VI.B.1 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 (HTFC) designed to produce power and hydrogen from digester gas.

- Complete a technical assessment and economic analysis on the use of HTFCs, including solid oxide fuel cells and molten carbonate fuel cells (MCFCs), for the co-production of power and hydrogen from digester gas (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 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) 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 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 DFC-300) to produce power and electricity for a minimum of 6 months. Current process projections put the electrical efficiency at 49%. 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 the detailed design and engineering development efforts with FuelCell Energy (FCE) to recover hydrogen from a FCE DFC-300 MCFC.
- Preliminary economics were validated.
- Modified process conditions for biogas feed conditions.
- Verified that the detailed design can handle biogas conditions.
- Recalculated process performance and preliminary economics for biogas feed.
- Anode off-gas treatment: Completed detailed process design to increase the hydrogen content in the anode off-gas and recover high-grade heat

- from the anode off-gas. Component testing was completed for a range of water-gas shift catalysts, heat exchangers, condensing systems, and anode gas filters.
- Hydrogen purification: Completed the detailed design of a pressure swing adsorption (PSA) process for hydrogen recovery and purification.
- System integration: Completed the detailed integration design.

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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 HTFC co-production concept. The basis of the demonstration will be a FCE 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 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 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. FCE's DFC-300 technology was selected for concept development.

In Phase 2, process design and cost estimates 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 FCE's facility in Danbury, CT for complete system check-out and validation.

In Phase 4, the system will be moved to the demonstration site in Fountain Valley, CA. Once in the field, the co-production system will be operated for a minimum of 6 months. Data from the operations period will be used to validate the system versus DOE and economic performance targets.

Results

Natural gas (NG) was the basis for the energy station initially, but has steadily lost favor due to reduced availability (and associated price increase) and increased concerns over greenhouse gas production. One comment from the 2006 annual review was, "We are running out of natural gas already – this makes no sense." A primary focus during FY 2006 was the re-evaluation of the system using other feedstocks. This work resulted in the new vision for the energy station shown in Figure 1. This vision takes advantage of the inherent fuel flexibility of the technology by coupling a fuel treatment module on the front end of the system. This evaluation was performed by the industrial partners

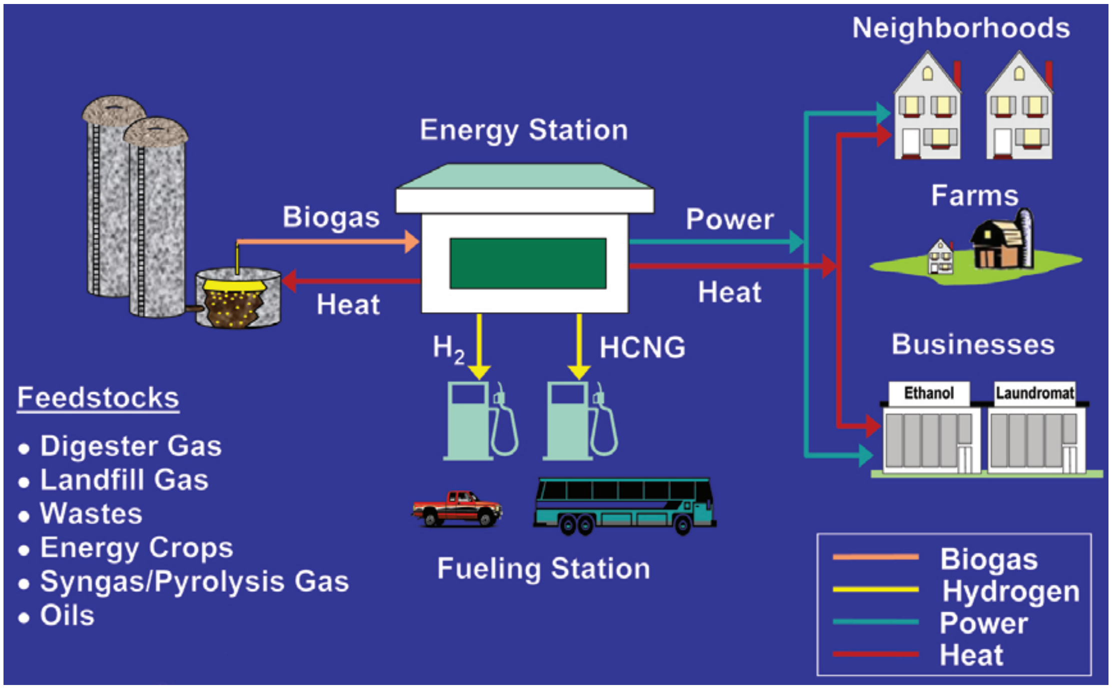

FIGURE 1. Renewable Hydrogen Energy Station Vision

(Air Products and FCE) at no cost to the project and resulted in a contract modification proposal to add anaerobic digester gas (ADG) feed to the project.

