IX.10 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 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 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 fuel cell companies.
- 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 2009 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 has contributed 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."

Fiscal Year (FY) 2011 Accomplishments

- Continued expansion of H_2E^3 curriculum adoption at host universities HSU and UCB, including activities for three additional courses:
  - Transport phenomena (ENGR 416) at HSU, in which students used a fuel cell test station to perform a heat balance on an operating fuel cell stack.
  - Renewable energy power systems (ENGR 475) at HSU, in which students evaluated fuel cell stack performance under different temperature and air stoichiometry conditions.
  - A hydrogen safety seminar at UCB, in which graduate engineering students visited UCB's new hydrogen fueling station and attended a safety presentation alongside local emergency responders.

- Visited and/or supplied sample experiment kits to faculty at seven California universities:
  - California State University, Los Angeles
  - San Francisco State University
  - Sonoma State University
  - University of California, Santa Cruz
  - Berkeley Center for Green Chemistry
  - University of California, Riverside
  - California State University, San Bernardino
- Successfully recruited faculty from three universities to adopt curriculum:
  - San Francisco State University
  - Sonoma State University
  - University of California, Riverside
- Fabricated 24 additional hydrogen experiment kits for placement at newly recruited campuses.
- Developed the project website (hydrogencurriculum.org) to include curriculum downloads, equipment user manuals, streaming videos, project news, and recommended readings.
- Planned, filmed, edited, and posted online (hydrogencurriculum.org) nine instructional videos explaining how to use the H_2E^3 laboratory equipment.
- Facilitated creation of two fuel cell development intern positions at Protonex Technology Corporation for summer 2011; filled these positions with two HSU engineering students who had previously participated in H_2E^3 curriculum.
- Performed monitoring and evaluation of classroom and lab activities.

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 California State University and University of California 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, 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 includes fuel cell industry partner Protonex Technology Corporation, which is providing internships for students who have participated in the curriculum.

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 have worked closely with engineering faculty as part of this project to develop lesson plans that can be substituted for segments of existing courses, including introductory engineering, introductory and advanced thermodynamics, renewable energy power systems, transport phenomena, and in courses on the general topic of energy and society. We have also developed laboratory hardware that students 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

During the first two years of the project, the focus was primarily on development of curriculum and the related lab equipment. In the third year, we are focused on marketing and distributing the curriculum to other universities and creating follow-on internships for participating students.

Curriculum Development and Deployment. At HSU and UCB, we continued use of the curriculum in courses where it was introduced in year two. We also brought the curriculum into several new courses at these and other campuses. Table 1 details progress to date in incorporating curriculum in various courses.

While the project was originally designed to reach undergraduate engineering students, we have found the curriculum has broader appeal. For example, the curriculum is being used at Sonoma State University with students in a non-engineering energy management and design program. The curriculum is also being evaluated for use in training high school science teachers at California State University, San Bernardino. Reviewers at the 2011 Annual Merit Review meeting also suggested that the curriculum should be adapted for use with high school students.

Equipment Deployment. Using $15,000 in supplemental funding from DOE, we produced an additional 30 hydrogen experiment kits for distribution to newly participating campuses. We have placed most of these kits at the campuses that have joined the project during year three. Most of the kits are being used to perform lab activities developed by Schatz Energy Research Center. However, one UCB chemistry professor assigned her students to work in teams to analyze performance of the

TABLE 1. California Campuses and Courses where H_2E^3 Curriculum has Been Used to Date

Campus	Fall 2009	Spring 2010	Fall 2010	Spring 2011
Humboldt State	• Intro to Engineering (Engr) • Intro to Thermo	• Intro to Engr • Intro to Thermo • Advanced Thermo	• Intro to Engr • Intro to Thermo • Statistical Analysis • Renewable Energy • Energy for non-Engrs	• Intro to Engr • Intro to Thermo • Statistical Analysis • Transport Phenomena
UC Berkeley	• Energy and Society	• Intro to Engineering	• Energy and Society	• General and Quantitative Chem. Analysis • Hydrogen Safety
Sonoma State				• Energy Forum
San Francisco State				• Engineering Experimentation
UC Riverside				• Green Engineering

kits and recommend improvements. The students presented their work in a May 2011 poster session (see Figure 1).

