IV.H.2 New York State Hi-Way Initiative*

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Subcontractor:
State University of New York (SUNY) at Albany – Albany, NY

Start Date: April 1, 2004
Projected End Date: December 30, 2005

**Congressionally directed project*

Objectives

- Quantify market requirements for low-cost electrolysis systems.
- Develop technical concepts to enable low-cost electrolysis.
- Explore materials and methods for high performance electrochemical cells.
- Validate key concepts in laboratory testing.
- Demonstrate a bench scale system incorporating developed concepts.
- Develop a novel hydrogen sensor concept (SUNY).
- Report conceptual design for technology validation and demonstration.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- G. Capital Cost
- J. Renewable Integration

Technical Targets

The goal of this project is to develop a low-cost alkaline electrolysis system. The relevant DOE hydrogen production targets are:

			Project	2005 Target	2010 Target
Cell Stack	Cost	\$/gge H_2	*see below	\$0.80	\$0.39
	Efficiency	%	68%	68%	76%
Electricity	Cost	\$/gge H_2	*see below	\$2.47	\$1.89
O&M	Cost	\$/gge H_2	*see below	\$0.71	\$0.38
Total	Cost	\$/gge H_2	*see below	\$4.75	\$2.85

GE is currently evaluating the cost of hydrogen for all production technologies on a consistent basis utilizing the just released H2A model. Based upon the old models and assumptions, we expect this technology to achieve \$2.85/kg.

Approach

- Quantify market requirements
- Design low-cost concept
- Analyze electrochemical cell
- Build bench scale system
- Test bench scale system
- Develop sensor technology
- Design power park concept

Accomplishments

- Set performance and cost targets for early adopter customers with available low-cost electricity.
- Designed an electrolyzer stack concept with entitlement for order of magnitude cost reduction.
- Demonstrated target performance of low-cost wire arc sprayed electrodes.
- Demonstrated low-cost stack manufacturing concept in a series of bench scale tests.
- Completed power park design concept including drawing package and 3D virtual tour.
- Completed reliability measurements and sensitivity analysis for low temperature hydrogen sensors.

Future Directions

The following work has been proposed as a continuation of the current project:

- Scale-up successful bench scale design to full size prototype stack and system design.
- Construct electrolyzer system capable of 1 kg/hr H_2 production rate.
- Gather operational and maintenance operation through long term testing of electrolyzer system.
- Assess and extend lifetime of critical electrolyzer materials.
- Integrate system with hydrogen end-use devices.

Introduction

Hydrogen may be produced from water in an electrolyzer at the point of use or sale, eliminating the need for a delivery network. The main barrier to such distributed production of hydrogen is the capital cost of the electrolysis equipment. GE has invented a low-cost electrolyzer made primarily of advanced plastics that addresses this problem. The reduced costs made possible by this new technology will make the costs of hydrogen produced on-site at a filling station competitive with the costs of delivered gasoline.

Approach

Our approach uses plastics developed by GE Advanced Materials to build a monolithic electrolyzer stack. The GE stack uses fewer parts and requires much less manufacturing time than traditional metal stacks. Electrodes made by a low-cost spraying process enable a high production rate in a comparatively small stack to further reduce costs.

After evaluating the plastic material for suitability in the hot caustic environment and performing small scale tests to determine the optimal electrode composition, we constructed a laboratory bench scale stack as a proof of concept. Testing of this stack confirmed our ability to hit the performance targets at a scale consistent with the DOE cost targets.

Results

Market Requirements

The primary commercial interest in electrolyzers is from power utilities, who wish to fully utilize power generation, transmission, and distribution assets during periods of low consumer demand. Since excess wholesale electricity is inexpensive, the primary requirement for the utility customer is low capital cost. Low maintenance costs are also important in keeping the cost of hydrogen down. The product specification for a utility customer will therefore include requirements for unattended operation with dispatch from a central location and limited planned maintenance.

The end-use of the electrolyzed hydrogen determines the target product sizes. Potentials for end-uses are:

Generator cooling hydrogen makeup skid . . . . 1 kg H_2/hr

Power parks, small renewable farming, fleet refueling . . . . .5 kg H_2/hr

Grid substation energy storage . . . 20-800 kg H_2/hr

Based on these customer needs, we are developing a product prototype at the 1 kg/hr scale which will become the modular building block for larger systems. The product prototype will be designed in accordance with the priorities of low capital cost and minimal maintenance costs.

Conceptual Design

A major component of electrolyzer stack cost is the stack structural materials and assembly labor. Taking advantage of GE's advanced materials capability, we have invented a low-cost electrolyzer stack which eliminates the cost and complexity of the traditional assembly of the cells with bolts and insulating gaskets. The GE stack module is constructed by assembling multiple cells into a single non-conductive plastic frame which also provides for internal liquid and gas passages. The frame may be constructed from individual plastic components by various joining methods or, preferably, in one piece by injection molding. A patent application on this concept was filed on April 12, 2005 with the U.S. Patent & Trademark Office.