The addition of ADG results in significant, but manageable, changes to the project. The relevant issues are summarized below:

- The system process flow diagram and piping and instrumentation diagram were reviewed for compatibility with ADG. The result was the addition of the ADG treatment (ADGT) skid to the front end. The rest of the process remained unchanged.
- The ADGT is required to condition ADG to be suitable in the DFC, including:
  - Remove H_2S
  - Remove trace contaminants (siloxanes and other sulfur compounds
  - Reduce moisture
  - Remove oxygen
- The ADGT has already been demonstrated commercially by FCE (at FCE cost) on power-only DFC systems. This ADGT design has been evaluated as compatible with the energy station system. The basic ADGT design was developed at no cost to the project.
- The ADGT addition forced the plot plan to expand from 50' x 50' to 60' x 50'.
- As before, the entire system will consist of skidded modules for ease of transportation and installation.
- The project is expected to end on schedule; however, the increased system capability may warrant additional testing. (This will be evaluated during Phase 4.)

As a result of the process changes required for ADG, new performance projections were developed. The ADG results are compared to the 2006 results for a NG-based system in Table 1. As shown, the performance impact associated with the change to ADG is small. Overall the efficiency for the tri-production of hydrogen, power and heat decreased from 76% to 70%. The impact was even less for the efficiency for the combination of power and hydrogen, which decreased from 66% to 63%. The overall co-production system performance for ADG still exceeds the estimate made in Phase 1b for NG (60%) and supports the economic viability of the co-production

TABLE 1. Performance Projections – NG vs. Biogas

	Units	NG	Biogas
Overall Efficiency – "Tri-Gen" (Net Power + Hydrogen + Heat) / (Fuel)	LHV, %	76	70
Overall Efficiency – H2 + Power (Net Power + Hydrogen Product) / (Fuel)	LHV, %	66	63
Hydrogen Product	kg/day	~175	~160
Net Power	kW	~250	~240
Heat Export	kW	~75	~50

Digester Biogas - No impact on MCFC; Small impact on PSA
LHV - lower heating value

system. Preliminary economics predict that this small performance reduction from NG to ADG and the associated cost for the ADGT will be more than offset by a decrease in feedstock cost. A detailed update of these economics will be prepared at the end of Phase 3.

An ADG-producing host site was identified. The host site will be Orange County Sanitation District's (OCSD's) sewage treatment plant #1 in Fountain Valley, CA. OCSD's plant #2 in Huntington Beach, CA will serve as the alternate site. For the Hydrogen Energy Station (HES) demonstration, OCSD will provide utility hook-ups for NG, ADG, power and cooling water. OCSD will also serve as the recipient of the renewable power and process heat products. The renewable hydrogen product will be made available to fuel hydrogen vehicles.

Detailed design was initiated as part of Phase 3 activities. The following items were completed in 2006: anode gas handling skid, water-gas shift (WGS) reactor, hydrogen purification system, and the integration of all system components. The results of the process and component testing completed as part of Phase 3 verify the system technical viability and support the performance requirements necessary to make the HES an economically attractive route for distributed hydrogen production. Figure 2 shows the full-scale equipment used to verify the direct contact cooling tower operation. Figure 3 shows the performance data from the WGS reactor optimization experiments.

