IV.H.11 Hydrogen Filling Station FY 2005 Progress Report*

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Subcontractors:
UNLV Center for Energy Research, Las Vegas, Nevada
Proton Energy Systems, Wallingford, Connecticut
Altair Nanomaterials, Inc., Reno, Nevada
Hydrogen Solar LLC, Guildford, United Kingdom

Start Date: June 6, 2003
Projected End Date: December 31, 2005

**Congressionally directed project*

Objectives:

- 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).
  - 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 for hydrogen fuel use.
  - 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.
- Enhance the system by designing, testing and implementing a high pressure electrolysis hydrogen production and dispensing system:
  - Validate high pressure electrolyzer design.
  - Install high pressure production system with booster storage skid at host site.
  - Monitor and analyze system performance data.
- Develop and optimize nano-crystalline thin films to maximize the efficiency of photo-catalytic reaction of sunlight to generate hydrogen at low manufacturing cost:

- Identify and optimize best materials for photo-catalytic thin films.
- Identify and optimize methods to deposit nano-crystalline thin films on conducting substrates.
- Determine hydrogen production rate from a single solar Tandem Cell™.
- Optimize the solar Tandem Cell™ configuration.

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:

- A. Vehicles
- C. Hydrogen Refueling Infrastructure
- H. Hydrogen from Renewable Resources

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 1: Make awards to start fuel cell vehicle/infrastructure demonstration activity and for hydrogen co- production infrastructure facilities.*
  In FY 05 awards were made to: 1) design the Hydrogen Filling Station infrastructure at the host site in the city of Las Vegas, Nevada; 2) develop and optimize nano-crystalline thin films to generate hydrogen through photovoltaic processes at low manufacturing cost; 3) optimize the proprietary Tandem Cell™ configuration; and 4) manufacture the high pressure electrolyzer booster assembly.
- *Milestone 7: Test results from student designed hybrid fuel cell and internal-combustion engine vehicles.*
  A 5.5 kW fuel cell has been ordered from Nuvera Fuel Cells of Cambridge, Massachusetts. Fuel cell and battery integration issues have been analyzed. A typical vehicle driving cycle of the vehicle has been determined by measuring the instantaneous power demand with a data logger. Modifications to the vehicle are being studied for housing the fuel cell, radiator, hydrogen tank, and power converter. An accurate battery state of charge (SOC) indicator has been ordered. A computer model of the electrical system including fuel cell, battery, and DC motor, is being developed to analyze the vehicle performance under various conditions. For the internal combustion engine (ICE) conversion, an engine test stand has been constructed and configured with the engine and dynamometer. Testing will commence upon receipt of the direct injection fuel delivery component.
- *Milestone 11: Validate cost of producing hydrogen in quantity.*
  A Tandem Cell™ with higher light harvesting efficiencies to produce competitively priced hydrogen is being developed. Materials and components are in the research state.
- *Milestone 16: Demonstrate prototype energy station for 6 months.*
  A 14 kW fixed photovoltaic system layout has been designed for optimum annual energy production. Quotes for the mounting structure have been obtained and a 15 kW grid-tie inverter has been located.

Approach

- Select fueling station site and execute appropriate use permit.
- Complete site infrastructure design.
- Complete site and utilities construction and install low pressure hydrogen production system.
- Complete conversion of one battery powered vehicle and one ICE powered vehicle.

- Install photovoltaic panels and connect to grid.
- Optimize efficiency of photovoltaic collection/hydrogen production process through nano-materials research.
- Replace low pressure hydrogen production system with high pressure system.
- Collect and analyze hydrogen production, storage and dispensing data.
- Collect and evaluate converted vehicles performance data.

Accomplishments

- Completed site infrastructure design.
- Successfully tested a prototype high pressure proton exchange membrane (PEM) cell stack that produces hydrogen at 1,100 psig and 10 scfh for 200 hours. Producing hydrogen at higher pressure may eliminate the need for 1 or 2 stages of compressor and hence can help reduce the overall production cost of hydrogen.
- Successfully validated the ventilation design for hydrogen generating module. The ventilation air pressure inside the module was 0.13 inches of water column, which is adequate to meet the ventilation safety requirements of NPFA 496. This helps meet the challenge of providing a safe system.
- Oxide materials identified under preliminary investigation.
- Conductive polymers identified with low (<300°C) and high (>300°C) temperature stability.
- A computational fluid dynamics (CFD) model has been developed and initial investigations performed on Tandem Cell™ operational parameters.
- Established Altair's dedicated Hydrogen Lab infrastructure for electrode fabrication and characterization, including ultrasonic spray pyrolysis (USP) equipment.
- Achieved preferred platelet morphology (10 nm thick) of nano-crystalline iron oxide by USP at ambient pressure at 270°C and confirmed morphology by scanning electron microscope.
- Established scalable USP deposition parameters with minimal equipment engineering.
- Acquired state-of-the-art current-voltage and quantum efficiency measurement equipment for electrical characterization of photoanodes.
- Identified transparent plastic film substrate material with requisite chemical, physical, and processing properties for transition to roll-to-roll electrode fabrication.
- Ordered 5.5 kW fuel cell.
- Acquired ICE for conversion and beginning tests on dynamometer test stand.