With respect to choosing an operating point and performance targets, the market requirements indicate that high current density will be required to achieve a compact, low-cost stack. However, the electrical efficiency need not be very high as the low energy costs for this customer make the cost of hydrogen somewhat insensitive to efficiency. This tends to select a point of high current and moderate overvoltage as a target for cell performance.

In addition to the obvious effect of cell performance on energy costs, cell performance also affects capital cost. Hydrogen production rate is directly proportional to stack current, so increasing the current density allows a smaller, less costly stack to produce the required amount of hydrogen. Increasing the current density, however, reduces the efficiency of the cell and increases energy costs. For a given system, an operating point may be chosen to minimize the sum of energy and capital costs. Performance targets for the conceptual design of the scaled-up electrolyzer product are set based on an understanding of this relationship and selection of the operating point for minimum cost of hydrogen.

With respect to the balance of system costs, we have studied the projected costs of equipment such as compressors, water treatment systems and storage tanks. By taking advantage of economies of scale for systems in the 20-800 kg/hr size desired by our target customer the costs of the balance of system can be reduced to a level consistent with the overall cost of hydrogen target.

Electrochemical Cell Performance

The relationship between current and voltage in an electrochemical cell is a good indicator of its performance. The thermodynamic minimum voltage required to split water into hydrogen and oxygen at 25^{o}C and 1atm is 1.23V. The rate of hydrogen production is directly proportional to the current, and to produce hydrogen at rates of industrial interest a higher voltage must be applied to the cell. The excess voltage is determined by the overpotentials of the anode and the cathode, the electrical resistance of the solution and the electrical resistance across the membrane. The electrode overpotentials can be estimated from Tafel plots, which describe the current/potential relationship for specific electrode materials.

The excess voltage increases the power consumption of the stack and reduces its efficiency. The efficiency can be determined by the ratio of the thermodynamic voltage to the voltage necessary to achieve the required production rate. Typical alkaline electrolyzers operate at 1.8 to 2.6V, which translate to cell efficiencies of 68% and 45% respectively.

To reduce the overall cost of hydrogen we are developing electrode materials that can be manufactured at low cost and maintain high efficiency in high current density operation.

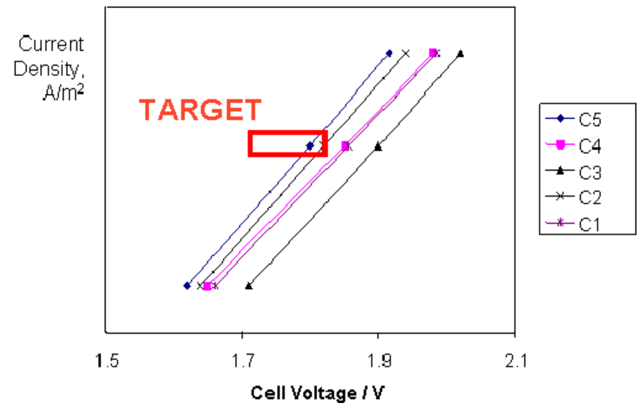

Figure 1. Electrode Composition Testing

Figure 1 shows a comparison between several electrodes of differing composition made by depositing an active layer on a base metal substrate. The active layer requires no precious metal catalysts and in full scale production its cost will approach that of the base materials bulk costs. The performance benefit comes from the deposition method and resulting microstructure, which results in an extremely high effective surface area. The C5 composition achieves the required current density at a voltage consistent with the energy cost targets.

Bench Scale System

Our design concept for low-cost manufacturing has been proven by tests on a stack of five cells embodying the monolithic plastic design described earlier. Construction costs for this first unit stack show feasibility to reach the aggressive targets we have set for full scale production. The test stand pictured in Figure 2 is capable of measuring hydrogen flow rate, temperatures and pressures at various points, and evolved gas compositions by means of an online micro GC (gas chromatograph). At present the stack operates at ambient pressure and the gases are released to atmosphere.

Tests have concluded on a 5-cell stack with electrodes comparable to the “Electrode C4” of Figure 2. Gas purity as measured by the micro GC is acceptable for safe compression, storage and use. Stack performance is stable and linear over a wide range of cell operating voltages as shown in Figure 3.

Hydrogen output rate should be directly proportional to the input current. On the graph of

Figure 3, the blue line represents input current as a function of average cell voltage and the red line represents measured hydrogen output flow as a function of the voltage. The two axes are scaled such that if the input current is fully utilized in the stack to make hydrogen, the current and flow points would be coincident. Nearly 100% of the current is making hydrogen through the entire operable range of 1.6 to 2.0 volts per cell. This indicates that shunt current losses and current collection and distribution losses are minimal. The remaining inefficiency is accounted for by the small amount of hydrogen crossing the diaphragm to the oxygen side, which is within the specification limits.

