Hydrogen Energy in Engineering Education (H_2E^3)

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Schatz Energy Research Center

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Project ID #
ED004

Overview

Timeline

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

Barriers

As identified in HFCIT MYPP, Section 3.9.5:

- Lack of educated trainers
- Regional differences

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

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

National Hydrogen Energy Roadmap (2002)

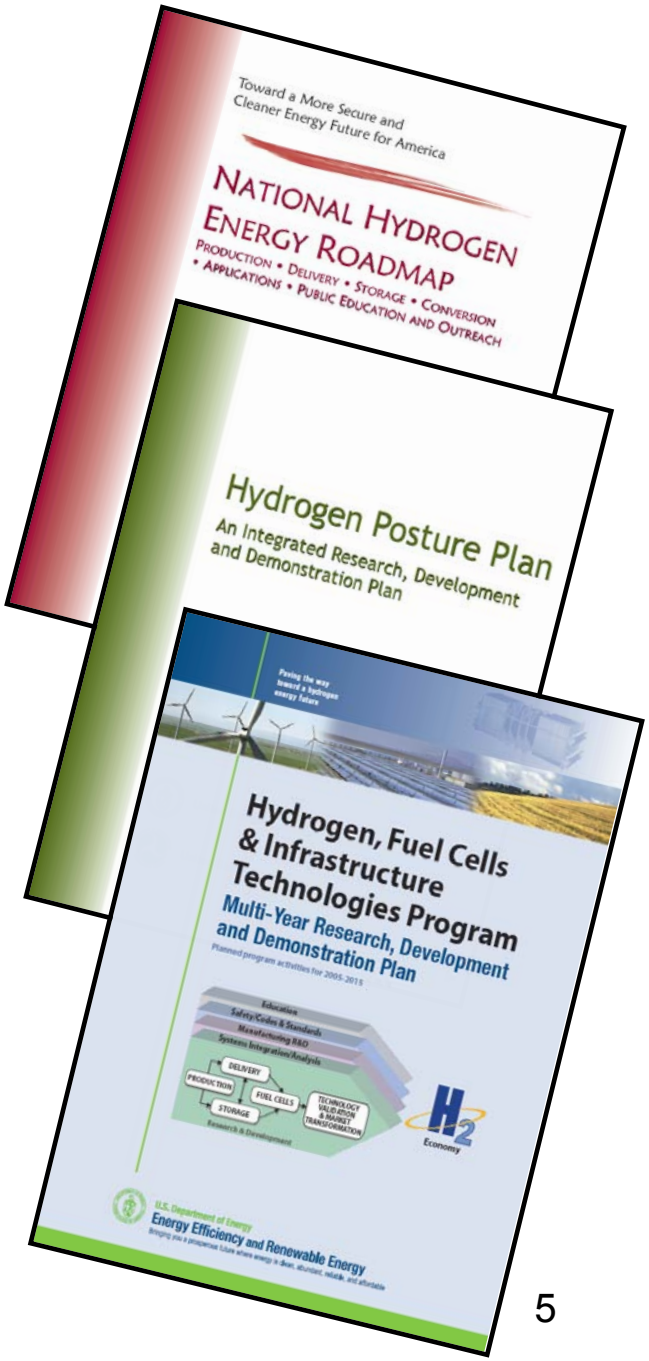
Notes that “hydrogen education programs are minimal” (still the case) and identifies college students and science teachers as target outreach audiences

Hydrogen Posture Plan (2006)

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

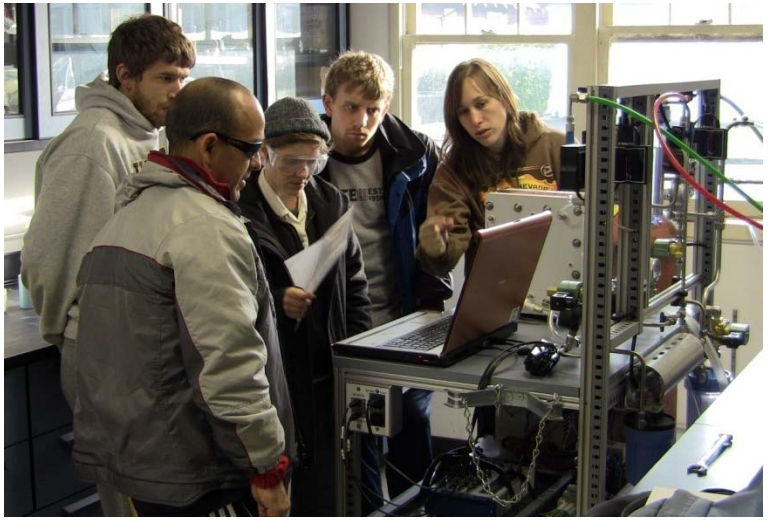
- Identified courses and interested instructors at HSU and UCB for introduction of curriculum.
- Met with faculty to introduce H_2E^3 project and solicit input on curriculum and hardware
- Developed draft module outlines, worked with instructors to refine
- Designed and fabricated 24 electrolyzer/fuel 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 H_2E^3 test station, December 2010

