

VIII.5 Validation of an Integrated Hydrogen Energy Station

Edward C. Heydorn
Air Products and Chemicals, Inc.
7201 Hamilton Blvd.
Allentown, PA 18195
Phone: (610) 481-7099
E-mail: heydorec@airproducts.com

DOE Technology Development Manager:
John Garbak
Phone: (202) 586-1723
E-mail: John.Garbak@ee.doe.gov

DOE Project Officer: Jim Alkire
Phone: (303) 275-4795
E-mail: James.Alkire@go.doe.gov

Contract Number: DE-FC36-01GO11087

Subcontractor:
FuelCell Energy, Danbury, CT

Project Start Date: September 30, 2001
Project End Date: March 31, 2011

Objectives

Demonstrate the technical and economic viability of a hydrogen energy station using a high-temperature fuel cell designed to produce power and hydrogen.

- Complete a technical assessment and economic analysis on the use of high-temperature fuel cells, including solid oxide and molten carbonate, for the co-production of power and hydrogen (energy park concept).
- Build on the experience gained at the Las Vegas Hydrogen Energy Station and compare/contrast the two approaches for co-production.
- Determine the applicability of co-production from a high-temperature fuel cell for the existing merchant hydrogen market and for the emerging hydrogen economy.
- Demonstrate the concept at a suitable site with demand for both hydrogen and electricity.
- Maintain safety as the top priority in the system design and operation.
- Obtain adequate operational data to provide the basis for future commercial activities, including hydrogen fueling stations.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section (3.5.4) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- (C) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data
- (I) Hydrogen and Electricity Co-Production

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 Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 37:** Demonstrate prototype energy station for 6 months; projected durability >20,000 hours; electrical energy efficiency >40%; availability >0.80. (4Q, 2008)
- **Milestone 38:** Validate prototype energy station for 12 months; projected durability >40,000 hours; electrical energy efficiency >40%; availability >0.85. (1Q, 2014)

Accomplishments

- Completed shop validation test of hydrogen energy station at FuelCell Energy's facility in Danbury, CT, including >7,000 hours of integrated operation, producing 2 to 4 kilograms per hour of hydrogen (total in excess of 2,350 kilograms of hydrogen) and >200 kW-net alternating current (AC) power, and performing a 7-day continuous operation test. Fuel used was pipeline natural gas.
- Operated Hydrogen Energy Station on simulated digester gas by addition of carbon dioxide to the methane supply. System performance matched predictions for power and hydrogen production. Verified ability to switch between anaerobic digester gas and natural gas.
- Developed operating map (cycle time vs. feed rate) for hydrogen pressure swing adsorption (PSA) system.
- Tested and validated programming for automated integration and de-integration of PSA system from fuel cell and anode exhaust gas processing skid.
- Ordered new fuel cell stack for 3-year demonstration program at Orange County Sanitation District (OCSD), with funding also

- provided by CA Air Resources Board and South Coast Air Quality Management District.
- Began packaging hydrogen energy station for shipment to OCSD.
- Extended DOE cooperative agreement to 31 March 2011, with additional funding toward procurement of fuel cell stack for operation at OCSD.



Introduction

One of the immediate challenges in the development of hydrogen as a transportation fuel is finding the optimal means to roll out a hydrogen-fueling infrastructure concurrent with the deployment of hydrogen vehicles. The low-volume hydrogen requirements in the early years of fuel cell vehicle deployment make the economic viability of stand-alone, distributed hydrogen generators challenging. A potential solution to this “stranded asset” problem is the use of hydrogen energy stations that produce electricity in addition to hydrogen. To validate this hypothesis, a four-phase project is being undertaken to design, fabricate and demonstrate a high-temperature fuel cell co-production concept. The basis of the demonstration will be a FuelCell Energy DFC[®]-300 Molten Carbonate Fuel Cell modified to allow for the recovery and purification of hydrogen from the fuel cell anode exhaust using an Air Products-designed hydrogen purification system.

The DFC[®] technology is based on internal reforming of hydrocarbon fuels inside the fuel cell, integrating the synergistic benefits of the endothermic reforming reaction with the exothermic fuel cell reaction. The internal reforming of methane is driven by the heat generated in the fuel cell and simultaneously provides efficient cooling of the stack, which is needed for continuous operation. The steam produced in the anode reaction helps to drive the reforming reaction forward. The hydrogen produced in the reforming reaction is used directly in the anode reaction, which further enhances the reforming reaction. Overall, the synergistic reformer-fuel cell integration leads to high (~50%) electrical efficiency.

