A Case Study on Students' Senior Design Experience in the EPA P3 Competition

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After serving as a Navy Nuclear Reactor Operator for 6 years aboard the nuclear powered submarine, the USS Asheville, a new path was paved into the power generation community. With the experience that was gained not only professionally but personally as well, it became possible to achieve anything attempted. The decision to come to school was a thoughtful one, which would allow for the skills learned in the military to flourish in an educational environment. Becoming a leader in the Clean Energy Senior Design allowed for the excelling of the program in a way that was never thought possible. By adhering to strict deadlines and turning in quality work, the project was completed on time, while meeting every customer requirement designated. The unparalleled managerial skills that were implemented in the senior design project, which are taught in the military, allowed for an overall project success.

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Abstract

The P3 (People, Prosperity, and the Planet) competition is a national collegiate sustainability design competition sponsored by the U.S. EPA (Environmental Protection Agency). Since 2012, we have integrated the P3 competition with the capstone design course of Clean Energy Systems track in mechanical engineering as an effective educational vehicle for introducing the concept of sustainable design. This paper presents the senior design project to demonstrate how a collegiate design competition could effectively motivate and engage students. The paper explains the design challenges, the design process, examples of the design work, and the students' performance evaluation.

Background

Finding appropriate projects for capstone design courses has never been an easy task [1, 2]. A good capstone design project should not only equip students with essential design skills but also need to fit in the budget constraints and the time constraints of a two-semester course. Because of small number of senior students and limited resources and experiences, it is even more challenging for a new and small program like the Mechanical Engineering (ME) program at Embry-Riddle Aeronautical University which was established in the Fall 2005. Since its inception, the ME program has adopted the project-based learning strategy to enhance students' learning experience. All capstone projects are related to collegiate engineering design competitions such as EcoCAR, Formula Hybrid, AUVSI student competitions etc. With the steady growth of enrollment, a new track Clean Energy Systems (CES) was created in 2010 to diversify the ME program and increase student competitiveness in the growing energy job market. Inspired by the success of the other two tracks, we were seeking a collegiate design competition suitable for the capstone design course of the CES track. The EPA P3 (People, Prosperity, and the Planet) program showed up on the top of the search results [3].

Aiming at fostering future generations of scientists, engineers, and decision makers to meet the sustainability challenges, EPA launched the P3 Student Design Competition for Sustainability in 2004. The competition has two phases. For the first phase, teams are awarded a $15K (it was $10K from 2004 to 2010) grant to develop their sustainability solution. Then they present the design in April to the National Sustainability Design Expo in Washington DC to compete for the P3 award and a grant of $75K to refine the design, implement it in the field, and bring it to the marketplace. During the past ten years, the EPA P3 program has funded over $12 million in grants to more than 500 student teams. These projects mainly address challenges from a wide range of categories including water, energy, agriculture, built environment, materials and chemicals, clean cook stoves, and green infrastructure. Figure 1 illustrates the phases of P3.

We have participated in the EPA P3 competition consecutively since 2011. In total, we have won five Phase I awards and three Phase II awards. Since we need to propose a new project relevant to the P3 elements for each competition. it would be extremely challenging for us if we proposed a completely different project each year because of the small enrollment and availability of faculty advising time and effort. Our strategy is to form a faculty advising team, pick a long-term goal for projects, and propose a project relevant to the goal each year. Because of the job market needs, our location and faculty expertise, we chose to center our projects on solar energy. With this strategy, we have won four awards relevant to the goal. In this paper, we will share our experience of furthering our exploration through the EPA P3 program.

