VI.F.1 Hydrogen Filling Station*

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Proton Energy Systems, Wallingford, CT
Hydrogen Solar LLC, Henderson, NV
Altair Nanomaterials, Inc., Reno, NV

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Projected End Date: December 31, 2006
(includes Amendment No. 2)

*Congressionally directed project

Objectives

1. Design, install and analyze operation of a hydrogen generation and vehicle fueling system using solar energy
   - Enter use agreement with selected host site property owner (Las Vegas Valley Water District, LVVWD).
   - Construct infrastructure including site preparation and utilities extensions.
   - Install proven and tested low pressure hydrogen production components and operate with conventional electrical energy.
   - Convert two utility vehicles.
   - Monitor operation of the fueling system and the converted vehicles and characterize system performance.
   - Install a solar energy collection system and connect to electrical power grid.
2. Enhance the system by designing, testing and implementing a high pressure electrolysis hydrogen production and dispensing system and convert another vehicle
   - Validate high pressure electrolyzer design.
   - Install high pressure production system with booster storage skid at host site.
   - Monitor and analyze system performance data.
   - Convert one conventional pickup to be a hybrid internal combustion/fuel cell (ICE/FC; where the fuel cell is used to support the electrical load) vehicle, use it in everyday travels, and compare its various performance aspects to a conventional vehicle of the same type.
   - Consider the design of a true hydrogen ICE/FC hybrid vehicle.
3. Develop and optimize nano-crystalline thin films to maximize the efficiency of photo-catalytic reaction of sunlight to generate hydrogen at low manufacturing cost
   - Develop Tandem Cells™ technology and produce carbon-free hydrogen via sunlight splitting water pathway.
   - Innovate cost-effective technologies to achieve the DOE hydrogen cost target of $< \$3$/kg.
   - Develop new Tandem Cells™ working electrodes.
   - Conduct cell array engineering work along with enhancement of material photoelectrochemical (PEC) performance.
   - Improve cell configuration, including novel cell construction materials.
   - Test array using solar simulator and sunlight.
   - Conduct balance of plant engineering work, including modeling and simulation.
   - Optimize the solar Tandem Cells™ configuration using computational fluid dynamics (CFD) analysis and other engineering tools.
4. Perform outreach activities to constituencies
   - Organize a workshop on hydrogen codes and standards and safety.
   - Plan and carry out a roadmapping effort for hydrogen development in Nevada.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies

Program Multi-Year Research, Development and Demonstration Plan as well as issues in production and safety:

3.1.4.2.2 Hydrogen Generation by Water Electrolysis

(H) System Efficiency

(J) Renewable Integration

3.5.4.2 Technology Validation

(A) Vehicles

(C) Hydrogen Refueling Infrastructure

(H) Hydrogen from Renewable Resources

3.7.4.2 Safety, Codes and Standards

(H) Lack of Hydrogen Knowledge by Authorities Having Jurisdiction

3.8.4.1. Education

(A) Lack of Awareness

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE technology validation milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 7:** Test results from student-designed hybrid fuel cell and internal combustion engine vehicles.
  - We have accomplished this milestone with this year's work.
- **Milestone 14:** Validate $3.00/gge hydrogen cost.
  - It is uncertain whether this target can be achieved.

