# AC 2011-1901: RENEWABLE ENERGY-BASED SENIOR DESIGN EXPERIENCE FOR UNDERGRADUATE STUDENTS

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# Renewable Energy-based Senior Design Experience for Undergraduate Students

**Abstract**

Energy is becoming very important in the economic development of our society. The combination of the limited fossil fuel supply together with concerns about pollution and global warming has brought the development of clean and renewable energy to the forefront of future technological endeavors. This has ignited considerable interests in education and research on renewable energy methods and renewable energy systems projects. As such, there is an unprecedented priority for educating and training a technologically solid workforce with an energy focus. Senior design examples are discussed to show our experiences of incorporating Renewable Energy projects in the senior design course**.** Introduction of renewable energy projects into our curriculum has impacted students, faculty, and university community positively and promoted feasibility and adoption of more eco-friendly energy technologies.

## Introduction

Energy literacy and renewable energy programs are vital to prepare future students to be competitive for careers in the growing fields of energy-related engineering, science, and technology. Preliminary projections from the Bureau of Labor Statistics states that the number of expected energy-related "green jobs," by 2016 is expected to increase by 11%, and most of that growth is expected to be in the environmental or energy-related sectors[1, 2]. Several studies have shown that energy-related knowledge among American students – as well as the general public – is low[4, 5], underscoring the need for improvement.

ABET defines Engineering Design as: "The process of devising a system, component, or process to meet the desired needs. It is a decision making process, in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation" [1].

For the last few years the focus of the mechanical engineering program of Aerospace and Mechanical Engineering department at Saint Louis University has concentrated towards incorporating renewable energy projects in our senior design courses.

In this paper, we will demonstrate the following three points, (1) constraint-based innovative design concepts exercising fundamental engineering and science principles, (2) well defined project scope to satisfy student, industrial reviewers and sponsor's needs, and (3) systems engineering concepts including project management, team work, communications, and ethics etc. Multidisciplinary design teams are used whereby the students interact with their peers and with the faculty inside and outside of the class room. Some design examples are offered to show our experiences of incorporating Renewable Energy projects in the senior design course, like design and development of a biomass bioreactor test-bench, design and development of vertical axis wind turbine. The primary goal of the projects is to provide students with a deeper understanding of the need for renewable energy sources, the advantages and disadvantages of a particular energy type, and the global and economic impact of the chosen energy type.

**Constraint-based Design**

Successful design involves working within constraints to achieve a design that meets customer needs. Customer needs are clearly defined at the onset of a design project and are the criteria that determine whether a certain design is successful[3]. Constraints are factors the design must take as given.

Engineering design projects encounter both Technical Constraints and Non Technical Constraints, which are both equally important for successful completion of the design process. Technical constraints include engineering design constraints, economical constraints and conforming to various standards. Specifically, the following are critical:

1. Engineering design constraints (for example, mass, volume, power etc.)
2. Manufacturing constraints which includes applying the concepts of Design for Manufacturing and Design for Assembly in the design process
3. Economical constraints in terms of budget, manpower etc.
4. Following the Systems Engineering Process which includes design, manufacturing/fabrication, assembly/integration, test and verification and developing operational and maintenance procedures, and documentation.

Non-technical constraints are equally important to achieve successful project results. Some of the non-technical challenges are shown below:

1. Balanced teams, whose members exhibit the full range of thinking modes, leadership, and communication skills, must be formed at the start of the project.
2. Project requirements must be identified by the sponsor (if any) and the project manager, with the teams of students then optimally matched in engineering capabilities to the projects within the constraint of achieving balanced teams.
3. The development of team dynamics and leadership must be monitored and issues resolved within the constraints of available staff: class instructor, assistant, advisors and faculty experts.
4. Resources to pay for the thinking skills assessment and other staffing must be obtained and proved to be especially difficult during the last years of economic downturn.

**Systems Engineering Concepts**

Systems engineering is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system.
The system engineering design concepts crucial for project success are:

1. Successfully understanding and defining the mission objectives and operational concepts are keys to capturing the stakeholder expectations, which will translate into quality requirements over the life cycle of the project.
2. Complete and thorough requirements traceability is a critical factor in successful validation of requirements.

