V.A.4 Validation of an Integrated System for a Hydrogen-Fueled Power Park

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Objectives

- Complete a technical assessment and economic analysis on the use of high-temperature fuel cells (HTFCs), including solid oxide (SOFC) and molten carbonate (MCFC), for the coproduction of power and hydrogen from natural gas (energy park).
- Determine the applicability of coproduction for the existing merchant hydrogen market and for the emerging hydrogen economy.

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. H_2 Refueling Infrastructure
- I. Hydrogen and Electricity Coproduction

Approach

- Complete a preliminary literature search on the use of HTFC technology for the coproduction of electricity and hydrogen/synthesis gas.
- Complete a first pass high level feasibility study using publicly available data.
  - Develop heat and material balances using AspenPlus simulation software.
  - Write an economic model to evaluate coproduction scenarios.
- Develop a coproduction product specification in order to get technical and economic input from HTFC developers. Input will be gathered for two different SOFC technologies and one MCFC technology. HTFC vendors will provide:
  - Fuel cell performance projections
  - Fuel cell cost projections
  - Flow diagrams
  - Process data
- Estimate the hydrogen purification requirement.
- Refine the initial feasibility study using data from the HTFC vendors.
- Complete a more detailed overall process and economic analysis.

Accomplishments

- Completed a technology assessment and economic analysis on the use of HTFCs to coproduce hydrogen and electricity.
  - Developed preliminary heat and material balances in AspenPlus.
  - Developed an economic model to evaluate the coproduction scenarios.
  - Gathered data from several HTFC vendors to better understand the technical and economic potential of coproduction.
- Concluded that HTFCs configured to coproduce hydrogen have the ability to meet the DOE hydrogen targets as specified in the Multi-Year Research, Development, and Demonstration Plan (MYRDDP) while producing power for less than 0.10 $/kW.

Future Directions

- Pursue an engineering development and design project to validate and demonstrate the technical and economic viability of a HTFC coproduction system.
  - HTFC Partner Selection
  - Phase 2: Preliminary Design, Engineering Development, Firm Bid Estimate, and Site Selection
  - Phase 3: Detailed Design and Construction
  - Phase 4: Operation, Testing, Data Collection

Introduction

One of the immediate challenges facing Air Products is finding the optimal means to roll out a hydrogen fueling infrastructure coincident with the deployment of low-production hydrogen vehicles in locations around the country. One potential distributed hydrogen solution that shows promise, as concluded in this phase of the Power Park project, is the use of high-temperature fuel cells to coproduce hydrogen and electricity. As shown in Figure 1, an HTFC producing electricity can be configured to produce hydrogen as well by recovering the unreacted hydrogen in the anode off-gas. Furthermore, tri-generation is possible by recovering the waste heat from the fuel cell exhaust.

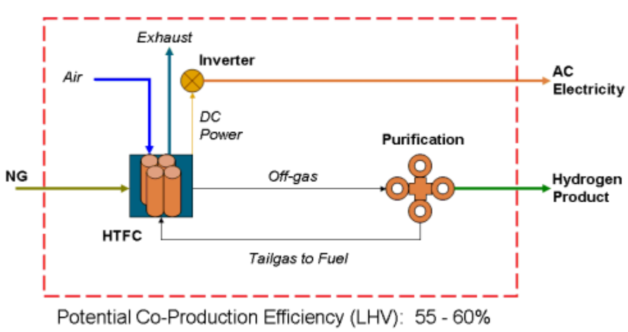

Figure 1. HTFC Coproduction Schematic

The benefits of coproduction from a HTFC include:

- High efficiency
- Low emissions
- Potential use of waste hydrocarbons as a fuel source
- Grid benefits
- Multiple product slate that improves capital utilization and provides for flexible product pricing options
- Potential integration with a low-temperature fuel cell in a hybrid power cycle

Over the last year, Air Products completed a detailed evaluation of the technical and economic potential of HTFCs for distributed hydrogen and power generation. The costs of recovering hydrogen from HTFCs and the resulting economics of combined hydrogen and power were investigated. The applicability of this concept to the existing merchant hydrogen market and the hydrogen economy was explored.

Approach

Initially, a literature search on the use of high-temperature fuels cells for the coproduction of electricity and hydrogen/synthesis gas was completed. Using the information from this literature search, a preliminary feasibility study was undertaken. Heat and material balances were developed using AspenPlus simulation software, and an economic model was written to evaluate coproduction scenarios. To further validate the technical and economic feasibility of the coproduction concept, three high-temperature fuel cell vendors were approached to provide information on the feasibility of coproduction using their existing high-temperature fuel cell technologies (two SOFC technologies and one MCFC technology). Air Products developed preliminary product specifications that were provided to the three HTFC vendors for this purpose. The HTFC vendors provided preliminary coproduction schemes, along with fuel cell performance projections, fuel cell cost projections, flow diagrams, and process data. Air Products provided hydrogen purification expertise as necessary and performed a detailed economic analysis on the overall system. The results from the economic analysis were used to determine the commercial viability in the merchant hydrogen market as well as the emerging hydrogen economy.

