RENEWABLE ENERGY SYSTEMS TRAINING PROJECT DEVELOPMENT

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Abstract

Renewable energy resources encompass several technologies, mainly including hydroelectricity, wind farms, solar photovoltaics, biomass, and geothermal power plants. Worldwide, solar- and wind-based energy production has been growing considerably in the past few years, and the trend is increasing over time. Therefore, it is predicted that within a few years there will be a high demand for technicians and engineers with hands-on skills in solar and wind technologies. In this current National Science Foundation-sponsored project, the author focused on solar photovoltaic technology. In this project, a new state-of the-art laboratory and its associated course were developed at the New Jersey Institute of Technology in close collaboration with industry partners. Moreover, K-12, faculty development workshops, and undergraduate research and senior design projects were other significant activities of this project. Finally, a dedicated public website was created to disseminate all the instructional materials.

Introduction

The renewable energy share in the U.S. energy production market is growing rapidly, while the fossil energy share is declining (Mohtasham, 2015; Owusu & Asumadu-Sarkodie, 2016; Department of Energy). According to the Energy Information Administration, the percentage of renewable energy production (out of total energy) has risen from 12.1% in 2012 to 19.7% in 2021. Hydro has constituted a major share of the renewable energy generation, but its trend over the years has been almost constant. The same constant trend was observed for biomass and geothermal. However, the share of solar and wind has been growing considerably in the past few years, and the trend is increasing over time. Due to the advancement of relevant technologies, it is expected that these trends will continue with steeper slopes in the following decades.

In 2018, the state of New Jersey passed two bills that require power companies to generate 35% and 50% of their electricity demand from renewable energy resources by 2025 and 2030, respectively (Corasaniti & Plumer, 2018). These legislative goals would put New Jersey in line with some of the leading states on the issue, such as New York and California. To this end, development of renewable energy skills among STEM students is important in today's economy. Education and training in the realm of renewable energy technologies are central to the growth and wellbeing of America's industries and technological sectors. Electrical engineers and technicians require a wide spectrum of knowledge and skills to effectively contribute to this rapidly growing sector of electricity generation and distribution industries.

According to the Energy Information Administration, the net electrical energy generation by solar sources increased from 24.9 TWh in 2015 to 115.2 TWh in 2021. Based on information from the Bureau of Labor Statistics, employment of solar photovoltaic installers is projected to grow 27% from 2021 to 2031, which is much faster than the average for all occupations. The typical entry-level education requirement is a high school diploma or equivalent. About 2500 openings for solar photovoltaic installers are projected for each year, on average, over the decade. These statistical data indicate the importance of curriculum development for solar energy technology to train hands-on students and technicians to meet the future demand of the solar electricity power generation industries.

Figure 1 depicts this current, multi-objective National Science Foundation-sponsored project. The renewable energy systems training (REST) laboratory and the associated curriculum were developed for engineering technology students and faculty development workshops. Moreover, the REST-portable package was developed for outreach to K-12 students through summer camp programs. In addition, the REST website was created to disseminate all of the developed materials and results. The project was conducted in close collaboration with industry partners.

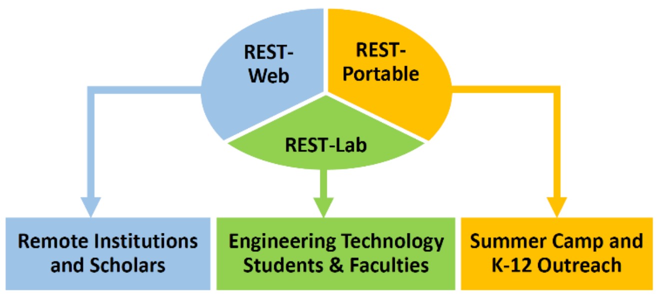


Figure 1. An overview of the Renewable Energy Systems Training (REST) project.

Similar efforts have been undertaken by other institutions to develop NSF-funded renewable energy laboratories and curricula. Santa Monica College launched a solar photovoltaic installation program that included outreach activities to K-12 students. Daytona State College in partnership with the University of Central Florida developed a program on solar photovoltaic installation and service. The University of Arkansas Little Rock established a photovoltaic test station and integrated it into several courses.

