X.4 Hydrogen Energy in Engineering Education (H_2E^3)

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Objectives

- The Hydrogen Energy in Engineering Education (H_2E^3) project is designed to increase awareness of and hands-on experience with hydrogen and fuel cell technology among undergraduate engineering students in California's public universities. H_2E^3's objectives are:
  - to deliver effective, hands-on hydrogen energy and fuel cell learning experiences to a large number of undergraduate engineering students at multiple campuses in the California State University (CSU) and University of California (UC);
  - to provide follow-on internship opportunities for students at hydrogen and fuel cell companies; and
  - to develop commercializable hydrogen teaching tools including a basic fuel cell test station and a fuel cell/electrolyzer experiment kit suitable for use in university engineering laboratory classes.

Technical Barriers

This project addresses the following technical barriers from the Education section (3.9.5) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(D) **Lack of Educated Trainers and Training Opportunities.** Only a small number of universities in California offer hydrogen and fuel cell-specific learning opportunities for undergraduate engineering students. Even at these campuses, the number of engineering faculty with direct experience using fuel cells remains small, and fuel cell course content is underdeveloped.

(E) **Regional Differences.** California has the advantages of being home to many hydrogen and fuel cell developers and on the leading edge of hydrogen energy infrastructure development. These features call for a special hydrogen energy education effort in California universities that makes use of these existing resources available in close proximity to many campuses.

Contribution to Achievement of DOE Education Milestones

This project will contribute to achievement of the following DOE milestone from the Education section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 21**: Launch new university hydrogen education program (4Q, 2009).

The project supports attainment of the above milestone by creating curriculum, teaching tools, and industry-based learning opportunities that can be replicated by other universities working with industry partners. By the same token, the project also supports completion of Task 5 in the Multi-Year Research, Development and Demonstration Plan: "Facilitate Development and Expansion of College and University Hydrogen Technology Education Offerings," specifically the subtask described as "Work with university partners to develop and expand hydrogen technology course offerings and facilitate networking among schools with similar programs."

Accomplishments

- Established working relationships with faculty from UC Berkeley and Humboldt State University

committed to using H_2E^3 curriculum and laboratory equipment in their courses.
- Designed and fabricated 30 benchtop electrolyzer/fuel cell experiment kits and accompanying laboratory activity guides for use in introductory engineering and thermodynamics courses.
- Designed and fabricated two fuel cell test stations capable of operating fuel cell stacks of up to 500 W.
- Began development of written curriculum materials for use in undergraduate engineering courses.

Introduction

A recurring theme in the hydrogen energy field is the unmet need for a new generation of graduating engineers trained specifically in hydrogen and fuel cell energy technologies. The purpose of our project is to help meet this need, specifically in the context of the CSU and UC systems. Together these universities grant over 7,000 engineering degrees each year.

The three-year project, branded as "Hydrogen Energy in Engineering Education" (H_2E^3) is being led by the Schatz Energy Research Center (SERC), a unit of the Humboldt State University (HSU) Sponsored Programs Foundation. Our principal partner on the project is the University of California, Berkeley (UCB), represented by their Institute of Transportation Studies (ITS). Industry partners include Jadoo Power Systems, Inc., Protonex Technology Corporation, UTC Power, and IdaTech LLC.

Approach

Adding hydrogen curriculum to existing undergraduate engineering programs is not a trivial task. Engineering departments and the organization that accredits them require students to meet numerous stringent requirements in order to graduate. There is little slack in a typical undergraduate engineering course plan to add new curriculum. In order to add hydrogen education to existing engineering programs, we need to find creative ways to fold it into courses and help instructors meet their existing course objectives.

We are working closely with engineering faculty to develop lesson plans that can be substituted for segments of existing courses, including introductory engineering, introductory and advanced thermodynamics, manufacturing engineering, upper-division engineering laboratory, and in courses on the general topic of energy and society. We are also developing laboratory hardware that the students will be able to use to perform hands-on experiments that reinforce key points covered in the lecture material. The partners on this effort bring years of relevant experience in teaching about hydrogen energy and developing fuel cell technology.

Results

Our work to date has focused primarily on establishing needed relationships and developing the hardware that will be used for student laboratory activities. At the time of preparing this report we have completed fabrication of 30 benchtop electrolyzer/fuel cell kits and are nearly ready to deploy two fuel cell test stations, which include fuel cell stacks built by SERC.

Working Relationships – We have established a subcontract for $75,000 with UCB and have consulted extensively with UCB's principal representative on the project, Timothy Lipman of UCB's ITS. We held a project kickoff meeting in October 2008 with faculty members from UCB's mechanical engineering department and secured their support for the project. We also met with engineering faculty and technical support staff at HSU who agreed to pilot H_2E^3 curriculum in their courses. Through the Annual Merit Review meeting and other connections, we have identified educators both within and outside the UC and CSU systems who are interested in the H_2E^3 project.

