Integrated Hydrogen Production, Purification and Compression System

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Project ID # PD7

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Overview

Timeline

- Project start date - April 1, 2005
- Project end date – Sept. 30, 2009*
- Percent complete: 50

* *Current phase completion: Sept. 2008*

Barriers addressed

- Production Barriers
  - Capital and O&M Costs
- Delivery Barriers
  - Reliability and Costs of Hydrogen Compression

Budget

- Total project cost - $3,840,009
  - DOE share (@65%): $2,854,202
- Funding in FY07: $948,892
- Funding for FY08
  - $435,073 carryover from FY07; supplemental funds requested

Partners

- Key partners:
  - MRT
  - Ergenics Corp. *(formerly HERA USA)*
- Other collaboration/interactions:
  - Safety & Product certification
  - Pd membrane suppliers

Program objectives

To develop an integrated system that directly produces high pressure, high-purity hydrogen from a single integrated unit

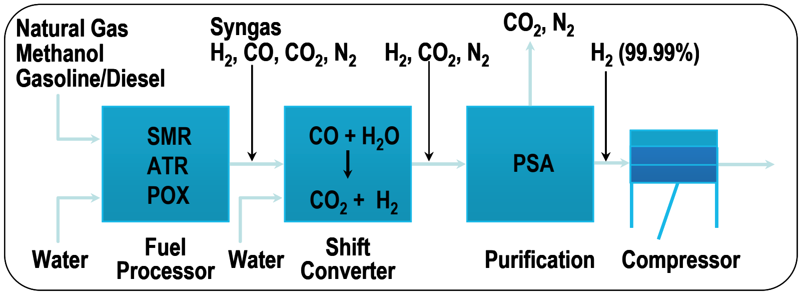
- **Task 1:** Verify feasibility of the concept, perform a detailed techno-economic analysis, and develop a test plan
- **Task 2:** Build and experimentally test a Proof of Concept (POC) integrated membrane reformer / metal hydride compressor system
- **Task 3:** Build an Advanced Prototype (AP) system with modifications based on POC learning and demonstrate at a commercial site
- **Task 4:** Complete final product design capable of achieving DOE 2010 H_2 cost and performance targets

Milestones and decision points

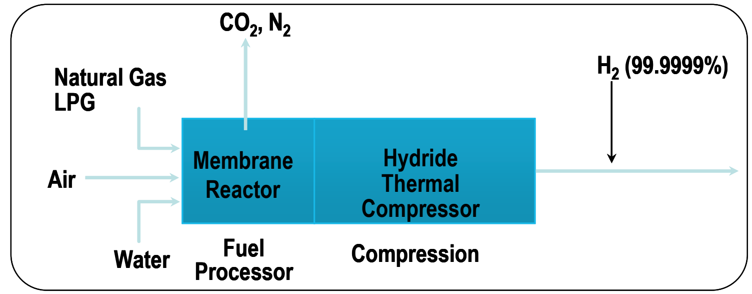
Key Task	Milestones	GO / NO GO Decision Points	Date
Techno-economic assessment	Concept validated at lab scale	Feasibility of system integration confirmed	Feb. 2006
	Preliminary system design and economic model developed	Potential of achieving the cost target of \$2/kg H_2 for a commercial system verified	
Proof Of Concept (POC) prototype	Unit commisioned with output capacity of 15 Nm^3/hr, FC grade H_2 at 100 bar	Integration of FBMR & MHC proven. System operability demonstrated	Aug. 2008
	Test data gathered and analyzed	Initial gas cost target of \$4.72/kg H_2 at FBMR and MHC efficiencies of 71 and 69% respectively validated	
Advanced Prototype	Unit commisioned with output capacity of 15 Nm^3/hr or higher, FC grade H_2 at 435 bar	System operability demonstrated; improvements over POC validated	Sept. 2009
	Test data gathered and analyzed	Intermediate gas cost target of \$2.81/kg H_2 at DOE LHV efficiency validated	
Final system design for mass production	Commercial system designed and mass production concept defined	Feasibility of achieving final cost target of \$2/kg at 1500 kg/day and 500 units/yr scale demonstrated - Dec. 2009	Dec. 2009
	Final cost estimation and economics assessment completed		