Accomplishments

- Components of phase I hydrogen filling station (HFS) system have been completed. Photovoltaic (PV) array configuration has been selected and is being purchased by LVVWD.
- Phase II HFS hardware (including a high pressure electrolyzer) has been developed and is currently being installed.
- An electric vehicle has been converted to a hybrid fuel cell vehicle (FCV) using an effective and relatively low-cost conversion method.
- Direct cylinder injection has been demonstrated locally and is being optimized. The application to a vehicle is underway. Plans are being developed for larger scale conversions, including a hydrogen V-8 ICE conversion with a FC for auxiliary power.
- A CFD model for understanding performance of Tandem Cells™ has been developed. Results have shown tradeoffs in performance that have been valuable in improved design directions.
- Developed the program for terminal voltage-current density and power density-current density relationships for water electrolysis.
- Proposed a photoelectrochemical model for the electrolysis process inside solar Tandem Cell™.
- An on-sun facility for evaluation of Tandem Cells™ is nearing completion. Data from this as well as from the CFD modeling, and from physical insights, are being used to develop a parametric prediction model for performance.
- Studies of balance of plant aspects for Tandem Cell™ applications have been initiated.
- Developed new substrates for Tandem Cell™.
- Demonstrated new PEC material durability for Tandem Cells™.
- Conventional pressure (200 psig) electrolysis/compression/distribution system was built, tested, and is being installed - 2 kg H_2/day.
- 1,100 psig electrolysis/compression/distribution system completely designed, built, tested, delivered. Site design completed. Site work initiated.
- 400 psig dryer design completed and hardware procurement in progress.
- A codes/standards/safety practices workshop was organized and presented for local regulatory personnel and others.
- A roadmapping workshop will take place prior to the end of this phase of the project.

Introduction

Las Vegas has one hydrogen fueling station which generates hydrogen from natural gas. The work under this project will provide another hydrogen generating and fueling station wherein the hydrogen is produced from the electrolysis of water. Initially, the energy for the electrolysis will be obtained from the conventional electric power grid. Then a solar panel array will be added to provide the energy for the electrolysis process.

Current commercial electrolyzers produce hydrogen at a pressure of 200 psig and then utilize compressors to increase the pressure to about 6,000 psig for dispensing into a vehicle storage tank. The objective of this project is to generate hydrogen at pressures approaching 2,000 psig, thus reducing the energy requirements for compression to 6,000 psig. Additionally, the energy for electrolysis will be entirely provided (or significantly augmented) by a solar energy panel array installed adjacent to the generating and fueling station. An additional focus of this project is the assistance with the development of the Tandem Cells™ to give a new approach to generation of hydrogen that promises cost savings.

A vehicle integration element is also a significant portion of this project. First, two small utility vehicles will be converted to operate on hydrogen using both fuel cell and ICE technology. Next, a full-sized ICE vehicle will be converted to hydrogen operation and comparison tested against a similar vehicle powered by natural gas. This effort supports the milestone relating to student-designed hybrid fuel cell and ICE vehicles.

Approach

The goal is to develop and demonstrate a renewable energy based compressor-free fueling station in steps and hence reduce the costs of producing hydrogen at required vehicle usage storage pressures. This year's tasks toward the goal are as follows:

- Execute final site use agreement with the LVVWD.
- Execute agreement with PV panel provider.
- Finalize and approve site infrastructure design.
- Complete site infrastructure construction.
- Test low pressure/intermediate capacity (200 psig/2 kg/day) electrolyzer and determine efficiency of the system (see Figure 1).
- Install the equipment and data acquisition system.
- Begin development of high pressure/high capacity (400 psig/12 kg/day) electrolyzer (see Figure 1).
- Convert two utility vehicles for hydrogen operation (see Figures 2 and 3).
- Design components for conversion of full-size ICE vehicle to hydrogen operation.
- Install PV panels and analyze total system performance.
- Continue work on developing and optimizing systems for direct production of hydrogen through photo-catalytic thin film methodologies including the proprietary Tandem Cells™ concept (see Figure 4).

Results

- The fueling station site use agreement was completed and the site infrastructure civil and mechanical work were completed during May 2006.
- The electrical work associated with the site infrastructure will be issued for bid by the LVVWD in July 2006.
- Simulations of several types of system operation, with the PV driver included, have been completed.
- An agreement has been signed between the LVVWD and the Arizona Public Services Co. for provision of a 14 kW solar panel array.
- The fuel cell utility vehicle conversion is complete (see Figure 2).
- The initial ICE vehicle is in the completion stages (see Figure 3).
- The low pressure electrolyzer system components have been shipped to the fueling station site and are scheduled for installation by July, 2006 (see Figure 1).
- The PV array is scheduled for installation in August, 2006.