CUNY Bronx Community College established a series of continuing education certificate courses with concentrations in energy assessment, operations and maintenance, resource management, and alternative fuel vehicle operations and maintenance. Their program includes a faculty professional development activity. El Paso County Community College developed a program in the field of photovoltaic and solar thermal installation and maintenance. Madison Area Technical College developed a series of online courses and offered face-to-face faculty development workshops in the field of alternative transportation, photovoltaic, solar home design, wind power, and biomass. Cabrillo College started a program to attract and retain students by involving them in a sustainable energy summer internship preparation program, and providing counseling, mentoring, and tutoring support.

As compared to the aforementioned projects, the REST project presented here is unique in that it develops laboratory and curriculum materials, while concurrently targeting several comprehensive activities. These activities include the following: outreach to K-12 students, faculty development workshops, undergraduate research and senior design projects, and online training resources for remote scholars, which all together greatly contribute to STEM education across the U.S. Moreover, this REST project was developed based on a close collaboration between university and industrial partners.

The contribution of this paper is to present all the activities fulfilled and the results obtained in the development process of the NSF-funded REST project. These activities and results are presented in seven sections, as follows: (i) new course and laboratory development; (ii) course evaluation and student feedback results; (iii) external advisory committee feedback results; (iv) faculty development workshop and survey results; (v) outreach to K-12 students; (vi) undergraduate research experiences; and, (vii) online training resource development. This complete project development process is presented for the first time in this paper.

New Course and Laboratory Development

The REST laboratory was developed at the New Jersey Institute of Technology (NJIT) to offer the new solar photovoltaic (PV) planning and installation course for engineering technology students and faculty development workshops. The REST-Lab provides state-of-the-art training equipment to teach site analysis, planning, installation, troubleshooting, protection, startup, and commissioning of solar PV systems. The new hands-on course trains students with skills immediately required by renewable energy power companies. It targets real industrial demands in the field and is being designed, developed, improved, and enhanced continuously in close collaboration with energy and power industry partners.

The REST curriculum plays an educative and informative role, provides operational knowledge, and develops understanding of facts, concepts, principles, and technologies. The desirable educational features and benefits of the curriculum include the following.

- Develop student awareness about energy challenges, renewable energy resources and technologies, and their development and utilization.
- Cover all renewable energy resources in general with a focus on solar PV system topics, including solar radiation, sun path characteristics, site planning, panel orientation, system analysis, wire selection and sizing, troubleshooting, protection, installation, startup, commissioning, and standards.
- Provide a balance between theory (lectures, tutorials, assignments, etc.) and practice (laboratory and demonstration experiments, hands-on skills training, troubleshooting, etc.).

Several vendors were considered and their products were closely tested and examined. The renewable energy products from Amatrol Inc. (n.d.) were found to be the best fit for this project. After consultation with the external advisory committee (EAC), the following products were purchased and utilized to develop the laboratory experiments: the Solar Site Analysis Learning System (see Figure 2), the Solar PV Installation Learning System (see Figure 3), the Solar PV Troubleshooting Learning System (see Figure 4), and the Solar Thermal Troubleshooting Learning System (see Figure 5).

Figure 2. Solar site analysis (Amatrol Inc.). Reprinted with permission.

Figure 3. Solar PV installation. Reprinted with permission.

Figure 4. Solar PV troubleshooting. Reprinted with permission.

Figure 5. Solar thermal troubleshooting. Reprinted with permission.

A textbook by Warmke (2021) was selected for the new course, based on which lectures were designed and developed. Table 1 shows the course schedule and contents, while detailed course objectives and contents, including the lecture notes and laboratory experiments, are presented in articles by Azizi and Fuentes (2022a/b). The assessment method was a combination of knowledge tests, hands-on troubleshooting scenarios of embedded faults, and a final research project.

Table 1. Course schedule.

Lecture (Lec) Topics and Laboratory (Lab) Experiments		**Week**
Lec 1	Introduction to solar PV systems and types	1
Lec 2	Parts of PV system and electrical concepts	2
Lec 3	Site survey and PV system design	3
Lec 4	Electrical system installation and testing	4
Lec 5	Introduction to solar thermal systems	5
Lec 6	Solar radiation fundamentals	6
Lec 7	Sun path characteristics	
Lec 8	Solar panel orientation	
Midterm Exam		7
Lab 1	Solar PV system installation, site planning	8, 9
Lab 2	Solar PV system troubleshooting	10, 11
Lab 3	Solar thermal system troubleshooting	12, 13
Final Project		14

Table 2 provides a sample of the laboratory protocol in which a short experiment with the open-circuit voltage measurement of PV modules.

Table 2. Sample laboratory experiment: Measuring the open-circuit voltage of a PV module.

