Center for Sustainable Energy
University of Massachusetts Lowell
Annual Report
August 12, 2005

1. Brief Overview of Center

In the abstract, the Center for Sustainable Energy exists to develop systems to provide energy for various end uses in an environmentally and economically sustainable manner. In the concrete, past and present projects in the center have focused on rural renewable energy systems for medical, educational, town, and agricultural use, solar/electric/fuel-cell systems, photovoltaic-assisted lighting, green building thermal efficiency test methods and case studies, solar crop drying, solar design tools, solar resource databases, and PV battery testing. The center is unique in the degree to which it combines undergraduate and graduate education, research, public service, service-learning, and public education into its projects.

Mission Statement

The Center for Sustainable Energy seeks to improve energy efficiency in end-use sectors and to increase the diversity of energy resources consistent with an economically and environmentally sustainable future. The center strives to combine undergraduate and graduate education, research, public service, service-learning, and public education into its projects.

2. Objectives

More specific objectives within this broad mission include:

- Be a leader in village renewable energy systems through research and education.
- Incorporate service-learning with sustainable energy projects into engineering courses at U Mass Lowell.
- Design and install solar/hydro systems for vaccine refrigeration, transceiver radio communication, lighting, laptop PCs, water purification, and agriculture for remote medical clinics, schools, and towns in Peru and develop infrastructures for local people to take over development and maintenance of such systems.

- Develop solar electrolyzer-fuel cell systems for remote areas.
- Provide access over the web to our database of solar resource measurements for developing countries.

3. Focus Areas: Discovery/Learning/Engagement (Research/Teaching/Service)

Some of our joint accomplishments in the last year include:

- ♦ Initial development work on the portable solar vaccine refrigerator with water energy storage and heat pipes, as discussed above.
- ♦ A study was completed on different solar–hydrogen energy systems: photochemical, photoelectrochemical, photobiological, electrolysis (photovoltaic and electrolyser) thermolysis and thermochemical methods. An integrated photovoltaic/electrolysis system and a photoelectrochemical (PEC) system were selected as showing more potential and promise for further study. On the basis of literature studies and assumptions a mathematical model was developed for an integrated photovoltaic /electrolysis system. The model was analysed and simulated for a silicon solar cell integrated with a hypothetical electrolytic cell and shows efficiency results slightly higher compared with that of water electrolysis in a photovoltaic-driven electrolyser. But it appears that costs would be lower than existing approaches. Samuel Geto, a graduate student, has written his MS thesis on this work while working at the Center this spring semester.

- ♦ Trips to Peru (January 2005, June 2005) with several graduate and undergraduate students to install systems, most of which harvest energy with photovoltaic modules, solar thermal collectors, and microhydro turbines and which provide radio transceiver communication, lights, vaccine refrigerators and other medical devices, water supply and water purification, roads, aquaculture fish, laptop computers, and science experiments in schools, medical clinics, and municipalities. The villages in general have no electricity, no telephone service, no space heating, biweekly bus transportation, and untreated drinking water, in several cases only from open streams. What makes this rural development program unique is that most of the work has been done by students in credit-bearing courses with service-learning.

- January 2005 trip highlights include:
  - We installed radios in two medical clinics: Victoria, near Huarmey, that serves 3500 people, and Huanchay-Huaraz, at about 2600 m in altitude (8400 ft), above Raypa.
  - We reinstalled our solar sterilizer in Huamba, an adapted pressure cooker to be used with the existing parabolic concentrator there. Marc Evans had made some improvements since last summer in the anodized coating and several other features.
  - We distributed more efficient pediatric oxygen masks to several clinics, which had oxygen tanks, along with directions on how to adapt the masks to include the soda bottle-plastic bag system which Linda and Jen developed.
  - We did a fair bit of preventive maintenance work on the microhydro system in San Miguel: a new battery and new brushes for the generator.
  - We tested the "agua potable" in a number of villages. Fortunately, our UV water purification system in Quian seemed to be working quite well since the water showed a complete absence of bacteria. Unfortunately, in the other villages, the "potable" water had high levels of bacteria. We transfer the information to the hospitals so they can pass on the word to purify the water before ingestion.
  - The aquaculture systems in San Miguel (crayfish) in cooperation with local farmers have made great progress. One of them produces about 3 to 4 kg per month and gets about S/20 ($6) per kg.

- June 2005 trip highlights include:
  - We installed radio systems in the clinics at Quillo and Pampachanca in the Casma network. We found out subsequently that these two towns are in the poorest district of Peru. In many of the 27 towns that we have radios in, our radios are the only means of communication. The hospital directors in Huarmey and Casma told us that the radios save many lives.
  - Started a microenterprise SolarTec based on a cost-effective solar lantern and a LED reading light, both designed by students. Helped start solar lantern ventures in Fortaleza and Quian (with the assistance of a New England Biolabs Foundation grant). We installed solar charging stations in both towns and signed agreements with entrepreneurs. A student in Lima, Tomas Riojas, built twenty lanterns with parts mainly from Peru, with help from Jesús Solis and Manuel

Heredia, originally from Lima but now graduate students in the solar engineering program.

