VII.4 Validation of an Integrated Hydrogen Energy Station

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Subcontractor:
FuelCell Energy, Danbury, CT

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

Fiscal Year (FY) 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 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 Fuel Cell 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 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)

FY 2011 Accomplishments

- In July 2010, the Hydrogen Energy Station was shipped from FuelCell Energy's facility in Danbury, CT, to Orange County Sanitation District (OCSD) in Fountain Valley, CA. System installation and tie-ins were completed in August, and first low-load power production from the high-temperature fuel cell unit took place on 13 September 2010. On 20 September 2010, the fuel cell operated for the first time at full load (300 kW) on natural gas feedstock.
- The first coproduction of hydrogen from the Hydrogen Energy Station took place on 20 October 2010.
- Over 1,000 hours of operation in power and (power + hydrogen) modes was completed during the performance period. Hydrogen quality met all performance standards.
- Achieved nominal 54% (power + hydrogen) efficiency of the unit when operating in hydrogen co-production mode.
- On 25 February 2011, the first hydrogen from the Hydrogen Energy Station was sent to the hydrogen fueling station. Initial test fills of fuel cell vehicles at the hydrogen fueling station were completed on 08–10 March 2011.
- The DOE Cooperative Agreement was extended to 30 September 2011.

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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 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 pressure swing adsorber (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 program with the California Air Resources Board, with co-funding by the South Coast Air Resources Board. DOE will receive six 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 a direct current voltage, which is then converted to alternating current (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 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 and simulated digester gas. 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

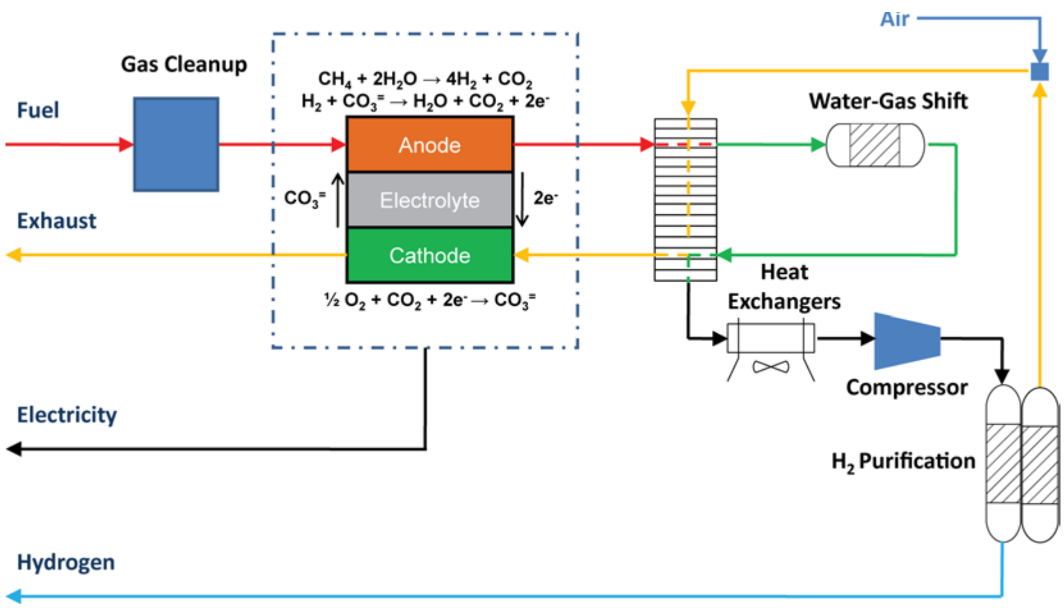

FIGURE 1. Hydrogen Energy Station Process Flow Diagram

upset conditions. The operation and control of the system, including automated integration and de-integration of the PSA from the balance of plant, was excellent.

In June 2010, the Hydrogen Energy Station was disassembled and prepared for shipment from Danbury, CT to the Orange County Sanitation District wastewater treatment plant in Fountain Valley, CA. The system was delivered in early July, and installation and tie-in work was completed in August 2010. A photograph of the installation at OCSD is provided in Figure 2. Following commissioning activities, the DFC®-300 was brought online on 13 September 2010, and full-load operation on natural gas was achieved on 20 September 2010.

