

## II.C.7 Integrated Hydrogen Production, Purification and Compression System

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Subcontractors:

- Membrane Reactor Technologies Ltd. (MRT),  
Vancouver, BC, Canada
- Ergenics Corporation, Ringwood, NJ  
(previously HERA USA)

Start Date: April 1, 2005  
Projected End Date: September 30, 2010

### Objectives

- To demonstrate a low-cost option for producing fuel cell vehicle (FCV) quality hydrogen to meet DOE cost and efficiency targets for distributed hydrogen production.
- To 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 the Production section (3.1.4) of the updated version (April 27, 2007) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development & 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 Table 1.

**TABLE 1.** Technical Targets: Distributed Production of Hydrogen from Natural Gas<sup>1</sup>

Characteristics	Units	2010 Target	Current FBMR-MHC Projection
Production Unit Energy Efficiency	%(LHV)	72.0	73.3
Production Unit Capital Cost (Uninstalled)	\$US	900K	1,029K
Forecourt Compressor Energy Efficiency	%	94 (CR = 19.8)	72 (CR = 895)
Compressor Installed Capital Cost (Basis: 1,500 kg/day @ 6,250 psi)	\$/kg/hr	4.0	4.43
Total Hydrogen Cost	\$/gge H <sub>2</sub>	2.50	2.81

<sup>1</sup> The H2A Production tool ([http://www.hydrogen.energy.gov/systems\\_analysis.html](http://www.hydrogen.energy.gov/systems_analysis.html)) was used for the cost modeling. Economic parameters used were for a production design capacity of 1,500 kg/day of hydrogen: 20 yr. analysis period, 10% internal rate of return after taxes, 100% equity financing, 1.9% inflation, 38.9% total tax rate, and Modified Accelerated Cost Recovery Schedule 7-year depreciation for 2005, 2010, and 2015. A 70% capacity factor was used for 2005, and 2010. A 75% capacity factor was used for 2015. The results for 2005, 2010, and 2015 are in 2005 dollars.

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

## Accomplishments

- FBMR
  - Redesigned and fabricated new membrane modules using higher quality membrane foils.
  - Conducted FBMR run in January 2009 to verify integrity of components after severe winter weather.
  - Operated FBMR for more than 400 hours, with one week of unattended operation.
- MHC
  - Completed MHC fabrication and shipped unit to Vancouver, Canada for integrated tests.
  - Installed MHC next to the FBMR and field tested MHC to obtain base line data.
- Ran integrated FBMR-MHC campaign.
- Developed advanced prototype (AP) system flow sheet.
- Updated and revised cost models for 100 kg/day and 1,500 kg/day systems.
- Utilized H2A Production Tool to explore production cost sensitivity to key parameters identified during proof-of-concept operations.



## 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<sub>2</sub>-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<sub>2</sub> 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 metal hydride compressor skid. These two skids were integrated to form the first proof-of-concept prototype to demonstrate the technology and to verify the assumptions in our analysis. The proof-of-concept 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 Ergenics 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<sub>2</sub>-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, which shifts equilibrium to enhance hydrogen production.
- Thermally integrating the hydride compressor with the membrane reactor to reduce compression energy consumption.

## Results

- FBMR
  - FBMR operated for over 425 hours, including one week of unattended operation.
  - No membrane degradation observed during runtime.

- Production capacity decreased due to partial deactivation of catalyst resulting from sulfur breakthrough in feed.
- MHC
  - Hydride heat exchanger third stage leaks prevented simultaneous demonstration of full flow with full compression ratio.
  - MHC maintained the design 7 psia suction and 1,515 psia discharge pressures at 75% of full flow and delivered full flow with 7 psia suction and 200 psia discharge, using two of the three stages.
- Integrated System Tests
  - The FBMR and MHC were operated together successfully for 8 hours; FBMR performance was stable and the system was not affected by MHC cycling.
  - Integrated operation was intentionally cut short after determining the low production capacity discussed above could not be increased during the run.
- Identified key cost drivers as membrane thickness and longevity, and MHC efficiency.
- AP Conceptual Design Completed
  - Revised cost model shows that H<sub>2</sub> can be produced at \$3.30/kg.
  - Quantified sensitivity of key parameters to help focus future work.

## Conclusions and Future Directions

- Project team recommends the project be re-directed because the current H<sub>2</sub>A cost model shows that the cost of H<sub>2</sub> can be reduced by:
  - Addressing key technical issues from Task 2 on full-scale components in a laboratory environment.
  - Long-term testing to prove operability, viability and longevity of key FBMR components.
  - Resolving MHC heat exchanger leakage problem.
  - Proving AP design concepts and cost assumptions through accelerated component testing.

## FY 2009 Publications/Presentations

1. U.S. DOE Annual Review, May 19, 2009.
2. Hydrogen and Fuel Cells Canada Conference, June 1, 2009.