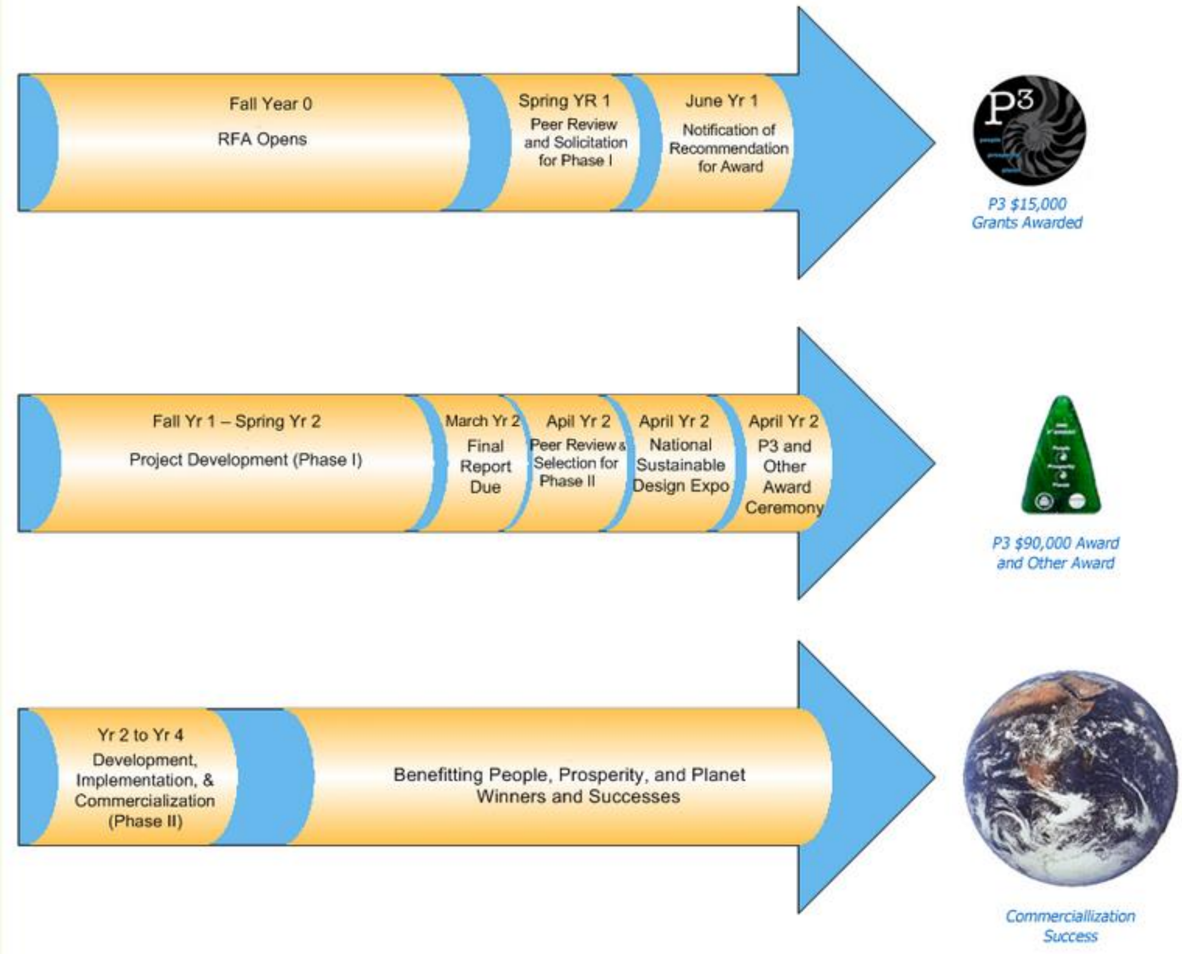

Figure 1 Grant and Award Timeline

Thermal Storage

We started our investigation of solar energy with solar thermal storage which was needed for a concentrating solar collector on campus (Figure 2). Our objective was to collect solar thermal power and store the heat in an energy accumulator. The primary technical challenge was to collect ample solar power during the daytime to power a thermally driven application after daylight hours.

Figure 2 4kW Parabolic Trough Concentrating Solar Collectors

Since this was a Phase I project, the senior design group built a demonstration unit to illustrate the cycle from solar thermal energy collection, storage to delivery as seen in Figure 3. The demo unit can store heat overnight in eight gallons of Canola oil heat transfer fluid to operate a small-scale absorption chiller. The outdoor solar collector was not integrated during Phase I as the goal was to demonstrate the idea.

Although the project did not win a Phase II award, we were inspired by the idea of thermal cooling when we worked on the project.