Approach to low-cost, forecourt hydrogen production, purification and compression

Integrate the membrane reformer developed by Membrane Reactor Technology (MRT) with the metal hydride compressor (MHC) developed by Ergenics in a single package



Conventional



Proposed System

- Lower capital cost compared to conventional fuel processors by reducing component count and sub-system complexity.
- Increase efficiency by:
  - directly producing high-purity hydrogen using high temperature, H_2 selective membranes; increased flux due to suction provided by the hydride compressor
  - improved heat and mass transfer due to inherent advantages of fluid bed design
  - equilibrium shift to enhance hydrogen production in the reformer by lowering the partial pressure of hydrogen in the reaction zone
  - using excess heat from reformer to provide over 20% of compression energy

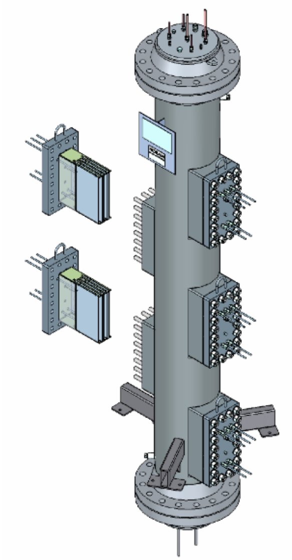
Reformer design is compact and allows uniform temperature and a high H_2 flux

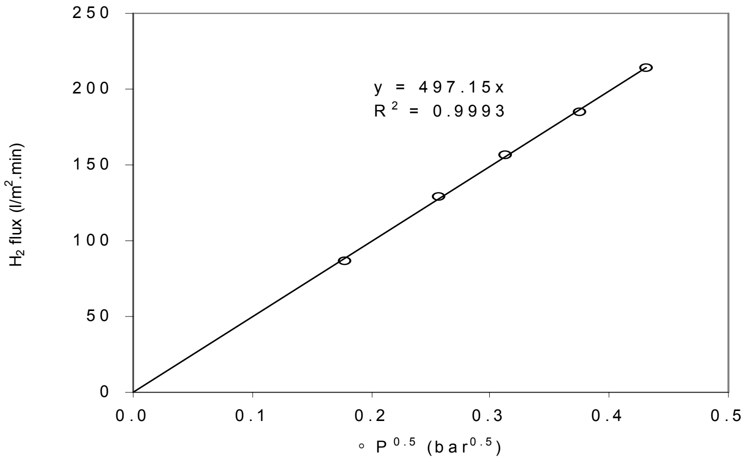
Novel Auto-thermal Fluidized Bed Membrane Reformer (FBMR)

- Design enables use of lower cost metals
- Better membrane access helps easy maintenance

New Membrane Design

- Current design helps lower substrate component costs
- Membranes operate at 550ºC, 25 bar
- Membrane modules (6” x 11” x ¼”) have double-sided, 25 μm foils





POC reformer skid assembly completed and the unit made operational

- Reformer skid installed and commissioned at National Resources Canada, Institute for Fuel Cell Innovation (NRC IFCI)
- Shakedown tests completed and performance data generated

Preliminary test results were encouraging and helped identify potential issues

- Eight runs with varying membrane loads completed
  - Each of the last 5 runs were over 100 hours duration
- Maximum production rate of 8.5 - 9 m^3/hr H_2 achieved with permeate at near atmospheric pressure
  - The results meet model expectations consistent with the design capacity of 15 Nm3/hr H_2 at 0.5 bar permeate pressure
- Maximum natural gas conversion of 55 - 60% achieved
  - Under design operating conditions, conversion of >85% is expected
- Axial reactor temperature variation of <10 ºC
  - Confirmed auto-thermal operation
- Problems were observed with membrane integrity, resulting in H_2 purity degradation
  - Primary cause determined to be transient conditions during startup / shutdown (procedures since revised)

