Hydrogen Energy in Engineering Education (H₂E³)

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Schatz Energy Research Center
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Project ID # ED004

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Overview

Timeline

- Project start date: 09/15/2008
- Project end date: 09/15/2011
- Percent complete: 90%
  (projected by 05/10/2011)

Budget

- Total project funding
  - DOE share: $410,532
  - Contractor share: $114,876
- Funding received in FY10: $15,000
- Funding for FY11: $0

Note: Most of the federal project funds were disbursed in FY 2008 and FY 2009

Barriers

As identified in HFCIT MYPP, Section 3.9.5:
- Lack of educated trainers
- Regional differences

Partners

- Project lead: Schatz Energy Research Center
  (PI: Peter Lehman)
- UC Berkeley/Institute of Transportation Studies
- Collaborators at other campuses
- Industry partners:
  - Jadoo Power Systems, Inc.
  - Protonex Technology Corp.
  - UTC Power
  - IdaTech LLC
Relevance

Objectives over 3-year project (2008-2011)

• 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)

• Provide follow-on internship opportunities for students at hydrogen and fuel cell companies

• 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
Relevance
Project Objectives over the past year (05/2010-03/2011)

- Implement curricula and conduct assessment for specific engineering courses at Humboldt State University, including
  - Introduction to engineering
  - Introductory engineering thermodynamics
  - Engineering data analysis
  - Renewable energy engineering
  - Advanced engineering thermodynamics
- Foster adoption of curriculum at other campuses
- Develop curriculum marketing and distribution tools (website, videos, brochure)
- Fabricate 30 additional benchtop electrolyzer/fuel cell kits (using supplemental funding from DOE)
- Facilitate student internships at collaborating fuel cell companies
Relevance

Relevance to DOE Hydrogen Program

Notes that “hydrogen education programs are minimal” (still the case) and identifies college students and science teachers as target outreach audiences

Education efforts need to “facilitate the expansion of hydrogen and fuel cell programs and learning modules at educational institutions, including…universities, for use in training a workforce of…engineers”

HFCIT Multi-Year RD&D Plan (2007)
“Work with university partners to develop and expand hydrogen technology course offerings and facilitate networking among schools with similar programs”
Relevance

Addressing Barriers

• Lack of educated trainers. Few universities in California offer hydrogen and fuel cell-specific learning opportunities for undergraduate engineering students. Even at these campuses, few faculty have direct experience using fuel cells; fuel cell course content is underdeveloped.

• 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. This calls for a special hydrogen energy education effort in California universities making use of these existing resources available in close proximity to many campuses.
Approach

• Curriculum
  – Undergraduate engineering student focus
  – Modules replace portions of existing course curricula, not adding to total instructional burden for faculty
  – Initial use at UCB and HSU, later replication at other campuses

• Fuel Cell/Electrolyzer Kits
  – Alkaline electrolyzer and PEM fuel cell
  – More robust and higher power capacity than existing kits

• Fuel Cell Test Stations
  – Designed to work with any ~500W internally humidified stack
  – Emphasis on component visibility and pedagogical use in a research grade instrument

• Fueling Station Analysis
  – Study performance & efficiency of Hydrogen Highway fueling facilities

• Industry Internships
  – Follows directly on classroom experience, extends learning for students while grooming engineers for fuel cell industry partners
Previous Technical Accomplishments and Progress: FY09, FY10

- Identified courses and interested instructors at HSU and UCB for introduction of curriculum.
- Met with faculty to introduce $\text{H}_2\text{E}_3$ project and solicit input on curriculum and hardware
- Developed draft module outlines, worked with instructors to refine
- Designed and fabricated 24 electrolyzer/fuel cell kits
- Designed and fabricated two fuel cell test stations
- Pilot tested curriculum in engineering courses at HSU and UCB
- Performed classroom/lab monitoring and evaluation (M&E)
- Approached industry partners about student internships

Portable fuel cell test station designed and fabricated by SERC engineers
Technical Accomplishments and Progress: FY11

Continued Pilot Testing & Refinement of Curriculum

- Completed new curriculum modules for use in advanced thermodynamics, renewable energy, and statistical analysis courses
- Updated existing curriculum modules based on M&E process
- Completed test station user manual
- Built 30 additional kits using supplemental funding from DOE
- Used curriculum in five HSU engineering and environmental science classes during fall semester 2010
- Currently developing new lab using test station to perform energy balance on fuel cell stack in transport phenomena engineering course
- Translated portions of curriculum into Spanish, used in class and workshops as part of Fulbright teaching project at two universities in El Salvador