- Two undergraduate mechanical engineering students designed and manufactured a leg prosthesis for Bruno, a young man, in Huarmey as well as a generic low-cost leg prosthesis made of wood and scrap metal. We delivered and fit the leg on this trip.
- Crystal Hopkin and Sarah Wright, graduate students in the Physical Therapy doctoral program, as part of a service-learning course taught by Deirdra Murphy, worked with the Center to:
    - Provide educational material in Spanish related to different diagnoses to a volunteer clinic in the town of Huarmey, in order for her to more appropriately manage her clients.
    - Acquire donations for physical therapy equipment and supplies from local physical therapy clinics. Sarah actually traveled with us to deliver the instructions and equipment to the clinic in Peru in June 2005 and worked with the local volunteers. The equipment is enabling the volunteers to provide more adequate care to clients.
- We installed a solar water pumping and storage system for the town of Utcu. As always we worked with the local people in installing such systems.

♦ Service-learning has been incorporated into a total of nine engineering courses by John Duffy (reportedly more than any other engineering professor in the country)

♦ Six students completed master's degrees in solar engineering with their theses or projects based on work done at the Center.

♦ Two doctoral students are expected to finish their theses in September, based on work done in the Center.

♦ Two graduate courses were taught entirely over the web (22.521 Solar Engineering Fundamentals and 22.527 Solar Systems Engineering)

♦ We submitted proposals or preproposals to: NSF, World Bank, Massachusetts Technology Collaborative Renewable Energy Trust, NIH, The Energy Foundation, and various UML Councils: Diversity Council and the Healy Service Endowment.

♦ We worked under six grants this past year:

- Assessment of MTC Green Buildings; sponsor: Massachusetts Technology Collaborative Renewable Energy Trust ($59,000; 2004-05)

- SLICE: Service-Learning Integrated throughout Courses in Engineering; sponsor: NSF planning grant ($100,000; 2004-05)
- Solar Lantern Micro-Enterprise for Peruvian Villages; sponsor: New England Biolabs Foundation ($8250; 2004-05)
- Diversity in Engineering through the Village Empowerment Project; sponsor: UML Council on Diversity and Pluralism ($2000; 2004-05)
- Multi-Disciplinary Service-Learning Capstone Design Course, Teaching and Learning Seed Grant, UML ($2000; 2004-2005).
- Interdisciplinary Service-Learning Projects, Healy service grant, UML ($8000, 2004-2006)

♦ We received word that we have been recommended for funding for the implementation phase of SLICE: Service-Learning Integrated throughout Courses in Engineering, at $1,000,000 over three years.

♦ In the Village Empowerment project we have emphasized sustainability by continuing to go back to the same network of villages, and we have continuously monitored the performance of systems with data loggers in three locations for several years.

♦ Innovative student design/research projects were completed at the center:

- Complete water supply system with solar pump for the town of Utcu.
- Generic low-cost prosthetic leg of wood and scrap metal for developing countries.
- Instructions and devices for patients with physical disabilities by a team from the Physical Therapy graduate program and designs for playground rides for children with disabilities in developing countries in cooperation with sophomore mechanical engineering students.
- Design and construction of an educational device for middle school students on different types of water wheels for the Tsongas Industrial History Center.
- A motorized tricycle for a client with disabilities by a senior in mechanical engineering and a senior in electrical engineering.

Facilities and Equipment

The center moved into a new lab E405 in the fall of 2004, courtesy of the dean of engineering. It has 10% more space than the previous lab in E407. The center has the following available for research, teaching, and public service: photovoltaic modules, pyranometers, electrical test equipment, inverters, charge controllers, an X-Y scanner for spatial response of PV cells and a variable spectrum cell tester, a

considerable library on photovoltaic systems, several displays on PV systems for the general public, the 1993 Sunrayce race car and trailer, a phase change heating system for electric vehicles, heat recovery ventilators, a lab-scale fuel cell, a lab-scale electrolyzer, a solar resource database for developing countries, rural electrification systems, microhydro systems, and water pasteurization solar collectors as well as four Campbell Scientific data loggers (three in Peru and one in the lab).

The center has historically concentrated on development, installation, testing, and/or monitoring of solar systems in the field. Most experimental work is done off campus, at sites ranging from Lowell to Latin America, Somerville to Sri Lanka, and Braintree to Bangalore. We have approximately 65 systems in remote locations presently that we continue to monitor and study, mostly in Peru.