3. Clear and unambiguous requirements will help avoid misunderstanding when developing the overall system and when making major or minor changes.
4. Document all decisions made during the development of the original design concept in the technical data package. This will make the original design philosophy and negotiation results available to assess future proposed changes and modifications against.
5. The design solution verification occurs when an acceptable design solution has been selected and documented in a technical data package. The design solution is verified against the system requirements and constraints. However, the validation of a design solution is a continuing recursive and iterative process during which the design solution is evaluated against stakeholder expectations.

Systems Engineering Practice when applied within a capstone design project has a greater potential to develop program outcomes within students compared to traditional capstone projects. The process provides an engineering framework for the design process, as well as alerting the students using the process to other issues, such as the social and environmental impacts of possible designs. It allows the development of their communication and teamwork skills far more due to the nature of the process.

The most rewarding aspect of renewable energy design projects in a university setting is the collaborative effort with students from multi-disciplinary engineering and science programs. Constraint-based design requirements drives the students to be more creative and efficient in decision making and designing complex systems that has enabled them to be increasingly competitive in the global market. Some of the "systems engineering" educational outcomes that the students benefit from these programs are listed below.

***Multi-disciplinary Teamwork***

Students must learn to work effectively with people that do not necessarily think or talk like themselves. They must learn to understand and value the skills that each team member provides, and then employ these various skills in an optimal way to realize the final design goal. The challenges of working within a multidisciplinary team environment include team problem-solving, project management, and team communication.

***Team Communications Skills***

Communications among various subsystem team members is a crucial facet in successful completion of a complex project. Students must be able to share ideas within the team, as well as clearly articulate, justify, and defend ideas with the team, external customers, and reviewers.

Additionally communication is essential to ensuring that the project will be continued on in future years and hopefully be completed. To make certain this happens, the team must seek out underclassmen to include them in the design and decision making processes. Therefore, when the upperclassmen leave school there will be other students with a vested interest in the project, increasing the probability of project completion. So far, teams have not been successful in this endeavor, causing a new project to be started each year.

***Problem Identification, Formulation and Solution***
In a capstone design course, the ability to identify problems and formulate solutions is an essential skill that students will develop with experience. In any design, the major problem identification is the initial motivation for the design. Through design verification and validation, brainstorming and trade off studies, students are exposed to many opportunities to develop problem-solving skills. Students are required to gather information to solve the various problems, another useful skill that they can develop for professional practice.

***Social, Cultural, Global, Environmental and Sustainability Awareness***
This outcome can best be developed using the tailored systems engineering project through the choice of a suitable project. If the project comes from a community need, then the students would be able to develop a social and cultural awareness. If then the project also had some environmental issues, then the students could develop environmental awareness. An understanding of the global nature of engineering could be accomplished by looking at how other groups around the world are solving the same sorts of problems, and what techniques they are using.

Sustainability is also a contemporary issue that engineers have to be aware of in the current global engineering profession. Choosing a project that considers sustainability mindset within the overall project can best develop the theme of sustainability within students.

***Ethical Responsibilities***
"Capstone design courses offer a unique opportunity to learn about ethics in a realistic context". Ethics is integrated into the design course through the use of the actual technical projects themselves. Students typically write two formal engineering design reports: the first at the end of the first semester's activity (i.e. a complete preliminary design) and the second due at the end of the spring semester (i.e. a final design with working prototype). Within each report, the student teams are challenged to discuss their designs in light of many criteria including not only reliability, manufacturability and economics but also sustainability, safety, societal impact, and impact upon the environment.

***Lifelong Learning***
Lifelong learning is an essential skill for engineers to possess and in the context of a capstone design project, almost impossible not to develop. Because of the nature of design projects, students will not have all the necessary knowledge that they will require to find a solution. They will have to research particular topics, learn how to use certain tools and overall, learn about the tailored systems engineering process. When the students realize that they have to reach outside of their experiences constantly in the design process, they are on their way to developing lifelong learning skills.

