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# The Contribution of Capstone Projects in Green/Renewable Energy Areas to Growth of the Engineering Curriculum in Global Sustainable Development


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## Abstract

The current global considerations regarding sustainable energy use and generation combined with the need of a well-rounded and skilled workforce able to serve a global sustainable industry leads inevitably to new trends and strategic areas in engineering education fields. Our task as educators in the engineering realm is to prepare students to be more effective in a global context as well as to be able to respond to today's challenges, giving them the essential competencies for global engineering work. **The paper aims to present the contribution of several capstone projects developed in the past five years by our students to the growth of the engineering technology curricula in our university.** The main aspects presented are related to the integrative approach in green energy harvesting and sustainability, with a clear assessment of student-led projects developed during past AYs and how they contributed directly to development of leadership skills along with untamed creativity. While a series of projects are strictly related to energy harvesting, serving as models of energy efficiency and sustainable energy power transmission, others are related to sustainable green energy manufacturing. A technical description of the projects along with clear connections between projects and curriculum development will be described in detail.


## Introduction

Current global energy and sustainability trends are rapidly moving towards conservation of natural energy resources and to cleaner and greener energy generation. Although traditional energy sources (such as fossil fuels) still meet most of our energy demands, the benefits of renewable energy have no match of being environmentally friendly while they are virtually inexhaustible. Sustainable development includes solving the sustainable energy resources problem[1, 2]. "A sustainable energy system may be regarded as a cost-efficient, reliable, and environmentally friendly energy system that effectively utilizes local resources and networks."[3]. The development of renewable and sustainable energy sources will lead to an increase in energy independence which, in turn, will lead to advancement in local and regional sustainable manufacturing industries and to promotion of regional development of the workforce specialized in the renewable energy area with a direct impact upon workforce development.

Our Engineering Technology program offers a combined electrical and mechanical engineering technology major, filling in the gap between the industry demand and the current educational majors offered in the area and nationwide. Looking at the global educational and industry demands, our curricula augmented with several courses relating to renewable energy, energy conversion, green energy manufacturing and sustainability. As a result of this enhancement we had an afflux of capstone project topics in the green/renewable energy area reaching a maximum this year when all of our capstone topics are related directly to green and sustainable energy sources or sustainable manufacturing [3-6]. As a consequence, our curricula moved towards educating students in controversial topics such as global warming, energy security, air pollution, ecological damage, reducing the carbon footprint and green-house emissions. During the past two years, several new courses have been developed and further steps have been taken to improve the existing curricula.

Students are actively involved in self-directed learning to find sustainable solutions to design problems, and to recognize that they are part of a global community [4]. These projects also served as a platform for course learning modules to enhance existing curricula as well as to develop new courses that ultimately led to a new minor in Green and Sustainable Energy in our department. This paper presents the contribution of all these projects to the new developments, and to building our modern curricula, including assessment, module spin-offs and continuous improvement based on student and faculty feedback.

To instruct students in complex and challenging topics such as climate change, energy sustainability, and environmental damage, reducing the carbon footprint and green-house emissions, just to name a few of them, requires a curricular change in engineering education[6]. To fill in the gap between the industry demand of specialized job skills and the current educational majors offered in the Greater Philadelphia and surroundings local colleges and universities, our Drexel University, Engineering Technology (ET) program offers a combined electrical and mechanical engineering technology major, with several courses related to renewable energy, energy conversion, green energy manufacturing and sustainability. Our main goal is to create a highly skilled professional workforce ready to "hit the ground running" after graduation and also having most of the qualities of a "global engineer", a critical thinker and an innovator which is in total agreement with ABET criterion c ("an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability") [7], [8]. During the past 8 years, our ET program developed courses oriented towards energy conversion and green energy and sustainability. Due to this enhancement of our program, the past five years have seen an afflux of capstone project topics in the renewable energy area.

During last and current academic year (AY), more than 50% of the capstone projects were in the green and renewable energy and sustainability fields. This coincides with a general trend of students' increased interest in developing sustainable systems and honing their acquired skills in sustainable energy systems development through our series of capstone design courses, which is more in tune with the aforementioned criteria.