Operating procedure modified to improve membrane life and hydrogen purity

Issue observed	Cause determined	Action Implemented
Membrane damage during installation	Reduced clearance and operator error	Installation procedure revised
Purity drop during operation (one run)	Startup heater failure, causing damage to some membranes	Heater electrical setup reconfigured to prevent impact of potential process upsets
Diminished purity in subsequent run following shutdown	Insufficient hydrogen purging in reactor shell chamber during shutdown	Shutdown procedure revised

- Results of subsequent run after corrective actions
  - No membrane issues during startup, operation, or shutdown
  - Product H_2 purity > 99.99% (no reformate impurities detected; current detection limits at ~50 ppm)

The metal hydride compressor uses thermal rather than electrical energy

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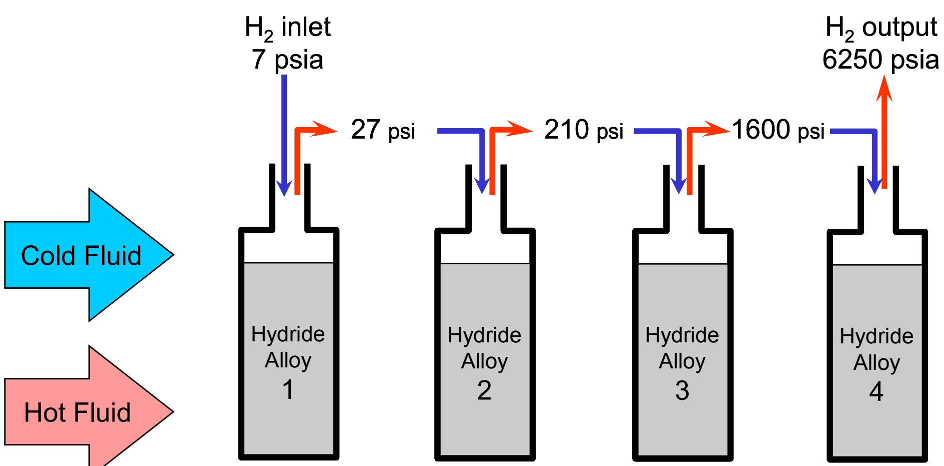
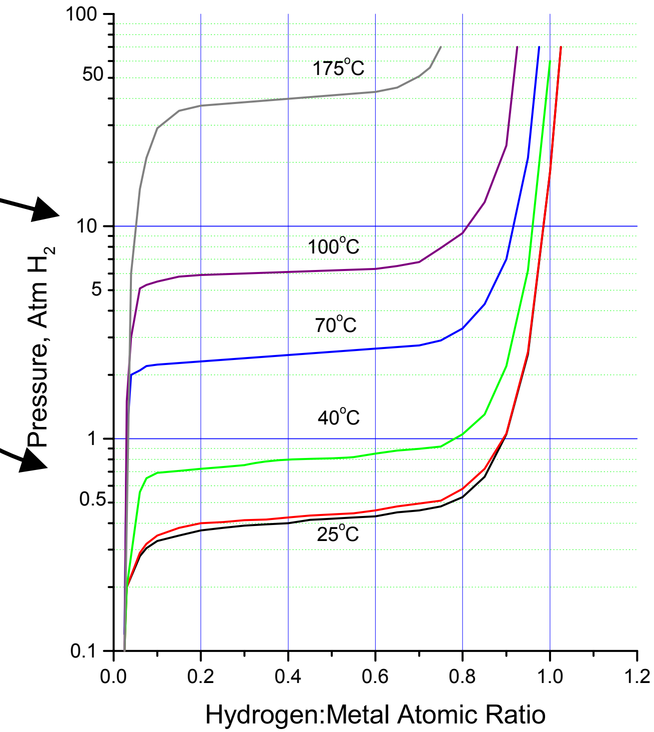
- Multi-stage metal hydride hydrogen compressor creates work (pressurized gas) from heat.
- Ergenics engineers the composition of hydride alloys to operate at different pressures.
- Staging progressively higher pressure alloys lets the hydride compressor achieve very high pressures, using only the energy in hot water or hot air.