The hydrogen purification system was then commissioned, and initial co-production of hydrogen from the Hydrogen Energy Station on natural gas at OCSD

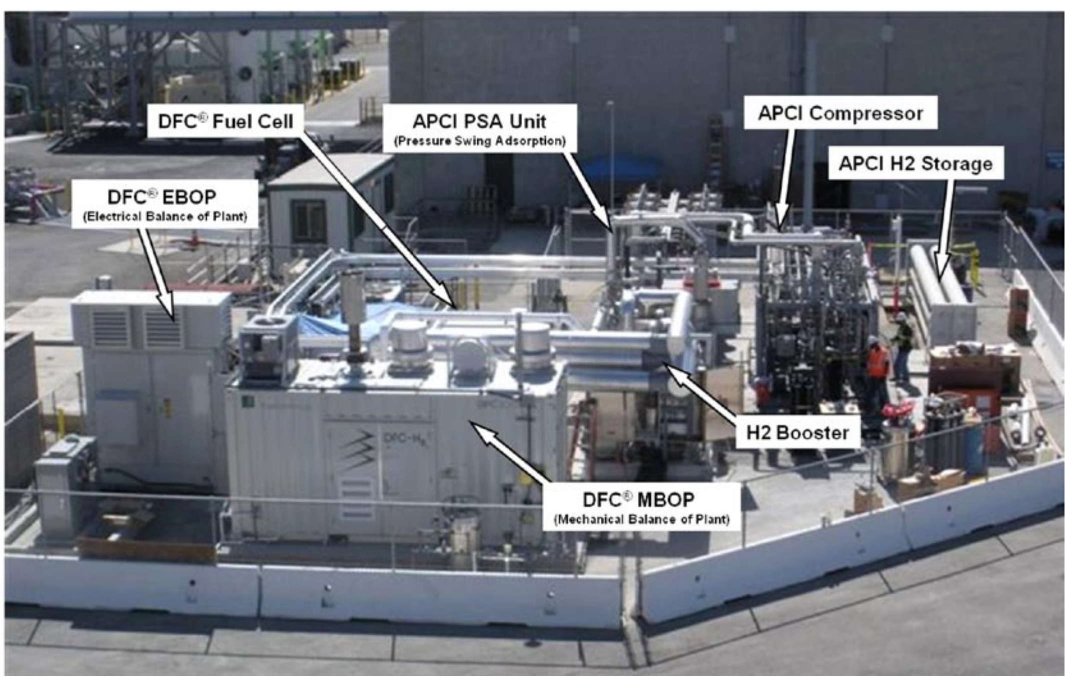

FIGURE 2. Hydrogen Energy Station Installation at Orange County Sanitation District

occurred on 20 October 2010. A heat and material balance was performed during this initial operating period, and a (power + hydrogen) efficiency of 54.5% was calculated. A summary of the heat and mass balance is provided in Figure 3.

Following this initial operating performance, power quality issues associated with the local grid within the wastewater treatment plant were identified. The power conditioning unit/inverter associated with the fuel cell showed unusual behavior in its ability to connect with the local grid, and changes were required to match the highly inductive power factor (0.6 to 0.8) and larger voltage sags (5-10%). On 14 December 2010, a module within the inverter was damaged by an electrical fault. Repairs and determination of the root cause were completed by FuelCell Energy and their supplier of the inverter, and the fuel cell was restarted in February 2011. Hydrogen co-production was then brought online, and the first hydrogen from the Hydrogen Energy Station was sent to the hydrogen fueling station; the 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 are being installed under a second DOE project (Cooperative Agreement No. DE-FC36-05GO85026). Initial test fills of fuel cell vehicles at the hydrogen fueling station were successfully completed on 8-10 March 2011.

