VIII.6 Validation of an Integrated Hydrogen Energy Station

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Subcontractor:
FuelCell Energy, Danbury, CT

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Projected End Date: March 31, 2010

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 H2 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 Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(C) Hydrogen Refueling Infrastructure

(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 Hydrogen, Fuel Cells and Infrastructure 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 installation of fuel cell and anode exhaust skid for shop validation test at FuelCell Energy's facility in Danbury, CT, and completed >4,000 hours of integrated operation.
- Completed fabrication and installation of hydrogen purification equipment at FuelCell Energy.
- Completed commissioning and start-up of hydrogen energy station equipment and full integration of fuel cell with hydrogen purification system.
- Successfully demonstrated >84 hours of unattended hydrogen production.
- Air Products executed a grant agreement with California Air Resources Board to support the existing DOE project and to add a new 100 kilogram per day fueling station to provide renewable hydrogen to fuel cell vehicles; the system will be installed and operated for three years at Orange County Sanitation District in Fountain Valley, CA. The board of South Coast Air Quality Management District has also approved funding into the project.

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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 electric DFC® 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 recovered from the dilute anode effluent gases. The recovery and purification of hydrogen from the anode presents several challenges:

1. The anode off-gas is a low-pressure, high-temperature gas stream that contains ~10% hydrogen by volume.
2. The anode exhaust stream must be heat integrated with the fuel cell to ensure high overall system efficiency.
3. 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 pressure-swing adsorption (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 will be fabricated and shop tested. Prior to shipping to the field, the entire system will be installed at FuelCell Energy's facility in Danbury, CT for complete system check-out and validation. In Phase 4, the system will be operated for a desired period of 6 months. Data from the operations phase will be used 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 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 a direct current voltage, which is then converted to alternating current (AC) by an inverter in the electrical balance of plant (E-BOP). The system produces 480 VAC, 60 HZ, and a nominal 300 kW without hydrogen production. Excess carbon dioxide and 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

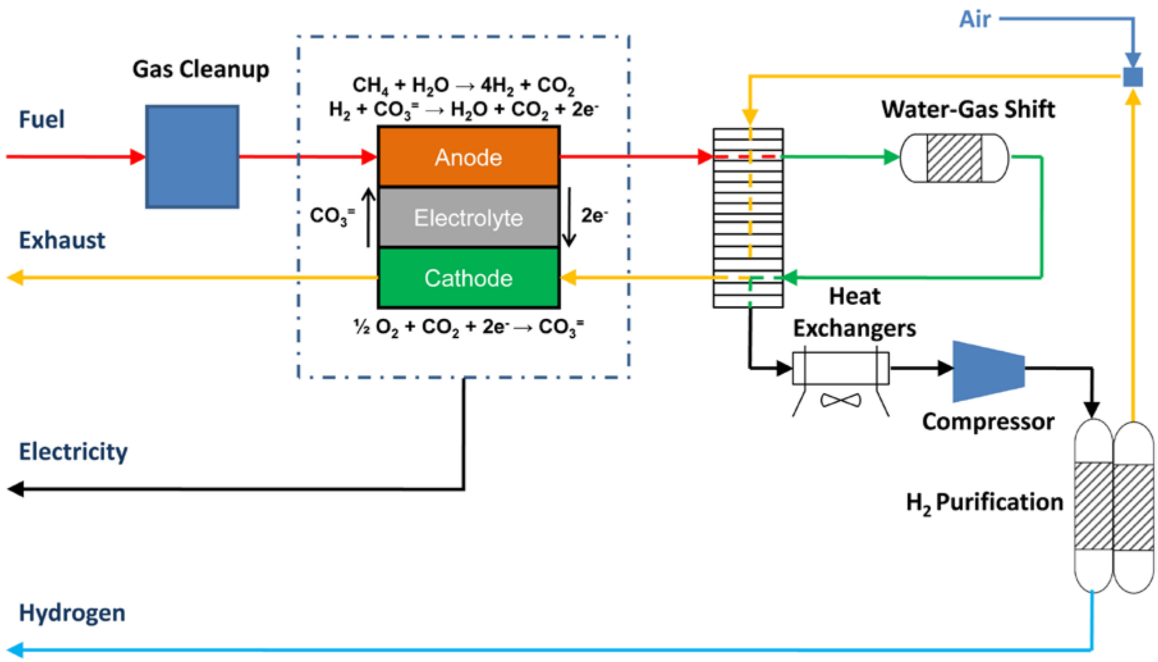

FIGURE 1. Hydrogen Energy Station Process Flow Diagram

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 DFC®300 is provided in Figure 2, and a photograph of the anode exhaust processing and hydrogen purification system is provided in Figure 3.