**Synopsis of Senior Design Capstone Courses**

Senior Design is a 3-quarter sequence (3 credits each sequence) during Fall, Winter and Spring terms, and is a mandatory course (core curriculum) – MET 421, 422 and 423. The syllabus for each sequence is attached. The course involves developing a comprehensive project during these 3 quarters; including a demonstration of a working prototype (a physical product rather than a computer based model or data from experiments/process/procedure). Students must develop a new or improved product or technology during their senior design sequence. Each project will be developed by a team of 3 to 4 students. Usually teams are a mix of both mechanical and electrical engineering technology concentrations.

This course is an excellent capstone experience, which requires both teamwork and individual skills to solve a modern industrial problem. Senior design project seminars in fall, winter and spring quarters bring the students, faculty, and industrial partners together to see the student's results and to give them the additional experience of public presentation for their work.

**Course Objectives:** The main objectives of the 3 course sequence are geared towards students 'abilities to identify and specify a design problem of current commercial or technological interest and subsequently formulate and evaluate design solutions, for which they will analyze and identify optimum designs. Students will generate alternate solutions and analyze them based on their proposed topic to be solved. During their product/process development they should study and present societal and environmental impact of their product/process, develop and test their prototypes and prepare and present a detailed progress report as well as a final engineering report and present their work in a seminar-type venue.

**As Student Learning Outcomes the following are pertinent to our sequence:**

1) Students gain experience and expertise in solving real-world design problems and communicating their results in a professional format, in both written reports and presentations.
2) Significantly improve students' skills in the areas of system analysis and design, technical writing, public speaking, teamwork, project and time management.

Senior design course sequence is a part of our core curriculum since the inception of this program (2002) and ever since the following schedule has been followed:

<u>Deliverables:</u>

<u>Pre-proposal:</u> Before the beginning of the Fall quarter, students must submit a pre-proposal containing the project description and answers to couple of questions about their proposed topic as follows: (1) What are the objectives of the project? (2) What are the elements of engineering design involved? (3) What is novel and what is challenging about this project? (4) What are the specific deliverables you will produce? (5) What are the resources, funding or external support for the project?

<u>Proposal:</u> A written proposal report and a proposal PowerPoint presentation. The report must contain at minimum: Problem description, Literature review & patent search, Progress toward a solution, including design feasibility study, considerations for design alternatives,

design selection, and proposed approach for analysis, testing and design validation, Design for X (Design for Manufacturing, Design for Assembly, Design for Environment, etc.), Human Factor considerations; QFD, Economic analysis, Target cost, Budgets and Schedule; Timeline or up-to-date **Gantt Chart;** Considerations for Societal, Environmental or Ethical Impacts; Summary, Conclusions; References. The presentation should follow the report.

Progress report and progress presentation (slides). The report will depict the team progress towards a solution. Team must have a prototype work-in-progress by the end of winter term.

Final project narrative (comprehensive) and Final project presentation: Students must deliver a final comprehensive report, including presentation of the prototype as a fully functional and operational product according with the design specifications.

Although our students receive an integrated theoretical and experiential learning throughout our curricula, it is crucial for engineering/technology to transition from classroom work towards a more comprehensive experiential learning with applications of technology and design. ***The main objective of senior design courses in engineering and engineering technology curricula is to bridge the gap between academic theory and real world practice. As discussed in the ABET criteria [8] senior capstone projects should include elements of both credible analysis and experimental proofing.***

### Curricular Context for Capstone Projects

As we mentioned before, our entire Engineering Technology curriculum has been continuously improved based educational formative and summative assessment o of each course, on students 'feedback, and Industrial Advisory Committee recommendations. As a result, we included in our course more learning modules pertinent to the nowadays energy charged agenda. The knowledge acquired during these courses and other courses in our curricula is put together in creating their design solution for the chosen system. While in respective courses students are asked to design components and/or subsystems, mainly guided by their instructor, during senior design sequence courses students are asked to create their original system with minimal input from the adviser, this endeavor being a showcase of their overall engineering skills, allowing us to evaluate not only their preparedness for real jobs but also our curricula as well.