Future Directions

- Evaluate the outdoor capability of the high pressure electrolzyer by installing the hydrogen generating module inside an outdoor enclosure.
- Evaluate the operation of the high pressure electrolyzer with booster-storage skid.
- Analyze the power requirements of the high pressure electrolzyer and the booster-storage skid.
- Integrate high-pressure electrolyzer along with booster-storage system with the dispenser from previous phase of this project.
- Test the operation of current system with dispenser.
- Establish set of standard material characterization techniques – Altair, University of Nevada Reno, UNLV, and outside labs – to evaluate nano-crystalline think film electrodes.
- Confirm relationship of particle morphology, film thickness, and composition to photocatalytic activity.

- Introduce "in-situ" variable angle spectral ellipsometry as a process control tool so that film thickness, dopant concentration, and surface morphology may be measured in real time during the electrode deposition process.
- Investigate effects of aluminum, gallium, and indium, among other p-type dopants on improving photocatalytic activity by enhancing hole mobility.
- Modify USP process by employing different metal-organic precursor to enable thin film deposition on flexible plastic films at 150°C.
- Utilize USP to coat a transparent conducting oxide layer on transparent plastic prior to depositing metal oxide semiconducting material.
- Develop low cost methods to deposit the platinum based hydrogen evolving counter-electrode and explore the use of lower cost alternative catalytic materials.
- Optimize hybrid cell configuration to ensure maximum conversion efficiency for the overall device. This includes back cell voltage matching, optimization of electrolyte composition, and long-term stability testing for the entire package.
- Investigate in-situ growth of identified nano-sized metal oxides on conductive substrates.
- Continued development of conductive polymer materials with UNLV.
- Optimization of cell configuration including electrolyte composition and gas handling and collection.
- Further development of CFD modeling with UNLV.
- Complete fuel cell and ICE vehicles conversion and testing.

Introduction

One of the most promising long-term avenues to the sustainable generation of hydrogen is through the use of renewable resources. These approaches are currently not cost effective and further work needs to be done to make them so. Another major impediment is that development of infrastructure and community familiarity with the concept of hydrogen use needs to move forward. Finally, the cost-effective means of utilizing hydrogen have generally not been economically developed. All of these issues are being dealt with in this project.

Approach

The goal of this work is to develop a platform upon which solar driven hydrogen generation is a reality. Simultaneously with this is the development of utilization technology that is cost effective. Finally, a strategy has been formulated for introduction of both in the greater Las Vegas area.

A first step in this all-encompassing goal is to develop a solar-driven electrolysis system, currently a costly approach. Issues are being addressed that might make these costs more economical. New approaches to electrolysis are being considered including high-pressure electrolyzer development and bringing Tandem Cells™ to a reality that have both the solar cell and the hydrogen generation incorporated in the same unit.

Various utilization technologies are also being addressed including the use of fuel cells and the development of a new generation of hydrogen internal combustion engines. In the latter, work is progressing on the use of direct cylinder injection of hydrogen to combat traditional issues of pre-ignition and NOx formation.

Results

Several steps have been accomplished. Included are the design and construction of the initial filling station using conventional electrolyzer technology, see Figures 1 and 2. We have been working with the host of the station (the Las Vegas Valley Water District) and the City of Las Vegas for final approvals of the proposed installation.

Work has started on advanced electrolysis approaches. Pressure elevations in PEM-based electrolyzers have been accomplished, although additional work needs to be done to bring these pressures up to target ranges. The Tandem Cells™

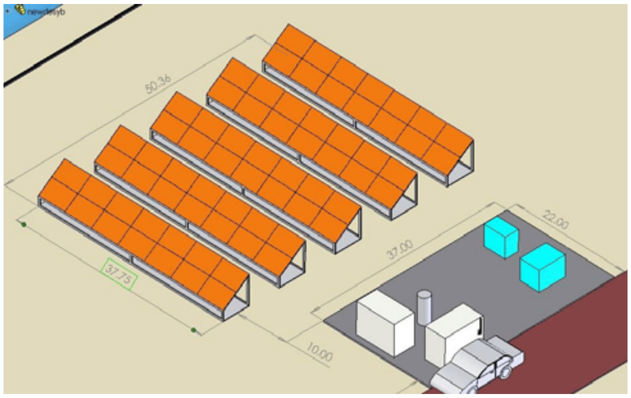

Figure 1. Artist's Conception of the Filling Station Facility at the Las Vegas Valley Water District - Two types (low pressure and high pressure) of electrolyzers are shown in blue, and the photovoltaic array is shown in orange.