## Project Examples

This section discusses two renewable energy capstone design projects that were designed at Saint Louis University, namely, (1) design and development of a biomass bioreactor test-bench, and (2) design and development of vertical axis hubless wind turbine. Although the objectives for each individual project were different, the presented examples share common practices, including[6]:

- Students achieved a basic understanding of engineering principles by taking the courses related to the assigned projects or/and conducting literature searches.
- Students learned how to define specifications of the systems from the faculty members with expertise in the field.
- Students designed experiments to meet their project objectives.
- Students fabricated hardware and assembled test systems by working closely with their project advisors.
- Students analyzed the test results and prepared a final report to document their learning and findings.

**Project 1: Hubless Vertical Axis Wind Mill – VayuWind**

Background and Motivation: Many countries are seriously developing renewable and nonpolluting technologies, such as wind energy, to solve their energy needs. However, harvesting of wind energy often occurs far away from the areas in need of power. An inexpensive method of tapping wind energy in cities and industrial centers in both developed and developing countries is much needed at this time. Tapping wind energy in an urban environment imposes different criteria such as low noise level, continually changing wind directions, and aesthetics on the synthesis of windmill design. In this project, the team decided to pursue a radical innovation strategy, deviate from the common windmill design – a horizontal-axis wind turbine.

***Goals of the Project:***

- To harness clean, renewable and non-polluting energy from wind source.
- Develop a scalable system using symmetrical airfoils suitable for residential, commercial and university uses.
- Make a more environmentally friendly alternative to the ever increasing demand in energy consumption by using renewable resources and to do this on a smaller scale.
- Assess the market needs and market acceptance for such technology to be used in an urban environment.

***Ideas and Design Approach:*** The initial idea of the windmill group is to mount a wind turbine on a high-rise building. This exploits the existing structures to mount the wind turbine. From this common solution, the group deviated to propose their innovation to solve the problem– VayuWind – a hubless windmill that can be used effectively both in urban and rural environments. VayuWind deploys airfoils parallel to the rotational axis so that, unlike other vertical axis windmills, it rotates around a ring frame, leaving the central portion open for other uses (figure 1).

The innovative design, VayuWind, extracts wind power using existing commercial buildings with minimal noise pollution. This concept is appealing for skyscrapers with significant energy demands because it generates electricity without taking up any ground space. Because the windmill is mounted on top of or around large buildings, the boundary layer close to the ground does not interfere with the air flow. The windmill design will add uniqueness and aesthetic appeal to both buildings and the city skyline (refer to figure 2). The real-estate companies can capitalize on the green-image and charge higher rates for offices. These windmills pose minimal additional structural and real-estate needs. VayuWind can potentially revolutionize the use of wind power in everyday life by bringing windmills to urban centers. Figures 3 and 4 shows the concepts for institutional and residential applications generated using PRO/E computer aided design software.

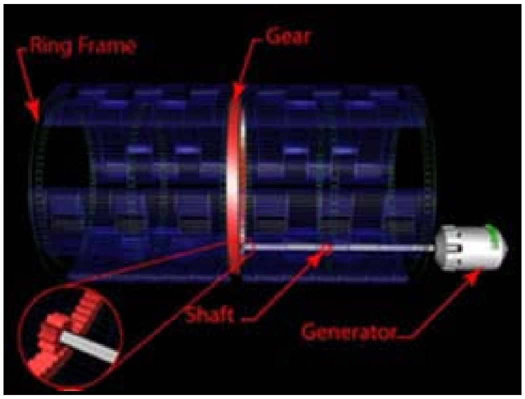


Figure 1: VayuWind design

Figure 2: VayuWind adding aesthetic appeal to the skyline

Figure 3: VayuWind for institutional applications

Figure 4: VayuWind for residential applications

***Results:*** Experimental testing of the wind mill was performed using a wind tunnel. Lift and drag coefficients of the air foil for various angles of attack was calculated using the data collected. Wind energy that can be harvested at various wind speeds were calculated and compared with the analytical results. The wind mill design was patented and the design is currently being commercialized through collaboration with the industry.

The project proceeded from the design class to technology commercialization. Currently, Saint Louis University is working with a commercial partner in the development of a commercial wind turbine technology. The initial scaled model testing showed significant promise. The second round of testing is currently being conducted in the wind tunnels.

