

FINAL REPORT

Project Title: HYDROGEN AND FUEL CELL EDUCATION AT CALIFORNIA STATE UNIVERSITY, LOS ANGELES

Covering Period: October 15, 2008 through June 30, 2011

Date of Report: September 25, 2011

Recipient: California State University, Los Angeles
5151 State University Drive
Los Angeles, California, 90032

Award Number: DE-FG36-08GO18106

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Project Objective: California State University, Los Angeles, has partnered with the Department of Energy in addressing the workforce preparation and public education needs of the fuel cell industry and the US economy through a comprehensive set of curriculum development and training activities:

- Developing and offering several courses in fuel cell technologies, hydrogen and alternative fuels production, alternative and renewable energy technologies as means of zero emissions hydrogen economy, and sustainable environment.
- Establishing a zero emissions PEM fuel cell and hydrogen laboratory supporting curriculum and graduate students' teaching and research experiences.
- Providing engaging capstone projects for multi-disciplinary teams of senior undergraduate students.
- Fostering partnerships with automotive OEMs and energy providers.
- Organizing and participating in synergistic projects and activities that grow the program and assure its sustainability.

Project Summary

There are five main tasks pursued by the project. These tasks and major accomplishments are shown below:

1. Develop curriculum in hydrogen technology
 - CSULA has developed fully dedicated courses TECH 478-Fuel Cell Applications and graduate ME 554-Fuel Cell Systems; and one-, two-week modules addressing fuel cells and hydrogen infrastructure for several courses: ME 454-Renewable Energy and Sustainability, TECH 370-Power, Energy and Transportation, TECH470-Electric and Hybrid Vehicles, TECH 250-The Impact of Technology on the Individual and Society. The latter serves as a university course where any major student can take it (about 600 students in 3 years).
 - A Molten Carbonate Fuel Cell Project has been made available at:
http://www.calstatela.edu/faculty/blekhman/MCFC_Project.html
2. Develop the Zero Emissions Fuel Cell and Hydrogen Laboratory (ZEFC)
 - CSULA operates the educational and research laboratory that has the following equipment supporting the fuel cell education: Heliocentris -- Dr. Fuel Cell, Nexa Training System Complete, Nexa Integration Kit; and Proton-Hogen GC600 Electrolyzer. A senior design team custom built a flammability limits experiment
 - The laboratory integrates a 10 kW solar photovoltaic installation
 - ARRA NSF funding will be used to upgrade the laboratory space.
3. Provide engaging student projects
 - CSULA students participated in 2010 and 2011 Hydrogen Design Contests organized by the National Hydrogen Association
 - A team of students demonstrated the very first application of fuel cells to power LEGO Mindstorms robotic kits:
<http://www.youtube.com/watch?v=1B1H0VexQ9w&NR=1> .
 - Funded by Sempra Energy, a senior design team built a Hydrogen Dispenser Calibration Unit, which could be used to certify hydrogen stations for sale of hydrogen at 350 bar
 - CSULA students built a fuel cell vehicle and participated in 2011 Shell-Eco competition, Houston, TX
 - CSULA has been selected for EcoCAR 2 *Plugging into the Future* competition 2011-2014.
4. Provide public outreach and foster relationships with fuel cell OEMs and other state and government officials
 - The ZEFC Laboratory hosted dozens of student tours introducing visitors to fuel cell technologies as well as Power, Energy and Transportation Program
 - CSULA built fuel cell vehicle Hydrogen Super Eagle was on display at AltCar Expo, Santa Monica 2010, October 2010, Los Angeles Auto Show, in November

2010 and the Metropolitan Water District of Southern California Sustainable Expo, May 2011

The vehicle participated in filming the Mercedes-Benz F-Cell World Drive video EcoTrek 7 (at 3rd minute): <http://www.youtube.com/watch?v=qDPHJsMUBR4>

