine can increase energy performance when lift to drag ratio is maximized.

The design of the wind turbine and its specific components are another integral part of the research. For instance, it was discovered that wind turbine blades on horizontal axis machines are given a twisted taper in order to prevent vortex formation with an even pressure distribution. Structurally, a twisted blade is stronger than a non-twisted blade. Using computer aided drafting software and hand drawings, scale models to place into our turbine and hook up via a direct motor to see their power output were created. Two different types of blades were designed. The first curved blade was based on the aerodynamic geometry profile. It can span a greater area than other designs. The twist and slope were imported by using Computer Aided Design Solidworks. The second one was designed with flat blade. All of these two types of blades were designed and printed for running six blades on a mini-wind turbine in green energy laboratory.

The curved blade by comparison has air flowing around it with the air moving over the curved top of the blade faster than it does under the flat side of the blade, which makes a lower pressure area on top, and therefore, as a result, is subjected to aerodynamic lifting forces which create movement. These lifting forces are perpendicular to the curved blade's upper surface which causes the blade to move rotating around the central hub. As shown in Figure 1, the faster the wind blows, the more lift that is produced on the blade, hence the faster the rotation. The advantages of a curved rotor blade compared to a flat blade is that lift forces allow the blade tips of a wind turbine to move faster than the wind is moving generating more power and higher efficiencies.

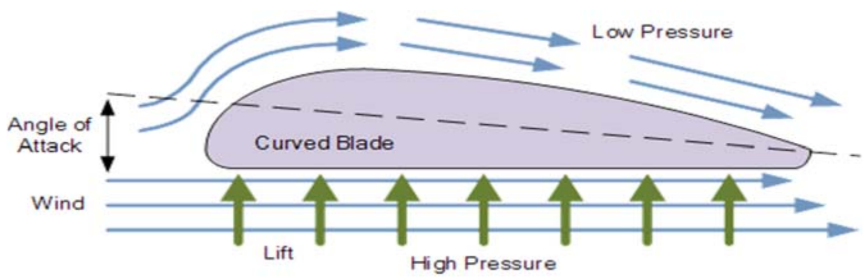


Figure 1: Curved blade design

Since the blade material should be stiffer and stronger while lighter and adaptive in order to reduce system loads, ABS (Acrylonitrile Butadiene Styrene) plus material was provided for the University's 3-D printers. The rapid prototyping 3-D printer has a fast manufacturing process, especially for the shapes of blades with twist angles. The design had many constraints that included the following objectives, including: 1. same area as the flat blade and 2. same amount of material. The blade has a curved front end with the null point of the airflow close to the flatter edge than the center line containing the rotation point and the midpoint of the end surface. The bottom and the back of the top surface has a slight curve to it so that the drag would be reduced as a slight twist reduces the drag on the blade. Figure 2 shows the surfaces of the curved blade design at 45 degrees.

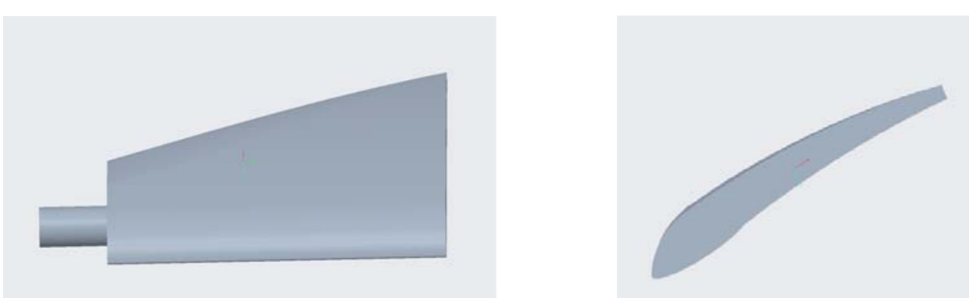


Figure 2: Blade design by Solidworks and manufactured by rapid prototype 3-D printer

To utilize Bernoulli's principle, the area over the top of the blade was increased so that it was larger than the base. The images below show the different surface areas however are slightly larger on the bottom calculation because the area added also has a portion above the null point of the curve where the wind would go to the top portion of the blade.