Step 1	Put on safety glasses.
Step 2	Position the lamp directly above the PV modules and turn the lamp on.
Step 3	Use a multimeter to measure the voltage for PV module 1 between terminals PV MOD 1 (+) and PV MOD 1 (-), and for PV module 2 between terminals PV MOD 2 (+) and PV MOD 2 (-).
Step 2 	**Step 3** 

The instructional materials developed in this project were evaluated in three different ways: a) course evaluation and student feedback; b) external advisory committee including industry representatives from relevant companies; and, c) faculty development workshop survey including faculty members and instructors from other institutions, universities, and community colleges across the U.S.

Course Evaluation and Student Feedback

The new Solar PV Planning and Installation course was offered to engineering technology students at NJIT during the 2021-2022 academic year. In fall 2021 and spring 2022 semesters, the numbers of enrolled students were 13 and 12, respectively. The course was an elective for engineering technology undergraduate students. It was a three-credit-hour course with two hours per week of lecture and two hours per week of laboratory experiments. It was open to sophomore or higher-level students, but mostly junior- and senior-level students took it.

The university's standard end-of-semester questionnaire, which includes three questions about the course and eight questions about the instructor, was provided to the students. Figures 6 and 7 show the aggregated results of the two questions about *course material quality* and *course educational value*, respectively, for both semesters. The course evaluation was completed by 11 of 13 students enrolled in the fall 2021 term (85% response rate) and all 12 students enrolled in spring 2022 term (100% response rate).

Student feedback was obtained using a scale ranging from 4 (excellent) to 0 (poor). The captions of Figures 6 and 7 also show the means and standard deviations for course material quality and course educational value. These figures indicate an increase in student satisfaction level. This was due in part to integrating their suggestions for improvement, which included: i) adding more instructions and explanations on the conduct of the laboratory experiments, and ii) adding a real-life solar PV system design exercise. The increase in student satisfaction level was also due to implementing suggestions from the external advisory committee (EAC).

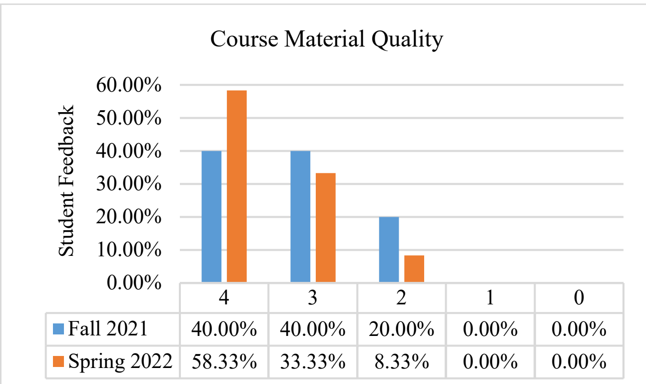


Figure 6. Student feedback for course material quality: fall 2021 (mean 3.20 and standard deviation 0.79) and spring 2022 (mean 3.50 and standard deviation 0.67). Horizontal axis scale: 4 (excellent), 3 (good), 2 (satisfactory), 1 (fair), and 0 (poor).

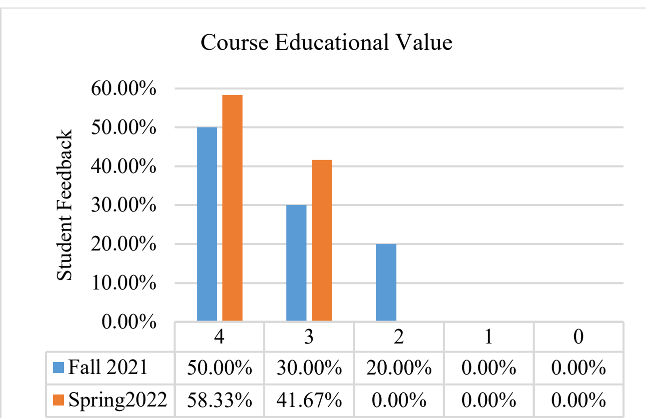


Figure 7. Student feedback for course educational value: fall 2021 (mean 3.30 and standard deviation 0.82) and spring 2022 (mean 3.58 and standard deviation 0.51). Horizontal axis scale: 4 (excellent), 3 (good), 2 (satisfactory), 1 (fair), and 0 (poor).

