VII.2 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: December 31, 2011

Fiscal Year (FY) 2012 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 H_2 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 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 2012 Accomplishments

- On 25 May 2011, the clean-up system for anaerobic digester gas (ADG) was commissioned, and renewable hydrogen was produced for the first time from the Hydrogen Energy Station. System efficiency of 53.5% exceeds the goal of 50%.
- The formal opening of the Hydrogen Energy Station and hydrogen fueling station at Orange County Sanitation District (OCSD) was held on 16 August 2011.
- Hydrogen coproduction economics based on the installation and operation at OCSD were prepared, with costs of \$3 to \$5 per kilogram achievable with next-generation hydrogen purification technology.
- The DOE Cooperative Agreement was extended to December 31, 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 was undertaken to design, fabricate and demonstrate a high-temperature fuel cell co-production concept. The basis of the demonstration was 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: (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; and (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 was 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 this 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 integrated the 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 was fabricated and, 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 was operated on municipal waste water-derived biogas at OCSD, Fountain Valley, California, under a 3-year program with the California Air Resources Board (CARB), with co-funding by the South Coast Air Quality Management District (AQMD). DOE received 6 months of data from the initial operating phase to validate the system versus DOE's economic performance targets.

Results

Figure 1 shows the process flow diagram for the Hydrogen Energy Station. Methane 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 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. In June 2010, the Hydrogen Energy Station was disassembled and prepared for shipment from Danbury, CT to the OCSD wastewater treatment plant in

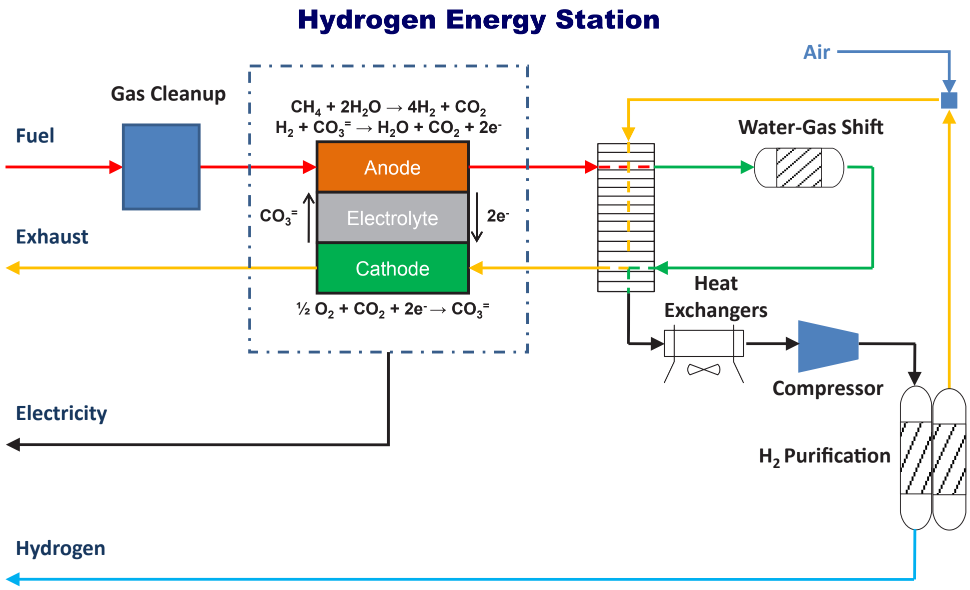

FIGURE 1. Hydrogen Energy Station Process Flow Diagram

Fountain Valley, CA. The system was delivered in early July, and full-load operation on natural gas was achieved on September 20, 2010. Initial co-production of hydrogen from the Hydrogen Energy Station on natural gas at OCSD occurred on 20 October 2010. Figure 2 shows the installation of the Hydrogen Energy Station at OCSD.

On 25 May 2011, the clean-up system for ADG was commissioned, and renewable hydrogen was produced for the first time from the Hydrogen Energy Station. This system was deployed under a second DOE project. June 1, 2012 marked the beginning of a three-year operating project under sponsorship of CARB and AQMD. One of the improvements made to the system was the addition of capability to direct hydrogen from the gas storage system to the ADG clean-up system to assist in the removal of sulfur species. In addition, hydrogen not used to replenish the storage system can now be routed to the fuel cell instead of vented to atmosphere as was the case during initial operation in 2010.