- CSULA participated in numerous meetings and discussions of future projects and collaborations with fuel cell vehicle OEMs, federal and state government officials. Significant collaboration has been developed with California Fuel Cell Partnership
 - The PI provided leadership in collaborating with other institutions on sharing the concepts of fuel cell and hydrogen development:
 - 1. Blekhman, D., J. Keith, A. Sleiti, E. Cashman, P. Lehman, R. Engel, M. Mann, and H. Salehfar "National Hydrogen and Fuel Cell Education Program Part I: Curriculum," 2010 ASEE Annual Conference & Exposition, Louisville, KY.
*2nd best paper in the Energy Conversion and Conservation Division
 - 2. Blekhman, D., J. Keith, A. Sleiti, E. Cashman, P. Lehman, R. Engel, M. Mann, and H. Salehfar "National Hydrogen and Fuel Cell Education Program Part II: Laboratory Practicum," 2010 ASEE Annual Conference & Exposition, Louisville, KY.
5. Assure program sustainability and participate in synergistic projects
- CSULA has initiated the construction of a \$4.5 M hydrogen station on campus. It deploys the latest technologies with the production capacity of 60 kg/day, sufficient to fuel 15+ vehicles or a bus and 5 more vehicles. The station utilizes a Hydrogenics electrolyzer, first and second stage compressors capable of fast-filling at 5,000 psi and 10,000 psi, and 60 kg of hydrogen storage. The station will be grid-tied and powered by 100% renewable power. The station construction is in final stages and full operation is expected in August 2011
 - CSULA will have an NSF funded laboratory that will test purity of hydrogen.

Introduction

California State University, Los Angeles is actively engaged in variety of activities that support education and research needs of the fuel cell industry and the US economy. The educational program includes a mix of new courses or special modules in existing courses to introduce the concepts of fuel cell technologies, hydrogen and alternative fuels, alternative and renewable energy technologies as means of zero emissions hydrogen economy, and sustainable environment. CSULA established a Zero Emissions Fuel Cell and Hydrogen Laboratory (ZEFC) to support curriculum, undergraduate and graduate students' teaching and research experiences. Further, enrichment of student experiences is accomplished through projects and fostering partnerships with automotive OEMs and industry. This includes the ongoing construction of a Hydrogen fueling station on campus.

Community education and public outreach goals are met through a series of on campus and off-campus public events and demonstrations. The comprehensive nature of the university, its strategic location in the hydrogen and fuel cell abundant industrial region and a historically minority-serving charter has made CSULA one of the leading universities carrying out the tasks listed in the objectives.

Develop curriculum in hydrogen technology

The major task of the project was to develop a set of courses and modules that would comprehensively introduce students to fuel cell and hydrogen technology.

TECH 478-Fuel Cell Applications and graduate ME 554-Fuel Cell Systems were developed as courses fully dedicated to the topic of the grant.

ME 454-Renewable Energy and Sustainability, TECH 370-Power, Energy and Transportation, TECH470-Electric and Hybrid Vehicles were enhanced by adding one- and two-week modules addressing fuel cells and hydrogen infrastructure.

TECH 250-The Impact of Technology on the Individual and Society course serves as a university course open to all majors taking environmental theme. Several faculty working with the course were trained on the topic and introduce the material in one week module (about 600 students have taken the course in the duration of the course).

As part of the curriculum developed for TECH 478, Molten Carbonate Fuel Cell Project has been designed and made available on-line: http://www.calstatela.edu/faculty/blekhman/MCFC_Project.html

In preparing the project, the author collaborated with Dr. Stephen McClain, Baylor University.

Develop the Zero Emissions Fuel Cell and Hydrogen Laboratory (ZEFC)

With help of this grant CSULA established the Zero Emissions Fuel Cell and Hydrogen Laboratory. The following equipment supporting the fuel cell education was acquired: Heliocentris -- Dr. Fuel Cell, Nexa Training System Complete, Nexa Integration Kit; and Proton-Hogen GC600 Electrolyzer.

