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

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Subcontractors:
Membrane Reactor Technologies, Vancouver, British Columbia, Canada
HERA USA, Ringwood, NJ

Start Date: April 1, 2005
Projected End Date: March 31, 2008

Objectives

- To demonstrate a low-cost option for producing fuel cell vehicle quality hydrogen that can be adopted 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 and a hydride-based compressor.

Technical Barriers:

This project addresses the following technical barriers from the Hydrogen Production and Delivery sections of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

<u>Production Barriers</u>

- A. Fuel Processor Capital Costs
- B. Fuel Processor Manufacturing
- C. Operation and Maintenance (O&M)
- D. Feedstock Issues
- E. Carbon Dioxide Emissions
- F. Control and Safety

<u>Delivery Barriers</u>

- B. Reliability and Costs of Hydrogen Compression

Technical Targets

The overall system and individual unit operations within the system must be optimized to reduce the cost of delivered hydrogen from natural gas to $2.50 by 2010. There are many potential tradeoffs in a tightly integrated package. Hence, the initial activity is to understand these tradeoffs, identify the best initial approach to systems integration and determine realistic performance targets for the integrated system. Once this is accomplished, two generations of prototypes will demonstrate progress towards achievement of the targets.

- Proof of Concept Prototype: a) the membrane reactor package will supply energy to the metal hydride compressor system, b) the hydride compressor will use a low-temp differential of 40 to 50^{o}C in multiple compression stages, c) the target pressure >1,000 psig, d) system controls will be discreet for each component to allow optimization.
- Advanced Prototype: a) will incorporate lessons learned from the proof of concept prototype, b) will have heating, cooling, and all controls in a single combined package, c) will have a high-temp differential compressor with fewer stages and lower capital cost, d) will have delivery pressure of >5,000 psig.

The project will conclude with design and performance projections for a mass-produced, integrated distributed hydrogen production package for up to 10,000 psi.

Approach

The project team will integrate the membrane reformer developed by Membrane Reactor Technology and the hydride compression system developed by HERA USA in a single package.

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:

- Producing high-purity hydrogen using high temperature, H_2 selective membranes
- Improved heat and mass transfer due to inherent advantages of fluidized catalyst beds
- Equilibrium shift to enhance hydrogen production in the reformer by lowering the partial pressure of hydrogen in the reaction zone
- Improved thermal efficiency and lower compression energy by integrating compression with the reactor system

Accomplishments

- A kickoff meeting was held with DOE personnel to determine targets, overall approach and contractual requirements. Project status was presented at the DOE Annual Review Meeting in May.
- Various reformer-membrane configurations and options were tested and evaluated. It was determined that reformers with integral membranes are advantageous and that planar membrane architecture offered the highest membrane area/catalyst volume allowing for more compact reactors and were easier to fabricate.
- Case studies were done to compare auto thermal reforming (ATR) and steam methane reforming (SMR) for different reactor geometries and 10-50 micron membrane thicknesses. The key trade-offs are the additional membrane area for ATR systems versus the additional cost/complexity to introduce heat transfer surfaces for SMR.
- Different options for heat integration of a metal hydride compressor with the fluidized bed membrane reactor system were explored using process simulations.

The main task for the first quarter of 2005 was the techno-economic analysis along with supporting bench-scale tests. Progress against each of the sub-tasks is summarized below:

1. Review/revise overall system requirements:

Based on several team meetings and detailed analysis the proof of concept targets are being finalized.

2. Evaluate integration options and select the most promising scheme:

Various system-integration options involving reactor off-gas utilization and both open- and closed-loop heating schemes have been formulated and will be compared to finalize.

3. Perform detailed design of integrated reformer/compressor components:

Efficiency versus capital cost calculation (within H2A and proprietary analysis tools) suggests that low capital cost should be a priority for both the proof of concept prototype and the advanced prototype packages.

- Elimination of components and subsystems are being evaluated based on:
  - SMR instead of ATR to eliminate the need for a custom 25 bar air compressor
  - Direct heating of the hydride compressor utilizing the reactor off gas
  - Single common control system for all functions
  - Reduced low-quality heat recovery

4. Economic Analysis of Integrated System:

A preliminary system evaluation using the H2A model was conducted. However, since this is an integrated system, the reformer and purification cannot be considered separately and some changes need to be incorporated into the H2A model, which will be completed and submitted to DOE in November 2005.