The hydrogen-ready DFC®300 fuel cell was installed and brought onstream first, and stable operation at varying loads up to 200 kW-net AC was achieved. Procedures were developed for startup, shutdown and upset conditions during this operability test. The fuel cell was then integrated with the anode exhaust gas system, which includes the water-gas shift reactors and gas cooling systems. The hydrogen purification system was bypassed during this period to integrate this equipment with the fuel cell. During testing, the content of carbon monoxide exiting the reactors achieved the design target of less than 0.5 vol%, and hydrogen concentration was increased from 18 vol% to 29 vol%.

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

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

The final step of the shop validation test was in the integration of the hydrogen purification equipment. The technical challenges during this operation are (1) the minimization of pressure fluctuations during the return of tail gas from the PSA system and (2) the need for continuous flow of CO_2-containing gas to the cathode of the fuel cell in order to maintain the continuity of the electrical circuit. Through mid-March 2009, the hydrogen energy station has been operated at 50% electrical load, and purified hydrogen has been produced from the PSA system.

Air Products was selected under California Air Resources Board Solicitation 06-618, "Establish Demonstration Hydrogen Refueling Stations," to install a renewable-based hydrogen fueling station and cleanup system for anaerobic digester gas at Orange County Sanitation District (OCSD) in Fountain Valley, CA. Hydrogen will be produced utilizing the hydrogen energy station. Figure 4 shows the integration of the hydrogen energy station with the existing water treatment facility at OCSD. 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).

Conclusions and Future Direction

Planned future work includes:

- Complete the shop validation test of the hydrogen energy station. Additional operation on natural gas will be performed to generate data at higher production rates and to automate the integration and de-integration of the hydrogen purification system from the fuel cell. Testing on a simulated digester gas stream will also be performed to obtain baseline performance.
- Ship the hydrogen energy station to OCSD. Operation will begin on natural gas to compare performance with the results of the shop validation test. Digester gas will then be introduced to the system to demonstrate the production of renewable electricity and hydrogen and to supply the hydrogen fueling station.
- The current DOE project includes operation of the hydrogen energy station for up to 6 months.

FY 2009 Publications/Presentations

1. Presentation at the "Future is Green" Conference sponsored by the California Air Pollution Control Officers Association, Long Beach, CA, September 2008.

2. Presentation at National Hydrogen Association Fall Forum on Renewable Hydrogen, Golden, CO, September 2008.

3. Presentation at Fuel Cell Seminar 2008, Phoenix, AZ, October 2008.

4. Panel presentation at DOE-EERE Workshop on Integration of Stationary Fuel Cells in Transportation Fuel Cell Applications, Phoenix, AZ, October 2008.

5. Presentation at National Hydrogen Association 2009 Conference, Columbia, SC, April 2009.

6. Presentation at the DOE Annual Merit Review Meeting, Arlington, VA, May 2009.

7. Presentation at Canadian Hydrogen Fuel Cell Conference 2009, Vancouver, CN, June 2009.

8. Presentation at DOE Trigeneration Workshop at UC Irvine and ASME International Conference, Newport Beach, CA, June 2009.

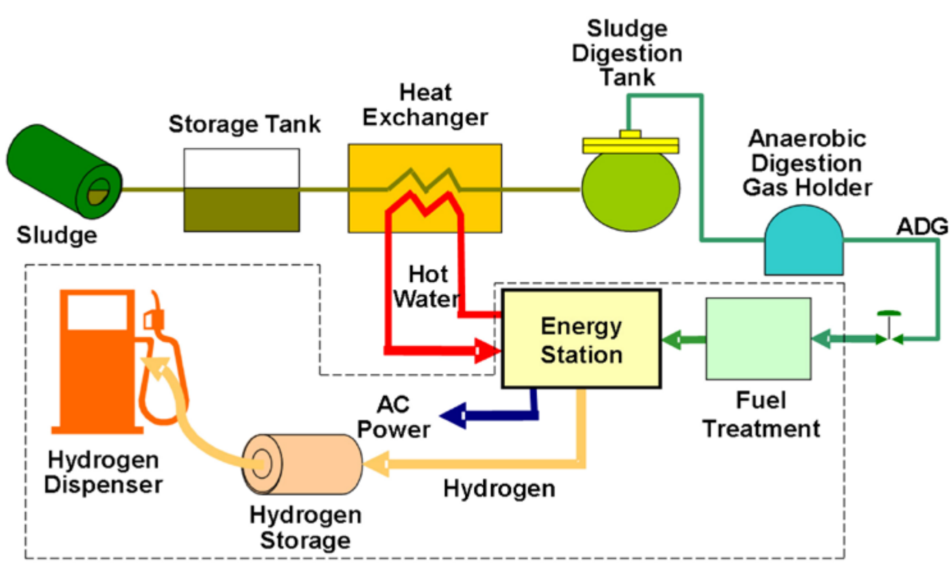

FIGURE 4. Hydrogen Energy Station Demonstration at Orange County Sanitation District