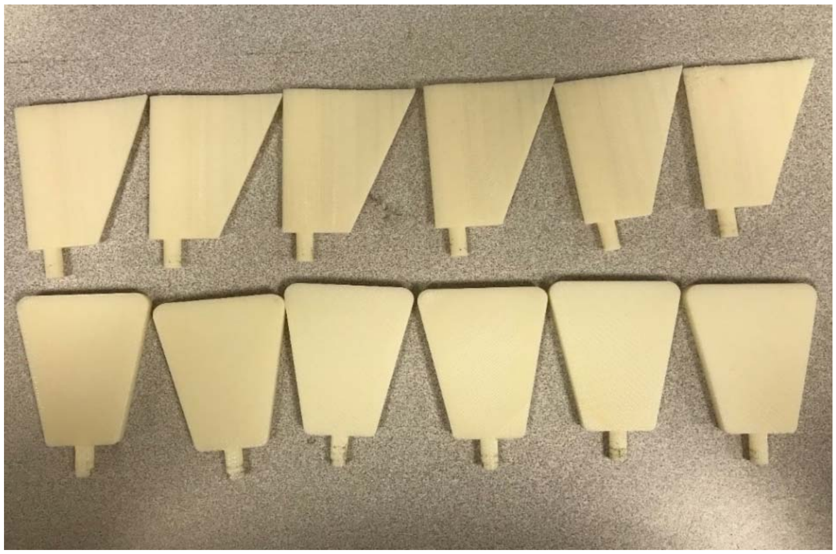


Figure 3: The actual 3-D printed curved and flat blades

For this experiment, two different windmill blades were designed. Both blades were designed to be made of roughly one cubic inch of printing material. The first blade we made was flat. The second blade was designed to have a curved shape that would be more advantageous for catching wind and less likely to drag on the air it is spinning through. First, each of these blades was tested at different angles and a constant wind speed to find their ideal angles of energy production. For this experiment the students used the optimal angle of each of the blades to test the power output for three different wind speeds. They then compared the curved blade and the flat blade to see how different the energy output would be. While doing this, they also measured the wind speed and the wind plane area to make accurate power calculations. Finally, they took the optimal wind speed and blade angle to do testing for the maximum power point. They did this by using the multi resistance dial and a constant wind speed and blade angle.

A wind turbine is comprised of four major components: rotor, nacelle, tower and blades. Tower height, blade length and generating capacity are the basic design parameters of horizontal wind turbines. A direct drive wind turbine, one of the newest technologies being implemented into wind turbines today, was designed for this project. The blades were designed to provide a relatively "high" surface area to harness more wind. The impact of pitch or the degree of rotation of the blades into power generation was also considered. To test the performance of the wind turbine, a box fan was used to blow wind at 10 mph, and 3V output with 280 mA of current was recorded from the wind turbine. 840 mW of usable power was used to illuminate a LED.

Figure 4: Experimental setup with a mini-wind mill mounted with six 3-D printed blades

As the results shown in Figure 5, there is a large difference in the efficiencies and the power generated by using the curved blade design as opposed to the flat blade design. They were 17.8, 18.5, and 16.4 percent difference in the efficiencies for the high, medium, and low wind speeds respectively. These results show how utilizing Bernoulli's principle increases the rotation of the wind mill. A notable result is the increase in efficiency was at a maximum for the high-speed trail at a tilt angle of 30% as opposed to the 45-degree tilt angle of the other two trials. This is due to how the apparent wind velocity hits the blade. As the design shows the top curvature near the main body of the blade starts below the tilt axis, which would increase the rotation at smaller angles at higher wind speeds allowing more energy to be produced throughout the entire trial. This hypothesis was also supported as only the high wind speed trial had a power output at 15-degree tilt angle. The values found for efficiency for the high and medium wind speeds roughly came to 39%. This is an accomplishment considering that Betz's Law states the maximum efficiency can be 59.3%.

