# VII.10 Validation of an Integrated Hydrogen Energy Station

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FuelCell Energy, Danbury, CT

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## 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 (HTFCs), including solid oxide and molten carbonate fuel cells (MCFC), 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 HTFC co-production 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)* We will be demonstrating the use of a MCFC (FuelCell Energy's Direct Fuel Cell, DFC-300) to produce power and electricity for a minimum of six months. Current process projections put the electrical efficiency at 47%. Based on actual field performance data, both the durability and availability of the technologies selected for demonstration are expected to exceed the 2008 and 2014 milestone values.
- **Milestone 38:** *Validate prototype energy station for 12 months; projected durability >40,000 hours; electrical energy efficiency >40%; availability >0.85. (1Q, 2014)* See explanation under Milestone 37 above.

## Accomplishments

- Completed Phase 3 design.
- Completed selection of catalyst system to maximize hydrogen content available for separation from the DFC-300 anode exhaust.
- Completed fabrication of the anode exhaust processing skid.
- Completed fabrication of fuel cell system components (mechanical balance-of-plant, M-BOP, and electrical balance-of-plant, E-BOP, etc.).
- Initiated fabrication of hydrogen energy station modules.
- Initiated procurement of all components for pressure swing adsorption (PSA) process for hydrogen recovery and purification.

## 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 HTFC co-production concept. The basis of the demonstration will be a FuelCell Energy DFC-300 MCFC 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 fuel cell 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-300 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 HTFCs 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 HTFC 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 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 six 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 circuit voltage, which is then converted to alternating current (AC) by an inverter in the E-BOP. The system produces 480 VAC at 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.