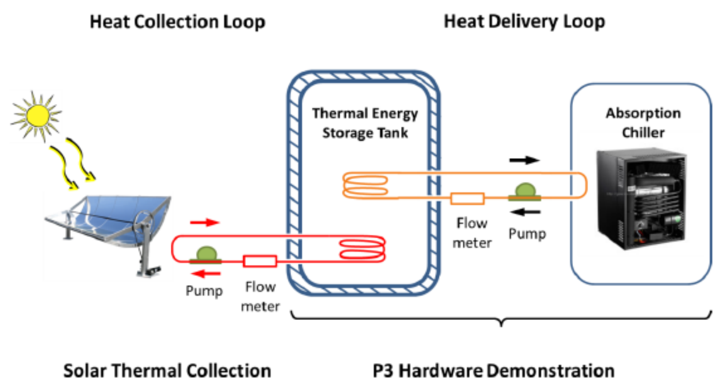

Figure 3 Solar Thermal Energy Collection, Storage, and Delivery

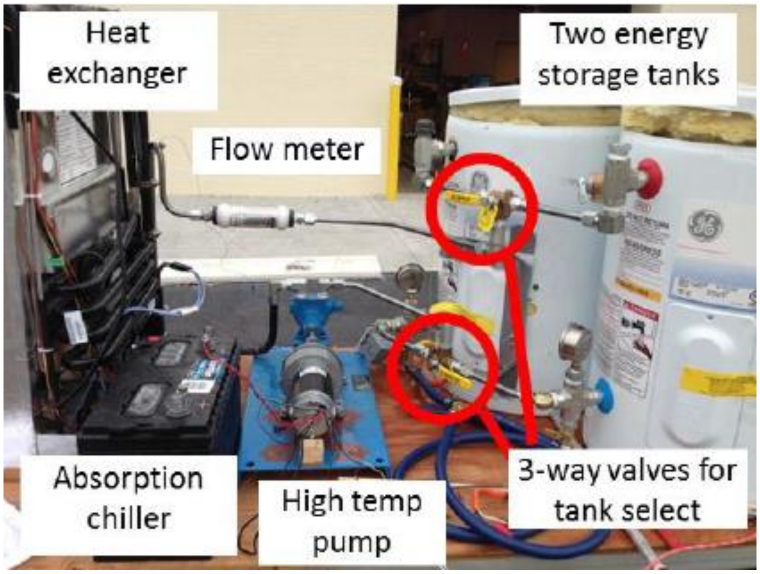

Figure 4 Demo system.

Thermal Cooling

As we have seen absorption chillers have been used in commercial buildings, we were motivated to investigate the thermal cooling concept, so we proposed to develop a small scale cooling system using the parabolic troughs. Based on the existing thermal storage project from the previous year, this project mainly focused on the heat exchange design to deliver heat for the ammonia absorption cycle of a RV refrigerator.

The senior design team built a heat delivery loop to test the heat exchanger design (Figure 5). Students compared the surface area and heat flux generated by each heat exchanger design through simulation and experimental studies and chose the collar design (Figure 6) for its best performance.

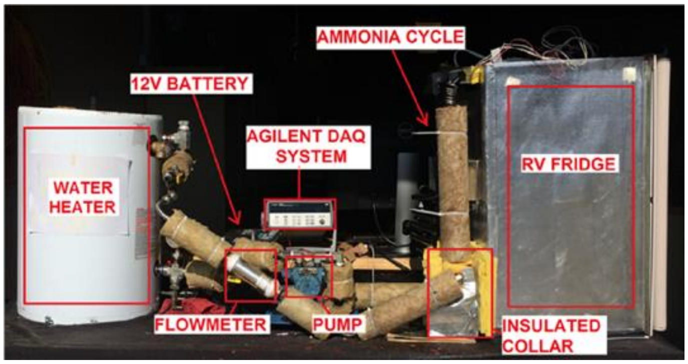

Figure 5 The heat delivery loop with insulated collar heat exchanger.

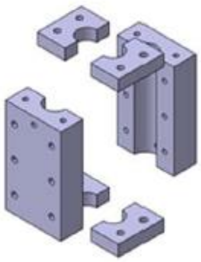

Figure 6 Exploded view of the collar exchanger design.

The project received much attention during the EPA P3 expo and won the Phase II award which supported us to continue the research.

Photovoltaic Solar Panel Efficiency Increase

With our further investigation, however, we realized that small scale thermal cooling is not realistic due to its large space requirement and the availability of absorption chilling for residential cooling. So we continued to investigate an alternative solution of solar cooling: using photovoltaic panels to power solar split air conditioning system which is commercially available shown in Figure 7. Our focus is to improve the efficiency of the photovoltaic panels because the efficiency will drop when the temperature increases [4]. The team has found that the phase change material (PCM) could regulate and remove the heat from the solar panels, so the major design task has shifted to build a testing rig to validate and quantify the improvement of the solar panels with the PCM.