Several projects developed during the past years became either learning modules for our courses or they were idea generation for new learning modules for existing course. Traditionally we had one to two senior design capstone project related to energy conversion, however starting about five years ago, as our program included more and more energy related courses and learning modules, the number of projects in the area of energy and sustainability followed an upward trend. In the Figure 1 below, we represent the major project based learning courses that require students to design a system, a component or a subsystem of an engineering system.

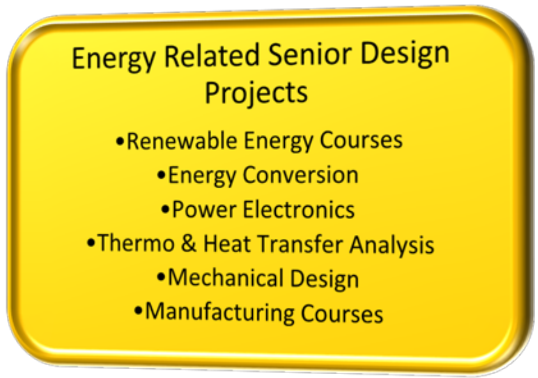


**Figure 1: Project-based and experiential based learning courses as knowledge feeders for capstone projects**

**Evaluations:** The senior design project, as a capstone course series, is used to establish that the Engineering Technology Program is meeting its Program Educational Objectives (PEO) and Program Outcomes. Learning outcomes are what students of our program are expected to know or be able to do by the time of graduation as they were presented above.

To demonstrate these outcome expectations are achieved, team reports and oral presentations are measured based on teams meeting specific performance criteria and also individual students are measured based on their meeting specific performance criteria. Each performance criterion is scored and your grade is reported based on your total score, which are team and individual scores added together as explained for each course. As assessment tools, our department developed based on ABET-ETAC a-k criteria [7], a series of Performance Criteria based on our ET-PEO and are presented in the Table 1.

All our PEO are presented later in the Assessment section of this paper with appropriate cumulative assessment. Each presented project in this paper was assessed based on the criteria shown below for each quarter term. The assessment was composed of 33% Oral Presentation, 33% Written Report and 33% Individual Student Contribution. While the first two are assessed by a panel of faculty and industry experts input, the students are evaluated individually by their advisers only.

Our main strength rests in the industry experts 'input in all three instances of formative and summative evaluations. Students are to incorporate their feedback from one step to the next, reporting during next phase about their progress. In this way the projects become more and more relevant to solving today's key challenges in industry. Also, based on the external evaluators 'feedback, we improve our topic offerings for next senior design cycle (next academic year), as well as we incorporate more relevant experiential activities and theoretical knowledge in our existing courses to keep the pace with ever changing industry demands in terms of skills and preparation of our graduates.

**Table 1 ET Department and Program Performance Criteria for course assessment**

| |
|---|
| a1. Demonstrates ability to apply knowledge and techniques of the discipline.<br>a2. Demonstrates mastery of the techniques and skills of the discipline.<br>a3. Demonstrates mastery of modern tools used in their discipline. |
| b1. Demonstrates an ability to apply knowledge of mathematics to engineering technology problems.<br>b2. Demonstrates an ability to apply knowledge of computer programming to engineering technology problems.<br>b3. Demonstrates an ability to apply knowledge of science to engineering technology problems.<br>b4. Demonstrates an ability to apply knowledge of engineering and technology to engineering technology problems. |
| c1. Can explain theory, procedure and standard testing methods used in the experiments.<br>c2. Performs experiments properly.<br>c3. Analyzes and interprets results of experiments including, where applicable, comparison of results to theory, and error analysis.<br>c4. Correctly applies experimental results. |
| d1. Demonstrates an ability to identify system, component, or process requirements.<br>d2. Demonstrates an ability to define an optimal, realistic, and technical approach that meets requirements in terms of technical, economic and societal criteria with realistic deadlines. |
| e1. Participates in development and support of team objectives.<br>e2. Shares the work fairly.<br>e3. Respects other teammate's points of view. |
| f1. Identifies problems that are suited for technical solution.<br>f2. Produces practical solutions based on meeting requirements of analyzed problem components. |
| g1. Reports describe goals, methods and solutions at the level appropriate for the reader. Relevant technical literature is identified and used appropriately.<br>g2. Presentations clearly describe goals, methods and solutions.<br>g3. Responds to questions, comments and criticism in a clear and appropriate manner in oral interactions. |
| h1a. Exhibits curiosity & initiative.<br>h1b. Exhibits reflection.<br>h2. Participates in discipline-relevant professional societies and organizations. |
| i1. Demonstrates an understanding of the Code of Professional Engineers.<br>i2. Recognizes importance of respect for diversity. |
| j1. Identifies both potential benefits and adverse impacts of engineered systems on society or the environment.<br>j2. Develops and evaluates alternative designs of engineered infrastructure systems to minimize adverse environmental and societal impacts. |
| k1. Manages time effectively and specifically plans for general review of work to improve results.<br>k2. Demonstrates a commitment to quality and continuous improvement. |