Curriculum Marketing. Our project Web page (hydrogencurriculum.org) is aimed principally at faculty and features downloadable presentations, streaming videos produced in-house on using the equipment (see Figure 2), handouts for lab activities for a variety of courses, and a recommended readings list. Project staff visited faculty at four campuses (see Figure 3), bringing them sample kits and curriculum. Additional kits were shipped to interested faculty at other campuses.

Monitoring and Evaluation. We continued to use pre- and post-activity assessments of student learning at HSU in all courses where the curriculum was used. In addition, faculty at University of California, Riverside and Sonoma State University agreed to provide pre- and post-activity assessments and written feedback on use of the lectures and labs in their courses. This process has been helpful

FIGURE 2. Still from one of the H_2E^3 lab equipment instructional videos produced and posted online.

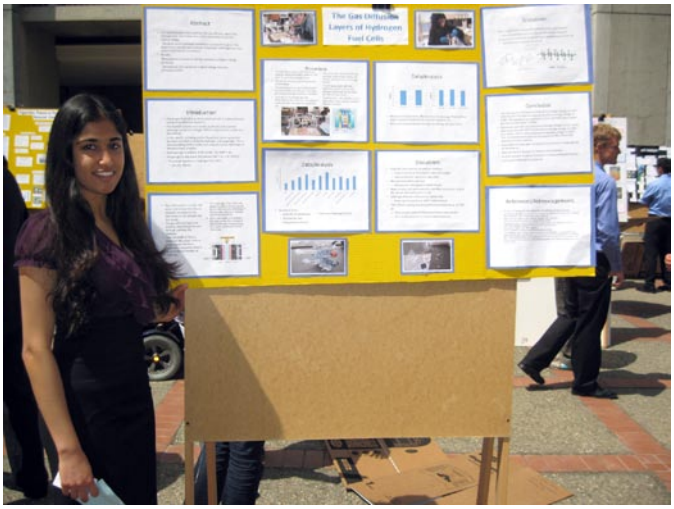

FIGURE 1. UC Berkeley chemistry student Nisha Mair displays her team's poster explaining their efforts to measure and improve performance of the H_2E^3 hydrogen experiment kits.

FIGURE 3. San Francisco State University engineering faculty evaluate H_2E^3 hydrogen experiment kit.

in making iterative improvements to the curriculum and equipment (see Figure 4).

Fuel Cell Industry Internships. Due to the economic downturn, we experienced difficulty during years two and three in placing interns with fuel cell companies as had been originally envisioned. In the second quarter of 2011, we determined that we could reallocate a portion of our project budget to cost share with companies on intern stipends. Using this funding mechanism, we successfully placed two HSU students at Protonex Technology Corporation, where they are currently working on proton exchange membrane and solid oxide fuel cell projects.

Conclusions and Future Directions

As this three-year project nears its September 2011 conclusion, it has been a success on many fronts, reaching well over a thousand students at five campuses. Student and instructor responses to the curriculum and equipment have been very positive. The strategy of using fuel cells and hydrogen energy concepts to meet the teaching objectives of existing engineering courses has been well-received by faculty.

In order to bring the funded project to completion we will:

- Continue to facilitate and evaluate the ongoing student internships.
- Produce two additional instructional videos, a virtual tour of the hydrogen fueling station at HSU and assembly of a PEM fuel cell stack.
- Continue to refine and extend the Web page.
- Determine who will be given continuing stewardship of the lab equipment.

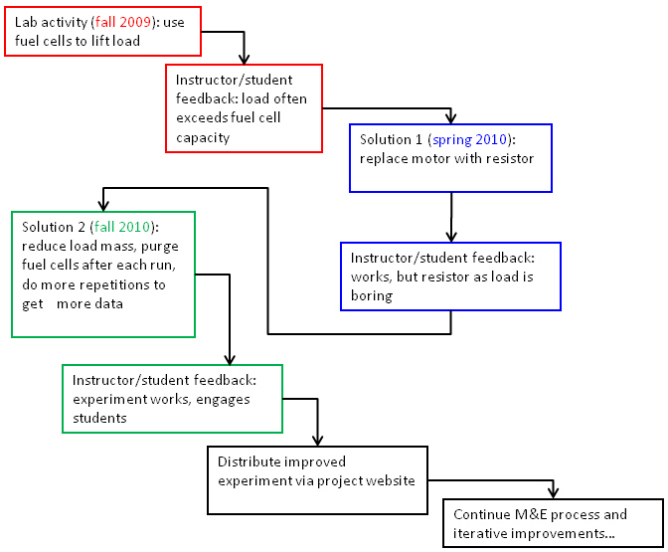

FIGURE 4. Example of iterative improvements to curriculum using monitoring and evaluation process.