In the future, the indices of student enthusiasm and deep understanding will be explored in close collaboration with colleagues whose research focuses specifically on engineering education. It is expected that the enrollment number will increase as students get to know more about the course, thereby providing more statistical data for engineering education research.

External Advisory Committee (EAC)

The EAC included industry partners who reviewed, evaluated, and advised the project team. The EAC was comprised of industry representatives from the S&C Electric Company, Energy Vault, GE Power, and SunLight General Capital. The feedback form provided to the EAC requested that they evaluate the course in four main areas, including lecture notes, laboratory experiments, student evaluation methods, and overall course quality. Their feedback included minor technical changes, which were all applied to the lecture notes and laboratory manuals. The major suggestion was to add an exercise on PV sizing and siting using a website or software. This was addressed by adding the three hands-on laboratory experiments listed in Table 3. The details of these experiments are presented in the study by Azizi (2023).

Table 3. Additional labs in response to the EAC's suggestion.

PV Sizing and Siting	
Lab A	Perform load analysis using the Whole House Load Calculation in the following website: gensizer.assurancepower.com
Lab B	Perform PV system design using the following website: pvwatts.nrel.gov
Lab C	Perform PV site survey using the website in Lab B.

Faculty Development Workshop

The REST-Lab was used to develop and offer two, one-day workshops entitled "Solar PV Installation and Troubleshooting" to faculty members and instructors from other institutions, universities, and community colleges across the U.S. Table 4 lists the lecture topics, laboratory experiments, and additional topics presented in the workshop.

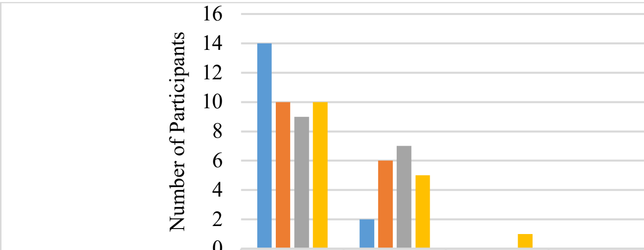
Table 4. Faculty development workshop contents.

Lecture (Lec) Topics, Laboratory (Lab) Experiments, and Additional (Add'l.) Materials	
Lec 1	Certification programs, electrical codes, and standards
Lec 2	Solar panel ratings, and types and parts of PV systems
Lec 3	Load analysis, site survey, and PV array sizing
Lec 4	Financial overview and benefits
Lab 1	Connecting and operating a stand-alone AC PV system
Lab 2	Troubleshooting a stand-alone AC PV system
Lab 3	Designing a residential PV system using online tools
Add'l.	Designing and developing a similar course and laboratory at other institutions, and planning for budget, equipment, and course materials.

A total of 16 participants attended the workshops in person. At the end of the workshops, participants received an evaluation form, which was a self-measure of the following four areas:

- Participation in the workshop
- Interest in the subject
- Learning of materials in lectures
- Learning of concepts in hands-on activities

The workshop evaluation was completed by all 16 participants (100% response rate). Overall, the participants reported that the one-day workshops were very helpful for them to gain exposure to the principles of solar PV systems, specifically in the stand-alone mode of operation. Suggestions included future workshops that are longer in length and cover grid-connected and grid-interactive modes of operation. Figure 8 provides a summary of the participants' feedback.



	Strongly Agree	Agree	Disagree	Strongly Disagree
Enjoyed Workshop	14	2	0	0
Interest Increased	10	6	0	0
Informative Lectures	9	7	0	0
Effective Labs	10	5	1	0

Figure 8. Faculty development workshop evaluation summary (16 total participants).

Outreach to K-12 Students

The REST-Portable package was developed to include small-scale renewable energy training equipment, which was used for demonstration to middle school students through mini-workshops at summer camp programs sponsored by the Center for Pre-College Programs (CPCP) at NJIT. Table 5 summarizes the contents of the workshop, including lectures and laboratory experiments.

Table 5. K-12 workshop contents.

Lecture (Lec) Topics and Laboratory (Lab) Experiments	
Lec 1	Preliminaries: current, voltage, series/parallel
Lec 2	Renewable versus nonrenewable energies
Lec 3	Solar energy and solar PV systems
Lec 4	Hydro and wind energies
Lab 1	Power a motor by a battery and a variable resistor
Lab 2	Use PV panel to power a LED and a motor
Lab 3	Use series PV panels to power a motor
Lab 4	Use a wind turbine to power a motor

Figure 9 shows the Renewable Energy Science Kit from Horizon Educational Inc. that was used. The REST-Portable package included brief and simplified laboratory experiments and step-by-step instructions to guide the middle school students through the experiments. The workshop was offered virtually to 12 students in the summer of 2021, and in person to 20 students in the summer of 2022. The summer camp programs offered by CPCP specifically target first-generation, minority, and other underserved and underrepresented populations. The programs facilitate student exposure to, and interest development in, STEM education in the fields of renewable energies, robotics, environmental science, mechanical engineering, chemistry, computer coding, and general college-prep classes. CPCP annually serves more than 3000 elementary and secondary students and their teachers.

