VIII.D.2 Validation of an Integrated System for a Hydrogen-Fueled Power Park

Gregory R. Keenan
Air Products and Chemicals
7201 Hamilton Blvd
Allentown, PA, 18195
Phone: (610) 481-2077; Fax: (610) 706-4819; E-mail: keenangr@airproducts.com

DOE Technology Development Manager: Sigmund Gronich
Phone: (202) 586-1623; Fax: (202) 586-9811; E-mail: Sigmund.Gronich@ee.doe.gov

DOE Project Officer: Doug Hooker
Phone: (303) 275-4780; Fax: (303) 275-4753; E-mail: Doug.Hooker@go.doe.gov

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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 from natural gas.
  - Complete a technical assessment and economic analysis on the use of high-temperature fuel cells (HTFCs), including solid oxide fuel cells (SOFCs) and molten-carbonate fuel cells (MCFCs), for the co-production of power and hydrogen from natural gas (energy station).
  - 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 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 of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- B. Storage
- 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 milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- *Milestone 16: Demonstrate prototype energy station for 6 months; projected durability >40,000 hours; electrical energy efficiency >40%; availability >0.80.*
  We will be demonstrating the use of an MCFC (FuelCell Energy's DFC-300) to produce power and hydrogen 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 milestone values.
- *Milestone 17: Validate prototype energy station for 12 months; projected durability >40,000 hours; electrical energy efficiency >40%; availability >0.85.*
- *Milestone 19: Complete Energy Station demonstrations and make recommendations for business case economics.*
  We will build on our Las Vegas Energy Station experience to compare and contrast the two approaches - low-temperature fuel cell versus high-temperature fuel cell-based energy stations. Recommendations will be made after the 6-month demonstration and validation.

Approach

The demonstration and validation of a hydrogen energy station using a high-temperature fuel cell configured to produce both hydrogen and electricity will be executed in four phases with a go/no-go decision after Phase 2:

- Phase 1 - Technology and Economic Evaluation
- Phase 2 - Engineering Development and Preliminary Design
- Phase 3 - Final Design, Fabrication, and Installation
- Phase 4 - Demonstration, Data Collection, and Reporting

During the past year, the project team completed Phase 1: Technology and Economic Evaluation and began Phase 2: Engineering Development and Preliminary Design. Phase 2 was managed as a comprehensive development program, wherein work was organized by process sub-system (fuel cell, hydrogen purification, and integration). Significant progress was made through a combination of simulation, laboratory R&D, real-world component testing, collaboration with vendors, and engineering design work.

Accomplishments

- Completed a technology assessment and economic analysis on the use of HTFCs to co-produce hydrogen and electricity.
  - Concluded that HTFCs configured to co-produce hydrogen have the potential to meet the DOE hydrogen targets as specified in the multi-year plan, while producing power for less than $0.10/kW.
  - Selected FuelCell Energy (FCE) as the fuel cell supplier for the engineering development and demonstration phases.
- Initiated the preliminary design and engineering development efforts with FCE to recover hydrogen from an FCE DFC-300 molten-carbonate fuel cell. Development activities were initiated in the following areas:
  - Anode off-gas removal: Completed a preliminary process design to increase the hydrogen content in the anode off-gas and recover high-grade heat from the anode off-gas. Initiated shift catalyst and heat exchanger testing.
  - Hydrogen purification: Evaluated over 25 different processes and technologies for the recovery of hydrogen from the anode and down- selected to three potential near-term solutions. Initiated preliminary design activities and process development work to validate the design.
  - System integration: Initiated work to optimize the integration of the hydrogen purification system with the fuel cell. This includes the integration of the purification system off-gas with the fuel cell in order to minimize the cost of energy products from the system.

Future Directions

- Complete the preliminary design and engineering development activities necessary to cost effectively remove and purify hydrogen from an FCE DFC-300 (Phase 2).
- Update the economics and business case based on the preliminary design criteria (Phase 2).
- Select a site for the demonstration (Phase 2).
- Complete the detailed design, construction, and installation of the energy station (Phase 3).
- Operate, performance test, and collect data on the energy station for a minimum of 6 months (Phase 4).