4. Faculty/Staff/Student Members

The following faculty/staff are members of the center:

John Duffy, Director (as of May 1996), Mechanical Engineering Department (solar electrolyzer/fuel cell systems, electric vehicles, thermal testing of buildings, passive solar systems, PV systems, solar rural systems)
Raul Raudales, Principal of Mesoamerican Development Institute (solar crop drying, solar water purification)
Paul Soper, former University Chaplain, Catholic Center (developing countries)
Cheryl West, research associate, formerly with the Center for Work, Family, and Community, presently doctoral candidate Work Environment program (aquaculture and service-learning)
Juan Rodriguez, Professor Emeritus, Graduate School of Education (bilingual education, distance learning, sociology of Quechua people)
Alan Rux, Electrical Engineering Department (solar radios, assistive technology)
Bill Moeller, Professor Emeritus, Civil Engineering (sustainable development)

There are about 25 faculty members that are engaged in the service-learning initiative in the college of engineering. The initiative is led by John Duffy of the Center.

The following graduate students have worked in the center since June of 2004:

Salinee Tavaranan, solar rural development in Thailand (D.Eng. in process)

George Nitschke, solar ponds for hydrocarbon and water production (D.Eng. in process).

Steve DaSilva, energy efficient vaccine refrigerator (MS thesis in process).

Nelly Vladmirsky, CPC photovoltaic roof shingles (MS thesis in process)

Peter Dubro, solar water purification with TiO_2 catalyst (MS thesis in process)

Ujjwal Bhattacharjee, financial incentives for renewable energy (D. Eng. in process)

Christopher Lin, engineering service-learning modules for high school students (MS thesis in process)

Kushagra Nandan, performance of ventilated photovoltaic modules (MS thesis completed)

Somchai Jiajitsawat, solar vaccine refrigerator experimental development (D. Eng. in process)

Nuchida Suwapeat, optimal design algorithm for reliability of solar remote communication systems (D.Eng. thesis in process)

Ittipon Tungarayasub, biodigester and efficient housing for rural Thailand (MS thesis completed)

Micah Krider, design of a solar-powered trolley system for a town in FL (MS project completed)

Dave Webber, photovoltaic two-meter airplane development (MS project completed)

Nto Diarra, stochastic systems approach to solar design with applications in Mali (D. Eng. in process).

Jesús Solis, development of a headlamp for remote locations.

Manuel Heredia, service-learning in the college of engineering.

Molly Rice, service-learning in the college of engineering.

Jorge Barrientos, green building case study.

Tanya Martinez, green building case study.

Samuel Geto, a guest student, originally from Africa, now enrolled at a university in Sweden, photochemical hydrogen production (MS thesis completed)

Seven undergraduate mechanical engineering students worked on their capstone design projects through the center.

Publications (since the summer of 2004)

- Six papers were presented at the Solar World Congress Aug. 6-12 in Orlando, FL and are included in the *Proceedings*.
  - Bhattacharjee, U., and J. Duffy, 2005, "Renewable Energy Portfolio Standard: Impacts of financial incentives on residential owners of photovoltaic system," *Proceedings of the 2005 Solar World Congress*, International Solar Energy Society.
  - Duffy, J.J., 2005, "Village Empowerment : Sustainable Solar Solutions, *Proceedings of the 2005 Solar World Congress*, International Solar Energy Society. Suwapaet, N., and J. Duffy, 2005, "Optimal Reliability Design Method for Remote Solar Systems," *Proceedings of the 2005 Solar World Congress*, International Solar Energy Society.
  - Diarra, N., and J. Duffy, 2005, "A New Design Method for PV Pump System Optimization," *Proceedings of the 2005 Solar World Congress*, International Solar Energy Society.
  - Tavaranan, S., and J. Duffy, 2005, "Solar Lanterns for Remote Areas," *Proceedings of the 2005 Solar World Congress*, International Solar Energy Society.
  - Aurora, P., and J. Duffy, 2005, "Solar Hydrogen Fuel Cell Modeling," *Proceedings of the 2005 Solar World Congress*, International Solar Energy Society.
- A paper was published in *Solar Energy*, and another was accepted for publication. Another is in press for a chapter in the most recent volume in the series *Advances in Solar Energy*. All three are on solar electrolyzer/fuel cell systems.
  - Ananthachar, V., and J.J. Duffy, 2005, "Efficiencies of Hydrogen Storage Systems Onboard Fuel Cell Vehicles," *Solar Energy*, Vol 78, No. 5, p. 687 - 694.
  - Shapiro, D., J. J. Duffy, M. Kimble, and M. Pien, 2005, "Solar-Powered Regenerative PEM Electrolyzer/Fuel Cell System," *Solar Energy*, in press.

- Aurora, P., and J.J. Duffy, 2005, "Modeling Solar Hydrogen Fuel Cell Systems," Chapter XX in Goswami, Y. (ed.), *Advances in Solar Energy 16*, American Solar Energy Society (ASES), Boulder, CO.

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