Table 2 below presents a synopsis for the past year of the evolution of our capstone design in the investigated area. Analyzing the table, it can be inferred that, with some exception, there is a trending in topics related to environmentally conscious projects. Several of these projects have been also presented in various instances in other publications, including IEEE and ASEE publications.

**Table 2: Synopsis of Senior Design projects in renewable Energy and Sustainability areas**

| AY | Number of Capstone Projects | Title |
|---|---|---|
| 2011-2012 | 4 out of 9 | "Bottom-of-the-Pyramid" Exhaust Fan; Automated Probing and Testing of Solar Cells;<br>Indoor Solar Harvesting for Sensor Nodes;<br>Design of Maximum Point Power Tracker for PV Systems |
| 2013-2014 | 5 out of 8 | Micro Direct Methanol Fuel Cell;<br>Green Energy Solar Collectors; Solar Tracking – Dual Axis;<br>Design and Implementation of a Micro-Wind Turbine;<br>A Digitally Controlled and Portable Photovoltaic Power Source |
| 2014-2015 | 5 out of 8 | Autonomous Solar Powered Car<br>Integrated Wind and Solar Powered Outdoor Area Lighting Kit<br>Portable Power Source using Micro Direct Methanol Fuel Cell<br>Automated Green Energy Solar Heating<br>Self-Powered Rain Gauge and Weather Station |
| 2015-2016 | 1 out of 8 | Harvesting Energy using Hybrid Piezo-Electric System: Applied to Roadways |
| 2016-2017 | 4 out of 7 | Smart DC Power Grid<br>PHiLTER - A Pico Hydroelectric Generator and Water Filtration System<br>Combined Algae Bioreactor/Solar Cell Array for Biofuels and Photovoltaic Electricity<br>Camouflaged/Aesthetic Hybridized Energy Harvesting Installation: Project Green Tree |

In the next section, we will briefly describe some samples of senior design projects developed during past years, which currently are used as laboratory modules for different courses.

**Selected Projects 'Descriptions:**

***System Design of a PV Power System Project***

**Problem Statement:** *The multi-disciplinary team was tasked with designing, assembling, and testing a 500 W photovoltaic setup that they could simulate, assemble, and test in order to validate their simulation results. [9]*

This gave the students an opportunity to reinforce the classroom lessons on solar energy and to apply it in a real-life situation using the same equipment as in large scale solar installations that are becoming more prevalent across the world. Students worked with suppliers and manufacturers to acquire equipment and testing supplies, troubleshoot devices, and to better understand how solar power is harnessed in large scale operations. The students came-up with testing scenarios to test different aspects of the system, and designed a system that could test many different variables including panel orientation, battery charging algorithm, and charge controller configuration. The team was given a maximum budget of $3,000 to spend on all aspects of the system, which include the PV panels and necessary mounting, required power electronics, energy storage, and other miscellaneous components. Students were given approximately three weeks of classroom background on photovoltaic systems before being asked to purchase components. With that knowledge in hand, they were assigned components and asked to work together to design a system that will meet the required objectives.