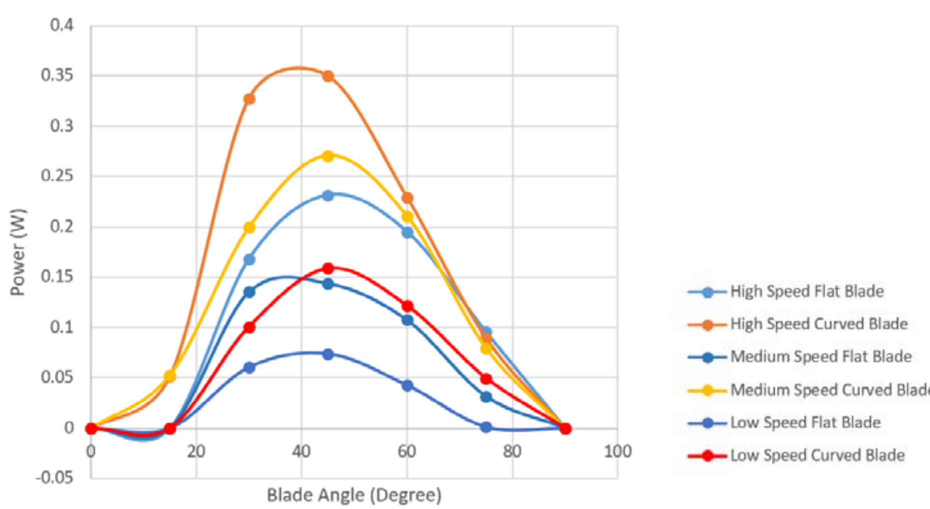


Figure 5: Energy efficiency comparison between curved and flat blades

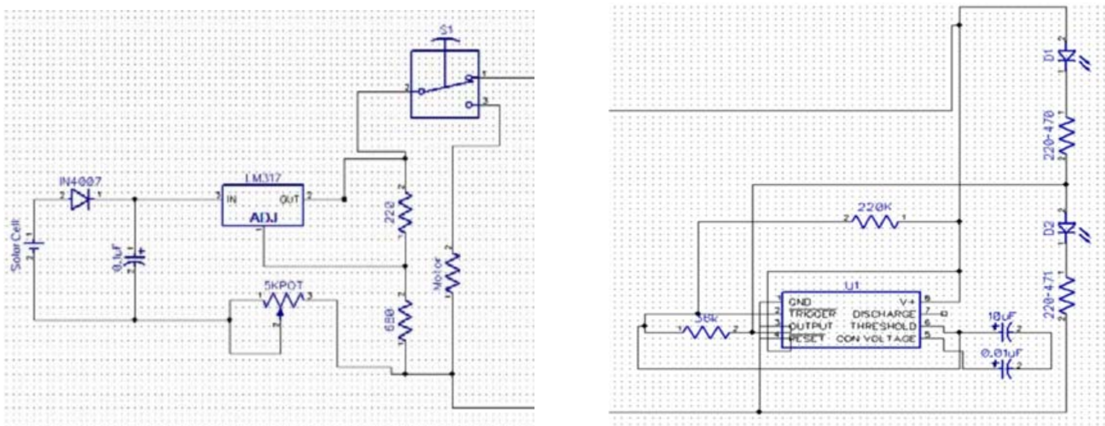
4.2. Design of a Solar Powered System

This paper also discusses an educational effort that incorporates green energy manufacturing concepts for the prototype design of a solar energy powered system. The goal of the design project was to engage students in real-world learning experiences for the design of an energy harvest and storage system integrated with 3-D printing as an initial stepping stone for the future construction of complex energy systems in industry. The renewable energy integrator component in the project seeks to explore the technology of renewable and eco-friendly sources of electricity on a large scale. In addition to researching the subject, a prototype of the system has been built for future students to learn green energy manufacturing as part of engineering and technology programs. Through this project, students learned how to provide a green design method for evaluating the characteristics of clean energy manufacturing and storage. The students incorporated real-world experience with innovative design with the reduction of energy waste and use of renewable energy, as well as incorporating green manufacturing. In addition to that, 3-D manufacturing techniques were used in order to print a PCB board. For the sake of comparisons for green energy manufacturing, experiments were conducted. A concluding section discusses the student learning experiences during this project.

The purpose of this project is to design a voltage regulator circuit that uses solar, to maintain a constant DC output to drive the DC motor and power LED lights. Through the completion of this project, students were able to understand how to harvest solar energy and put the energy to use in various ways. The concept that energy stored is greater than energy used was proven through the completion of this project. This project is significant because solar power is the most available renewable energy resource, with an entire year supply of solar power striking the earth every hour. The problem with this is that the efficiency of solar panels is often very low, below 20%. The main objective of this project is to utilize the ability of solar panels to convert radiant energy from a light source to electrical energy to power two different loads, a mechanical motor and a circuit of blinking LEDs.