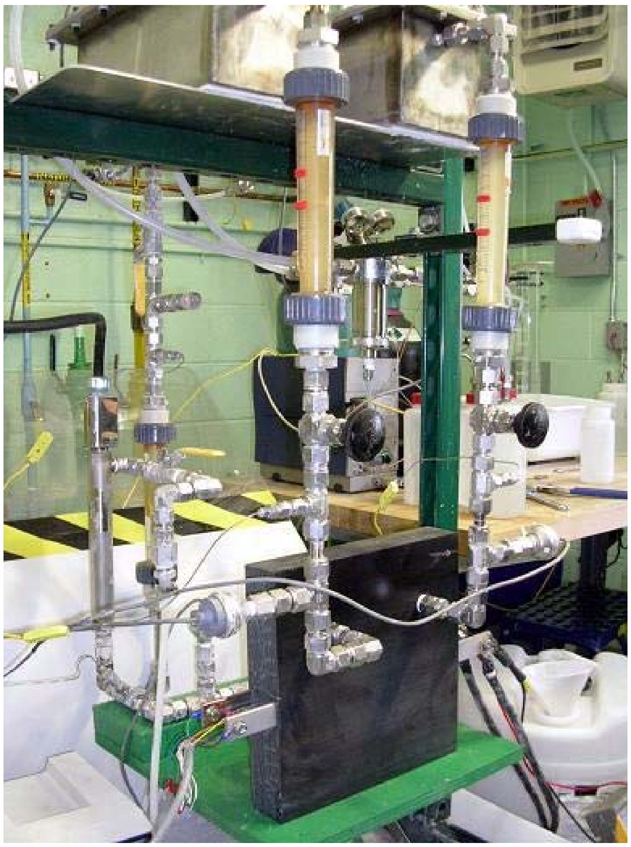

Figure 2. Bench Scale Test Stand

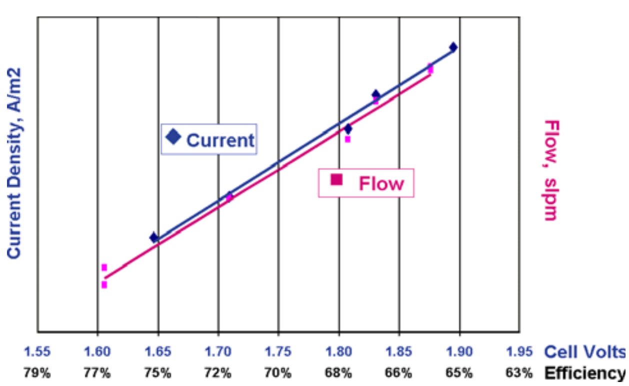

Figure 3. Bench Scale Test Results

Power Park Conceptual Design

The Conceptual Design document prepared under this contract focuses on key planning considerations required to develop turnkey hydrogen vehicle refueling or hydrogen fueled electrical generation facilities. It provides a hydrogen vehicle refueling and hydrogen fueled electrical generation reference conceptual design. The Conceptual Design document is intended to provide a referent starting point for future development of these types of facilities as well as a basis of design for engineering and planning purposes. Furthermore, it is an excellent tool for education and detailed information dissemination in support of furthering the objectives of hydrogen technology and application advancement. In support of these objectives, a 3-D virtual tour illustrating how these conceptual designs could be applied to a highway service facility will be provided.

Hydrogen Sensor Development

Reliability measurements of the low temperature hydrogen sensor have been completed, as has an analysis of sensitivity measurements in the presence of air, CO, and background humidity. A manuscript detailing the results was accepted for publication by *Sensors and Actuators B* in March 2005. We have also completed initial measurements and analysis of data for the high temperature hydrogen sensor based on YSZ-Pd/PdO. A manuscript reporting on this work was accepted for publication by the Journal of Applied Physics in April 2005.

Conclusions

- There is a need for low capital cost hydrogen electrolysis equipment in the electric utility industry. These customers represent early adopters of the technology in advance of a full-scale hydrogen economy.
- The GE electrolyzer has demonstrated the ability to reach the DOE distributed hydrogen cost target.

- The next logical step for the project is to scale-up to a product prototype capable of serving the needs of early adopters.

Special Recognitions & Awards/Patents Issued

1. Patent Pending: Monolithic Multicell Electrolysis Stack

FY 2005 Publications/Presentations

1. Quarterly Progress Report for DOE HFCIT, 1st Quarter 2005
2. Zhou, Z. and Carpenter, M.A. :"Annealing Advanced Hydrogen Absorption in Nanocrystalline Pd/Au Sensing Films"; Journal of Applied Physics 97, 124301 (2005)
3. Zhou, Z. *et. al*: "All Optical Hydrogen Sensor Based On a High Alloy Content Palladium Thin Film"; Sensors and Actuators B, March 2005