As mentioned above, the objective of the project was to design a system rated for 500 W. The test setup would consist of four-125 W PV solar panels with a nominal output voltage of 12 V, to allow for optimal testing versatility. **Charge Controlle**r: The charge controller is a component that goes inline between the solar panels and the battery bank. This unit takes the power generated from the panels and manipulates it to safely and efficiently charge the batteries. The unit's rated current is 45 A, which far exceeds the requirements of the system, while also providing clearance for additions to the system in the future. **Inverter**: A power inverter is needed to convert DC power, either from the PV array or battery bank, into 120 VAC, 60 Hz power that can be used to supply most traditional household devices, or could potentially be connected to the grid if the inverter is grid-tie. **Batteries**: There are many different options for energy storage of renewable energy systems on the market today, each with their own advantages and disadvantages. Options for energy storage include batteries, flywheels, compressed air, superconducting magnet, and ultra-capacitors. Batteries are generally the most practical form of energy storage for the project due to their size to weight ratio and their cost. This is the most commonly used energy storage device and has a charging and discharging efficiency of 80% to 90%. For this project there was no specified load, as many different loads were to be tested. The load would also be interchanged depending if a gird-tie inverter or a non-grid-tie inverter was being used.

**Assessment:** The project scored an average score range between 3.6 to 4.5 for criteria a, b, d, f and g and a score of 5 on criterion "e", while for the remaining criteria they had lower scores on a LIKERT scale from 1 to 5. The students had more difficulty on the testing procedures part, on critically defending their product during presentations and also on the team building area.

***Solar Powered Autonomous Vehicle***

**Problem Statement:** *This project aims to design, build, and test an autonomous solar powered ground vehicle. The vehicle will be based on a customized remote control car whose steering and acceleration will be controlled autonomously using an Arduino microcontroller. The vehicle will drive to preset destinations using a GPS receiver module and a compass to navigate to waypoints until the destination is reached.*

The vehicle will be powered using a lithium polymer (LiPo) battery that will be recharged using solar panels. A maximum power point tracking (MPPT) solar charger will be used in between the panels and the battery in order to provide the maximum charging current to the battery that it is able to safely handle. A Bluetooth module will be used to allow for wireless communication between the vehicle and an Android smartphone.

Goals of the project: 1. Fuse the concepts of sustainability into the undergraduate engineering and technology laboratories and projects. 2. Inspire the design methods that support and sustain a renewable way for improving products and reducing environmental impact.

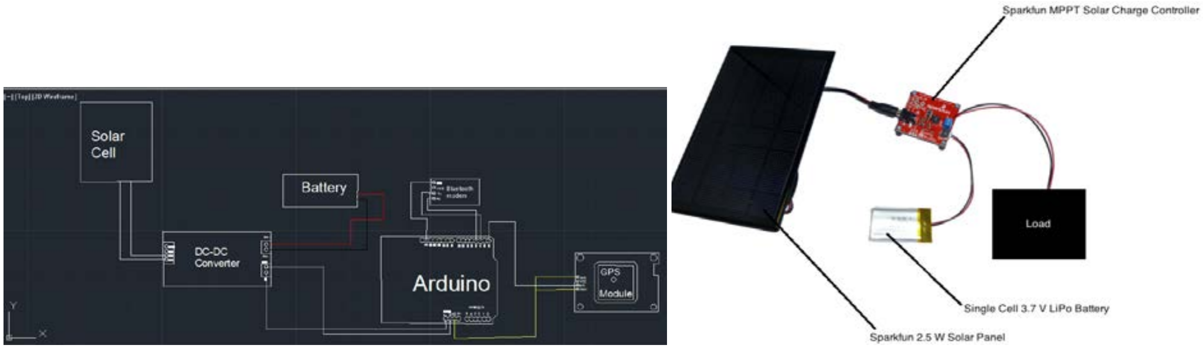


**Figure 2: Autonomous Solar Vehicle**

**Assessment:** The project scored an average score range between 3.2 to 4.2 for criteria a, b, d, f and g and a score of 5 on criterion "e", while for the remaining criteria they had lower scores on a LIKERT scale from 1 to 5. The students had more difficulty on the testing procedures part, on critically defending their product during presentations and also on the team building area.