Design Process

The project end-product consists of an efficiently operating circuit comprising of the following components, including a solar panel - 20V, LM317 voltage regulator, DC battery, Diode - ln4007, capacitor - 0.1, 10, 0, 01uF, Schottky diode - 3A, 50V, resistors - 220, 680, 36K, 220K, 220-470K ohms, Pot - 5K, various connecting wires, LED, and motors. The provided circuit can be broken up into two sections to better explain how it works. The first half of the circuit is shown in Figure 6. From left to right, we see a number of different components. The solar panel, which will be the source of the DC voltage used to power the whole circuit. The solar panel is then in series with a diode. Diodes act as electrical check valves, so this is in place to prevent any current from going back to the panel and damaging it. The next section of the circuit is meant to regulate the incoming voltage from the solar panel. In the lab with a stationary lamp, there will be a constant voltage output, however, this is not the case in real life examples. The most used source for radiant energy is the sun, and the sun can be wildly inconsistent so the voltage produced will vary throughout the life cycle of the circuit. To compensate for the variability of the incoming voltage, we have a voltage divider set up with a LM317 voltage regulator. In addition to the voltage regulator, there is a potentiometer included which can allow for a manual adjustment of the produced voltage. The next component in the top right of the circuit is a toggle switch, which allows the user to switch between powering on the motor and the LEDs. The last component in this half of the circuit is the motor, which will be powered when the switch is in its second position.



(a) (b)

Figure 6. (a) The first half of the circuit and (b) The second half of the circuit to be designed.

The operation of the second half of the circuit is much simpler. The goal of this half is simply to utilize to supply voltage to make two LEDs blink in an alternating pattern. The main component is a 555 timer. This timer converts the DC voltage input into a square wave that supplies power to only one LED at a time. As is the case with most LEDs, they all have a resistor in series. With the concept of the circuit to be designed and laid out, the last step is the selection for the solar panel design.

PCB Design and 3-D Printing

Diptrace is used for the PCB design and 3-D printing. From the component list add the required components by selecting and dragging onto the workspace. The schematic is then converted to a PCB and auto routing is done to complete the traces (Figure 7).

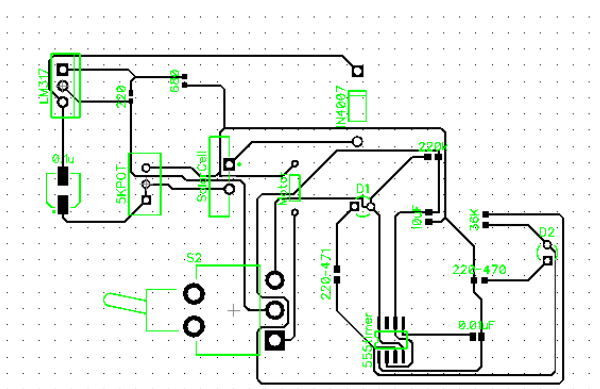
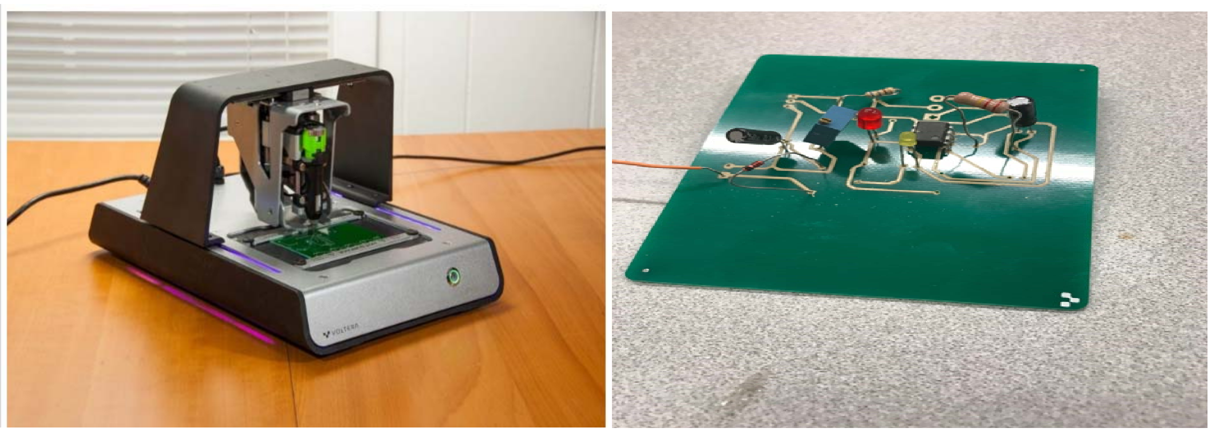