The baseline DFC[®] power plant (electricity only) is designed to operate at 75% fuel utilization in the stack. The remaining 25% of fuel from the anode presents a unique opportunity for low-cost hydrogen, if it can be efficiently recovered from the dilute anode effluent gases. The recovery and purification of hydrogen from the anode presents several challenges:

- The anode off-gas is a low-pressure, high-temperature gas stream that contains ~10% hydrogen by volume.
- The anode exhaust stream must be heat integrated with the fuel cell to ensure high overall system efficiency.
- The parasitic power used for purification must be optimized with the hydrogen recovery and capital cost to enable an economically viable solution.

Approach

A hydrogen energy station that uses a high-temperature fuel cell to co-produce electricity and hydrogen will be evaluated and demonstrated in a four-phase project. In Phase 1, Air Products completed a feasibility study on the technical and economic potential of high-temperature fuel cells for distributed hydrogen and power generation. As part of the Phase 1 analysis, three different high-temperature fuel cells were evaluated to determine the technology most suitable for a near-term demonstration. FuelCell Energy’s DFC[®]-300 technology was selected for concept development. In Phase 2, a process design and cost estimate were completed for the hydrogen energy station that integrates the high-temperature fuel cell with a PSA system selected and designed by Air Products. Economics were developed based on actual equipment, fabrication, and installation quotes as well as new operating cost estimates. High-level risks were identified and addressed by critical component testing. In Phase 3, a detailed design for the co-production system was initiated. The system was fabricated and shop tested. Prior to shipping to the field, the entire system was installed at FuelCell Energy’s facility in Danbury, CT for complete system check-out and validation. In Phase 4, the system will be operated on municipal waste water derived biogas at OCSD, Fountain Valley, California, under a 3-year project. DOE will receive 6 months of data from the initial operating phase to validate the system versus DOE and economic performance targets.

Results

Figure 1 shows the process flow diagram for the hydrogen energy station. Methane (in this case, from natural gas) is internally reformed at the fuel cell anode to hydrogen and carbon dioxide. The fuel cell operates near 600°C and uses molten carbonate electrolyte as the charge carrier. Heated air is combined with the waste gas from the hydrogen purification system and oxidized. These resultant waste gases are fed to the cathode. The fuel cell cathode converts waste gas carbon dioxide to the carbonate charge carrier to complete the fuel cell circuit. The fuel cell stack generates direct current voltage, which is then converted to AC by an inverter in the electrical balance of plant. The system produces 480 VAC, 60 Hz, and a nominal 300 kW without hydrogen co-production. Excess carbon dioxide and

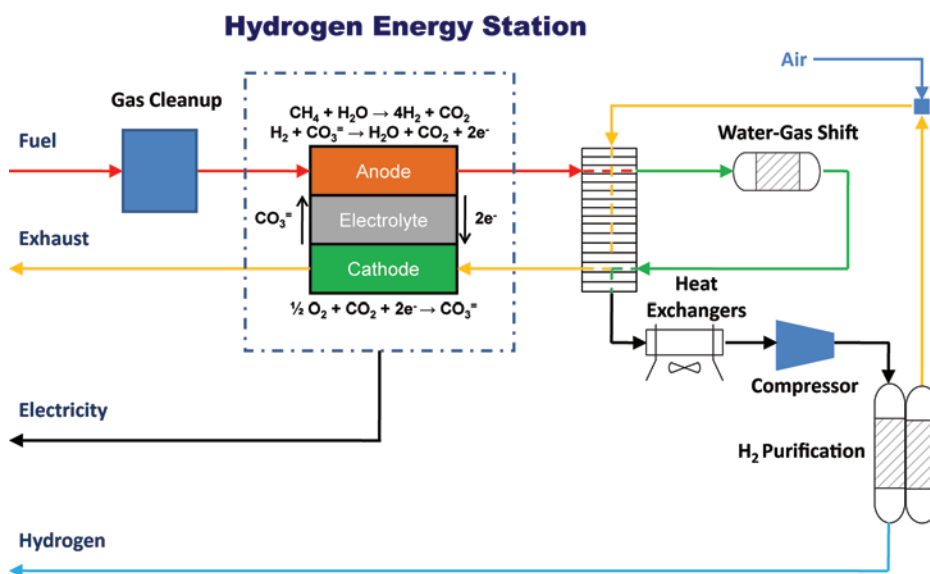


FIGURE 1. Hydrogen Energy Station Process Flow Diagram

water leave the cathode as exhaust, and heat can be recovered from these exhaust gases.