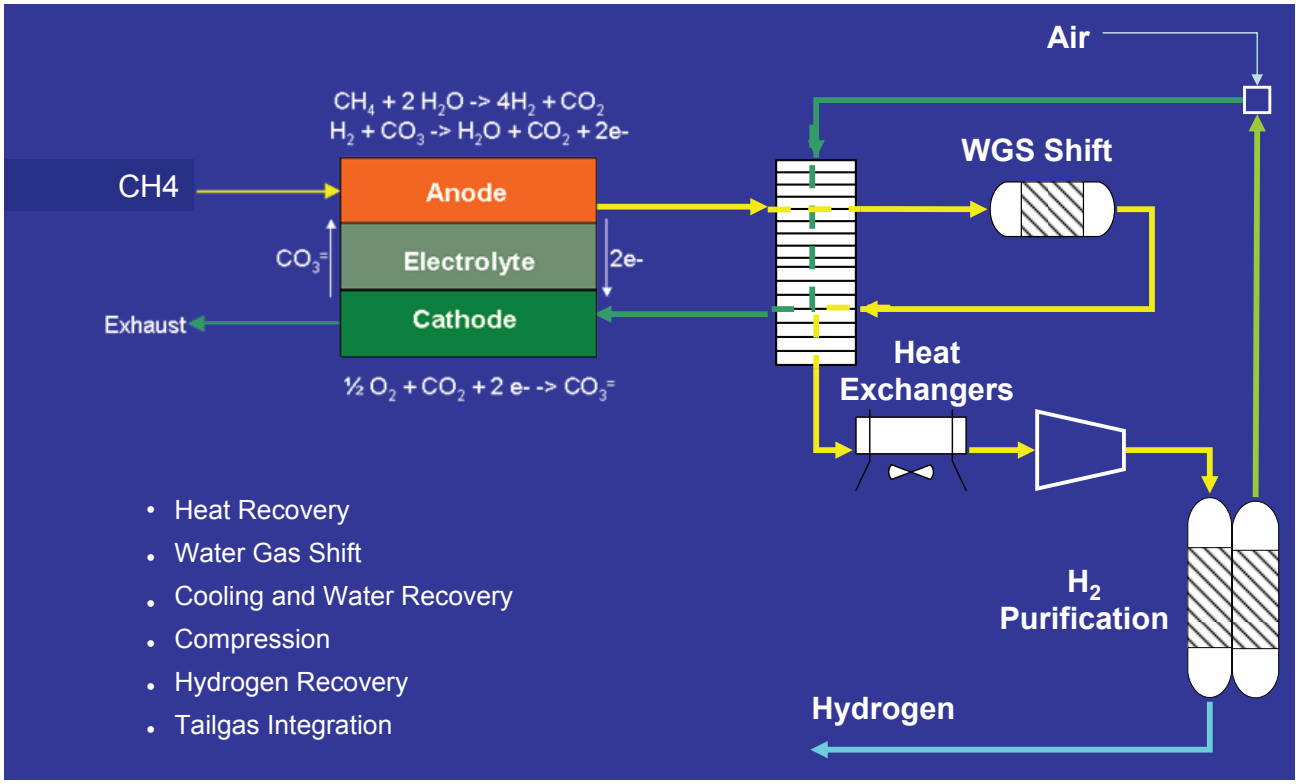


**FIGURE 1.** Hydrogen Energy Station Process Flow Diagram

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-300 system, thereby improving the system efficiency and economics. Figure 2 shows an example of the capability of the system to maximize either the production of electricity (for example, when the price for electricity is maximized during peaking or super-peaking periods) or hydrogen (during off-peak hours for power production).

During the past fiscal year, work focused primarily on detailed engineering design efforts at both Air Products and FuelCell Energy. At FuelCell Energy, the fabrication of the hydrogen-ready fuel cell components for the M-BOP and E-BOP was initiated. In addition, the fabricator for the anode exhaust gas skid was selected, and work began on the detailed design. Figures 3 and 4 show the layout drawing and a photograph during fabrication; the skid recently passed final inspection by FuelCell Energy and was shipped to their Danbury facility. FuelCell Energy also selected and procured the catalyst system to maximize the hydrogen content in the anode exhaust gas. At Air Products, the design for the hydrogen purification system was completed. Long lead items such as the compressor were ordered, and design drawings for the PSA system were prepared for release to be fabricated.

Meetings were held with safety and environmental staff from Air Products and FuelCell Energy to review the setbacks and permitting requirements for the Phase 3 testing in Danbury. Based on this review, the M-BOP, E-BOP, and anode exhaust skid were set in place in preparation for the Phase 3 validation test at FuelCell Energy's Danbury, CT facility.

## Conclusions and Future Direction

Planned future work includes:

- Complete the construction and installation and testing at FuelCell Energy's Danbury installation (Phase 3).
- Operate and collect data on the energy station for a desired period of 6 months (Phase 4).