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. To meet this challenge, distributed generation of hydrogen has been proposed as a potential sourcing solution. However, the low-volume hydrogen requirements in the early years of fuel cell vehicle deployment and the sporadic nature of vehicle fueling make the economic viability of stand–alone, distributed hydrogen generators particularly challenging. One significant challenge for fueling station developers will be minimizing the financial risk associated with stranded capital assets. A potential solution to this "stranded asset" problem is the use of hydrogen energy stations to produce electricity in addition to hydrogen. One such station concept that shows promise, as concluded in Phase 1 of this project, is the use of high-temperature fuel cells to co-produce hydrogen and electricity. It was shown in Phase 1 that high-temperature fuel cells configured to co-produce hydrogen and electricity have the potential to meet the DOE hydrogen cost targets, while producing power for less than \$0.10/kW. To validate this conclusion, project phases are proposed to design and, if appropriate, fabricate and demonstrate the co-production concept from an HTFC. The expected basis of the demonstration would be an FCE DFC-300 MCFC modified to enable the separation and purification of hydrogen from the fuel cell anode exhaust using an Air Products-designed hydrogen purification system.

Approach

A hydrogen energy station that uses a high-temperature fuel cell to co-produce electricity and hydrogen will be evaluated and demonstrated in four phases, with a go/no-go decision after Phase 2.

In Phase 1, Air Products completed a detailed evaluation on the technical and economic potential of HTFCs for distributed hydrogen and power generation. The applicability of this concept to the existing merchant hydrogen market and the hydrogen economy was explored. As part of the Phase 1 analysis, three different HTFCs 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, a detailed cost estimate will be completed for the hydrogen energy station that integrates FCE's DFC® power plant (Model DFC-300 series) with a hydrogen separation system selected and designed by Air Products. Finally, a site will be recommended for the demonstration. A go/no-go decision will be made after the completion of Phase 2.

In Phase 3, a detailed design will be completed for the co-production system. The system will then be fabricated, shop tested, and installed at the site selected in Phase 2.

The co-production system will be operated for a minimum of 6 months in Phase 4. During this period, performance tests will be performed to validate the economics of the system.

Results

After three different high-temperature fuel cell technologies were evaluated in Phase 1, FCE's DFC-300 fuel cell was selected for the development and demonstration phases of the project. Preliminary process designs are underway to integrate the DFC-300 with an Air Products-designed hydrogen purification system. Results from the design effort to date continue to support the economics completed as part of Phase 1.

The recovery and purification of hydrogen from the anode of the DFC-300 presents several challenges:

- The anode off-gas is a low-pressure, high-temperature gas stream that contains <15% 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.

FCE and Air Products are pursuing complementary parallel engineering development and design programs to address the above challenges. FCE has developed a preliminary process design for an anode exhaust train that recovers the high-grade process heat, while also increasing the hydrogen content via a shift reactor. The design also incorporates a water recovery and recycle system. Air Products has initiated a development effort to design a purification system to separate and purify the hydrogen from the low-pressure anode exhaust gas. Air Products evaluated over 25 purification options and down-selected to an adsorption-based system that results in a system that can recover over 85% of the hydrogen in the anode off-gas, while using minimal electrical power. The projected overall system performance based on the preliminary design supports the economics completed in Phase 1. Furthermore, the initial process and component testing that has taken place as part of Phase 2 has indicated the overall system performance will exceed the performance necessary to make the economics favorable for co-production and will also exceed the DOE milestone targets.

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 as specified in the multi-year plan, while producing power for less than $0.10/kW.
- FCE's DFC-300 is the preferred fuel cell system to demonstrate the potential of co-production using high-temperature fuel cell technology.
- Based on the preliminary process design and initial process/component testing, the hydrogen energy station proposed in this project will meet or exceed the DOE validation milestones and support the economics completed in Phase 1.
- The anode exhaust from a DFC-300 can be cost effectively and efficiently recovered using an adsorption-based purification system.

FY 2005 Publications/Presentations

1. Keenan, G., "The Use of High Temperature Fuel Cells for Distributed Hydrogen Production," NHA Hydrogen Conference, Washington D.C., March 2005.
2. Keenan, G., "The Use of High Temperature Fuel Cells for Distributed Hydrogen Production," NHA Hydrogen Conference, March 2005, SAE Government / Industry Meeting, Washington D.C., May 2005.
3. Keenan, G., "Validation of an Integrated System for a Hydrogen-Fueled Power Park," DOE Annual Review, Washington D.C., May 2005.

References

1. A.L. Dicks, R.G. Fellows, C.M. Mescal, C. Seymour, "A Study of SOFC-PEM Hybrid Systems," Journal of Power Sources, vol. 86, 2000, pp. 501 - 506.
2. H.E. Vollmar, C.U. Maier, C.Nolsher, T. Merklein, M. Poppinger, "Innovative Concepts for the Coproduction of Electricity and Syngas with Solid Oxide Fuel Cells," Journal of Power Sources, vol. 86, 2000, pp. 90 – 97.
3. J. Larminie and A.L. Dicks, Fuel Cell Systems Explained, John Wiley & Sons, 2000, pp. 175-177.