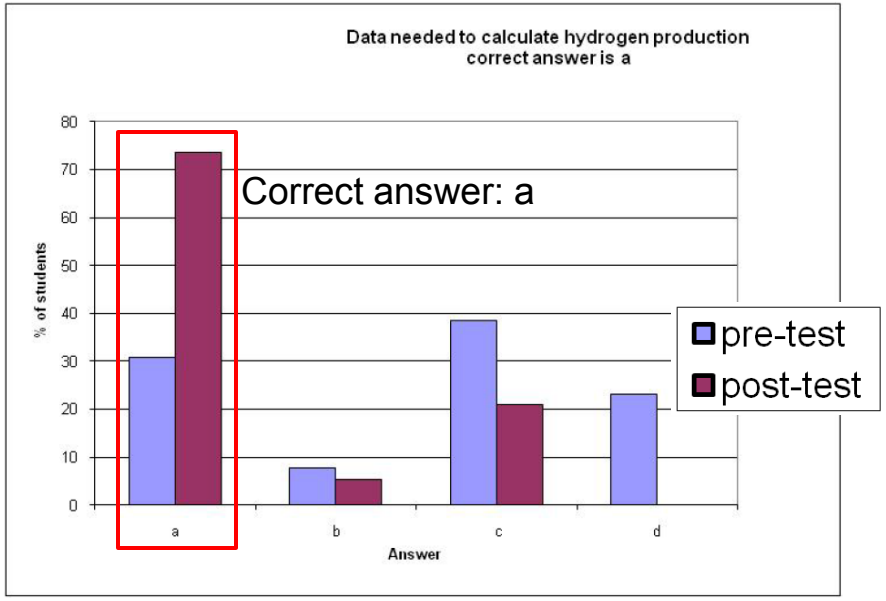
Technical Accomplishments and Progress: FY11

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



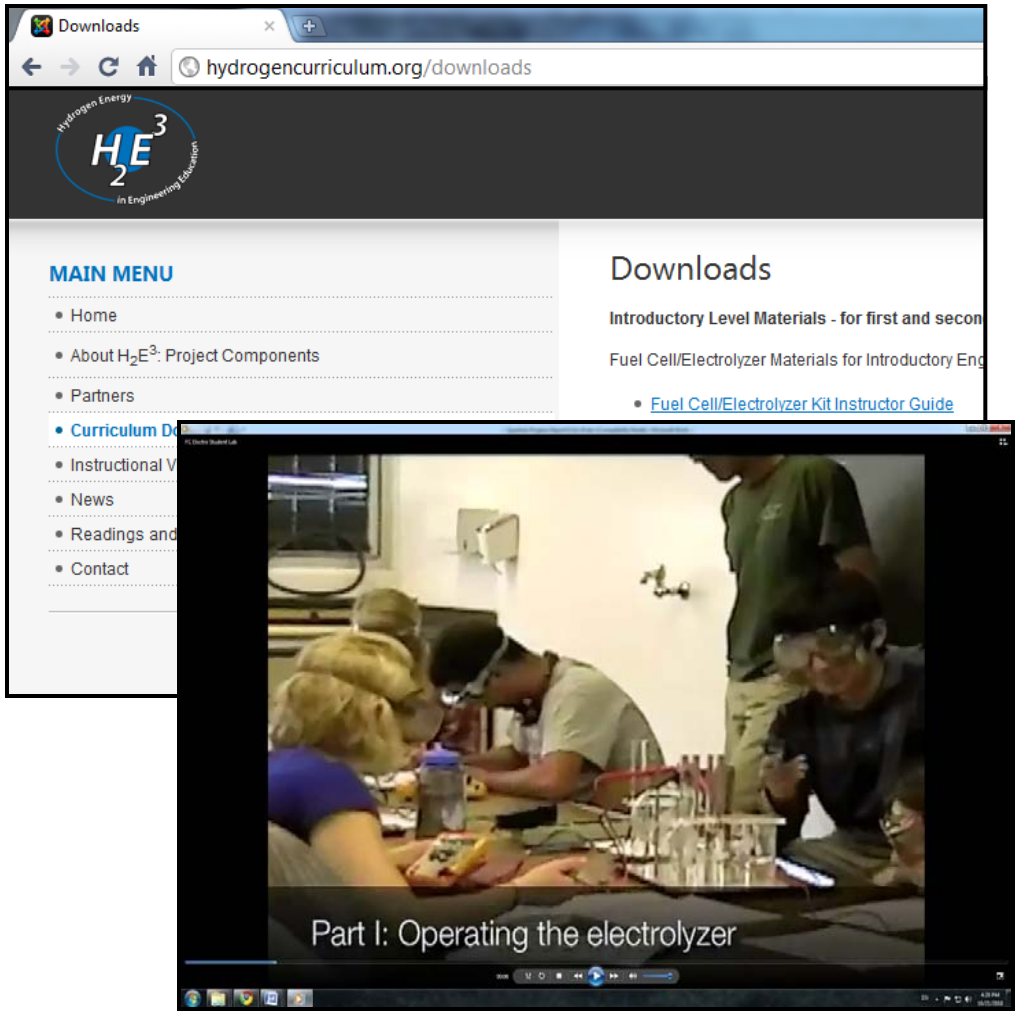
Example of results from monitoring and evaluation showing improved understanding

