Center for Sustainable Energy
University of Massachusetts Lowell
Annual Report 2006-07

August 17, 2007

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. The mission and major purposes of the University of Massachusetts Lowell are to provide to students an affordable education of high quality and to focus some of its scholarship and public service on assisting sustainable regional economic and social development. The Center goals help support the overall mission of the university.

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 projects into engineering courses at U Mass Lowell.
- Work with faculty to incorporate service-learning projects into mainstream courses throughout the College of Engineering in particular, but other colleges and other universities also.
- 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.

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

Our focus areas that in general combine discovery, learning, and engagement (research, teaching, and service) include:

- The Village Empowerment Project involves the development of systems appropriate for use in developing countries: low cost; reliable; sustainable in terms of energy, environmental impact, and economics. Students, both graduate and undergraduate, develop such systems as parts of service-learning projects in courses and theses for graduate degrees. Trips have been made twice as year for two weeks since August of 1998, led and organized by the center.
- Service-Learning Integrated throughout a College of Engineering: SLICE. The goal here is integrate service-learning (S-L) projects into mainstream required courses in the engineering programs so that every student has at least one course every semester with S-L. One of the objectives, besides better learning of subject matter in the courses, is recruitment and retention of underrepresented groups in engineering. To date, over half the engineering faculty (along with a few others in other colleges) have incorporated S-L into at least one course. The center director is the faculty coordinator for this project.
- What appears to be the only academic program with graduate degrees explicitly in energy engineering (solar) is essentially run in collaboration with the center. The director of the center is the graduate coordinator of that program.
- Applied research and development of: fuel cell and electrolyzer thermal modeling; electrolyzer and hydrogen and oxygen storage systems development; fuel cell vehicle hydrogen storage comparisons; complex solar system design tool for reliability; PV-thermal collector field testing; solar lantern and LED lamp development; data acquisition systems for remote PV systems; thermoelectric, phase-change vaccine refrigerator development; solar crop dryers; photocatalytic water purification with dye indicator; life cycle environmental impact analysis of PV modules; energy efficient aquaculture; optimal design method for solar water pumping systems; solar autoclaves; in-depth case studies of green buildings; energy implications of scoring systems for green buildings; biogas digesters for cold climates; geopressured-geothermal, solar conversion system to produce potable water; and remote sustainable development.

4. Faculty/Staff Members

The following faculty/staff are members/collaborators 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)

Hong Wei Sun, Assistant Professor, Mechanical Engineering (MEMS micro systems, solar thermal concentrators).

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 (service-learning)

Alan Rux, Electrical Engineering Department (solar radios, assistive technology)

Bill Moeller, Professor Emeritus, Civil Engineering (sustainable development)

5. New Faculty and Staff Affiliations (last three years)

We have collaborated with the following new faculty and staff:

- Linda Barrington, Director of Service-Learning College of Engineering. Linda reports directly to John Duffy and is supported in part by the NSF SLICE grant and in part by the university.
- Hong Wei Sun, Assistant Prof., Mechanical Engineering. Collaborated on service-learning projects related to heat transfer and energy efficiency and was working with a Fulbright Fellow coming from Nigeria for the next academic year to study solar thermal concentrators to produce heat and hydrogen.
- Yan Luo, Assistant Professor, Electrical and Computer Engineering. Worked on service-learning projects in his computer architecture courses involving remote sensors for monitoring and control of temperatures, purchased with SLICE funds.
- Chris Niezrecki, Assoc. Prof., M.E. Chris was the co-PI on the first solar water purification project funded by the NCIIA. We also collaborate on some service-learning projects in his design of machine elements course.
- Joel Therrien, Assistant Prof., ECE. Joel is a former student in energy engineering, and we collaborated on a service-learning project in his circuits course for a hydro educational display system at the Tsongas History Center.
- Amy Cannon, Adjunct Assistant Professor, Work Environment. Amy helped two graduate students with TiO2 as a photocatalyst for solar water purification in recycled PET plastic bottles for remote areas.
- Deirdra Murphy, Assistant Professor, Physical Therapy. Advises PT students working on the Village Empowerment Project; went to Peru June 2007 to work with disabled local students and develop service-learning projects.
- Nicole Champagne, Associate Professor, Health Education. Service-learning projects for Health Education students.