In this project, the senior design group was in charge of the installation of the solar powered air conditioning unit while a group of masters students are working on it as a research project to conduct both simulation and experimental studies. Their knowledge and project management skills make them good mentors for the senior design team.

Throughout the Preliminary Senior Design Project and the Capstone Senior Design Project we were initially tasked with designing a system that could be used throughout the world with minimal restrictions to allow common Photovoltaic Solar (PV) Panels to be made more efficient. With the use of the EPA P3 Phase II Grant we were able to purchase several pieces of equipment that would allow us to monitor the PV panel efficiency and performance. Without the use of the Phase II Grant money these items would otherwise be unobtainable due to extravagant prices. These instruments are not only necessary in providing accurate solar data and solar irradiance that is incident on the earth, but also validate several mathematical models that find the actual solar irradiance based on exact location and time of year.

Figure 7: HotSpot Energy Air Conditioning Unit Powered by 3-265 Watt Solar Panels

The first and most vital instrument that was purchased using the Phase II P3 Grant was a pyranometer with a digital output shown in Figure 8. This instrument allows for the measurement of Beam and Diffuse irradiance as well as reflected irradiance. A Pyranometer is an instrument that has a 180° field of view so it absorbs all the solar irradiance from its surroundings and delivers a digital reading that can be logged with a micrologger (not shown). The micrologger used is capable of measuring a change in voltage as low as one microvolt. The specific reason in which this instrument and supporting equipment were purchased was to allow for solar panels to be tested during similar solar conditions. This validated our work by making solar panels more efficient at turning the solar energy from the sun into electricity by allowing us to test the panels on several different days with similar solar conditions.

Figure 8: Huksflux SR20-D1 Pyranometer measuring 180^0 field of view of Solar Irradiance

The second piece of test equipment that the Phase II grant allowed us to purchase is IV-400 shown in Figure 9. This instrument allows for us to measure the exact performance of the solar panel in real time. This instrument not only measure the current and voltage output from the PV panel in test, but it also does two sets of curve sketches. The first would be the most familiar, it Current vs. Voltage curve (a sample shown in Figure 10), and the second curve that is produced by the instrument would be the Efficiency vs. Voltage curve (shown in Figure 11)