***Automated Green Energy House Solar Heating***

**Problem Statement:** *The overall objective of this design project was to modify a previously constructed heat exchanging solar collector system for implementation in the effective heating of a farming greenhouse. This process consisted of two phases: the initial modification and the final implementation.*

The first stage of this process included troubleshooting the previously built heat exchanging solar collector system. This system is comprised of an evacuated tube and a flat panel solar collector both attached to a hot water tank heat exchanger for maximum efficiency. Having two different solar collectors present with varying ideal operating conditions enables the unit to operate effectively under changing environmental circumstances in the North Eastern Region of the United States. A new control system was designed to actively monitor the thermal energy transferred to the fluid from both solar collectors and allows the fluid to flow through the most effective heat exchanger using electronically activated pumps. The second stage was the implementation of the solar collector system connection to the greenhouse for ideal effective heating. The control system was specifically designed to actively monitor soil temperatures with the use of a thermocouple sensor all the while maintaining ideal greenhouse conditions by pumping heated fluid through coils underneath the soil surface. The addition of this active negative feedback control system is to maximize the heat transfer from each panel with minimal energy loses. The intention of this project is the replacement of expensive energy costs for heating a greenhouse with an alternative sustainable solar heating design. The expected outcome of this undertaking is the successful incorporation of the heat exchanging solar collectors as the exclusive energy input required to heat the greenhouse system in order to decrease farming costs,

expand the profitability of fruit and vegetable harvests, and decrease the environmental impact of greenhouse heating.
Below is the design of the system.