In addition, there are about 36 faculty members total (including the dean and three department chairs in the College of Engineering) that have incorporated service-learning into their courses as part of the SLICE initiative in the college of engineering. The initiative is led by John Duffy of the Center.

6. Students

The following graduate students have worked in/with the center since June of 2006:

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

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

Peter Dubro, solar water purification indicator with TiO_2 catalyst (M.S. thesis)

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

Nto Diarra, stochastic systems approach to solar water pumping design with applications in Mali (Ph.D. thesis in final editing).

Jesús Solis, biogas systems for farms in cold remote areas and service-learning (M.S. thesis).

Manuel Heredia, solar water purification with bottles coated with TiO2 and service-learning (M.S. thesis).

Jorge Barrientos, green building case studies and life-cycle environmental impact of PV modules (M.S. candidate).

Tanya Martinez, indigenous peoples reservations green building designs (M.S. candidate).

Eric Morgan, service-learning and photocatylst coating of bottles for solar water purification (M.S. candidate).

Robert Williams, service-learning and study of byproducts safety of photocatalyst and dye indicator from solar water bottle purification (M.S. candidate).

Carolina Barreto, **Fulbright Scholar**, solar agricultural irrigation systems (M.S. candidate).

Rafael Castro, solar fuel cell systems (M.S. candidate).

Vivian Crespo, service-learning and rural solar systems (M.S. candidate).

John Wang (bioengineering program), service-learning and rural health delivery (Ph.D. candidate).

Chigbo Mgbemene, **Fulbright Fellow** for one year, faculty member from Mechanical Engineering Department of University of Nigeria, Nsukka; solar compound parabolic concentrators with thermoelectric modules for electricity generation.

Several others supported by the SLICE grant on service-learning under the direction of other faculty.

In all, 12 graduate students were supported financially through the center.

In addition, 6 undergraduates (ME and EE) worked on capstone design projects through the center.

- Degrees awarded by the university, with theses based on work at the center:
    - George Nitschke, geopressured- geothermal, solar conversion system to produce potable water (DEng thesis 2006).
    - Manuel Heredia, manufacture of bottles with TiO_2 catalyst for solar water purification (MS thesis 2006)
    - Jesús Solis, biodigester design for cold regions (MS thesis 2006)
    - Peter Dubro, solar water purification indicator with TiO_2 catalyst (MS thesis 2007)

7. Current Discovery/Learning/Engagement Projects

Major current projects include:

- Portable solar vaccine refrigerator: This was the specific project funded with the half research assistantship from the CFCI to Somchai Jiajitsawat. The objectives of this work are: 1. Design a portable solar refrigeration system capable of maintaining vaccine temperatures between 2 °C and 8 °C for at least 4 days of operation without access to grid electricity. 2. Test the feasibility of using the system in different remote locations having a high number of unvaccinated children and lacking grid electricity.

  The basic concept is to integrate direct-coupled PV thermoelectric modules (TEMs) with latent heat energy storage (LHES) using water as the phase change material along with heat pipes. In this concept, a photovoltaic panel (PV) directly powers thermoelectric modules (TEMs) to generate a cooling effect during the day. LHES is integrated into the refrigerator design as a cooling backup to maintain the cooling at night. Heat pipes are utilized in the system to passively control the temperature for vaccine storage.

  The coupling of PV and TEMs was investigated first with mathematical models. The results showed that sufficient cooling could be produced from the coupling. The heat pipe attached to TEMs appeared to be able to improve COP (coefficient of performance) of TEMs. An experiment showed that it is possible to use the heat pipes to maintain acceptable vaccine temperatures above that of ice as the energy storage medium.

  A feasibility field study of the system was then simulated for three remote sites. The results showed that the direct-coupled PV-TEM combined with latent energy storage (using ice) was fully adequate in providing cooling for the vaccines throughout the year.

  Two key components have been verified as follows: heat pipe and coupled PV and TEMs. The results revealed that problems related to the low melting point of the water could be solved by the installation of a cylindrical heat pipe between the LHES and the vaccine storage. An experiment showed that the vaccines were kept at a temperature of about 3 degrees C while the ice was at the freezing point of 0 C. The low COP of TEM was improved by incorporating a heat pipe as a thermal diode and sufficient cooling energy was produced from coupling PV and TEMs.