Electrolyzer/Fuel Cell Kits – The electrolyzer/fuel cell kits developed for this project are based on an earlier successful SERC design created for use in high school chemistry classes. With this kit, students use electric power to generate hydrogen gas through water electrolysis, then use the hydrogen to power a fuel cell connected to a mechanical load. The kit is instrumented so students can measure the efficiency of each energy conversion step. The new design improves kit performance and allows additional experimental activities such as measurement of waste heat generated during electrolysis (see Figure 1).

Fuel Cell Test Stations – We have completed and tested one of the two test stations to be built as part of this project, with the second station on track for completion during August 2009. The test stations allow the operator to directly observe and record data on a fuel cell stack while adjusting a number of operating parameters, including load current, temperature, air/fuel stoichiometry, and frequency and duration of hydrogen purges (see Figure 2). Each test station is supplied with a 500-Watt, 300 cm^2 active area fuel cell stack designed and built by SERC. The stacks are internally humidified and water-cooled (see Figure 3). We have completed assembly of both stacks and have tested the first stack, which is performing satisfactorily (see Figure 4 for a current-voltage polarization curve generated during stack testing).

Hydrogen Curriculum – We are creating lesson plans for use in the courses listed above. To date we have completed a lab activity guide for use with the

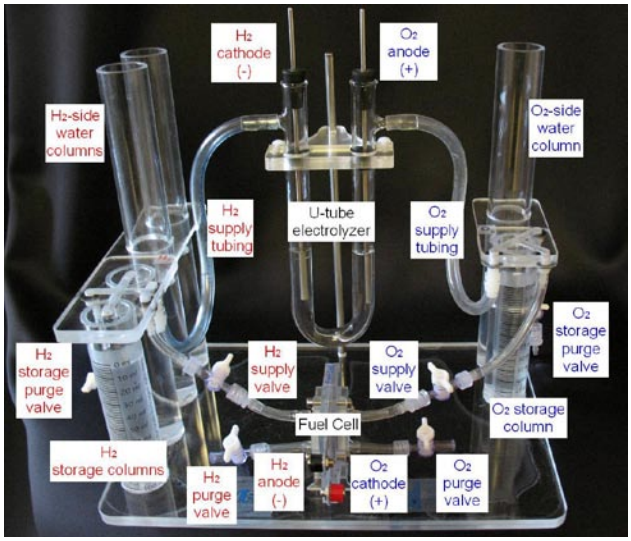

FIGURE 1. H_2E^3 Electrolyzer/Fuel Cell Kit Showing Component Nomenclature

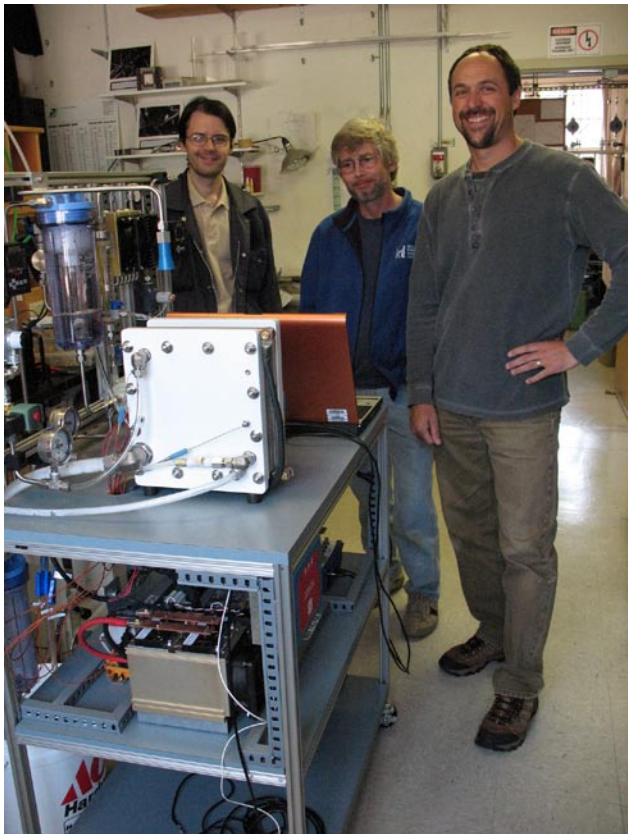

FIGURE 2. SERC Engineers Commission H_2E^3 Fuel Cell Test Station

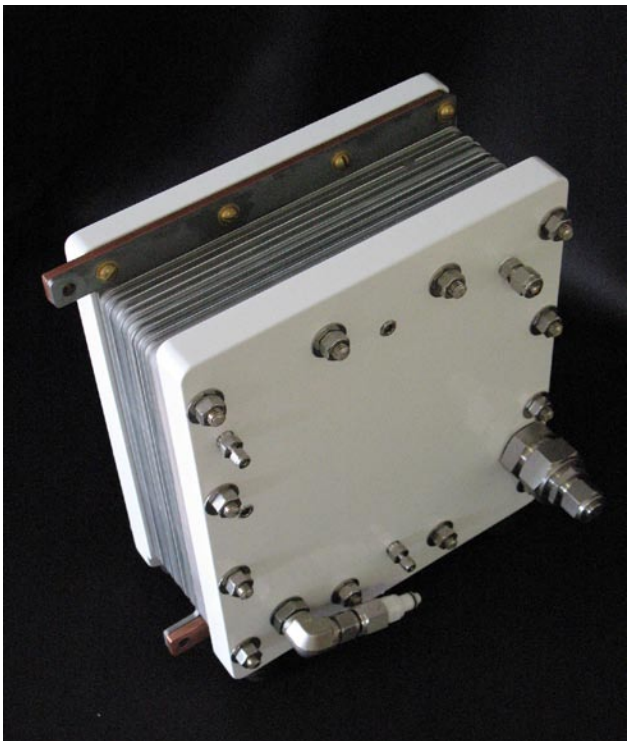

FIGURE 3. 8-Cell Fuel Cell Stack with 300 cm^2 Active Area

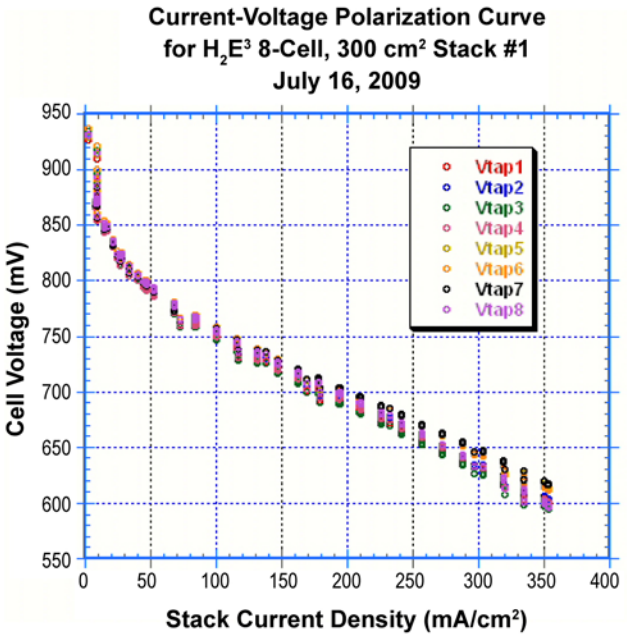

FIGURE 4. Current-Voltage Polarization Curve for Fuel Cell Stack