**Project 2: Biomass Bioreactor Test-Bench**

Background and Motivation: The original motivation for the project came from the requirement to propose novel designs that are less expensive and environmentally friendly utilization renewable energy sources for household and commercial consumption. Plant and Yard waste biomass is not widely utilized as an alternative energy source, to produce methane gas. Large amounts of organic wastes are generated daily throughout the world. Most of these wastes are simply left to decompose. These wastes have the potential to be converted into viable energy sources for society. This project was partially funded and collaborated with Fred Weber Inc.

***Goals of the Project:*** The goals of the project were as follows:

- To produce an energy source—Methane gas—via anaerobic digestion of waste organic materials.
- Develop a scalable system suitable for residential, university, and county use.
- Make a more environmentally friendly alternative to the ever increasing demand in energy consumption by using renewable resources and to do this on a smaller scale.
- The Methane that the Bio-Reactor will produce will be cleaner burning while maintaining efficiency.

***Ideas and Design Approach:*** The design went through various trade studies and design phases before a design was finalized. The final design consisted of a digester which was a 15 liter four necked flask for the anaerobic reaction to take place. The flask was heated to a temperature of about 500C using a hot plate and a stirrer. The produced methane gas was collected using a 250 mL synthetic gas balloon, which was flexible with two attached hoses. The produced gas was analyzed using Gas Chromatographer by taking a sample of the produced gas. Since the anaerobic reaction (using methanogens) required maintaining specific ranges of temperature and pH values, a combined Temperature and pH sensor was used.

***Results:*** The final Bio-reactor design is as shown in Figure 5, the anaerobic biomass methane generator was of an appropriate size for the project. Due to resource and time constraints, many of the planned experimental analysis were not completed. This project is currently in progress with the final goal of developing a working prototype of the Biomass Bioreactor Test Bench.

Figure 5: Anaerobic Biomass Methane Generator System

## Impact on Students and faculty

The relative success of these renewable energy senior design projects had a positive impact on the underclassman and senior students, as well as faculty to adopt more eco-friendly energy technologies. Sophomore students in the Introduction to Mechanical Engineering course performed the feasibility analysis of designing a “Solar Oven” for developing countries by adopting constrain-based designs taking into account the societal and sustainability issues. Senior standing students in Mechanical Engineering program embarked renewable energy/sustainability projects ranging from water harvesting designs to under-water pump using hub-less wind mill. Several faculty and senior design students from aerospace engineering program were involved in designing “green aircrafts” using alternative fuel sources like fuel cells, batteries etc.

## Conclusions

The hands-on experience from these senior design projects provided the students with the opportunity to demonstrate the knowledge that they have gained in previous courses. Students learned about various aspects of Systems Engineering including, but not limited to, problem identification, technical, social and environmental constraints, multidisciplinary team management, communications and documentation skills. These projects also provided the student with an opportunity to view their designs from ethical and sustainability awareness perspective, thus realizing a lifelong learning opportunity. Through practice, the students realized that the key success for a design project is team work and industry interaction and collaborations (RIXAN Inc. and Fred Weber Inc.). This collaborative effort demonstrates that a joint industry academic partnership will enhance engineering education.

## References


1. ABET, “Criteria for Accrediting Engineering Programs”, ABET, Inc., 2010
2. Ford, R., M., and Coulston, C., S., Design for Electrical and Computer Engineers, McGraw Hill, 2008.
3. Ulrich, K. T., & Eppinger, S. D. (2000). Product Design and Development, 2nd Ed. Boston, MA: McGraw-Hill.
4. T. Senjyu, Y. Kikunaga, A. Yona, H. Sekine, A. Y. Saber, T. Funabashi, Coordinate control of wind turbine and battery in wind power generator system, IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, pp. 1 – 7 (2008).
5. Datar, M.T., Rao, M.N., and Reddy, S., “Vermicomposting - A Technological Option for Solid Waste Management”, Journal of Solid Waste Technology and Management, v 24, n2, May, 1997, p 89-93.
6. Davis, Karen C., Perkey, Megan L., Harth, Nicholas B., and Dees, Nathan, “STEPing into the Classroom: An Alternative Capstone Experience”, Proceedings of the 2005 ASEE Annual Conference and Exposition, Portland, June 2005.