II.A.7 Integrated Hydrogen Production, Purification and Compression System

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Subcontractors:
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Projected End Date: December 31, 2009

Objectives

- Demonstrate a low-cost option for producing fuel cell vehicle (FCV) quality hydrogen to meet DOE cost and efficiency targets for distributed hydrogen production.
- Develop a hydrocarbon fuel processor system that directly produces high pressure, high-purity hydrogen from a single integrated unit by combining a fluidized bed membrane reactor (FBMR) and a metal hydride-based compressor (MHC).

Technical Barriers

This project addresses the following technical barriers listed in Section 3.1.4 of the updated version (April 27, 2007) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan.

Distributed Hydrogen Production from Natural Gas or Renewable Liquid Feedstocks

(A) Reformer Capital Costs
(C) Operation and Maintenance (O&M)

Hydrogen Separations

(K) Durability
(L) Impurities
(M) Membrane Defects
(N) Hydrogen Selectivity
(O) Operating Temperature
(P) Flux
(R) Cost

In addition, the project addresses the following technical barrier from Section 3.2.4 related to Hydrogen Delivery:

(B) Reliability and Cost of Hydrogen Compression

Technical Targets

Technical Targets and the current progress made towards achieving the 2010 milestones are presented in Table 1.

Accomplishments

- Main reformer skid has been commissioned and has generated performance data.
- Reformer design models have been validated.
- Membrane failure modes have been identified and procedures have been revised to prevent future failures.
- Modeled cost for 100 kg/hr production design capacity using the H2A model.
- MHC fabricated and undergoing factory tests.
- Integrated system expected to be operational in October 2008.

TABLE 1. Distributed Production of Hydrogen from Natural Gas Technical Targets and FBMR-MHC Projection

Characteristics	Units	2010 Target	Current FBMR-MHC Projection
Production Unit Energy Efficiency	%(LHV)	72.0	73.3
Production Unit Capital Cost (Uninstalled)	$U.S.	900,000	1,029,000
Forecourt Compressor Energy Efficiency	%	94 (CR=19.8)	72 (CR=895)
Compressor Installed Capital Cost (Basis: 1,500 kg/day at 6,250 psi)	K$/(kg/hr)	4.0	4.43
Total Hydrogen Cost	$/gge H_2	2.50	2.81

LHV – lower heating value; gge – gasoline gallon equivalent; CR – compression ratio

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Introduction

The DOE has determined that the delivered cost of hydrogen must be in the $2 to $3/gge range for hydrogen to be competitive with gasoline as a fuel for vehicles. For small, on-site hydrogen plants being evaluated for refueling stations (the "forecourt"), capital cost is the main contributor to delivered hydrogen cost. This project is based on achieving the target hydrogen cost by combining unit operations for the entire generation, purification, and compression system. It uses a membrane reformer developed by MRT which has H_2 selective, Pd-alloy membrane modules immersed in the reformer vessel, thereby directly producing high purity hydrogen in a single step. The continuous removal of pure hydrogen from the reformer pushes the equilibrium "forward" thereby maximizing reactor productivity with an associated reduction in the cost of product hydrogen. Additional gains are envisaged by the integration of the novel hydride compressor developed by Ergenics, whereby H_2 is compressed from 0.5 bar (7 psia) to 350 bar or higher in a single unit using thermal energy. Excess energy from the reformer provides over 25% of the power used for driving the hydride compressor so that system integration can improve efficiency. Hydrogen from the membrane reformer is of very high, FCV quality (purity over 99.99%), eliminating the need for a separate purification step. The hydride compressor maintains hydrogen purity because it does not have dynamic seals or lubricating oil.

Following the detailed design and assembly of the main reformer skid presented last year, the work this year was focused on commissioning and testing the main reformer skid and completing assembly of the MHC skid. These two skids shall be integrated to form the first proof-of-concept (POC) prototype to demonstrate the technology and to verify the assumptions in our analysis. The POC unit is designed to produce 1.35 kg/hr high purity, high pressure (100 bar) hydrogen.

Approach

The project team will integrate the membrane reformer developed by MRT and the hydride compression system developed by HERA in a single package. This is expected to result in lower cost and higher efficiency compared to conventional hydrogen production technologies, as follows:

Lower cost compared to conventional fuel processors will be realized by:

- Reduced component count and sub-system complexity.
- Tight thermal integration of all reactions/processes in a single package.
- Thermal metal hydride compression without rotating machinery, which should result in high reliability, low maintenance and low electricity usage.

High efficiency will be achieved by:

- Using H_2-selective membranes within the reformer vessel to directly produce high-purity hydrogen, eliminating losses associated with a separate purifier.
- Using a fluidized catalyst bed to improve heat and mass transfer.
- Using the compressor suction to lower the partial pressure of hydrogen in the reaction zone; this shifts equilibrium to enhance hydrogen production.
- Thermally integrating the hydride compressor with the membrane reactor to reduce compression energy consumption.

Results

- Main reformer skid commissioned and tested:
  - Over 500 hours of operating time.
  - 8.5-9.0 Nm^3/hr H_2 produced without MHC, i.e. without suction on the permeate side. This result is consistent with model predictions for these conditions, and it is expected that the design capacity of 15 Nm^3/hr H_2 will be achieved with 0.5 bara permeate pressure provided by the MHC.
- Prototype, large area membrane modules (6"x11") successfully tested:
  - Membrane integrity issues identified and resolved.
  - No purity degradations observed during operation after corrective actions taken.
  - Purity of 99.99+% observed.
- MHC with novel hydride heat exchangers fabricated and undergoing factory tests.

Conclusions and Future Directions

- Cost and efficiency targets unchanged since last year, pending assessment and revision based on POC test results.
- The plan is to complete POC performance tests, and report results and economic assessment by December 2008.
- Review POC test results and the revised economic assessment with DOE for decision to proceed to the next step, which is an advanced prototype incorporating lessons-learned and employing a higher degree of integration, with an associated reduction in the number of components to reduce capital cost.

FY 2008 Publications/Presentations

1. US DOE Separations and Purification Working Group, November 7, 2007.

2. US DOE Annual Review, June 11, 2008.