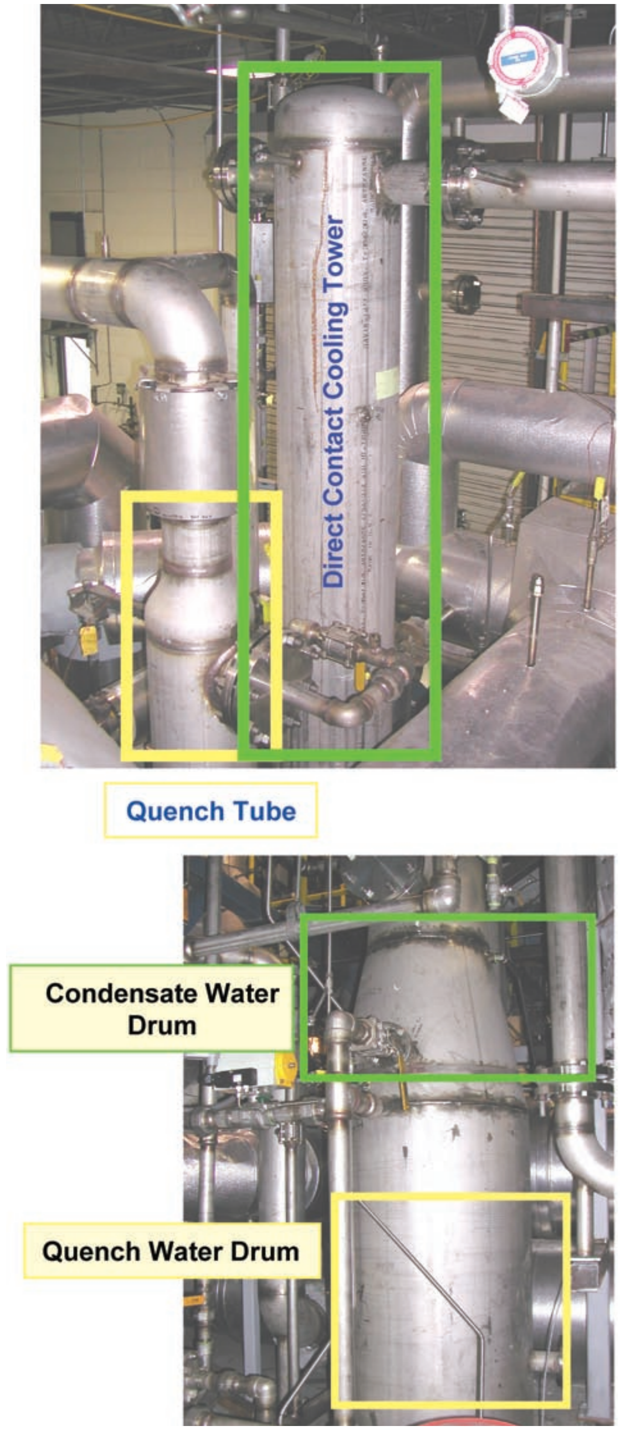

FIGURE 2. Direct Contact Cooling Tower

Conclusions

The work completed over the past year continues to validate that HTFCs configured to co-produce hydrogen and electricity can result in significantly lower costs for distributed hydrogen production, while generating power at commercially attractive rates.

- HTFCs configured to co-produce hydrogen and electricity have the ability to meet the DOE hydrogen cost targets while producing power for less than 0.10 $/kW.
- FCE's DFC systems are the preferred fuel cell systems to demonstrate the potential of co-production using high-temperature fuel cell technology.
- Hydrogen from the DFC anode exhaust can be cost effectively recovered using a PSA system.
- Based on the preliminary process design and initial component testing, the hydrogen energy station proposed in this project will meet or exceed the DOE validation milestones and continue to support the economics completed in Phases 1 and 2.

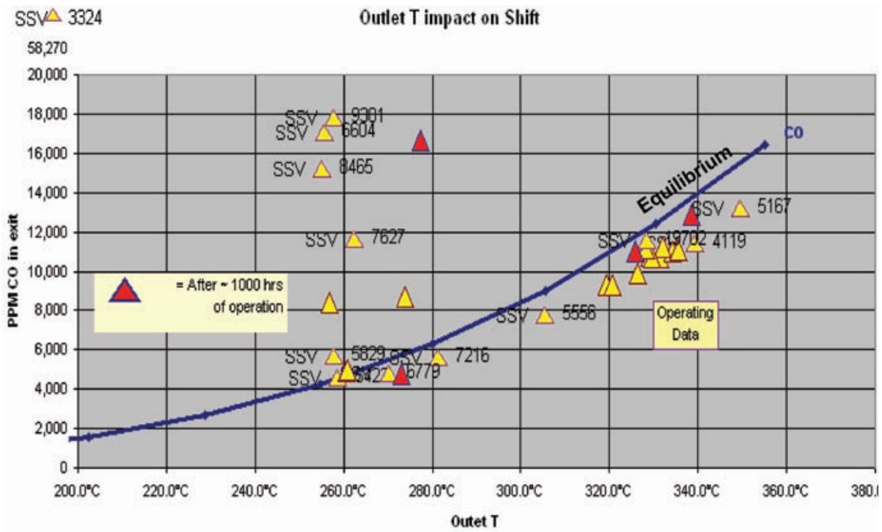

FIGURE 3. WGS Reactor Performance Data

Future Direction

- Complete the detailed design, construction, and Danbury, CT installation of the HES (Phase 3).
- Update economics for ADG feed (Phase 3).
- Evaluate the need for additional testing during operations period (Phase 4).
- Relocate energy station to host site in Fountain Valley, CA (Phase 4).
- Operate and collect data on the energy station for a minimum of 6 months (Phase 4).

FY 2007 Publications/Presentations

1. *Hydrogen Separation Technologies for Co-production of Hydrogen and Electricity*; P. Patel, L. Lipp, F. Jahnke, D. Guro, D. Tyndall; Fuel Cell Seminar – 2006; Honolulu, Hawaii; November 13-17, 2006.