Fig 1. Prototype of vaccine refrigerator

A prototype of the refrigerator has been built and tested using one and two TEM (Fig. 1). A vacuum insulated panel will be added.

More details are available in Jiajitsawat, Somchai, A Portable Direct-PV Thermoelectric Vaccine Refrigerator with Ice Storage through Heat Pipes, Dissertation Proposal, March, 2007.

- Village Empowerment: Two more trips to Peruvian villages, in January and June 2007, with 10 and 15 students/volunteers, respectively. We now have over 80 systems in 42 different villages in the same region. The villages in general have no electricity, no telephone service, no space heating, biweekly bus transportation, and untreated water, in several cases only from open streams. The systems, which harvest energy with photovoltaic modules, solar thermal collectors, and microhydro turbines and in some cases from the grid, 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. Some of the systems have dramatic impacts: In perhaps the most remote village of the group, Huallmi, with no electricity and no telephone, in the six months prior to our installing a transceiver radio in the medical clinic in January 2006 there were seven deaths related to childbirth due to delays in getting medical help; from January 2006 to our return in June 2006 there were no deaths in childbirth. Technologies developed and installed with graduate and undergraduate students as well as volunteers during the past year include:
    - Solar water purification with recycled soda bottles coated with an emulsion of TiO2 with a dye indicator.
    - Inexpensive radio transceivers for medical clinics, most solar powered.
    - Solar water pumping systems.
    - Biodigester for methane gas production, constant pressure type with moving hood.
    - Composting toilet.
    - Solar crop dryer.

- Service-Learning Integrated throughout a College of Engineering: SLICE. The goal here is integrate service-learning (S-L) projects into mainstream required courses in the engineering programs so that every student has at least one course every semester with S-L. To date, over half the engineering faculty (along with a few others in other colleges) have incorporated S-L into at least one course. The center director is the faculty coordinator for this project.
- Case studies of green buildings. Nineteen in-depth case studies were developed and documented in a report to the Massachusetts Technology Collaborative by Jorge Barrientos, Ujjwal Bhattacharjee, Tanya Martinez, and John Duffy as well as through entries into the High Performance Building Data Base of the U.S. Dept. of Energy.

There are many other current projects mentioned in various other sections under students, publications, grants, etc.

8. Publications/Awards

- Bhattacharjee, U. and J. Duffy, 2006, "Effect of PV on Reducing Demand Charges: Case of a 26 kW PV System in MA," *Proceedings Annual National Solar Conference*, American Solar Energy Society, July.
- Jamadagni, S., and J. Duffy, 2006, "Energy and Associated Environmental Impacts of the Draft High Performance School Rating System," *Proceedings Annual National Solar Conference*, American Solar Energy Society, July.

- Jiajitsawat, S., and J. Duffy, 2006, "A Portable Direct-PV Thermoelectric Vaccine Refrigerator with Ice Storage through Heat Pipes," *Proceedings of the 2006 National Solar Energy Conference*, American Solar Energy Society.
- Duffy, John, Linda Barrington, Cheryl West, John McKelliget, Eugene Niemi, Sammy Shina, Hongwei Sun, Chris Niezrecki, Robert Parkin, Majid Charmchi, Peter Avitabile, 2007, "Service-Learning in Core Courses Throughout a Mechanical Engineering Curriculum," *Proceedings American Society of Engineering Education Annual Conference.*
- Duffy, J., D. Kazmer, L. Barrington, J. Ting, C. Barry, Z. Zhang, D. Clark, A. Rux, 2007, "Service-Learning Integrated into Existing Core Courses throughout a College of Engineering," *Proceedings American Society of Engineering Education Annual Conference.*
- Barrington, L, and J. Duffy, 2007, "Attracting Underrepresented Groups to Engineering with Service-Learning," *Proceedings American Society of Engineering Education Annual Conference.*
- Barrientos, J., U. Bhattacharjee, T. Martinez, and J. Duffy, 2007, "Green Buildings in Massachusetts: Comparison between Actual and Predicted Energy Performance," *Proceedings Annual Meeting American Solar Energy Society.*
- Heredia, M., and J. Duffy, 2007, "Photocatalytic Destruction of Water Pollutants using a TiO2 Film in PET Bottles, *Proceedings Annual Meeting American Solar Energy Society.*
- Dubro, P., and J. Duffy, 2007, "Dye Indicator for the Effectiveness of TiO2 Water Purification," *Proceedings Annual Meeting American Solar Energy Society.*

