Robert Fletcher, Lawrence Technological University

Robert W. Fletcher joined the faculty of the Mechanical Engineering Department at Lawrence Technological University in the summer of 2003, after twenty-four years of continuous industrial research, product development and manufacturing experience. He teaches a number of alternative energy courses and is leading LTU’s efforts to establish a full energy engineering program that addresses both alternative and renewable energy systems, as well as energy conservation and optimization of traditional energy systems. He also is the Director of the Alternative Energy program at Lawrence Tech.

Dr. Fletcher earned his Bachelor of Science Degree in Chemical Engineering from the University of Washington, in Seattle, Washington, a Master of Engineering in Manufacturing Systems from Lawrence Technological University, in Southfield, Michigan, and the Master of Science and Ph.D. degrees in Chemical Engineering, both from the University of Michigan, in Ann Arbor.

Dr. Fletcher is also working with DTE Energy in operation and optimization of their Hydrogen Power Park in Southfield, Michigan, a photovoltaic, biomass, water electrolysis, hydrogen storage, hydrogen vehicle fueling station and fuel cell power demonstration project, funded by the Department of Energy. He and his student research team have a research contract with the Army to study the long-term durability of multiple PEM fuel cells used under a wide range of operational conditions. He is also establishing an alternative energy laboratory at LTU that will contain integrated fuel cell and hydrogen generation systems, as well as equipment for solar (thermal and photovoltaic), biomass, wind and other alternative and renewable energy generation equipment.
Using State or Federal Department of Energy Demonstration Grant Funds as Hands-on Educational Opportunities for Engineering Students

Abstract

All motivated engineering faculty regularly look for new and innovative opportunities to provide unique and meaningful learning experiences for their students. State and Federal demonstration grants to non-profit organizations provide such learning experiences. For example, our school, Lawrence Technological University, received a $60,000 grant from the State of Michigan in the summer of 2004 for an on-campus installation of a 10-kW photovoltaic demonstration project. We pursued this grant with the intent that the project be used to supplement Lawrence Technological University’s growing academic engineering curriculum in the field of Alternative Energy. We have found that such demonstration grants provide invaluable real-world educational enrichment opportunities for engineering students if the projects are managed appropriately, implemented within the skill sets of the students involved, and address the time constraints of the academic calendar year. The obvious benefits to students include key engineering activities such as the proper definition of a project and its scope, systems design, hardware and equipment procurement, installation, safety checks and trouble shooting, system validation and commissioning. Several other broader educational benefits to students include cross-departmental collaboration, teamwork, resources planning and scheduling, budget management and vendor relations from such projects. We installed our 10-kW PV project using volunteer student help outside the bounds of classroom activities. Here we present a summary of the project itself, along with a one-year post-installation assessment of the Lawrence Technological University’s project. Also reviewed are its benefits to Lawrence Technological University’s students and our Alternative Energy program, along with several recommendations for how other educators might also successfully proceed with similar efforts.

Introduction and Background

For the past several years Lawrence Technological University (also known as LTU) has been actively involved in the field of alternative energy in both design competitions and in the formal education of its students through its curricula and student projects in both the College of Engineering and well as the College of Architecture. In 2003 LTU received a significant grant from NextEnergy, a nonprofit organization in the State of Michigan, to augment its Alternative Energy curriculum. The NextEnergy grant helped LTU develop additional courses, but funds from the grant could not be used to purchase laboratory equipment or experimental hardware. This was an unfortunate limitation, so the faculty involved in our Alternative Energy program felt it was critical to secure additional funding specifically for procuring laboratory equipment and related hardware to augment and complement the education of or students in this important area.

During this time the Energy Office of Michigan’s Department of Labor & Economic Growth initiated a Request for Proposals at the start of 2004 from public and non-profit organizations to install and demonstrate a new 10 kW or larger solar photovoltaic (PV) system. The grant
incentive was for $60,000, but was not to exceed 90% of the PV system equipment, supplies and material costs, which ever was less. The grant funds were to be expended and the project was to be completed within 12 months of grant award. Proposals were due April 15, 2004. We felt this was a good opportunity to not only secure some of the needed equipment for our Alternative Energy program, in this case a complete photovoltaic system, but could also be used as an excellent student training opportunity in engineering project management.