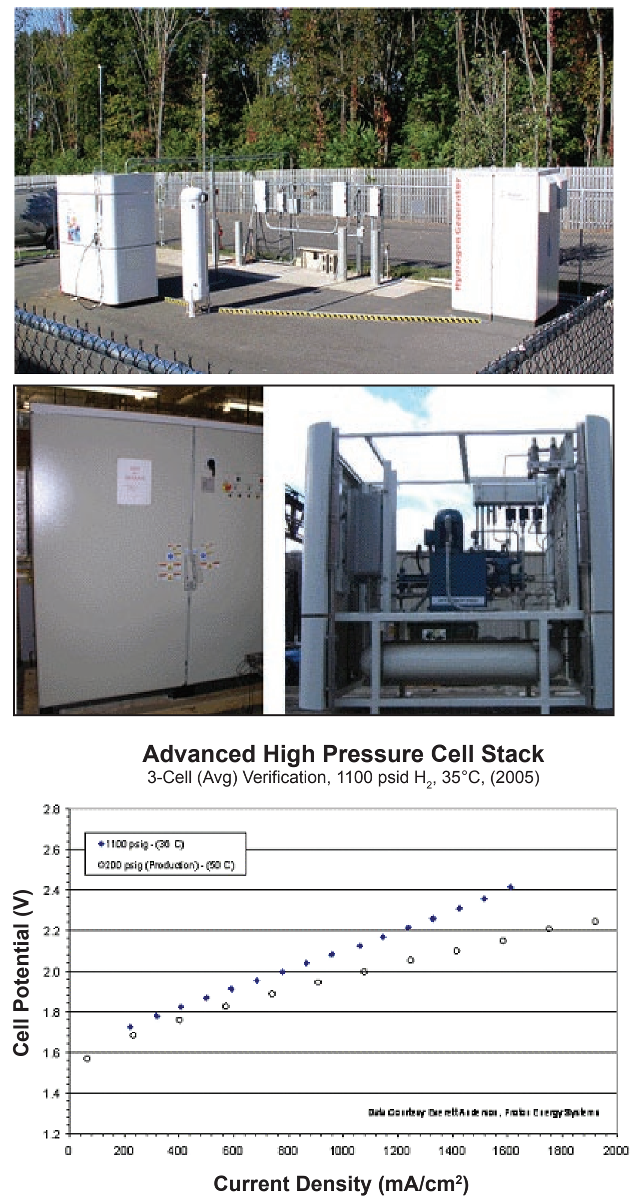

FIGURE 1. The Phase I (top) and Phase II (middle) electrolyzer units are shown. At the bottom, some characteristics of the high pressure electrolyzer are shown. The Phase I system generates hydrogen at 200 psig and stores at 6,250 psig, while the Phase II unit generates hydrogen at 1,100 psig and stores at 6,350.

- A significant CFD model has been developed to describe the influences of key parameters on the Tandem Cells™ (see Figure 4).
- The Tandem Cells™ field test array is under development.
- The initial two phases and some of the third phase will be unveiled at a ceremony at the LVVWD in the fall of this year.