Figure 7. PCB design with Diptrace

The designed PCB layout can be exported based on the file type required by the printer and is ready to print. As shown in Figure 8, a Voltera V-one 3-D printer is used to print out the circuits. The Voltera V-One creates two layer prototype circuit boards on your desk. Gerber files go in, printed circuit boards come out. The dispenser lays down a silver-based conductive ink to print your circuit right before your eyes. Assembling traditional and additive boards is easy with the V-One's solder paste dispensing and reflow features. Simply mount your board on the print bed and import your Gerber file into Voltera's software. No more stencils are required. From importing your Gerber files to the moment you press print, the software safely walks you through each step. The software by itself is self-explanatory as step by step guidance in provided as you navigate between processes.



(a) (b)

Figure 8. (a) Voltera V-one 3-D printer and (b) 3-D printed PCB.

The very first step for this project was to understand the minimum voltage and current required to power both of the loads that would be connected to our power source. There would be multiple options for solar panels with different output values, so in order to choose the one that would be best suited, the students would need to know which source could produce enough power. The procedure to test the required power for both loads was conducted. Both the loads, the car motor and a single LED, were individually connected to a DC power supply and the output voltage was set extremely low and slowly raised until the loads were powered on. For the LEDs, only one would be turned on at a time because of the 555 timer circuit explained in the review section, so it was necessary to only measure the voltage drop across one instead of both. In the laboratory part of our course, the maximum power point (MPP) of a solar panel based on internal resistance is shown in Figure 9. The MPP was achieved with internal resistance values of 33 Ohms. The solar panel selection available are the two smaller experimental solar panels used during the laboratory section of the course and there is a much larger panel available which has the capability to produce a significantly larger voltage. The selection of solar panels will be determined in the analysis section of this report, based upon both the maximum voltage output from both panel options, and the voltage required to power both loads.

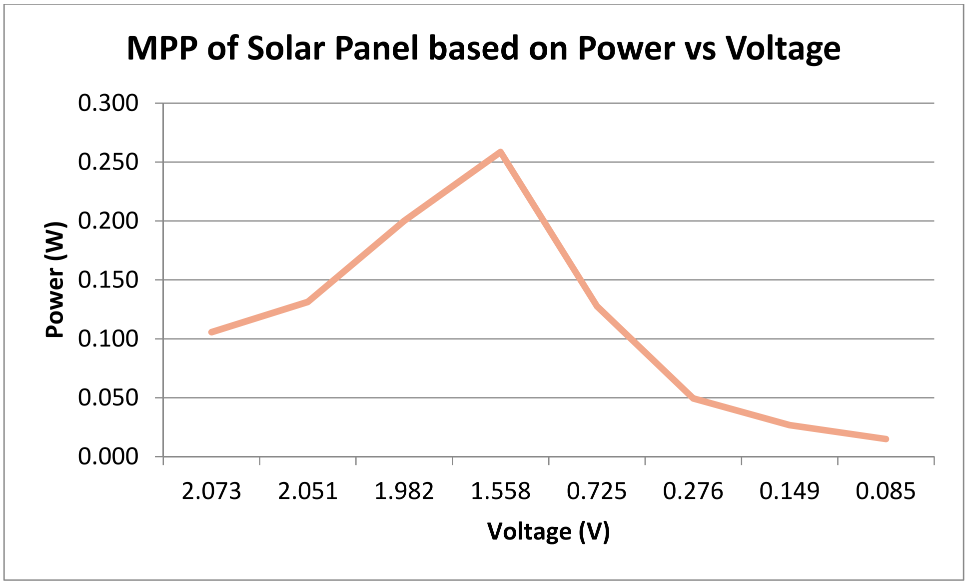


Figure 9. MPP of solar panel.