Awards

- U Mass President's Award for Public Service, 2006.
- Boston Celtics Heroes Among Us Award, 2007.
- The Massachusetts Campus Compact named the Village Empowerment project one of three finalists for the Jimmy and Rosalynn Carter Award for University Community Partnership, April 2007. Carter Foundation certified university-community partnership.

Patent

- Duffy, J.J., and D. Shapiro, Electrolyzer Pressure Equalization System, U. S. Patent No. 7097748, August 29, 2006.

9. Conference Presentations

- Duffy, J., 2006, Village Empowerment Project," invited presentation Merrimack Valley Venture Forum, Lowell, MA, December.
- Duffy, J., 2007, "Village Empowerment Service-Learning Project," invited seminar, Ill. Inst. Tech., Chicago, March.
- Duffy, J., 2007, "Village Empowerment: Peru Project," invited presentation, Boston University, March.
- Duffy, J., 2007, "Solar Systems for Developing Countries," invited presentation, MIT Energy Forum Thought Leaders Seminar, March.
- Duffy, J. and five students, 2007, subjects in "Village Empowerment Partnership," video produced by Jane Pikor, Emerson College, for the MA Campus Compact Carter Award Presentation, April,

- Duffy, J., 2007, "Sustainability in International Service-Learning Projects," invited presentation and panel discussion, Engineers Without Borders International Annual Conference, U Mass Amherst, April.
- Duffy, J., 2007, invited presentation and session chair, "Recruiting, Developing and Guiding Faculty as Team Project Coaches," Best Practices of Interdisciplinary Team Project Programs Conference, Ill. Inst. Tech., Chicago, April.
- Duffy, J., 2007, "Village Empowerment: Toward Sustainability in International Service-Learning Projects," workshop, annual conference of the Community College National Center for Community Engagement, Phoenix, May.
- Duffy, John, Linda Barrington, Cheryl West, John McKelliget, Eugene Niemi, Sammy Shina, Hongwei Sun, Chris Niezrecki, Robert Parkin, Majid Charmchi, Peter Avitabile, 2007, "Service-Learning in Core Courses Throughout a Mechanical Engineering Curriculum," *American Society of Engineering Education Annual Conference.*
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10. Collaboration with other Centers/Institutes and/or Departments

The center collaborates with approximately 35 faculty members through the SLICE project in developing S-L projects in undergraduate and graduate courses, including faculty in the college of health, college of arts and science, and the business school.

11. Regional/Local Outreach (Other Institutes of Higher Education, Industries, Government Agencies, schools, etc.)

The center collaborates with at least 12 local community partners in those S-L projects (http://slice.uml.edu). Of course, we collaborate with various government bodies (Ministry of Health, Ministry of Education, and local town governments) in over 42 villages in Peru. Other collaborative endeavors with other universities are mentioned under the faculty and publication sections above.

12. Proposals submitted/Awarded 2006/2007

Proposals submitted include (in addition to those under grants obtained below):

- NCIIA Sustainable Development Program, Oct. 2006.
- NCIIA Special E-Teams Program, January 2007.
- Equal Exchange Grant Program.

Grants obtained include:

- Implementation of Service-Learning Integrated throughout a College of Engineering (SLICE); PI, sponsor: NSF ($1,005,000; 2005-09) no-cost extension
- NSF International Research and Education in Engineering Program, supplement to SLICE grant ($31,480; 2007-08)
- Solar Water Purification Bottles with Dye Indicator for Developing Countries; sponsor: National Collegiate Inventors and Innovators Alliance ($17,500; 2007-2008)
- International Service-Learning Project in the Colleges of Health and Engineering, Healy public service grant, UML ($9600, 2007-09) with Deirdra Murphy and Nicole Champagne

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