Humboldt State students in renewable energy class perform fuel cell experiments using H₂E³ test station, December 2010
Technical Accomplishments and Progress: FY11

Monitoring and Evaluation

- Developed and used student learning evaluation instruments in five classes at HSU
- Interviewed instructors for feedback on effectiveness of curriculum
- Used outcomes from M&E to modify equipment, lecture slideshow content, and lab procedures
- Now incorporating M&E feedback from other campuses
- Prepared summary reports on evaluations of each class, included these in quarterly reports to DOE

In order to calculate hydrogen production at the fueling station, we need to know:

- a) hydrogen mass flow rate at each time step and time interval between data points
- b) total station power consumption and time interval between data points
- c) total station power consumption and hydrogen mass flow rate
- d) efficiency of each station component

Example of results from monitoring and evaluation showing improved understanding.
Developed web page to include curriculum downloads, manuals, videos, readings & resources: hydrogencurriculum.org

Produced and uploaded nine videos on use of test station and fuel cell/electrolyzer kits

Produced promotional brochure for distribution to faculty

Joint H₂ ed paper awarded 2nd place for Best Paper at ASEE conference

Project team member Dr. Eileen Cashman presented on project at ASEE/IEEE Frontiers in Education Conference

Promoted curriculum at Alliance to Save Energy’s Green Campus Summit in Long Beach, CA
Technical Accomplishments and Progress: FY11

Expansion to New Campuses

- Communicated with and visited interested faculty
- Coordinated with project managers for fuel cell power systems being installed at five UC/CSU campuses by PG&E, SoCal Edison
- Delivered 10 kits to Sonoma State Univ., gave guest lecture
- Provided sample kits to five campuses
- Participating and interested campuses:
  - UC Berkeley (Center for Green Chemistry)
  - San Francisco State University
  - UC Santa Cruz
  - Sonoma State University
  - Cal State San Bernardino
  - UC Riverside
  - Cal State Los Angeles

Faculty from UC Berkeley, San Francisco State University, and UC Santa Cruz collaborate on $H_2E^3$
Technical Accomplishments and Progress: FY11

Fueling Station Analysis

- Developed assignment that uses statistical analysis techniques to compare efficiency of HSU fueling station’s Proton Energy HOGEN electrolyzer before and after module replacement
- Student analysis supports manufacturer’s claim of higher efficiency in new module
- Posted assignment, lecture slides, and data files on project website
- Techniques used in the assignment can be replicated/adapted for use with data from other stations

HSU’s Hydrogen Fueling Station and fleet of two hydrogen-powered vehicles
Collaborations

SERC
project lead with multiple roles, emphasizing:
  • curriculum development & testing
  • hardware development

UC Berkeley Institute of Transportation Studies
• curriculum development
• in-class curriculum & hardware testing
• recruitment of additional universities
• liaison w/ industry partners

Industry Partners (fuel cell manufacturers):
  Jadoo Power
  Protonex
  UTC Power
  Idatech
  • internships for students

Collaborators at Other UC & CSU Campuses
  Sonoma State Univ.
  U.C. Santa Cruz
  San Francisco State U.
  UC Berkeley Green Chem
  • in-class curriculum & hardware testing
Proposed Future Work

Remainder of FY 2011:
• Continue implementation and M&E of curriculum modules in classrooms and labs at participating campuses
• Continue to recruit faculty at additional UC and CSU campuses
• Develop learning opportunities for campuses tied to Hydrogen Highway fueling stations (HSU, UCB, CSULA)
• Collaborate with UC Berkeley Green Chemistry program to improve kit design
• Assess student internships with industry partners; implement where feasible
• Produce additional instructional video: virtual tour of HSU hydrogen fueling station
• Continue to refine and extend web page
• Wrap up project: stewardship of equipment, final reports

Beyond current funding
• Maintain collaborations with other campuses in California
• Look for interested universities outside California
• Seek manufacturing partner to commercialize kits and test stations, scale up for mass production
Summary

• Relevance
  – SERC’s project objectives are closely tied to DOE’s Hydrogen Program objectives

• Approach
  – Curriculum modules  – Fuel cell/electrolyzer kits  – Fueling facilities
  – Fuel cell test stations  – Inter-campus outreach  – Internships

• Technical Accomplishments and Progress
  – Continued pilot testing and refinement of curriculum
  – Monitoring and evaluation
  – Marketing and outreach
  – Expansion to new campuses
  – Fueling station analysis