A graduate student was assigned to rewrite the manuals, creating a comprehensive set of instructions and sample calculations. The new lab manuals are related to lecture material and are designed with step-by-step procedures including detailed illustrations of DrFC modules, wiring diagrams and other items. Each lab has well-defined instructions in which students receive a brief description on the procedure and the expected fuel cell performance behavior. In two labs students obtain the electrolyzer and fuel cell's 1st law efficiency, Faraday's efficiency, performance/power curves and other parameters.

Hydrogen Safety Experiment is a self-built experiment by a four-student senior design team, see Figure 2. It is built to demonstrate hydrogen/air/oxygen mixture explosive characteristics as it compares to other explosive gases, such as methane, propane, and acetylene. The main goal is to demonstrate that other common gases are comparatively as dangerous as hydrogen but society accepts them.

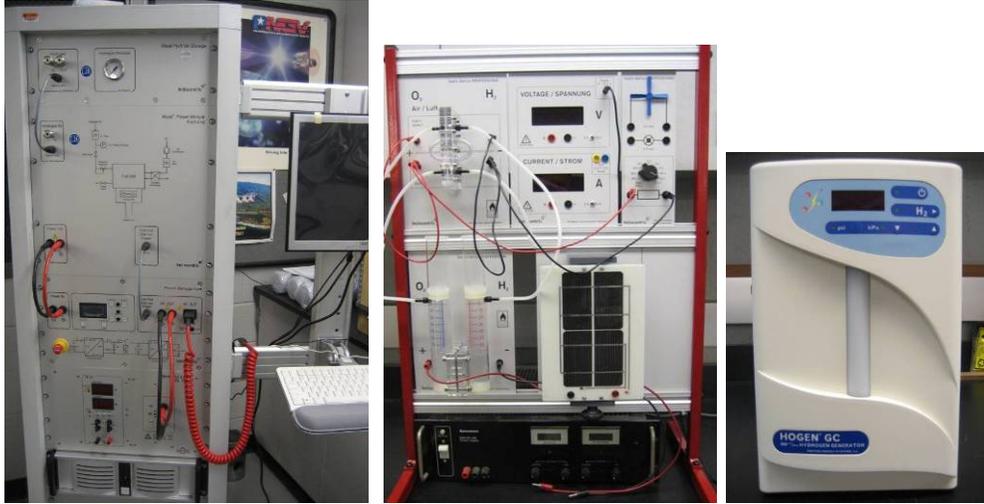


Figure 1. The Nexa Training System Complete (left). Dr. Fuel Cell test stand (right). Hogen GC 600 electrolyzer.

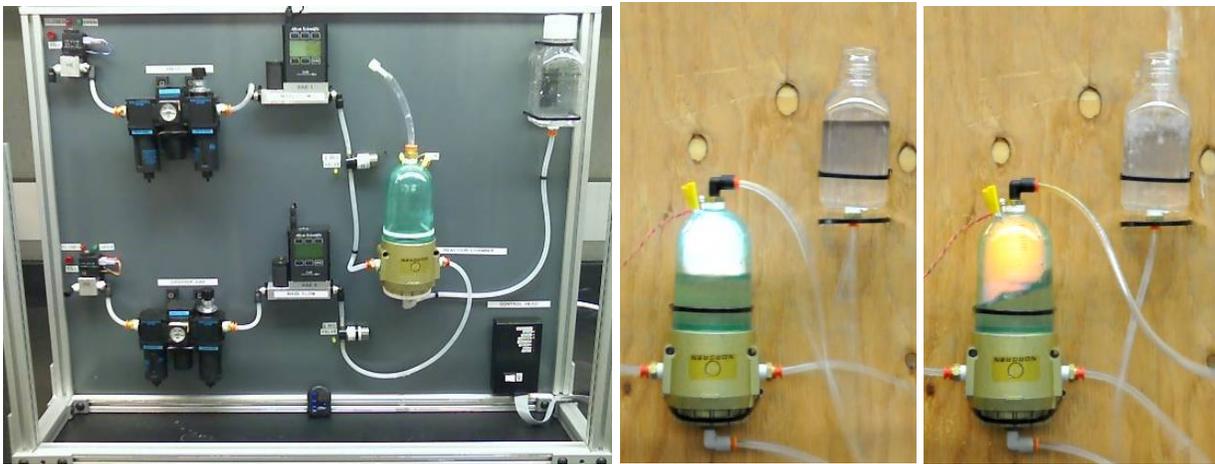


Figure 2. CSULA built Hydrogen Safety Experiment, safety shields removed (left). Gas explosions during prototype testing (middle and right).