Conclusions and Future Direction

- The Hydrogen Energy Station was shipped to OCSD and brought online. Initial performance in power and (power + hydrogen) modes was excellent. Issues with site power quality led to an electrical fault within the inverter of the fuel cell; repairs were completed, and operation resumed in February 2011.
- Operation on anaerobic digester gas from the wastewater treatment facility is expected to begin in May 2011 following installation of the gas cleanup skid that will remove trace contaminant species from the biogas. Data will be provided to DOE for the first six months of operation under a 3-year program sponsored by the California Air Resources Board and South Coast Air Quality Management District.

FY 2011 Publications/Presentations

1. Presentation at the DOE Annual Merit Review Meeting, Washington, D.C., May 2011.

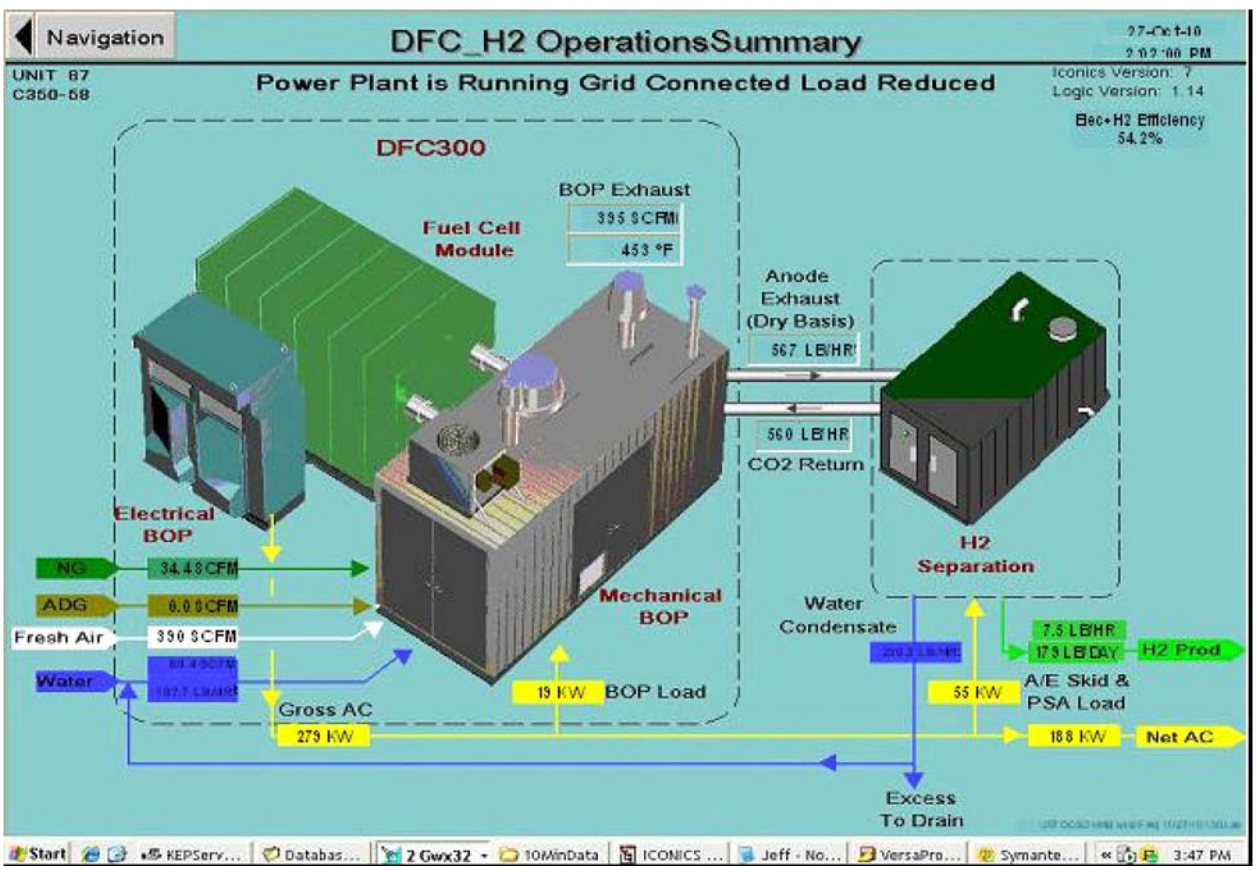

FIGURE 3. Hydrogen Energy Station Performance (October 2010)