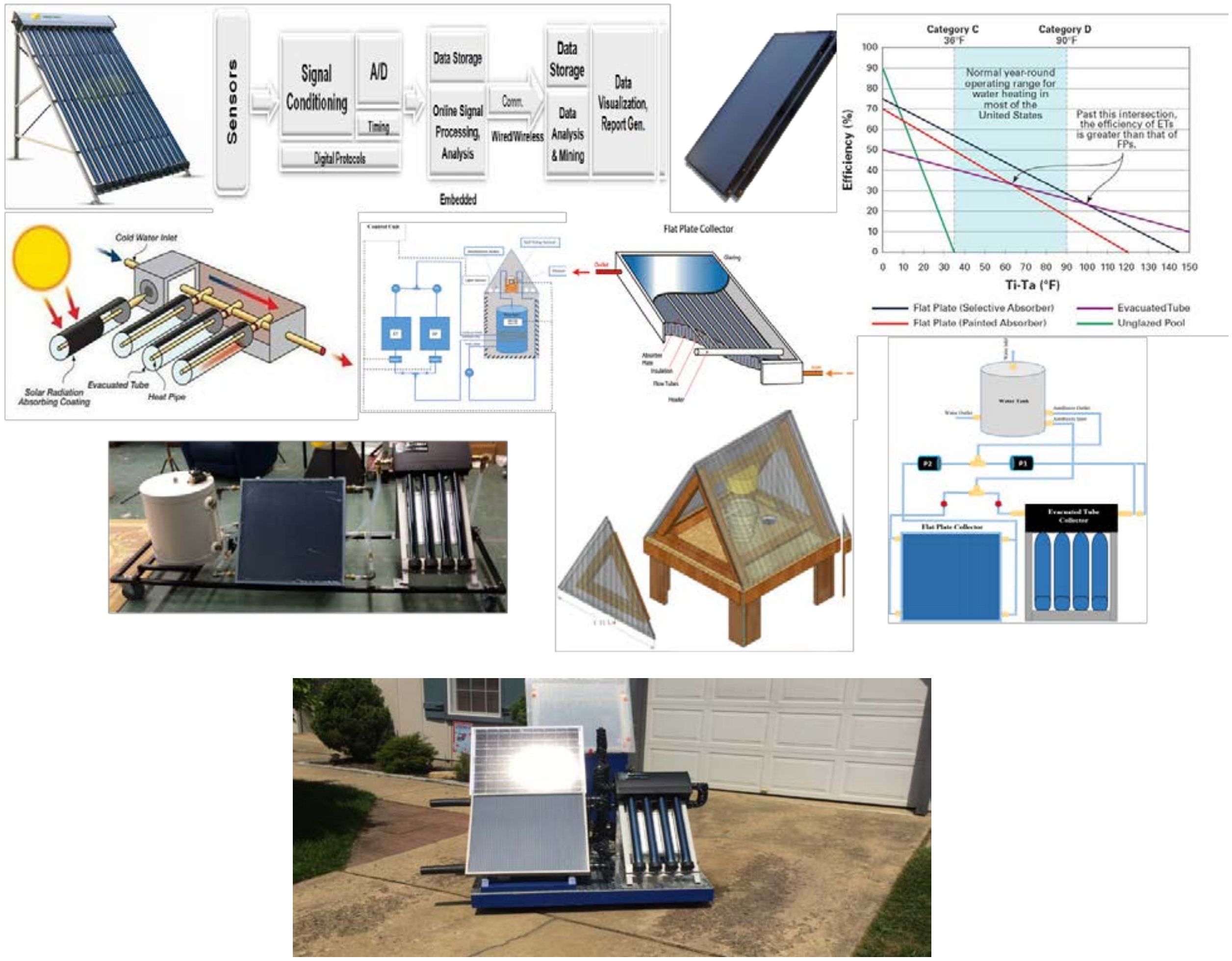


**Figure 3: Automated Green Energy House Solar Heating**

**Assessment:** The project scored an average score range from 3.9 to 4.5 for criteria a, b, c, d, f and g and a score of 5 on criterion "e", while for the remaining criteria they had scores lower than or equal to 4.0 on a LIKERT scale from 1 to 5. Students 'strengths were highlighted by their high scores in the applying engineering knowledge in developing engineering systems. Their weakness, as represented by lower scores was on applying science and mathematics based on their report evaluation. This project was awarded the Outstanding Outreach Learning Award at Drexel University Research Day.

### *Integrated Wind and Solar Powered Outdoors Area Lighting Kit*

**Problem Statement:** As a result of the current local market assessment regarding the use of hybrid renewable energy systems we found out that this type of systems are scarcely used in the urban area of Philadelphia. A market analysis revealed that hybrid wind and solar systems to be used in urban areas are rather expensive, running around $15,000 per street pole [10]. The concept design incorporated a Savonius and Darrieus combined wind turbine integrated with PV solar panels to be installed on existing street light structures. The main goal is to significantly reduce the cost per unit, along with the ease of implementation and simplicity of the system designed to further increase savings from installation and maintenance. The hybrid system will significantly reduce the needed power from the grid, reducing the annual cost for providing a safely lit environment while reducing the demand placed on the electric company.

The system is presented in the figures below (Figure 4):