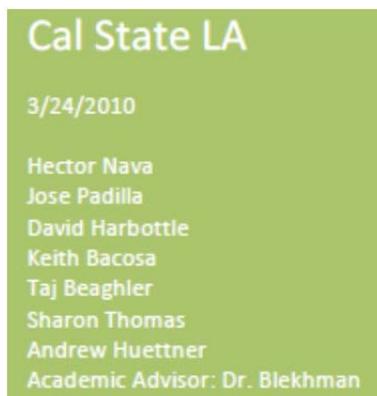
One of the last tasks completed by the project was the start-up of the CSULA solar system, see Figure 3. The system is composed of 56 Sharp and 21 Solec modules. The DC power of solar panels is converted to 3-phase AC by three SMA inverters. The system produces 5 kW AC during the peak solar hours. Part of the energy produced is used to generate sustainable hydrogen by Hogen GC600 electrolyzer for the lab needs, among which is powering student built fuel cell vehicle. The Zero Emissions designation for the laboratory is due to the hydrogen produced from solar power.



Figure 3. CSULA 6 kW Photovoltaic system.

Provide engaging student projects

CSULA students participated in 2010 and 2011 Hydrogen Design Contests organized by the National Hydrogen Association. In 2010, team of seven students completed project Soaring Eagle Hydrogen Community, 4th place. In 2011, the contest was to design a Home Hydrogen Refueling. Twelve-student team included two students from East Los Angeles College. CSULA took 7th place among 17 teams that submitted and 54 registered, 3rd place among the US teams.



A team of summer research students demonstrated the very first application of fuel cells to power LEGO Mindstorms robotic kits, see Figure 4. The project utilized Horizon's H-20 fuel cell to power the robot. We believe that is the very first application of fuel cells for powering Lego Mindstorms.

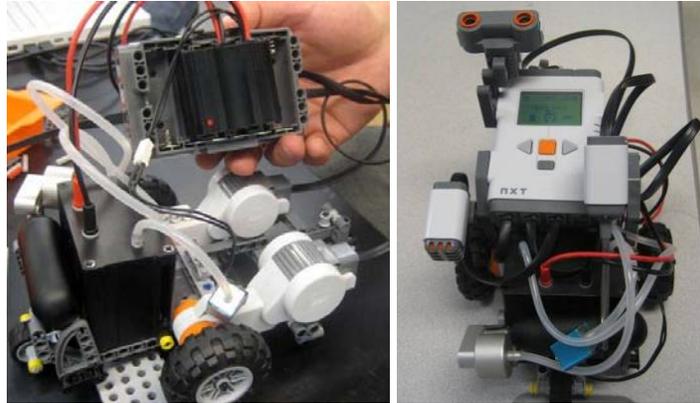


Figure 4. Horizon H-20 fuel cell is being installed on to a Lego Mindstorms vehicle platform (left) and completed robot (right).

Funded by Sempra Energy, a senior design team built a Hydrogen Dispenser Calibration Unit, which could be used to certify hydrogen stations for sale of hydrogen at 350 bar. The goal of the project is to create a calibration device for measuring the amount of H₂ dispensed by a hydrogen station to an accuracy of +/- 2% per mass and serve as the official verification standard approved by the CA Dept. of Food and Agriculture, Measurement Standards Division.