• Collaborations
  – Partners: UCB, industry partners, other UC/CSU campuses

• Proposed Future Work
  – Complete funded work, seek opportunities to commercialize/expand

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Technical Back-Up Slides
Curriculum Materials Produced to Date

**Introductory Level Materials - for first and second year engineering courses**
- Fuel Cell/Electrolyzer Materials for Introductory Engineering Course
- Fuel Cell/Electrolyzer Kit Instructor Guide
- Blank Wiring Diagrams
- Pre-Lab Lecture Presentation
- Fuel Cell/Electrolyzer Kit Lab Handouts - as used in HSU Intro to Engineering course

**Intermediate Level Materials - for third year engineering courses**
- Fuel Cell/Electrolyzer Materials for Introductory Thermodynamics Course
- Pre-lab lecture and PowerPoint presentation - as used in HSU Intro to Thermodynamics course
- Electrolyzer Lab Handouts - as used in HSU Intro to Thermodynamics course
- Fuel Cell Lab Handouts - as used in HSU Intro to Thermodynamics course

**Hydrogen Fueling Station Materials for Probability and Statistics Course**
- Pre-Lab Lecture Presentation
- Assignment Handout
- Data Files "Before" (Zip archive containing 10 data files)
- Data Files "After" (Zip archive containing 10 data files)
- About the Data Files (text file)
- Virtual Tour of Fueling Station Video (Coming Soon)

**Advanced Level Materials - for advanced thermodynamics, renewable energy, and energy & society courses**
- Materials for Test Station Lab
- Lecture Presentation on the Test Station
- Test Station Operations & Maintenance Manual
- Test Station Lab - as used in HSU Renewable Energy Power Systems course

**Materials for Energy & Society Course**
- Lecture Presentation (updated version coming soon)
## Classes Using Curriculum

<table>
<thead>
<tr>
<th>Campus</th>
<th>Fall ‘09</th>
<th>Spring ‘10</th>
<th>Fall ‘10</th>
<th>Spring ‘11</th>
</tr>
</thead>
</table>
| Humboldt State  | • Intro to Engineering  
                 • 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 Engr                               | • Energy and Society                           | • General & Quantitative Chem. Analysis         |
| Sonoma State    |                                                |                                               |                                                | • Energy Forum                                 |
| UC Santa Cruz   |                                                |                                               |                                                | • Renewable Energy Sources                      |
Lab activity (fall 2009): use fuel cells to lift load

Instructor/student feedback: load often exceeds fuel cell capacity

Solution 1 (spring 2010): replace motor with resistor

Instructor/student feedback: works, but resistor as load is boring

Solution 2 (fall 2010): reduce load mass, purge fuel cells after each run, do more repetitions to get more data

Instructor/student feedback: experiment works, engages students

Distribute improved experiment via project website

Continue M&E process and iterative improvements…
Test Station Inputs/Outputs

**Analog Inputs**
- Cell voltages (1-8)
- Air flow
- Hydrogen flow
- Stack current
- Stack voltage
- Temperatures (ambient + 5 internal stack temps)

**Analog Outputs**
- Air flow signal
- Load setpoint signal

**Digital Inputs**
- Reservoir float switch on/off

**Digital Outputs**
- Heater on/off
- Air supply solenoid
- Hydrogen supply solenoid
- Hydrogen purge solenoid
- Reservoir fill solenoid
- Cooling fan on/off
- Water circ pump on/off
- Load relay switch
# Fueling Station Assignment

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Compressor Outlet Temp (°C)</th>
<th>Storage Tank Temp (°C)</th>
<th>Top Tank Pressure</th>
<th>Bottom Tank Pressure</th>
<th>H₂ Flow (Low Pressure)</th>
<th>H₂ Flow (High Pressure)</th>
<th>Electrolyzer Power</th>
<th>Compressor Power</th>
<th>Program Run Hours</th>
<th>System Run Hours</th>
<th>Compressor Energy (kWh)</th>
<th>Cumulative H₂ Energy (kWh)</th>
<th>Cumulative H₂ Energy (kWh)</th>
</tr>
</thead>
</table>

**Graph:**
- **Top Tank Pressure**
- **Electrolyzer Power**

**Legend:**
- **Fill period**
- **Data Row**

**Data Row:**
- 38:05.0: 0.04724, 11.905, 12.442, 5117.9, 5121.9, 0.95344, 156.37, 5.3219, 0.00161, 0.03465, 17492.92, 1.97E-07, 0.0025229, 5.05615, 0.0059147, 0.007177

**Total:**
- Cumulative Energy (kWh)
- Cumulative H₂ Energy (kWh)