The formal opening of the Hydrogen Energy Station and hydrogen fueling station at OCSD was held on August 16, 2011. A total of 140 guests were in attendance. Speakers included representatives from project sponsors/participants Air Products, FuelCell Energy, the University of California, Irvine, AQMD, CARB, and the DOE, and also included U.S. Representative Dana Rohrabacher (CA 46th District).

During operation on ADG, a detailed heat and material balance was performed to determine the overall efficiency of the Hydrogen Energy Station. The calculated efficiency of 53.3% exceeded the target of 50%. During the 6 months of operation on ADG, the fuel cell continued to experience power quality issues at OCSD. A total of 115 trips (excluding trips less than 15 minutes apart) took place during the

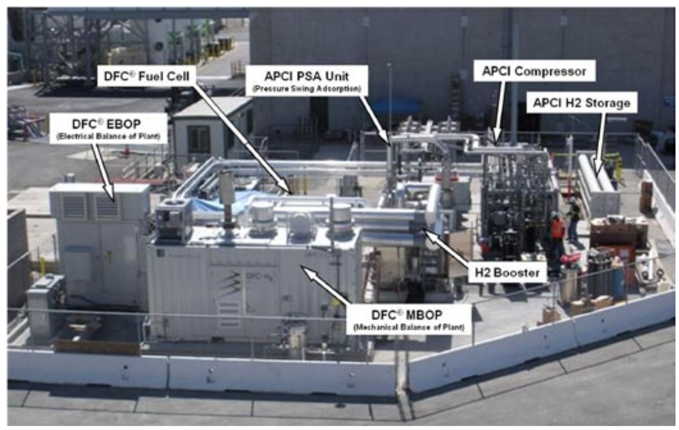

FIGURE 2. Hydrogen Energy Station Installation at Orange County Sanitation District

last quarter of calendar year 2011. These trips limited hydrogen production, as the system was programmed to de-integrate the hydrogen purification system each time the fuel cell power production is interrupted. Changes are being considered to this logic, especially to short-duration outages through which it may be feasible for the hydrogen purifier to continue operation. As a result of modifications within the power grid at OCSD, no trips related to power quality have occurred since January 31, 2012.

An overall operations summary (through April 2012) of performance of the Hydrogen Energy Station at OCSD is provided in Figure 3. Over 5 million standard cubic feet of ADG was processed, and over 1 million kWh of power was exported to the power grid at OCSD.