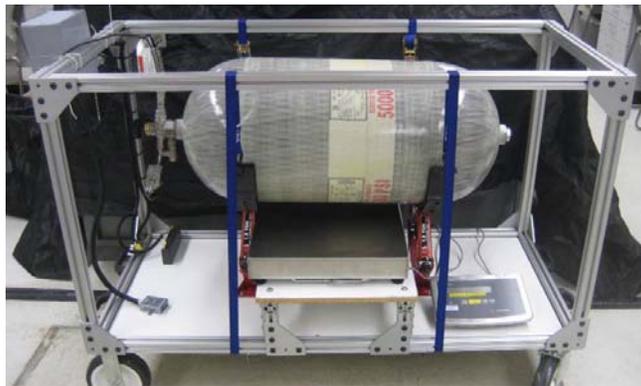


Figure 5. Hydrogen Dispenser Calibration Unit built by CSULA senior design team.

CSULA team of six students built a fuel cell vehicle using Nexa Integration Kit. The team participated in 2011 Shell-Eco competition, Houston, TX. The fuel cell vehicle called Hydrogen Super Eagle was also on display at AltCar Expo, Santa Monica 2010, October 2010, Los Angeles Auto Show, November 2010 and the Metropolitan Water District of Southern California Sustainable Expo, May 2011. The vehicle participated in filming the Mercedes-Benz F-Cell World Drive, see **Error! Reference source not found.** The multi-episode documentary is called Eco Trek and is available on YouTube. CSULA is featured in episode EcoTrek 7 (3rd minute).

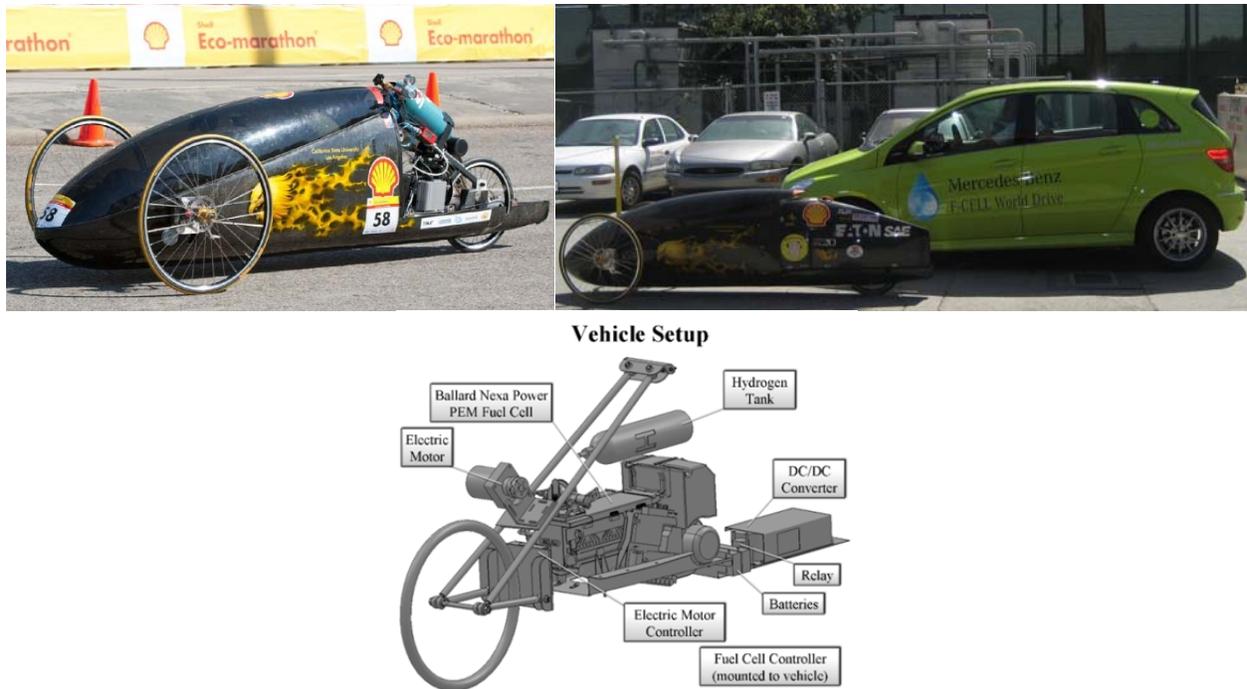


Figure 6. Hydrogen Super Eagle: CSULA built fuel cell vehicle during Shell Eco competition (top left) and again against Mercedes-Benz F-Cell World Drive car (top right); power plant and drive placement (bottom middle).