electrolyzer/fuel cell kits and are nearing completion of lecture material for a three-week module on hydrogen and fuel cells to be used in introductory engineering courses such as E10 in UCB's mechanical engineering program and ENGR 115 in HSU's environmental resources engineering program. We have also identified readings in several textbooks on hydrogen energy to be assigned as part of the curriculum modules under development. To assist with marketing of the H_2E^3 curriculum, we have created a project logo and Web site (www.hydrogencurriculum.org).

Conclusions and Future Directions

The first year of the three-year project has been productive, with the establishment of working relationships with faculty at the two pilot campuses, UCB and HSU, and completion of the bulk of our planned hardware development. In year two we will turn our attention to completing course lesson plans and piloting these lesson plans and associated lab activities in undergraduate engineering classes. We will also deploy the project hardware for use in lab sections of these classes. We will then refine the course materials as needed based on student and instructor feedback. We will work with our industry partners to secure internships for students who have participated in courses that include H_2E^3 material and will monitor outcomes for these interns and their industry hosts. In the final year of the project we will recruit other UC and CSU campuses to participate in the project and monitor and report on their learning outcomes. Students from these campuses will also have the opportunity to apply for industry partner internships during the project's final year. We will develop and implement a monitoring and evaluation process to determine the success of the curriculum, teaching tools, internships, and our marketing efforts. We will continue to look for relationships with interested educators and the opportunities they bring to share the project's deliverables with a wider audience.

FY 2009 Publications/Presentations

1. Lehman, Peter. "Hydrogen Energy in Engineering Education (H_2E^3)," presentation to 2009 U.S. DOE Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting. May 21, 2009, Washington, D.C.