Prior to proposal submission LTU, under the direction of the author, organized a preliminary planning group to help develop our grant proposal. The planning team was composed of the author; the Director of LTU’s Campus Facilities; Mr. Robert Pratt, PE and founder and President of RGP Pro, Inc, a technical and engineering consulting firm located in Farmington Hills, Michigan; the Managing Editor of the LTU’s News Bureau, Karen Sanborn; a Professor of Architecture at our school; and a representative from LTU’s Advancement Office. The planning group reviewed the RFP and provided guidance regarding content and approach for the LTU proposal. From the first meeting we focused on two areas, writing a winning proposal and how we could involve students at every level of the project. Mr. Pratt provided initial input as to the best on-campus location site for the project, and how best to design the system to comply with the grant requirements. Because the grant was for a maxim of $60,000, we knew additional funding was going to be required. Our Dean of Engineering has been very supportive of our Alternative Energy program and assured us that if we got the grant that he would help us secure the additional funds to complete the project. This was vital, as the proposal required us to document that matching funds would be available to complete the project.

After detailed review we proposed placing the system on top of the high-bay of the engineering building, as this location provided adequate solar exposure throughout the day, and possessed a roof that could withstand the structural loading of the system. A mono-crystalline or polycrystalline silicon PV system was also proposed for several reasons, 1) mono-crystalline or polycrystalline silicon PV systems have the highest efficiencies of commercially available technologies and, therefore, deliver a smaller system array footprint; 2) the higher efficiencies result in a smaller required mounting system size and, thus, a lower mass loading on the roof; 3) several amorphous silicon PV demonstration systems have already been installed in the Sate of Michigan, and it seemed that a state-of-the-art mono-crystalline or polycrystalline silicon PV system would provide worthy technical comparison to the amorphous silicon PV demonstration systems already in the region. The LTU proposal also suggested that in the future some of the power from the PV system would be routed to the new (but at that time not yet started) Student Services Center to power some type of alternative energy demonstration.

LTU received notice in the late spring of 2004 that we had submitted a successful proposal and had received the grant for funding to design and install the 10 kW solar photovoltaic (PV) system on our campus.

Getting Started

Upon notice of the grant award to LTU, the same planning team was reassembled to begin the detailed development of the project. When the fall 2004 academic semester began a core group of faculty from the college of Engineering, and College of Architecture & Design, and recruited
volunteer students from all four colleges of the University (Engineering, Arts and Sciences, Architecture, and Management) began to plan, design, and procure all items needed for the installation. A total of forty-three LTU students participated at various times over the project. Twenty-two were from the College of Engineering (fifteen from Mechanical Engineering, six from Electrical Engineering, and one from Civil Engineering), sixteen were from the College of Architecture and Design, and five were from the College of Arts and Sciences. All students were undergraduates. The students were organized into four major project teams relating to the needs of the project. We felt it was imperative to have the project lead by a student, so after discussions within our planning team a student project leader, who was majoring in Mechanical Engineering and Physics, was recruited to lead the student groups. The student teams were 1) Mechanical Systems; 2) Electrical Systems; 3) Data Acquisition and Management Systems; and 4) Program Demonstration and Publicity. Each team was required to develop a list of objectives, tasks and their own individual timeline that complied with the overall objectives of the project.

A formal project timeline was established after consulting with all the contributing parties associated with the project. The project was organized to span across the two semesters (fall and spring) for the 2004-2005 academic year. Each student group on the project was also headed by its own separate student group leader with technical expertise in their given team’s focus and typically was comprised of about ten to twelve students. The teams met once per week to plan, organize and to complete their tasks throughout the project. An overall team meeting open to all participants was also held once a week. Meetings were initiated in October of 2004 and continued until the project installation which took place in of March 2005. An organizational chart of the overall project team is given in Figure 1 below. All members in the project reported to someone on the organizational chart.