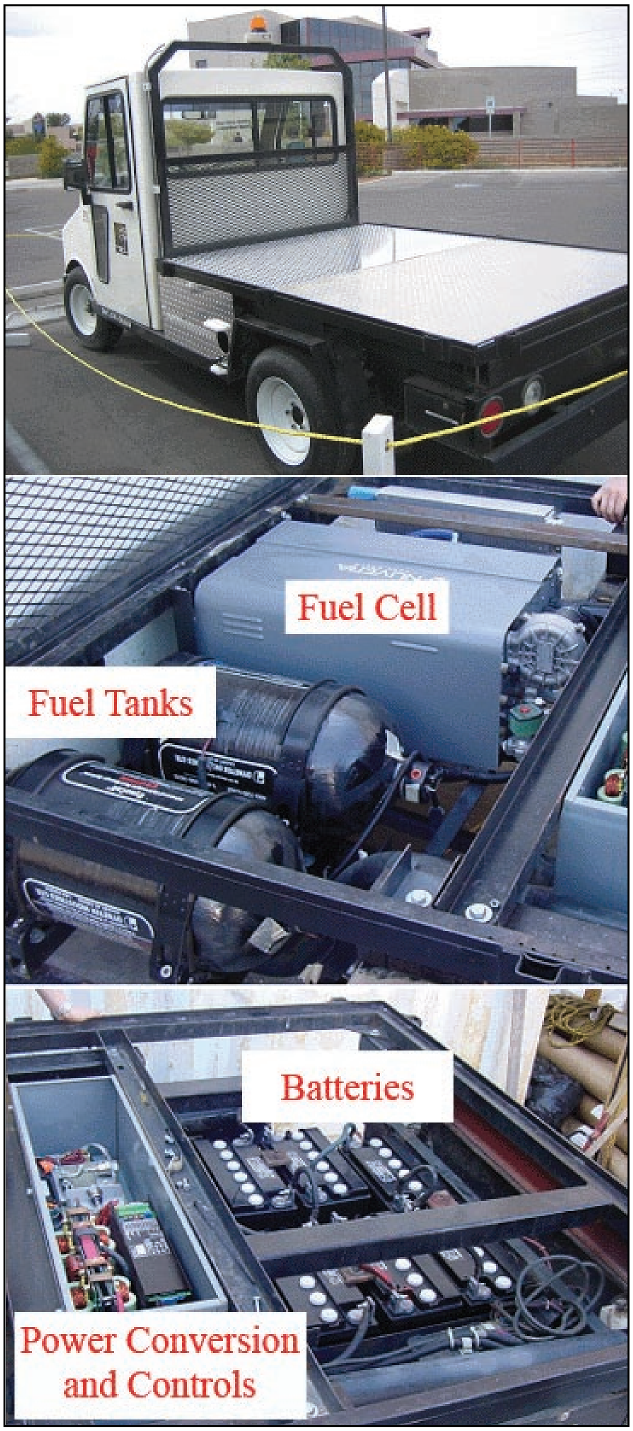

FIGURE 2. The Fuel Cell Vehicle Conversion

- A workshop covering Safety Practices and Relevant Codes and Standards for hydrogen usage, particularly oriented to local officials, has been held. People from all over the country were present, and the results are summarized on the web site: http://www.me.unlv.edu/research/cer/hydrogen_workshop.htm
- A roadmapping workshop for hydrogen development in Nevada has been organized and was given on June 20.

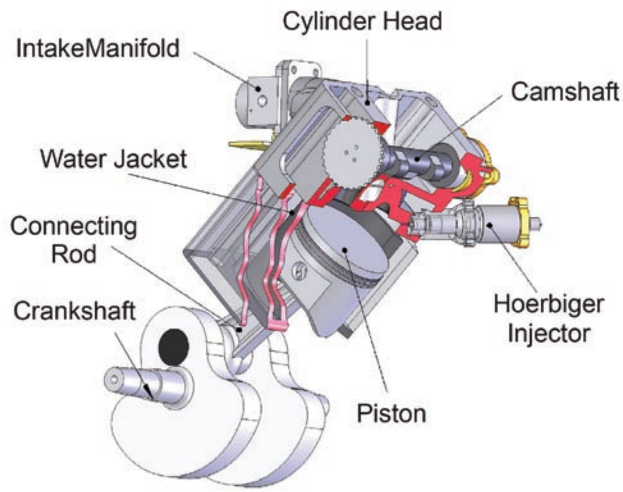

FIGURE 3. An artist's cutaway of the single-cylinder Polaris ICE that is undergoing conversion to direct injection is shown. Attached is one of the direct cylinder injector units we have been evaluating.

