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 Fuel Cell 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 Fuel Cell 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

- Successfully introduced H_2E^3 curriculum in three engineering courses at HSU and two at UCB.
- Successfully incorporated H_2E^3 hardware in lab activities in a total of four engineering courses at the two campuses.
- Continued development of new curriculum materials.
- Performed monitoring and evaluation of the curriculum and lab hardware in use, using feedback

from this process to improve the curriculum and hardware.
- Developed and added content to the project Web site (www.hydrogencurriculum.org).
- Authored or contributed to papers on H_2E^3 for presentation at two education conferences.
- Introduced the curriculum and fuel cell/electrolyzer kit at Don Bosco University in El Salvador as part of a Fulbright-funded teaching assignment.
- Made initial contacts with interested collaborators at other UC and CSU campuses where we plan to introduce H_2E^3 during the 2010-11 academic year.

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 Sponsored Programs Foundation. Our principal partner on the project is the UCB, represented by their Institute of Transportation Studies. The project also began with a number of fuel cell industry partners, but the participation of these manufacturers in the project as hosts for student interns is being reevaluated, as discussed in the following.

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

Having completed development of hardware and begun curriculum development during the first year of the project, in year two we focused on introducing the curriculum and hardware into several engineering courses at UCB and HSU, and refining H_2E^3 materials. We also worked on developing relationships that will allow us to reach out to additional campuses, incorporate studies of hydrogen fueling stations into H_2E^3 (Figure 1), and establish student internships during year three.

Curriculum Development and Deployment. We introduced our curriculum, in the form of PowerPoint presentations, lab activities, and supporting documentation for lab instructors, into several engineering courses: introduction to environmental resources engineering, introductory thermodynamics, and advanced thermodynamics at HSU; and engineering design and analysis and energy and society at UCB.

Equipment Deployment. The two fuel cell test stations (Figures 2 and 3) and 24 fuel cell/electrolyzer kits (Figure 4) were used in each of the above courses for hands-on lab activities and/or instructor demonstrations. All of the equipment performed satisfactorily.

Monitoring and Evaluation. Project team members used a variety of assessment tools to analyze the effectiveness of the H_2E^3 curriculum and lab activities. We had students complete pre- and post-lesson evaluations, we observed and made notes on lectures and lab activities, and we convened focus groups and one-on-one meetings with instructors and teaching assistants to solicit their feedback. Student and instructor feedback has been strongly positive but has also provided useful critique. We are using assessment outcomes to make iterative improvements to the curriculum and equipment.

FIGURE 1. HSU's hydrogen fueling station and fleet of hydrogen vehicles. The fueling station's performance will be analyzed by HSU engineering students as part of the H_2E^3 curriculum.

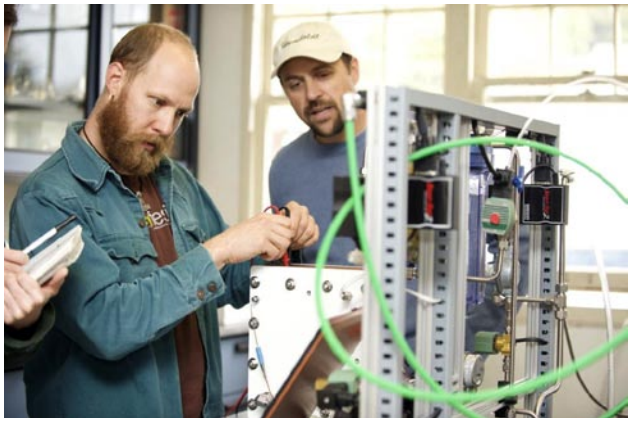

FIGURE 2. HSU engineering student measures fuel cell voltages on H_2E^3 test station while SERC fuel cell engineer Greg Chapman looks on.

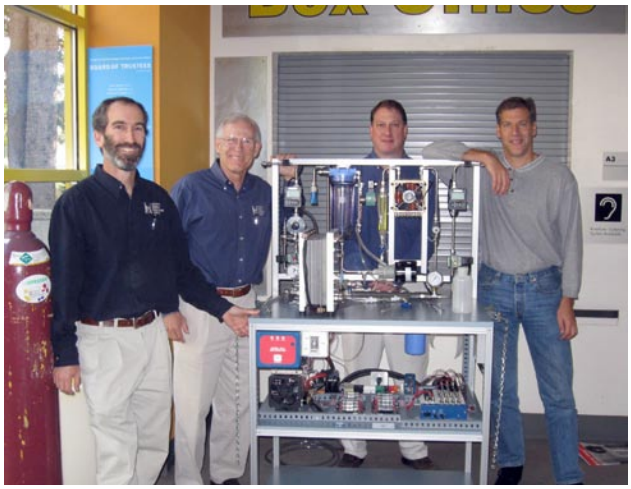

FIGURE 3. SERC's Richard Engel and Peter Lehman and UCB's Tim Lipman and Dan Kammen celebrate delivery of an H_2E^3 test station to UCB.