Results

As shown in Table 1, high-temperature fuel cells configured to coproduce hydrogen have the potential to meet the DOE hydrogen cost targets as specified in the MYRDDP while producing power for less than 0.10 $/kW. Table 1 shows the economic results for three scenarios as well as a few of the key assumptions for each scenario. The results shown in this table are based on the financial and operating assumptions listed in Table 3.1.2 in the MYRDDP.

It should be noted that the economics are based on coproduction systems that produce 690 kg/day of high-purity hydrogen while producing over 1.5 MWs of AC electricity. Furthermore, it is important to note that the cost of the HTFC is assumed to decrease from 2250 $/kW in 2005 to 800 $/kW in 2015.

The cost information under the heading "Base Energy Price" in Table 1 represents the equivalent cost of energy across the product electricity and hydrogen from the coproduction system. It can be seen that the 2005 scenario produces hydrogen at

Table 1. HTFC Coproduction Economics

	2005	2010	2015
Assumptions			
Hydrogen, kg/day*	690	690	690
Net Electricity, kw	>1.5 MW	>1.5 MW	>1.5 MW
HTFC Cost, $/kW AC w/o H2	2250	1200	800
Natural Gas Costs, $/mmbtu*	4.00	4.00	4.00
Production Volume, units/year*	100	100	100
Fueling Utilization*	90%	90%	90%
Capital Factor*	0.11	0.11	0.11
Base Energy Price			
Hydrogen Price, $/kgPower	2.97	2.15	1.88
Price, $/kwh	0.07	0.05	0.05
Fueling Scenario			
Hydrogen at the Pump, $/kg*	3.00	1.50	1.50
Station Allocation, $/kg H2*			
Compression, $/kg H2*	-2.52	-0.24	-2.24
Storage & Dispensing, $/kg H2*	-0.19	-0.11	-0.11
Hydrogen Production Price, $/kg	2.52	1.15	1.15
Power Price, $/kwh	0.08	0.07	0.06

*Assumptions from the DOE Multi-Year Research, Development and Demonstration Plan, Table 3.1.2, page 3-10, Draft 6/3/03.

2.97 $/kg while producing power at 0.07 $/kWh. This drops to 1.88 $/kg and 0.05 $/kwh in the 2015 scenario.

The cost information under the heading "Fueling Scenario" represents the targets set by the DOE in the MYRDDP for fueling station applications. The DOE hydrogen cost targets at the pump as shown in the table are 3.00 $/kg in 2005 and 1.50 $/kg in 2010 and 2015. The costs associated with compression, storage, and dispensing represent DOE targets and are subtracted from the pump price to come up with the required cost of hydrogen from the coproduction unit. For example, in 2005 the target price for hydrogen is 3.00 $/kg at the pump. Subtracting the cost of compression, storage, and dispensing from the pump price leaves 2.52 $/kg for hydrogen production. At this hydrogen price, the electricity must be sold for 0.08 $/kWh in order for the coproduction system to produce the revenue required to generate an acceptable economic rate of return. As can be seen in the table, hydrogen can be sold at the DOE target prices while selling power for much less than 0.10 $/kwh in all three scenarios. Finally, by comparing the Fueling Scenario results to the Base Energy prices, one can see that in all scenarios the revenue from the power is subsidizing the hydrogen product price.

Conclusions

The work completed over the past year has shown that HTFCs configured to coproduce hydrogen and electricity can result in significantly lower costs for distributed hydrogen production while at the same time generating power at commercially attractive rates. As a result, HTFCs that coproduce hydrogen in addition to electricty may offer a potentially attractive method to roll out a hydrogen fueling infrastructure.

- HTFCs configured to coproduce hydrogen and electricity have the ability to meet the DOE hydrogen targets as specified in the MYRDDP while producing power for less than 0.10 $/kW.
- Both MCFCs and SOFCs can be designed for coproduction.
  - Coproduction efficiencies were similar – 55%-60% (lower heating value – LHV)
  - Both technologies have the potential to meet the DOE targets while producing power for less than 0.10 $/kW.
- Several areas for engineering development have been identified in order to move the coproduction concept forward:
  - Anode off-gas recovery and conditioning;
  - Low parasitic power hydrogen purification;
  - System integration; and
  - Optimization of coproduced products.

References

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