Technical Accomplishments and Progress: FY11

Marketing and Outreach

- 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 H_2 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

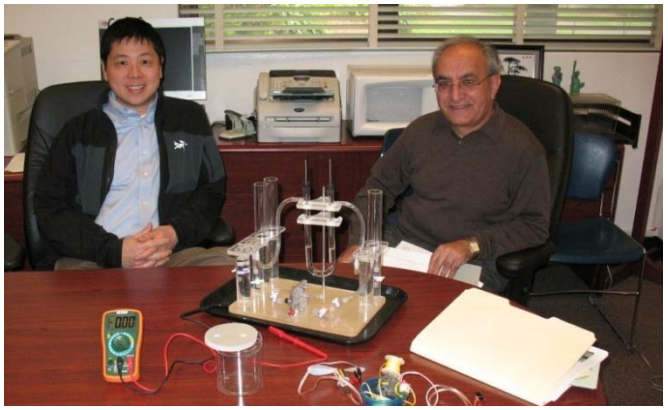
Play video: ED004_lehman_slide_11.mp4



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

Campus	Fall '09	Spring '10	Fall '10	Spring '11
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

Monitoring & Evaluation Feedback in Action

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

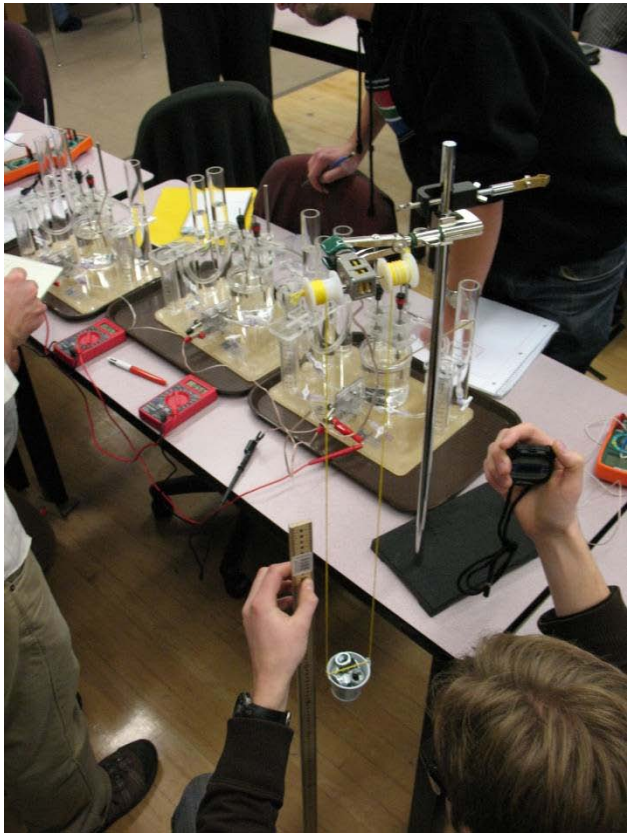
Instructor/student feedback: works, but resistor as load is boring