**10 kW Photovoltaic Project Organizational Chart**

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Prof. Janice Means
Prof. Dan Faoro
College of Architecture

Robert W. Fletcher, Ph.D.
Project Principal Investigator
Mechanical Engineering

Carey Valentine
Campus Facilities

Electrician - Jim Bates
PV Installer - Advanced
Distributed Generation

Robert G. Pratt, P.E.
Consulting Engineer
RGP Pro, Inc.

Elliott Schmitt
Student Project Leader
ME/PHY

Keith Abrahamson
Task Leader
Mechanical Group
ME

Alex Bienkowski
Task Leader
Electrical
EE

Laura Long
Task Leader
Arch/Publicity Group
Arch

Brad Dillon
DAQ Group
Comp Engineering

Student Members

Student Members

Student Members
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Figure 1: LTU’s 10 kW PV project organizational chart.
Four outside professionals were brought in to assist on the project and to work with the LTU faculty and students during different phases of the project to assure that no critical elements were overlooked, that the system was designed correctly, that it would operate safely, and would meet all the required specifications of the grant award. These professionals included two local consultants, one with extensive expertise in the area of photovoltaic system design to assure that the final system design met all specifications required by the grant, and the other with a Professional License in building structural loading to assess that the roof of the building chosen for the PV installation site could support the added load of the PV panels, mounting and required electrical systems needed for the project. A journeyman electrician, plus as a professional PV installer were both hired as consultants to assure that all electrical codes, wire hookup and final power-up of the system completed in accordance with NEC standards and accepted practices for electrical systems.

System Design

Students designed the panel mounting system under the guidance of the professional PV installer. An “A-frame” adjustable-angle module mounting frame system was chosen to allow seasonal adjustment for the sun’s high-angle position in summer, and low-angle position in winter. The frame has telescoping square aluminum tubing struts that can be adjusted to 15°, 30°, and 45° angles that correspond to summer, fall/spring and winter peak solar positions, respectively. To prevent invalidating the warranty of the roof membrane no mounting system could penetrate the roof, so the mounting system was anchored to the roof via cinderblock ballast weights resting on the module mounting frame. A ballasted mounting system also provides opportunity to repair or service the roof in the future with relatively easy repositioning of the mount and panels. With the ability to adjust the seasonal angle of the modules we also had to consider the shadow cast by each string of modules to prevent shadows on adjacent modules, or modules behind their neighbors. Students conducted a shadow study using appropriate CAD software available at LTU per various module layouts on the roof to determine required spacing between strings to assure no shadows interrupted solar exposure of any modules.

Once the system design was finalized, and before system installation, a detailed engineering analysis of the high-bay building was required to assure that its roof could support the static load of the system, and any additional seasonal snow or water loading. A preliminary analysis of the building roof was done by Prof. Dan Faoro, LTU College of Architecture, and students, which provided indicators of how to possibly configure the overall system on the roof. A structural engineer and P.E was hired, for insurance purposes, to undertake the detailed structural analysis of the engineering high-bay facilities and to formally approve roof loading. He also evaluated the wind blow-over and blow-off possibilities of the ballasted PV panel system. He found that the roof could support the load and also recommended that we use 8x8x16 heavy aggregate hollow core concrete masonry units (cinder blocks) for ballast and to provide more resistance to wind uplift. Students had a chance to review this analysis and to understand it value.

The installation of the PV system was done by students on the flat roof of the “high-bay” of the Engineering building. The “high-bay” is a large one-room engineering test lab with an interior steel open-lattice reinforced flat roof. This location was ideal because the Engineering building
is situated in a high traffic zone of the university. The PV system is visible to all entering the campus when oriented for winter sun (highest angle).