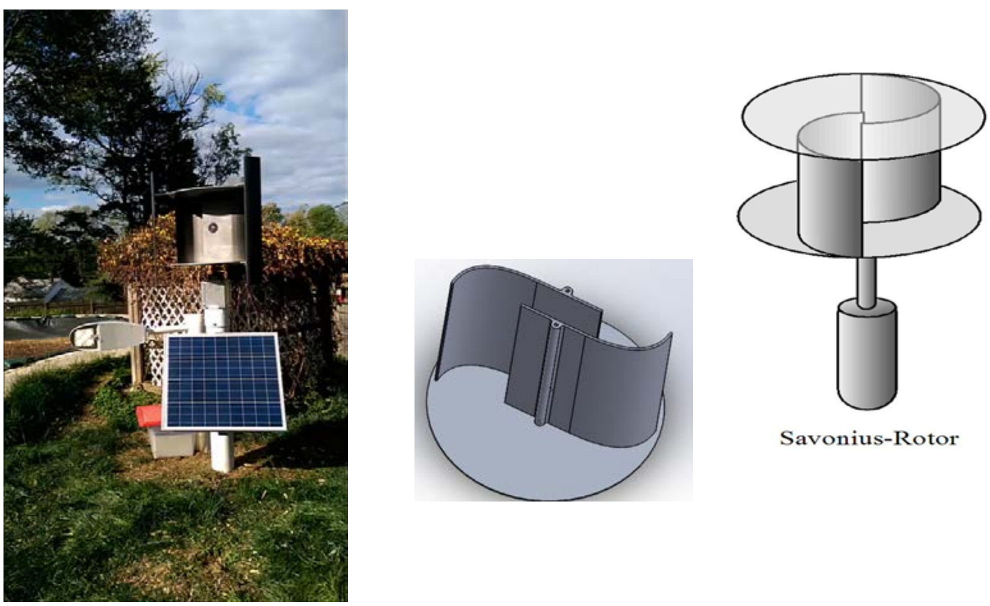


**Figure 4: Integrated Wind and Solar Powered Outdoors Area Lighting Kit**

**Assessment:** The project scored an average score range from 4.6 to 5 for all evaluation criteria from a through k on a LIKERT scale from 1 to 5. This project was awarded 2nd Place at Drexel University's College of Engineering Celebration of Engineering Senior Design Competition.

## Assessment and Evaluation

All capstone projects, this one included are assessed at the end of each quarter using performance indicators stemmed and mapped to the a-k ABET-ETAC criteria. Some of the performance indicators that are included in the evaluation of our capstone projects are as follows:

- Demonstrates ability to apply knowledge and techniques of the discipline.
- Demonstrates mastery of the techniques and skills of the discipline
- Demonstrates mastery of modern tools used in their discipline

- Demonstrates an ability to apply knowledge of science to engineering technology problems.
- Demonstrates an ability to apply a knowledge of engineering and technology to engineering technology problems
- Demonstrates an ability to identify system, component, or process requirement
- Demonstrates an ability to define an optimal, realistic, and technical approach that meets requirements in terms of technical, economic and societal criteria with realistic deadlines.
- Identifies problems that are suited for technical solution.
- Produces practical solutions based on meeting requirements of analyzed problem components.
- Presentations clearly describe goals, methods and solutions
- Responds to questions, comments and criticism in a clear and appropriate manner in oral interactions
- Identifies both potential and adverse impacts of engineered systems on society and the environment.
- Develops and evaluates alternative designs to minimize adverse environmental and societal impacts

These performance indicators are further detailed using a Likert type scale with an equivalence to the letter grading systems as follows: a score of 5 would be an A (≥ 90%);  4 would be a B (performance between 80% and 90%, and so on with 1 representing an F letter grade (< 60%).

**Conclusions**

The design experience develops the students' lifelong learning skills, self-evaluations, self-discovery, and peer instruction in the design's creation, critique, and justification. Students learn to understand the manufacturer data sheets, application notes, and technical manuals and component specifications. The experience of teamwork, prototype design and test, which would be difficult to complete individually, gives the students a sense of satisfaction and accomplishment that is often lacking in many engineering courses, not including projects. Furthermore, the design experience motivates student learning and develops skills required in industry. The students were able to make satisfactory estimations and calculations of these projects. Their results reflect that they have understood well all the basic ingredients of the modeling techniques and design of the renewable energy systems. They were also very pleased with the approach used to teach them. Our experience with the incorporation of renewable energy topics in the senior project design courses demonstrated that the abstract knowledge acquired by the students during their first three years of studies was put into practice. The students in these projects gained extensive knowledge of electronics and mechanical components and their characteristics, environmental and structural constraints, separating different aspects of the project, such as generator or converter type, its parameters and characteristics, and what are the final outputs and its relationship to the load, etc. They learned, during the three-quarter senior design project course sequence with increased renewable energy to identify a problem, conduct research on a particular project, and compare their finding with other similar projects. Semester/quarter long projects integrated within the course allow students not only to learn the material on renewable energy, but also to live it. This is very crucial in particular to renewable-energy-based engineering given its historic past and it's promising future. The course provided theoretical background on renewable energy integration and also the opportunity to apply learned principles on a small scale project. Students realized the practical challenges in integration issues and gained insight to tackle these issues in the future, while allowing them to use problem solving skills learned in other disciplines. The key elements to success were the interdisciplinary nature of the projects, the team work effort and the faculty advising and mentoring during completion of the projects. The lessons learned from this type of projects lead us to believe that they are very attractive and favorable for students, leading to an increased students' interest in this field. Finally, they may represent one of the ways to enhance engineering education in our college.

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