Figure 2. First Stage of Filling Station Undergoing Evaluation at Proton Energy Last Winter

have been demonstrated in the laboratory using solar simulators (Figures 3). This work will be moving to a system of these cells that may be realistic for field applications, and they will be tested locally in this configuration. Computational fluid dynamic studies are being used to give insights about how this needs to be done.

Two utility vehicles are being modified to incorporate hydrogen-fueled prime movers, including one fuel-cell vehicle (Figure 4) and one ICE-driven vehicle (Figure 5). Systems have been designed preliminarily and components have been purchased, but actual evaluations of the complete designs have not yet begun.

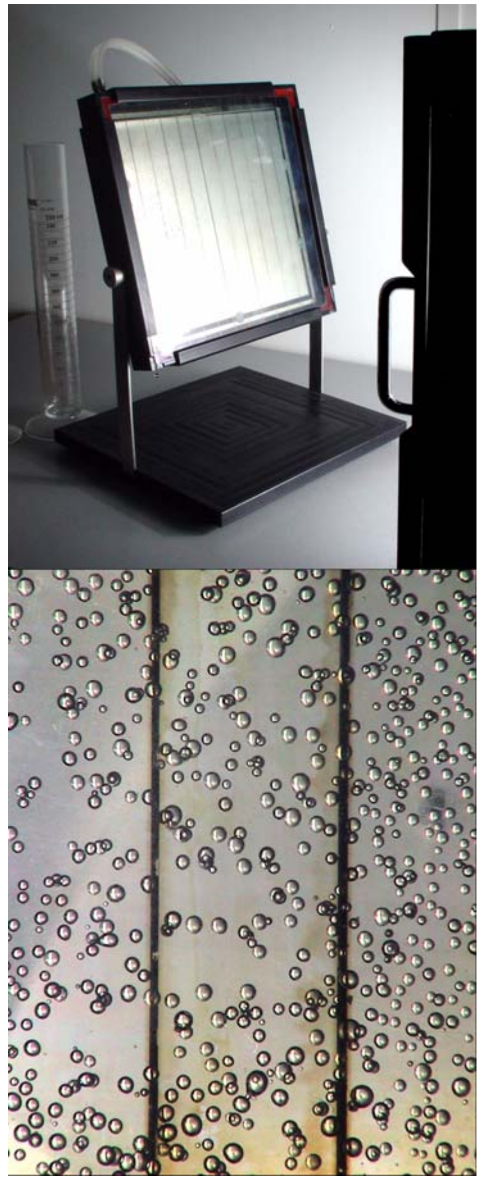

Figure 3. Photos of the Tandem Cell™ Being Illuminated in the Laboratory with a Solar Simulator Lower Photo shows Hydrogen Gas Formation.

Conclusions

Work is moving ahead on a project that addresses the sustainable use of hydrogen. A solar-powered filling station should be in place shortly, and several aspects related to advancing the technology for hydrogen generation and utilization are well underway.

Figure 4. Conversion to a Fuel Cell Vehicle Taking Place at the Las Vegas Valley Water District

FY 2005 Publications/Presentations

1. "Renewable Hydrogen Fueling Station", Poster Presentation at the 2005 DOE Program Review, May 2005.
2. R. Boehm, Y. Baghzouz, and T. Maloney, "A Strategy for Renewable Hydrogen Market Penetration.," accepted for the 2005 International Solar Energy Conference, Orlando, Florida.

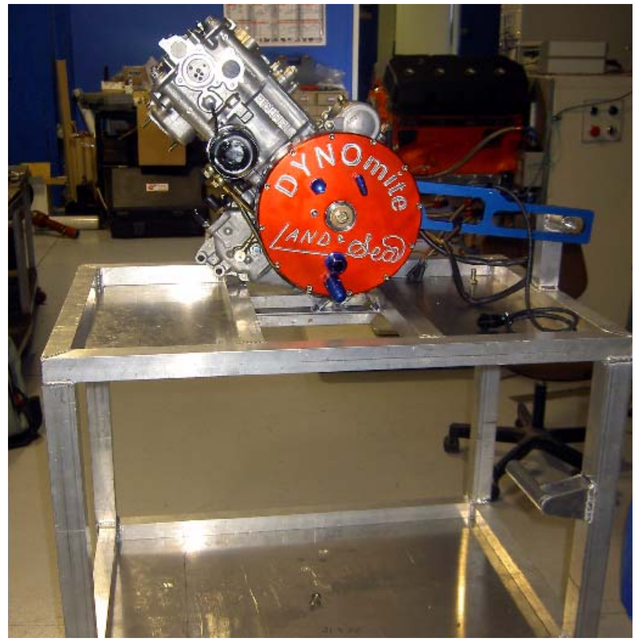

Figure 5. ICE Undergoing Modification to Hydrogen Fuel on the Dynamometer