Figure 9: Hukseflux IV-400 Curve Tracer measuring Solar Panel Electrical Output

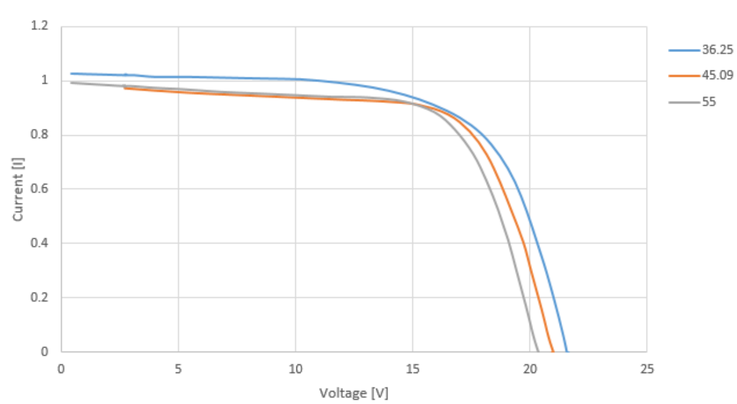

Figure 10: Current vs. Voltage Curve of a 15 Watt PV Panel Produced by IV-400

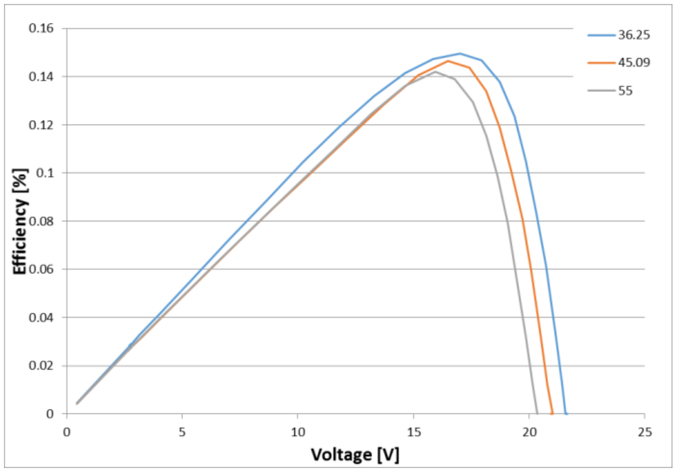

Figure 11: Efficiency vs. Voltage Curve of a 15 Watt PV Panel Produced by IV-400

To sum up the Senior Design Capstone Project, much like all projects, it had its trying moments and successful moments. By learning to use state of the art equipment on our project that professionals currently use at solar plants throughout the world, this gives us an advantage over any fellow applicants to major corporations with these instruments. By previously knowing the workings of high end pieces of equipment, this greatly reduces the cost it takes to train someone with no prior knowledge. Additionally by receiving the phase II grant from the EPA P3, this allowed all efforts on the project to be completely focused on engineering a way to make solar energy a more efficient and viable source of power instead of allocating numerous assets toward receiving funding. With the funding already in place prior to the start of our project, this ensured that we could make the best well designed system that there could be in an already short amount of time.

Building-integrated Photovoltaic (BIPV) Panels

The idea of our fourth EPA P3 project was also created while we worked on the solar cooling project. When we obtained some promising preliminary results, we thought of implementing building-integrated photovoltaic panels illustrated in Figure 12. The long-term goal is to capture the waste heat from the PCM and integrate it into buildings for space or hot water heating. The team is working on both simulation and experimental studies.

BIPV Panels are a new way in which solar panels can be attached to a preexisting roof, with minimal impact on the overall aesthetics of the structure. However, these panels still suffer a drop in efficiency due to increased temperatures much like off the shelf products shown in Figure 10 and Figure 11. This is the next area of study that will be examined using the Phase I grant that was won from the EPA P3 Competition over the past fall. Our proof of concept will be brought to the 4th Biennial USA Science and Engineering Festival, as well as our preliminary results, in April 2016 to compete to win a Phase II grant to allow us to continue our research into solar panel efficiency increase.

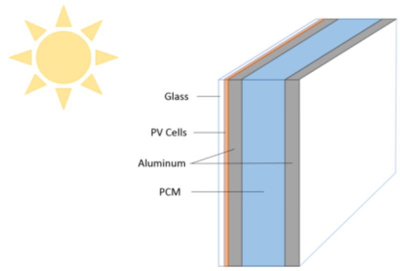

Figure 12 Schematic diagram of a basic BIPV-PCM module.

Discussion

It has been a unique and exceptional learning experience for students who have worked on the EPA P3 projects and presented their projects to judges and the general public during the expos. Because of the small enrollment, we have not had enough data to provide meaningful assessment results. When the enrollment increases, we will assess students' learning from the following perspectives:

1. Students' motivation. We will evaluate how the collegiate design competitions influence students' motivation.
2. Students' knowledge of sustainability. We will evaluate how such sustainability design projects affect students' knowledge about the sustainability. A questionnaire will be developed and use pre- and post-assessment as the assessment instrument.
3. Students' critical thinking skills. This has been an assessment focus for capstone design projects. We need to develop an assessment instrument to assess how students' critical thinking skills evolve while working with small groups.

The major goal of this paper is to promote the participation of the EPA P3 program. From our own experience as a small program in a private engineering oriented institution, we would like to provide the following comments and recommendations:

1. If your program is related to energy, built environment, materials and chemicals, water, and agriculture, the P3 Phase I would be a great funding resource for the capstone design. The Phase I begins in August and the competition is in April, which matches the schedule of standard capstone design courses. By participating the P3 competition, students will be more motivated to work. Their understanding of sustainability and their communication skills will be enhanced by presenting their designs to the audience visiting the competition.
2. If the program enrollment is small, you may propose projects focusing on a certain area (e.g., solar energy in our case) so both faculty and students could gain relevant experiences, which will increase the winning opportunities. On the other hand, if students continue the graduate school in the same institution, they could develop thesis projects out of the capstone projects while serve as student mentors to help faculty advisor manage the projects.

Conclusion

We have shared our experience of integrating the EPA P3 competition with the capstone design course for the Clean Energy System track. Our program has benefited from the P3 program on both curricula development and learning experience enrichment. We hope more institutions will participate the EPA P3 program to create more ideas and designs contributing to sustainability.

References

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