Fuel Cell Industry Internships. Project plans originally called for student internships with a number of fuel cell manufacturer partners during the summers of 2010 and 2011. Due to the economic downturn in general and attrition in the fuel cell industry in particular, we have had difficulty in developing these internships. The only internships we were able to identify for 2010 were existing co-op arrangements, which require students to be available for six months out of the year for full-time work. This is not compatible with the academic schedules of students in the universities we have been working with. We are investigating alternatives, as discussed below.

Conclusions and Future Directions

The main outcome of year two of the project has been the successful introduction of the H_2E^3 tools and curriculum into a variety of engineering courses at HSU and UCB. In year three we plan to expand the project by integrating the curriculum into still more engineering courses and reaching out to other California campuses. We have requested and been given tentative approval for an additional $15,000 in funding from DOE, which will permit us to build three additional sets of ten fuel cell/electrolyzer kits. We will distribute these sets to newly participating campuses, allowing current users of kits to keep using them at their campuses for longer periods.

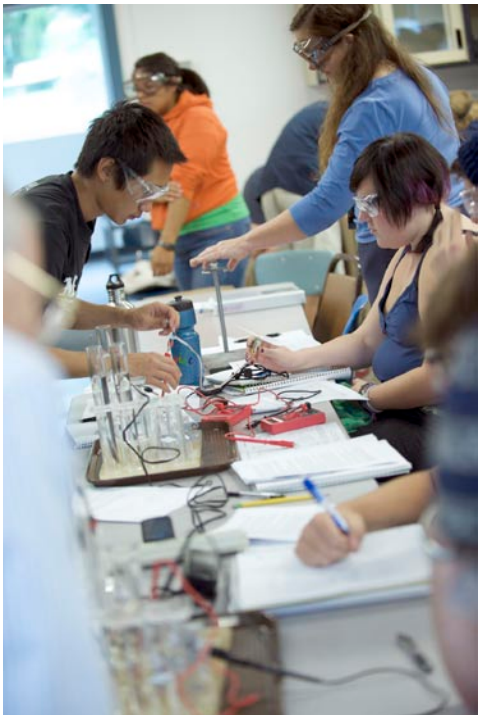

FIGURE 4. HSU engineering students perform experiments using the H_2E^3 fuel cell/electrolyzer kits.

In order to ensure the long-term success of H_2E^3, we will follow up with faculty to determine to what extent the use of the H_2E^3 materials persists among instructors who have been given access to the curriculum and equipment, and what the learning outcomes are in their courses. We will also continue to develop learning activities that incorporate analysis of operating fueling stations at HSU and elsewhere.

We hope to find or develop summer-season internships for 2011. In addition to making direct contacts with manufacturers, we plan to approach industry groups such as the U.S. Fuel Cell Council and the National Hydrogen Association to solicit their help with this. We are considering alternatives to manufacturer-funded internships, such as "distance internships," perhaps supported by fixed stipends from a third party.

Special Recognitions & Awards/Patents Issued

1. "National Hydrogen and Fuel Cell Education Program Part I: Curriculum," selected by Energy Conversion and Conservation Division of the American Society for Engineering Education as 2nd place winner of Best Paper Award at the 2010 ASEE Annual Conference & Exposition, Louisville, KY.

FY 2010 Publications/Presentations

1. Blekhman, D., J. Keith, A. Sleiti, E. Cashman, P. Lehman, R. Engel, M. Mann, and H. Salehfar, 2010, "National Hydrogen and Fuel Cell Education Program Part I: Curriculum, " American Society for Engineering Education Annual Conference & Exposition, Louisville, KY.

2. Blekhman, D., J. Keith, A. Sleiti, E. Cashman, P. Lehman, R. Engel, M. Mann, and H. Salehfar, 2010, "National Hydrogen and Fuel Cell Education Program Part II: Laboratory Practicum," American Society for Engineering Education Annual Conference & Exposition, Louisville, KY.

3. Cashman, E., R. Engel and P. Lehman, 2010, "Work in Progress: Hydrogen Energy in Engineering Education," Frontiers in Education Annual Conference, Arlington, VA.

4. Lehman, Peter A. "Hydrogen Energy in Engineering Education (H_2E^3)." Presentation for U.S. Department of Energy Hydrogen Program Annual Merit Review and Peer Evaluation Meeting. June 10, 2010.

5. Engel, Richard (ed.), *Fuel Cell Test Station Operation and Maintenance Guide*. November 2009.

6. Lab handout, blank wiring diagram, and safety guidelines for use in ENGR 115, introduction to environmental resources engineering (HSU).

7. Lab handout, blank wiring diagram, and safety guidelines for use in ENGR 331, introduction to thermodynamics (HSU).

8. PowerPoint presentation for E100, energy and society (UCB).

9. Monitoring and evaluation report on ENGR 331 (HSU) and E100 (UCB).

10. Lab handouts for use in ENGR 471, advanced thermodynamics (HSU):

- Lab Experiment #1 – Operating the Fuel Cell Test Station
- Lab Experiment #2 – Evaluating the Performance of a PEM Fuel Cell

11. Spanish translations of PowerPoint presentation originally developed for E100 and document on operation and maintenance of fuel cell/electrolyzer kits, for use at Universidad Don Bosco, El Salvador, by H_2E^3 project team member Richard Engel.