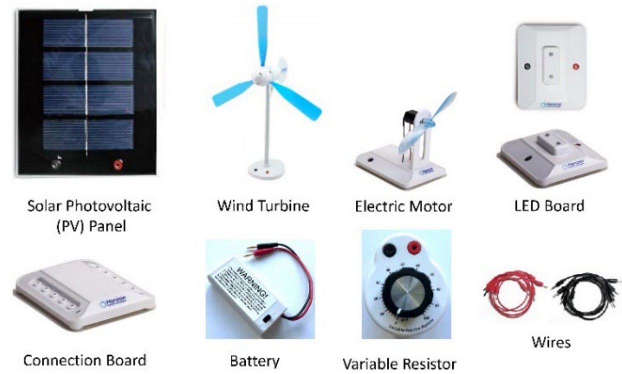


Figure 9. Renewable Energy Science Kit (Horizon Educational Inc.). Reprinted with permission.

Undergraduate Research Experience

Undergraduate research involvement has a positive impact on students' intellectual growth and retention rates (Depaola, Brey, Teymour, Anderson, Cammino, Haferkamp & Mohammadi, 2015; Atkins, Allison & Sandage, 2021). Several studies have supported the hypothesis that undergraduate research helps promote career pathways for members of underrepresented groups by increasing the retention rate of minority undergraduate students (Bickford, Peterson, Jensen & Thomas, 2020). The REST-Lab developed in this current project was used to enhance undergraduate research involvement and senior design projects in the field of renewable energy systems. The following opportunities have been provided to undergraduate students at NJIT:

- Undergraduate Research Project (spring 2022): Laboratory Development for Microcontroller Communication. Multiple microcontrollers were connected to cooperatively simulate a renewable energy system, which is computationally too expensive to be conducted on a single microcontroller.
- Senior Design Project (fall 2022): Solar Powered Speed Radar Measurement, Display, and Logging. A solar PV system was designed and implemented to power a speed control system including a radar sensor, camera, microprocessor, and data logging system.

Online Training Resource Development

A new website (http://research.njit.edu/rest) was created and publicized for use by all universities and colleges, and is being continuously updated. The website includes all lecture notes, course materials, and laboratory and classroom videos that were developed for REST-Lab and the associated new course, as well as all relevant publications. It also includes information about the K-12 and faculty development workshops. Moreover, there is a section on undergraduate research and senior design projects. An online feedback form is provided for users to provide suggestions for improvement.

Conclusions

The objective of this NSF-sponsored Renewable Energy Systems Training project was to develop a new state-of-the-art laboratory and curriculum at NJIT to train engineering technology students with hands-on skills required to fill the gap between market demand and workforce. Based on the new laboratory, the new Solar PV Planning and Installation course was developed and offered. The new laboratory was also used for undergraduate research and capstone senior design projects to improve student retention rates and academic progress. Moreover, one-day faculty development workshops were developed and offered for faculty members and instructors at 2- and 4-year institutions across the U.S. In addition, a portable instructional package was developed and served as the basis for K-12 workshops that were offered through summer camp programs. All instructional materials in this project were developed and enhanced in close collaboration with industry partners. A dedicated website was created to disseminate the materials resulting from the project. This project's long-term vision is to train and prepare a new class of engineers and technicians who can quickly integrate into and thrive in the renewable energy industry sector.

Acknowledgements

This material was based on work supported by the National Science Foundation (Advanced Technological Education program) under Grant No. 1902442. The author (PI of the project) would like to thank the external evaluator, Dr. Barbara Moskal, for her valuable comments and continuous support; the external advisory committee, Dr. Saeed Kamalinia (S&C Electric Company), Dr. Iman Naziri (Energy Vault), and Dr. Amir Kazemi (GE Power), for their valuable feedback; and the Center for Pre-College Programs (CPCP) at NJIT for collaboration in the K-12 workshops.

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Biographies

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