The PV system consisted of six module strings of crystalline silicon PV modules. Three strings consisted of ten PV modules, and three strings consisted of eleven modules. We used Shell Power Ultra Max 165PC mono-crystalline silicon modules, and are rated at 165 Watts each, with a module efficiency of 12.5%, peak power voltage of 35V, and a peak power current of 4.72 amperes. A total system rated maximum peak power of 10.1 kW to 10.8 kW was projected. It must be noted that LTU contacted several PV module manufacturers, but encountered significantly long lead-times for delivery of product. Some of the lead-times quoted were up to six months! This was because parts of Europe are buying the entire world’s supply of PV modules to comply with their signatory role on the Kyoto Protocol. LTU’s module order was, fortunately, large enough to take a priority in delivery and our lead-time was only twelve weeks! We intentionally ordered two spare modules in case of potential damage to any required units during installation.

Each panel was visually inspected by LTU students for defects after they were received from the vendor, and then tested in full sun to measure its open circuit voltage and short circuited current. All modules were found to be functionally within specification, but two modules were found to have manufacturing induced defects including missing mounting holes on the aluminum frame, or misaligned individual cells within the module. Shell replaced these modules free of charge.

A detailed electrical schematic of the system is illustrated in Figure 2 below. The grid-tied system taps into the existing three-phase 208V main building electrical panel as illustrated. Individual 208-volt breakers connected each inverter to the sub-panel. Grid synchronization and control are accomplished within the inverter. The series connected PV strings were wired to a combiner-fuse box, and appropriately fused. Local DC disconnects on the roof and also at each inverter allow for service and maintenance. Six Sunny Boy (SMA America Inc.) inverters were used in this system to convert the DC output of the PV strings to synchronized AC power going into the building. A data acquisition system was also incorporated with the inverters using the Sunny Boy Control Plus which also provides extra analog and digital channels for increased data monitoring. The Sunny Boy Control Plus provides communication between the Sunny Boy inverters and the Sunny Boy Control through a RS485 cable we installed and routed to a PC data storage system.

**System Installation and Start-up**

Faculty encouraged a practice trial-assembly of some PV modules to the mounting framing. This was done in the Alternative Energy Laboratory prior to system installation on the roof to assure the function and assembly of the mounting system. This also helped students working on the installation understand the system set-up and how it was to be erected on the roof. Several safety training sessions were also undertaken to assure that everyone understood the safe access and egress from the roof of the building, to assure that everyone followed campus safety rules, and how to move and work on the roof. Only students who had been through the safety training were permitted access to the roof and participate in the installation.
The system was installed on March 28th, 29th, and 30th of 2005. See Figure 3 below showing a photo of the installed PV system. Three faculty and twenty-six LTU students were involved in the installation. Some were able to participate for only an hour, and some much more time over all of the days of the installation. Materials were relocated onto the roof from ground level using a scissor lift. The installation went smoothly and, fortunately, we had some of the warmest and sunniest weather on record for the month of March. Mr. Pratt used a portable PV system i-V tester to assess the operation of the installed panels on March 31st and April 1st. All panels were found to be working well, with the exception of one string which had been reversed wired. This was corrected quickly, rechecked and found to be properly operational.
Forty-three LTU students, four LTU faculty members, and five LTU staff members directly supported the project at various times throughout its design, procurement and installation. No major mishaps, injuries, nor critical installation or operational problems were encountered. The system has run uninterrupted since start-up in early April of 2005 and to-date (of writing this paper) has delivered over 21.8 megawatt-hours of energy to the engineering building. See Figure 4 below for an example of performance for one string of the six string system.