CSULA has also been selected for EcoCAR 2 Plugging into the Future competition 2011-2014. The competition main sponsors are DOE and General Motors.

Provide public outreach and foster relationships with fuel cell OEMs and other state and government officials

The PI provided leadership in collaborating with other institutions on sharing the concepts of fuel cell and hydrogen education developed through current funding at five educational institutions:

- Blekhman, D., J. Keith, A. Sleiti, E. Cashman, P. Lehman, R. Engel, M. Mann, and H. Salehfar "National Hydrogen and Fuel Cell Education Program Part I: Curriculum," 2010 ASEE Annual Conference & Exposition, Louisville, KY. ---2nd best paper in the Energy Conversion and Conservation Division
- Blekhman, D., J. Keith, A. Sleiti, E. Cashman, P. Lehman, R. Engel, M. Mann, and H. Salehfar "National Hydrogen and Fuel Cell Education Program Part II: Laboratory Practicum," 2010 ASEE Annual Conference & Exposition, Louisville, KY.

CSULA participated in numerous meetings and discussions of future projects and collaborations with fuel cell vehicle OEMs, federal and state government officials. Significant collaboration has been developed with California Fuel Cell Partnership.

CSULA has actively pursued public outreach and educational activities through which the DOE-sponsored Fuel Cell and Hydrogen curriculum at CSULA was promoted. Every fall CSULA hosts a Boeing open house for middle and high-school students. More than a hundred of them tours ZEFC lab. The ZEFC Laboratory hosted dozens of other events and student tours introducing visitors to fuel cell technologies as well as Power, Energy and Transportation Program. There were multiple additional events with K12 students being introduced to fuel cells, see Figure 7.



Figure 7. Marengo elementary school Science Night, South Pasadena, CA; a fuel cell display is demonstrated, January 2011.

Synergistic projects and activities



Figure 8. CSULA hydrogen station in construction, May 2011

CSULA is nearing the completion of a \$4.5 M hydrogen station on campus, see Figure 8. It will deploy the latest technologies with the capacity of 60 kg/day, sufficient to fuel 15+ vehicles or a bus and 5 more vehicles. The station is utilizing a Hydrogenics electrolyzer, first and second

stage compressors capable of fast-filling at 5,000 psi and 10,000 psi, 60 kg of hydrogen storage. The station will be grid-tied and powered by 100% renewable power.

Multidisciplinary team of CSULA faculty, including the PI, received NSF funding to establish Center for Energy and Sustainability. The same group has secured ARRA funding to renovate laboratory spaces including ZEFC. The PI has been awarded NSF Major Research Instrumentation funding to conduct research into hydrogen purity. The PI received Fulbright Scholarship to promote fuel cell and hydrogen economy topics at Saint-Petersburg State Polytechnic University, Russia. These will contribute to the longevity of the educational and research programs.

Conclusions

CSULA has been very successful in meeting and exceeding the objectives proposed in the grant. A comprehensive educational program was created. The work in ZEFC laboratory progressed with the solar installation that is powering the lab electrolyzer and the rest of the engineering building. Students will be continued to be challenged through industry and competition projects.

CSULA is well poised to continue fuel cell and hydrogen educational and research efforts beyond current funding. Among future activities are operating the hydrogen station, participating in EcoCAR 2 competition and testing hydrogen purity in Southern California utilizing a high-quality GCMS. CSULA will also continue outreach and collaborations with the industry.