This project also showed the potential use of solar panels, as well as exposed some possible flaws. The students were able to construct the basis of a complex electronic circuit and had it perform exactly as expected, with only a solar panel as our power supply. This shows that solar panels can be used to help provide power for complex electronic circuits either as a supplemental power source, or as a main power source when traditional sources may not be available. They also discovered a potential flaw for solar panels as well. The large panel they used was rated for 20 watts, but in our environment we barely received 1 watt. This was to be expected because the small lamp has a smaller intensity than direct sunlight. Therefore in optimal conditions, it is a safe assumption that we would be able to produce enough current to power the car motor. However, as all engineers know, conditions are rarely optimal in real life applications. If there is a circuit that relies on solar panels for power, they will be susceptible to the ever changing environment, with elements such as shading and cloud cover, and there will be cases when the panel does not produce enough power to perform the tasks it is required to do, as was the case of our car motor.

5. Course Effectiveness Assessment and Student Learning

Overall the feedback received at the end of the term from the participating students was largely positive with regards to the experiments involving renewable energy systems. Many students appreciated the ease with which the wind turbine and solar cell panel can be designed and tested in an attempt to deal with issues as they arise. Without a doubt all of the students were exposed to the green product topic surrounding materials, fabrication, testing, and measurements. Students are required to analyze, design, simulate, and build a completely functional system by the end-of-term project. The goal of the class project was to enhance student understanding of the fundamental concept of design-for-environment (dfE) and hands-on team project learning in green energy manufacturing. Students understood the design for the environment by improving and optimizing the environmental performance of products, impact on human health, associated energy, and material and process costs. Students commented that they enjoyed working in such green energy manufacturing project with hands-on laboratory experiments. Students commented that they enjoyed working in the LCA virtual laboratory. Students' evaluation was conducted at the last week of the class (4.2/5.0).

A network analysis approach was also conducted to analyze online student interactions. The site was developed with GroupMe as the environment for the online learning community. It provided students the opportunity to discuss, share, and learn both from and with one another on topics related to green energy manufacturing. The study demonstrates that the online site supports interaction among the undergraduate students. The online assessment result was consistent with the class student evaluation. In particular, online students shared course-related advice and information across the site they sought out for support, information, or guidance. This study has implications for future research to determine why students chose to use the site to interact with their peers and what these interactions provided them. The fact that the students received notifications from other students' postings through text messages and that they could post to the group through the GroupMe phone app or through text messages greatly increased the quantity and quality of the discussion. The breakdown of participation is shown in Table 1. A number in cell (*x*, *y*) means that person in row *x* directed their post at the person in row *y*. If it looks like the person directed the post at themselves (i.e. the main diagonal entries), that means the post was not directed at any specific person, but at the group in general. If a cell has 0.5 as an entry, it means that there was one post directed at two specific people and there will be a 0.5 value in the column of each of those people. Such data could inform the ways the site helped support students both in their advancement in the program, and could be useful in assisting future development of such sites and similar learning spaces.

Table 1: Breakdown of participation in GroupMe

Name	[redacted]											Total Posts:	Grade:
[redacted]	7	0.5			0.5				1			9	N/A
[redacted]	1	5				1						7	A
[redacted]												0	D
[redacted]						1						1	C
[redacted]		1			3	1						5	A
[redacted]			0.5		0.5	4			1			6	A
[redacted]							2					2	B
[redacted]												0	D
[redacted]									5			5	A
[redacted]										2		2	B
[redacted]											2	2	B

6. Conclusion

In this study, students acquired knowledge of design process and were able to design components for various green energy generation technology. With the aid of 3-D printers, students were able to prototype their design. The prototypes allowed them an additional avenue to analyze the motion and functionality of their designs, and to evaluate the accuracy of their CAD models as well as helped to realize different errors and mistakes they have made. In other words, the prototypes helped students to reinforce their knowledge of basic machine design: concepts mapping, practical constraints, force and stress computation, size and material selection, and the interrelationships of the factors. Students were engaged in building a physical object based on their own calculation and analysis. The 3-D printer helped to close an existed loop of the design course by offering an effective prototyping method. The integration of 3-D printing into the design course helped to improve the rigor of the course in the areas of simulation and prototyping. Along with design knowledge, students acquired the hands-on skill of operating 3-D printers. They can use this skill in other classes including senior capstone design, and in future professional endeavors. Overall, student learning outcomes improved when 3-D printing technology is incorporated in the green energy design course.