Results of the Project and Lessons Learned

The installation of the LTU demonstration 10 kW solar photovoltaic (PV) system, as funded by the Energy Office of Michigan’s Department of Labor & Economic Growth, has been an unquestioned success. Without the funding this project could not have been undertaken. Such demonstration projects provide students a tremendous educational enrichment opportunity that cannot be delivered in the classroom. We conservatively estimate that at least ten thousand people have seen the system since its installation. Students who worked on this project still speak with great pride about their efforts and often bring family members to campus to show them the system and the results of their work. The system has worked flawlessly since its installation. A sample of student feedback regarding the project are listed in the Appendix of this paper.
Some of the observed benefits of the project include the following:

- The effort provided students a project with clear starting point, development, design, installation, and conclusion. The complete project cycle was evident to all participants, and was a great educational experience for students.

- Several opportunities for cross-college collaboration as well as collaboration within the various departments of the College of Engineering where gained in this project. Our industrial supporters often encourage our College of Engineering to enhance learning opportunities for our students to work in multi-discipline teams. This project delivered many opportunities for such interactions.

- We observed good technical skills development for students as this project gave them a chance to see the finished results of a major project within their academic year.

- A major benefit to students was the development of project management skills, and gave them an opportunity to see how all the pieces of a project fit together such as the procurement of equipment, the scheduling of activities, dealing with outside vendors, and how to manage the coordination of multiple project teams. Students especially learned about contingency plans and what to do when something did not work as intended.
“Soft skills” development for students was a major byproduct from this project. These included such things as true collaborative team work, and interpersonal skills with non-engineering students, particularly from our College of Architecture.

Students also learned about the benefits and processes used for publicity and public relations. Since its installation the project has become an excellent publicity tool for LTU and has provided many informative stories in the local press. The University’s public relations staff has since featured the installation on brochures, the University’s website and other important University publications.

The Alternative Energy curriculum at the University has gained the most benefit from the installation. It gives classroom students an opportunity to comprehensively review the design and composition of a complete PV system, provides students real system data for analysis. It is used as a one of the major cornerstones for our growing Alternative Energy program and our new Energy Engineering minor.

The project is now a showcase and recruitment tool for the University and has helped to demonstrate LTU’s commitment to the Alternative Energy curriculum and green energy technologies. We have new students who enrolled in the College of Engineering due, in part, to their seeing the 10 kW PV system during their campus visits.

Approximately 21.8 megawatt-hours of energy have been produced since the installation, all trouble-free.

Several lessons were learned from this project and serve as recommendations to other schools considering undertaking such a project. These include:

Initial recruitment of students to join the project was easy, but keeping students on board to sustain the project over the two semesters was challenging. We had approximately sixty-five students who wanted to participate in the project, but eventually a core group of about twenty students emerged who were dedicated to seeing the project through to completion. The challenge was to assure this core group of students could support the four student teams without over-committing their time to the project and experiencing mental “burn-out”. Faculty paid close attention to this and encouraged students to take time off if they seemed to be overloaded. When possible, we did recruitment for additional student participation over the two academic semesters.

For all their talents, engineering students still need guidance. Fortunately some students involved in the project had familiarity with NEC and design standards, but most did not. This is where the assistance from our outside professionals was invaluable. The professionals provided the needed guiding hand for the students to assure all codes and standards were met, and to point-out and correct shortcomings of their designs.

Academic periods around midterm examinations and final examinations took their toll on student participation. This was well-learned in the fall semester, and as a result, a significant push was made to complete the project one full month before the spring semester finals. This
helped assure students were available and not pressed for time demands on the project and for their studies.

- Due to the installation taking place on one of the highest roofs on campus, special precautions for student safety training were taken. The basic “buddy-system” was used (no one on the roof without a partner) and no students were permitted on the roof without faculty or professional support staff present. A roof access signup list was used to document who was on the roof at all times, and no more than eight students were permitted on the roof at a time. No students without documented health insurance coverage were permitted on the roof. But those without health coverage were still permitted to participate in the project as ground support personnel. No injuries to students or supporting staff occurred during any portion of this project.

- Faculty learned from this project as much, if not more, than the students. We gained insights on how to work collaboratively with students, and what they can realistically take on as work during an academic semester. We also gained valuable new insights into PV technologies and what they are capable of, and not capable of doing and delivering.