Beyond the current funding, we hope to:

- Maintain and build on our established collaborations with other campuses in California.
- Identify universities outside California interested in adopting the curriculum.
- Seek manufacturing partners to commercialize the kits and/or test stations, scaling them up for mass production.
- Seek an opportunity to adapt the curriculum for high school use, as recommended by reviewers at the 2011 Annual Merit Review meeting.

FY 2011 Publications/Presentations

1. Materials for Probability and Statistics Course

- Pre-lab lecture presentation: "The HSU Hydrogen Fueling Station"
- Assignment handout: "Performance of the Electrolyzer at the HSU Hydrogen Fueling Station"

2. Materials for Test Station Lab for Renewable Energy Power Systems Course

- Lecture Presentations: "Hydrogen and Fuel Cells" and "Using the Fuel Cell Test Station"
- Assignment handout: "Performance and Design of PEM Fuel Cell Stacks"

3. Materials for Test Station Lab for Transport Phenomena

- Assignment handout: "Fuel Cell Heat Balance Lab"

4. Materials for Energy Forum senior/graduate level course

- Lecture presentations: "Hydrogen, Electrolyzers, and Fuel Cells" and "Fuel Cell and Electrolyzer Lab Activity"

5. Materials for Graduate Level Hydrogen Safety Seminar

- Lecture presentations: "The Promise of Hydrogen" and "First Responder Training for UC Berkeley Richmond Field Station Hydrogen Fueling Station"

6. "Tools for Teaching About Hydrogen and Fuel Cells." Two-page flyer distributed to University of California and California State University faculty to publicize the H_2E^3 curriculum.

7. Instructional videos:

- H_2E^3 - Using and Caring for the H2E3 Fuel Cell/ Electrolyzer Kits. http://youtube/I6i3Z_WLyjM
- H_2E^3 - Introduction to Engineering Fuel Cell and Electrolyzer Lab. http://youtu.be/Rx_lcFp-mzs
- H_2E^3 - Introductory Thermodynamics Lab I and Lab II. http://youtu.be/7BKxYyKH2eU
- H_2E^3 - Fuel Cell Test Station Software Overview. http://youtu.be/IFooNsV8eqs
- H_2E^3 - Fuel Cell Test Station Orientation and Care. http://youtu.be/3xDSjetWob4
- H_2E^3 - Fuel Cell Test Station Startup and Shutdown Part I. http://youtu.be/GoywLP40e1I

- H_2E^3 - Fuel Cell Test Station Startup and Shutdown Part II. http://youtu.be/1mOfgnxqs-w
- H_2E^3 - Fuel Cell Test Station Startup and Shutdown Part III. http://youtu.be/Vm_uxl1222o
- H_2E^3 - Fuel Cell Test Station Startup and Shutdown Part IV. http://youtu.be/IvxjrIgMzzU

8. Spanish language publications:

- "Juego para Experimentos con Hidrógeno: Celda de Combustible y Electrolizador. Guía para docentes para uso en cursos introductorios en ingeniería y termodinámica" (translation/adaptation of "Hydrogen Fuel Cell / Electrolyzer Kit Instructor Guide for Use in Introductory Engineering and Introductory Thermodynamics Courses" from H_2E^3 curriculum collection).
- "Actividad: Diseño de Celda de Combustible" (translation/adaptation of "Fuel Cell System Design Activity" originally created as part of the DOE-funded HyTEC high school hydrogen curriculum development project).

9. Petroske, Jarad. "Positive Energy: The Schatz Energy Research Center is Building a Renewable Future Today." *Humboldt Magazine*. Spring 2011. http://magazine.humboldt.edu/magazine_pdf/humboldtMagazine_spring11.pdf

10. Presentation for May 2011 Merit Review and Peer Evaluation Meeting.