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…



Lab activity using fuel cells in series to lift load

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

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Source data file: S:\Projects\Prius Fueling Station\Data\2010 Fueling Station Data\03-2010\5182010_processed_Fueling_Station_201003.txt																
2	Time of Day	Time (hrs)	Compressor Outlet Temp (C)	Storage Tank Temp (C)	Top Tank Pressure	Bottom Tank Pressure	H2 Flow (Low Pressure)	Hogen H2 Pressure	Electrolyzer Power	Compressor Power	Program Run Hours	System Total Hours	Compressor Energy (kWh)	Cumulative Compressor Energy (kWh)	Hogen Energy (kWh)	Cumulative Hogen Energy (kWh)	Cumulative Energy (kWh)
3	07:07.5	0.01749	0											0	0	0	0
4	07:09.5	0.01805	11.351	1										3.34E-08	6.00E-06	6.00E-06	6.03E-06
5	08:09.5	0.03473	11.323	1										5.78E-07	9.32E-05	9.92E-05	9.98E-05
6	09:09.6	0.0514	11.348	1										9.61E-07	9.73E-05	0.00019652	0.00019749
7	10:09.6	0.06808	11.385	1										1.09E-06	8.19E-05	0.00027842	0.00027951
8	11:09.6	0.08476	11.393	1										1.22E-06	9.03E-05	0.0003687	0.00036991
9	12:09.7	0.10143	11.418	1										1.32E-06	7.86E-05	0.00044728	0.0004486
10	13:09.7	0.11811	11.432	1										1.39E-06	8.73E-05	0.00053456	0.00053595
11	14:09.8	0.1348	11.438	1										1.42E-06	7.61E-05	0.00061069	0.0006121
12	15:09.9	0.1515	11.436	1										1.47E-06	8.37E-05	0.00069441	0.00069588
13	15:20.0	0.1543	11.423	1										1.33E-05	5.43E-06	0.00069983	0.00071314
14	15:22.0	0.15485	11.42	1										2.61E-05	2.92E-06	0.00070276	0.00072885
15	16:22.1	0.17155	11.535	1										4.11E-05	3.28E-05	0.00073555	0.00077662
16	17:22.2	0.18825	11.421	1										5.74E-05	3.55E-05	0.00077109	0.00082847
17	18:22.4	0.20496	11.483	1										7.13E-05	3.08E-05	0.00080192	0.0008732
18	19:22.4	0.22164	11.493											8.67E-05	3.37E-05	0.00083565	0.00092231
19	20:22.6	0.23835	11.501	1										0.00010091	2.97E-05	0.00086533	0.00096624
20	21:22.6	0.25503	11.488											0.00011683	3.26E-05	0.00089793	0.0010148
21	22:22.8	0.27174	11.484											0.00013218	3.20E-05	0.00092997	0.0010621
22	23:22.9	0.28845	11.482	1										0.00014537	2.82E-05	0.00095814	0.0011035
23	24:23.1	0.30516	11.476	1										0.00015971	3.01E-05	0.0009882	0.0011479
24	25:23.2	0.32186	11.499	1										0.00017228	2.66E-05	0.0010148	0.001187
25	26:23.3	0.33855	11.504											0.00018648	2.98E-05	0.0010446	0.0012311
26	27:23.4	0.35524	11.551	1										0.00019869	2.57E-05	0.0010703	0.001269
27	28:23.4	0.37192	11.569											0.00021227	2.89E-05	0.0010992	0.0013115
28	29:23.6	0.38863	11.553	1										0.00022426	2.51E-05	0.0011243	0.0013486
29	30:23.7	0.40533	11.554	1										0.00023741	2.69E-05	0.0011512	0.0013886
30	31:23.8	0.42203	11.584	1										0.00024905	2.38E-05	0.001175	0.001424
31	32:24.0	0.43874	11.576	1										0.00026175	2.63E-05	0.0012013	0.001463
32	36:18.7	0.01745	0											0.00026175	0	0.0012013	0.001463
33	36:20.7	0.018	11.866	1										0.00026175	0	0.0012013	0.001463
34	37:20.7	0.03467	11.877	12.453	5117.9	5120.8	1.0171	156.37	5.3219	0.01639	0.03465	17492.92	4.17E-07	0.00026217	9.82E-05	0.0012995	0.0015616
35	38:06.0	0.04724	11.905	12.442	5117.9	5121.9	0.96344	156.37	953.02	0.00399	0.04722	17492.93	1.19E-07	0.00026229	0.005615	0.0069147	0.007177