**Conclusions**

LTU faculty have shown that State or Federal Department of Energy Demonstration Grants can go beyond their intended technology “demonstration” role, and should also be considered and used as valuable hands-on educational opportunities for engineering students.

We have found that such demonstration grants provide invaluable real-world educational enrichment opportunities for engineering students if the projects are managed appropriately, implemented within the skill sets of the students involved, and address the time constraints of the academic calendar year. The obvious benefits to students include key engineering activities such as the proper definition of a project and its scope, systems design, hardware and equipment procurement, installation, safety checks and trouble shooting, system validation and commissioning. Several other broader educational benefits to students include cross-departmental collaboration, team work, resources planning and scheduling, budget management and vendor relations from such projects.

Lastly, the administration, faculty, staff and students of Lawrence Technological University want to thank the State of Michigan Energy Office for providing the funds, and the trust in our abilities to successfully undertake and to complete this project. It is these kinds of projects and this level of funding that give our students the real-life experiences needed to understand the technology and apply the technical knowledge learned in classes to become competent professionals in the future.
Appendix – Student comments and feedback about the LTU 10 kW project

1) Overall, was your involvement in the project a satisfying experience?

“Yes, the project was a wonderful experience, that it allowed students to experience the industrial environment. The opportunity allows students to interact with Professional Engineers from the industry, thus incorporating precedence to a students' work habit. The project incorporated a leadership opportunity that allowed critical management skills to be developed and honed.”

“Yes, the project was extremely satisfying for both my professional and educational goals.”

“Yes, it was a very satisfying experience.”

2) How was the project a worthy learning experience, and how did it help in your understanding of the technology?

“The project brought a perspective of required communication, management, and technical skills to achieve team synergy. The project brought an appreciation of the principles and a better understanding of applicable us.”

“Prior to working on this project I had a very small understanding of alternative energy technology in general. Working on the project gave me a much better understanding of the capabilities of this technology and the practicality of the some of the technology that was already commercially available, i.e. solar technology. This project gave me the opportunity to be part of the design and installation of a PV system, which allowed me to learn more about the technology that could not be learned inside of a classroom. Furthermore, it personally had a major impact on my future educational and career choices. I am now extremely interested in the alternative energy technology and its impacts on society.”

“I really appreciated having the opportunity to work on the 10kW PV project. I have carried the knowledge gained from that experience through the remainder of my studio classes at LTU. In every studio since then, I either used the technology in building design myself, or I helped another student understand the technology for their project…”

“As an architecture student, I appreciated having the ability to work with engineering students. The interdepartmental experience is good for all students. It gives them the ability to engage with students in other disciplines and it gives students insights into other curriculums. There are not many opportunities for architecture and engineering students to work together. By making available these opportunities now, perhaps it can encourage collaboration later in our careers.”
The project introduced me to photovoltaic technology and how it works. By being involved in this project, it helped me to understand how to harness the sun's energy and use that power, which in turn can save you money on electricity.

3) Would you recommend that LTU students participate in other similar types of projects? Why?

“I would recommend any student at LTU to participate in any Alternate Energy project. The program provides students with an opportunity to participate in a stimulating peer brainstorming instead of the osmosis approach of a typical classroom. The projects provide an ideal environment to execute theoretical ideas into a tangible, measurable, and engineered solution.”

“Absolutely. The project had a major impact on my future choices and gave me exposure to an area of research and employment where I had previously little understanding. I was also able to make some extremely valuable connections through the people that I had an opportunity to work with including both students and professionals. Overall the experience was very rewarding.”

“Yes, I would recommend that other students get involved in similar projects because it is a great learning experience. It takes what you learned in your classes and text books and shows you how to apply it to “real world” applications.”

“Offering more projects like this to students would be a great thing. Students need to learn how to apply what they've learned before entering the workforce, it will make the school-to-career transition that much easier. This project was very enlightening and a great learning experience. It also helped in building teamwork skills and building leadership skills as well.”