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. Department of Energy - Clean Energy Manufacturing Initiative, http://energy.gov/eere/cemi/clean-energy-manufacturing-initiative.
2. 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.
3. Richard Chiou, Yalcin Ertekin, Tzu-Liang Bill Tseng, Shraman Kadapa, and Smarth H Chadha, “Incorporating Life-Cycle Assessment Issues for Green Energy Manufacturing Education,” the 124th Annual Conference & Exposition, June 25 - 28, 2017, Columbus, Ohio.
4. Richard Y. Chiou, Michael G Mauk, Tzu-Liang Bill Tseng, Regina Ruane, Chetana R Bayas, Abhishek Raja, and Carlos Ruiz, “Development of a Green Energy Manufacturing Laboratory Course on Clean Energy and Energy Efficiency,” the 123rd Annual Conference & Exposition, June 26 - 29, 2016, New Orleans, LA.
5. Tzu-Liang Bill Tseng, Richard Chiou, Radian G. Belu, Oscar H. Salcedo, Aditya Akundi, Eric D. Smith, “Enhancement of Green Energy Manufacturing Engineering Education Through Project-based Learning and Leadership Workshops,” American Society for Engineering Education (ASEE) in Indianapolis, Indiana for the 122nd Annual Conference & Exposition, June 14 - 17, 2015. Seattle, WA, USA.
6. Richard Chiou, Tzu-Liang Bill Tseng, Radian G. Belu, Michael G. Mauk, M. Eric Carr, and Regina Ruane,” Experience with Enhancement of Green Energy Manufacturing Learning in Course and Laboratory Development,” American Society for Engineering Education (ASEE) in Indianapolis, Indiana for the 122nd Annual Conference & Exposition, June 14 - 17, 2015. Seattle, WA, USA.
7. Robert Bogue, " 3D printing: the dawn of a new era in manufacturing?", Assembly Automation, Vol. 33 Issue 4, pp. 307-311, 2013.
8. Kaufui V. Wong and Aldo Hernandez, “A Review of Additive Manufacturing,” International Scholarly Research Network, ISRN Mechanical Engineering, Volume 2012, Article ID 208760, 10 pages doi:10.5402/2012/208760.
9. Ian Gibson, David Rosen, and Brent Stucker, “Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing,” 2nd Edition, ISBN 978-1-4939-2112-6, Springer, New York. http://explainingthefuture.com/3dprinting.html
10. Joseph T. Belter and Aaron M. Dollar, “Strengthening of 3D Printed Fused Deposition Manufactured Parts Using the Fill Compositing Technique,” PLOS ONE, DOI:10.1371/journal.pone.0122915, April 16, 2015.
11. Smith, R. T., and S. A. Melnyk. "Green Manufacturing: Integrating the Concerns of Environmental Responsibility with Manufacturing Design and Execution." *Dearborn, MI: Society for Manufacturing Engineering* (1996).
12. Govindan, Kannan, Ali Diabat, and K. Madan Shankar. "Analyzing the drivers of green manufacturing with fuzzy approach." *Journal of Cleaner Production* (2014).

13. “Investment in renewable energy generates jobs. Supply of skilled workforce needs to catch up.”, *Research brief, Skills and Occupational needs in Renewable Energy* (ILO, 2011)
14. Administration, General Services. (2016, August 2). *6.15 Lighting*. Retrieved from www.gsa.gov: https://www.gsa.gov/portal/content/101308
15. 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.*
16. DeLorenzo DL Greenkit manuals.
17. N. Jacksic, "Novel Experiential Learning Practices in Engineering Education Based on Inexpensive 3-D Printers," *Computers in Education Journal*, 2014.
18. A. M. Paudel, "Fostering Diversity and Educational Learning among Engineering Students through GroupStudy: A Case Study," ASEE-RMS, Ogden, UT, 2012.
19. B. Berman, "3-D printing: The new industrial revolution," *Business Horizons*, vol. 55, pp. 155-162, 3// 2012.
20. ABET, Criteria for Accrediting Engineering and Engineering Technology Programs, 2016-2017, http://www.abet.org/accreditation-criteria-policies-documents/
21. ABET, Inc., “Accreditation Standards and Program Criteria for Manufacturing Engineering and Similarly Named Programs”, Washington, D.C.: ABET, Inc., 2016-2017: http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2016-2017/#program.
22. Solidworks Tutorials, http://www.solidworks.com/sw/resources/solidworks-tutorials.htm
23. DipTrace Tutorials, https://diptrace.com/support/tutorials/