About 70 to 80% of the hydrogen is converted to power, and some hydrogen remains available for recovery. The anode exhaust gas is cooled and sent to a water-gas shift catalytic reactor to convert most of the carbon monoxide present in the stream to hydrogen and carbon dioxide. After an additional cooling step, this gas stream is then compressed and sent to the PSA system. The PSA uses adsorbents to remove carbon monoxide, carbon dioxide, and water to produce a high-purity hydrogen stream. The waste gas from the PSA is catalytically oxidized and returned to the cathode. The PSA system can also be placed in stand-by mode to stop hydrogen production and allow for maximum power production by the DFC[®] system, thereby improving the system efficiency and economics.

In late 2008, the hydrogen energy station was installed at FuelCell Energy’s facilities in Danbury, CT for a system check-out and validation of performance on natural gas. A photograph of the hydrogen-ready DFC[®]300 is provided in Figure 2, and a photograph of the anode exhaust processing and hydrogen purification system is provided in Figure 3. This testing had several key objectives, including the demonstration of variable production of both electricity and hydrogen, optimization of the process control system and overall controls philosophy, and testing and development (if needed) of systems that respond to upset conditions.

Figure 4 shows the main results of the shop validation test of the hydrogen energy station. During initial testing in March/April 2009, the system was operated in hydrogen coproduction mode for the first time; in order to better understand the dynamics



FIGURE 2. Hydrogen-Ready DFC[®]-300 Fuel Cell

and interaction of the fuel cell with the PSA system, limitations were placed on the rate of change in key control parameters surrounding the extraction and processing of anode exhaust gas from the DFC[®]300. Programming was then added to the control system to further automate the Hydrogen Energy Station to allow for unattended operation, and the process was restarted in July 2009. The operation and control of the system, including automated integration and de-integration of the PSA from the balance of plant, was excellent.

The feed gas to the fuel cell was then modified by the addition of sufficient carbon dioxide to simulate the anticipated concentration in anaerobic digester gas. The system performed well, and the map for cycle time as a



FIGURE 3. Hydrogen Energy Station Anode Exhaust and Hydrogen Purification Systems

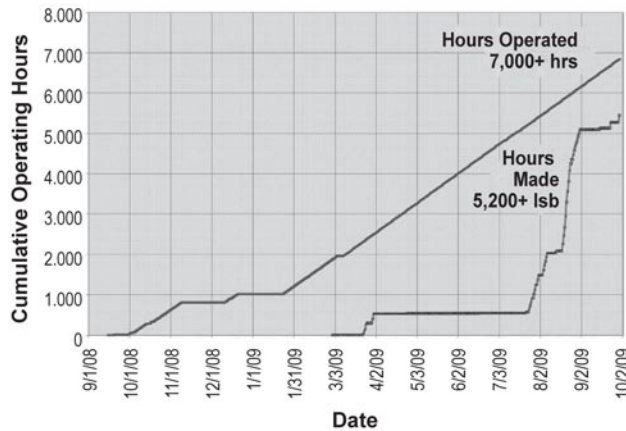


FIGURE 4. Hydrogen Energy Station Shop Validation Results (2008/2009)

function of feed gas flowrate was developed. The design hydrogen production rate (2 to 4 kilograms per hour) and purity (less than 0.2 parts per million by volume (ppmv) carbon monoxide and less than 2 ppmv carbon dioxide) were achieved at all operating conditions tested during the Danbury phase of the project.

Conclusions and Future Direction

- The shop validation test for the hydrogen energy station was completed during the reporting period. Excellent results were achieved that met or exceeded the expected performance of the unit.
- The hydrogen energy station is being shipped to OCS. Following installation and commissioning, operation will begin on natural gas to compare performance with the results of the shop validation test. Digester gas from the wastewater treatment facility will then be introduced to the system to demonstrate the production of renewable electricity and hydrogen. The hydrogen fueling station (sized at 100 kilograms per day) and a gas cleanup skid to remove contaminant species such as sulfur from the anaerobic digester gas supply will be installed under a second DOE project (Cooperative Agreement No. DE-FC36-05GO85026).
- The current DOE project includes operation of the Hydrogen Energy Station for up to 6 months.

FY 2010 Publications/Presentations

1. Presentation at 2009 FuelCell Seminar, Palm Springs, CA, November 2009.
2. Presentation at DOE-NREL Renewables-to-Hydrogen Workshop, Palm Springs, CA, November 2009.
3. Presentation at IPHE Meeting, Washington, D.C., December 2009.
4. Paper and Oral Presentation at ICEPAG 2010, Costa Mesa, CA, February 2010.
5. Presentation at the DOE Annual Merit Review Meeting, Washington, D.C., June 2010.