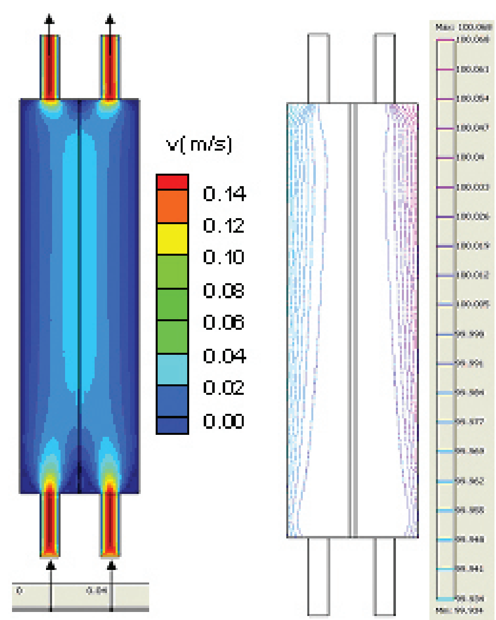

FIGURE 4. CFD results for the Tandem Cells™. The velocity field is shown on the left, and the H^+ species concentration is shown on the right.

- Approximately 12 engineering students (both graduate and undergraduates) have gained a valuable part of their education by being involved with this project.

Conclusions and Future Directions

The objectives to develop and enhance a renewable energy powered hydrogen generating and fueling station, convert vehicles to hydrogen fuel operation and conduct photoelectrochemistry (PEC) studies for the direct generation of hydrogen are being pursued. The fueling station infrastructure construction was significantly delayed due to architect-engineer slow performance. That issue has resulted in a delay of fueling station operation by four months. The ICE utility vehicle conversion was hampered by direct cylinder injector problems but is now on-track. The PEC studies and related Tandem Cells™ demonstration and testing are progressing at the anticipated rate.

The near future direction is to 1) achieve an operable hydrogen fueling station, 2) obtain performance data on a high pressure electrolyzer system, 3) demonstrate the operability and performance characteristics of two converted utility vehicles and one full-size vehicle, and 4) develop state-of-the-art photovoltaic components to allow direct generation of hydrogen from solar energy.

FY 2006 Publications/Presentations

1. R. Boehm, Y. Baghzouz, and T. Maloney, "A Strategy for Renewable Hydrogen Market Penetration," International Solar Energy Conference, Orlando, Florida, 2005.

2. R. Boehm, "Safety Approaches in UNLV Hydrogen Project," New Mexico Hydrogen Business Council, Santa Fe, New Mexico, 2006.

3. M. Popek, Y. Baghzouz, and R. Boehm, "Added Value of Hydrogen Fuel Cells in Electric Vehicles," NHA Annual Hydrogen Conference 2006, Long Beach, California.

4. R. Maldin, R. Hurt, J. Gardner, M. Popek, Y. Baghzouz, and R. Boehm, "Performance Evaluation of Fuel Cell-Battery Hybrid Vehicle," NHA Annual Hydrogen Conference 2006, Long Beach, California.

5. A. Khan, K. Dreier, N. Borland, T. Maloney, R. Boehm, Y. Baghzouz, M. Cardin, O. Chow, H. Garabedian, S. Goyette, M. Kowalski, S. Porter, E. White, "Real World Experience with Renewable Hydrogen Fueling Stations," PowerGen Renewable Energy Conference, Las Vegas, 2006.

6. S. Deshmukh and R. Boehm, "Mathematical Modeling of a Solar-Hydrogen System for Residential Applications," International Solar Energy Conference, Denver, Colorado, 2006.

7. R. Boehm, Y. Baghzouz, R. Hurt, R. Mauldin, E. Bulla, R. Fifield, and J. Gardner, "Development of a Renewably-Based Hydrogen Generation/Utilization System," International Solar Energy Conference, Denver, Colorado, 2006.

8. S. Deshmukh, Y. Baghzouz, and R. Boehm, "Design of a Grid-Connected PV System for a Hydrogen Filling Station," International Solar Energy Conference, Denver, Colorado, 2006.