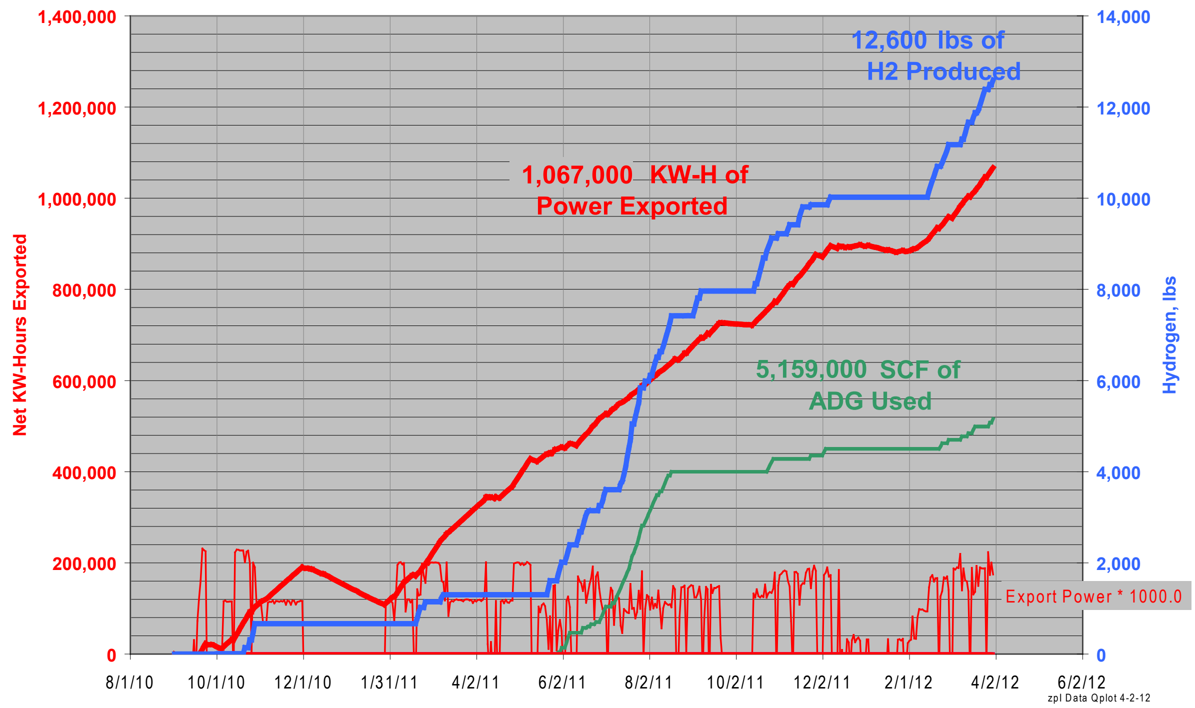

FIGURE 3. Hydrogen Energy Station Overall Operations Summary at OCSD

Based on the learnings from the design, installation, and initial operation at OCSD, an economic analysis on the cost of hydrogen from a Hydrogen Energy Station was performed. Hydrogen production rates up to 6,000 kilograms per day were considered, and Figure 4 shows two cases, (1) near-term pricing of $6 to $8 per kilogram utilizing PSA for hydrogen purification and (2) longer-term estimates of $3 to $5 per kilogram using next generation, electrochemical separation processes.

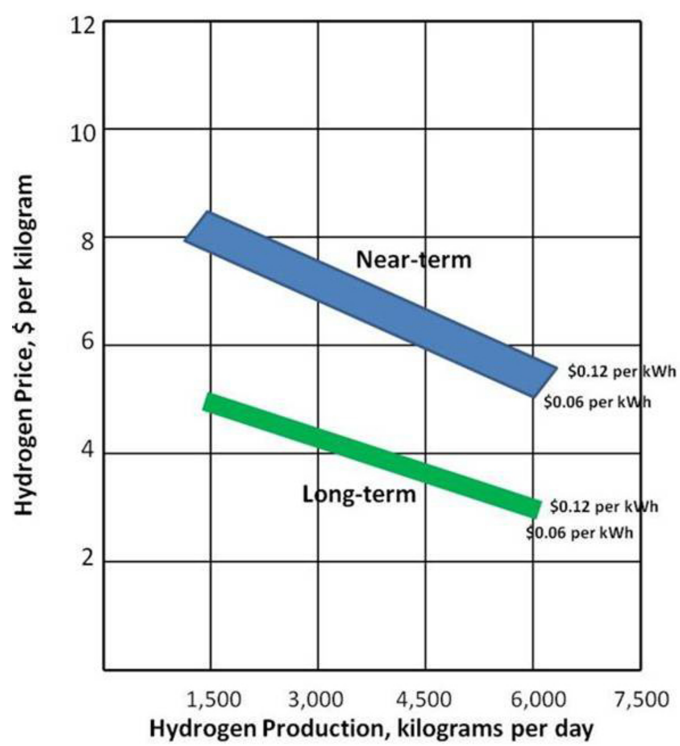

FIGURE 4. Hydrogen Energy Station Economics (updated December 2012)

Conclusions and Future Direction

- The Hydrogen Energy Station began operation on ADG at OCSD's wastewater treatment facility. System efficiency of 53.5% exceeded program targets. Over 1 million kWh of power was exported to the OCSD power grid. Hydrogen coproduction economics were updated.
- The DOE Cooperative Agreement has ended, but operation will continue at OCSD until May 31, 2014 under continuing sponsorship of CARB and AQMD.

FY 2012 Publications/Presentations

1. Presentation at the DOE Annual Merit Review Meeting, Washington, D.C., May 2012.