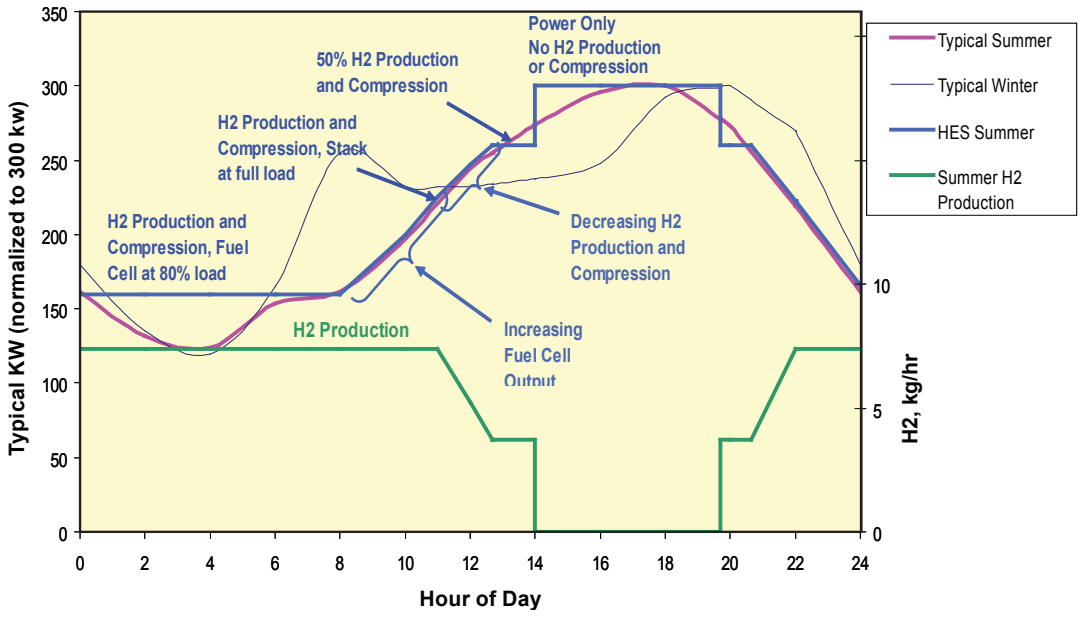


**FIGURE 2.** Hydrogen Energy Station Load-Following Capability

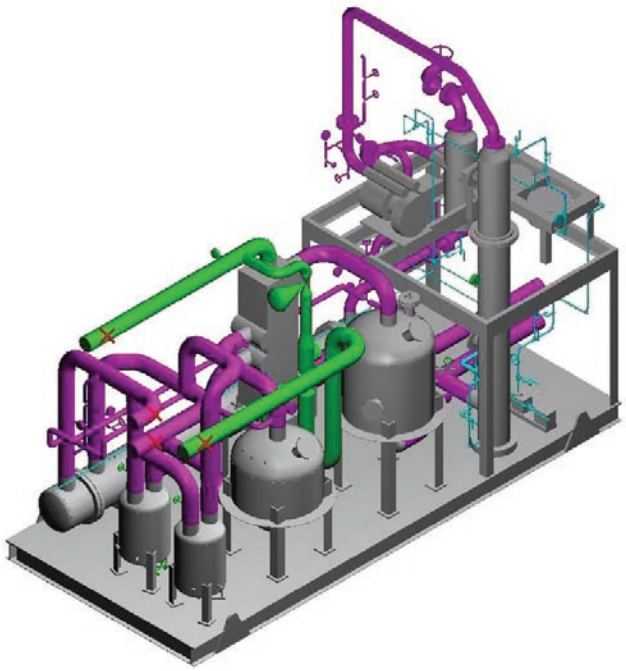

**FIGURE 3.** Anode Exhaust Skid Layout

**FIGURE 4.** Anode Exhaust Skid Fabrication

## FY 2008 Publications/Presentations

**1.** *Co-production of Hydrogen and Electricity Using High Temperature Fuel Cells*, P. Patel and F. Holcomb, FuelCell 2007, 5th International ASME Conference, New York, NY, June 2007.

**2.** *Transition to a Hydrogen Economy*, E. F. Kiczek, Great Plains Energy Expo, 29 October 2007.

**3.** *Flexible Co-Production of Renewable Hydrogen and Electricity*, P. Patel, L. Lipp, F. Jahnke, D. Tyndall and F. Holcomb, Fuel Cell Seminar, San Antonio, TX, October 2007.

**4.** *Renewable H2 from DFC® Fuel Cell, Renewable Hydrogen Co-Production from a High Temperature Fuel Cell*, F. Jahnke, P. Patel, D. Tyndall, and F. Holcomb, 2008 NHA Conference, Sacramento, CA, March 30, 2008.

**5.** *Renewable Hydrogen Energy Station - A Sustainable Path Forward*, D. Tyndall and P. Patel, 2008 CGA Hydrogen Seminar, Sacramento, CA - April 3, 2008.

**6.** A presentation regarding the overall project status was given at the DOE Annual Merit Review Meeting (June 2008).