Step 2: Hot fluid heats the alloy causing the hydrogen to be released with an exponential increase in pressure.

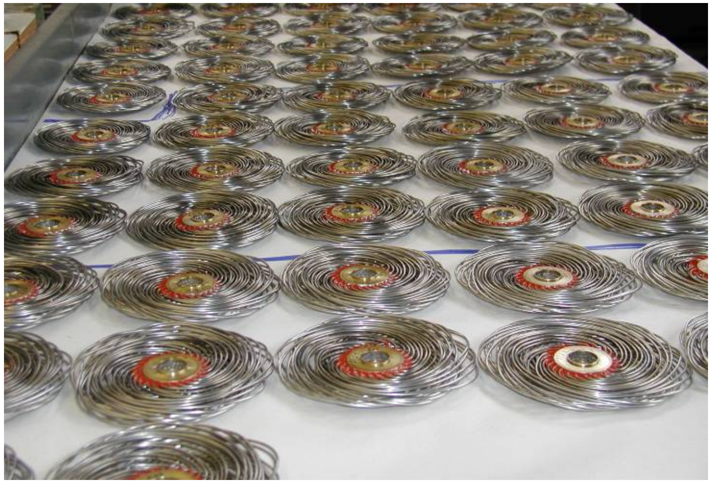
Step 1: Low pressure hydrogen is absorbed by an alloy at ambient temperature.





MHC work resumed in October 2007 with novel hydride heat exchangers

- The MHC work was on hold for ~8 months due to financial difficulties at Ergenics
- Newly designed hydride heat exchangers have been fabricated
  - 1/16” diameter tubes in a spiral geometry

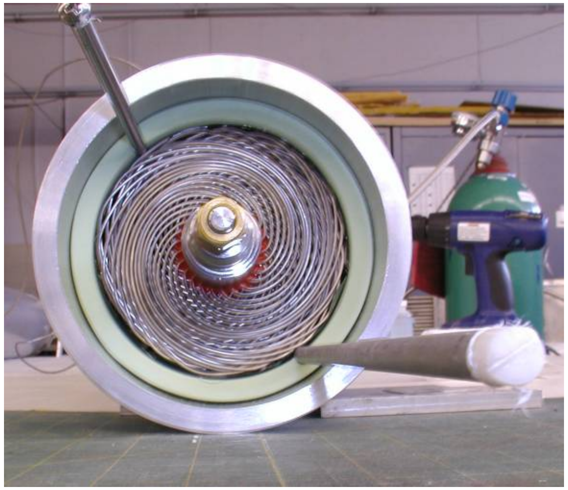


Ring Manifolds are the modular building blocks for efficient, cost effective hydride heat exchangers

They are stacked together to form very high surface area heat exchangers

MHC skid assembly completed and unit installed at test site in May 2008

- MHC balance of plant completed and factory tested
- Unit shipped and installed at the test site (NRC IFCI)
- Testing of the integrated reformer/compressor POC prototype commences in June 2008



Heat exchangers are internally insulated to reduce sensible heat loss

Each heat exchanger contains 3 stages to compress hydrogen from 0.5 bara to 100 bara

Tests with the integrated POC unit have begun and will be completed in August 08

- Current Status
  - Membrane reformer system commissioned and several test runs completed to debug the system
  - MHC skid construction completed and unit shipped to Vancouver
  - MHC installed and integrated with the reformer
- Future Plans (FY2008)
  - Performance tests of the integrated POC unit to be completed by early August 2008 with the following targets
    - Production capacity of 15 Nm3/hr
    - Hydrogen output pressure of 100 bar
    - Hydrogen purity of 99.99% (Fuel cell grade)
    - Production unit efficiency of 71% and compression efficiency of 69% (at compression ratio of 216)
  - GO / NO GO decision regarding the next phase (advanced prototype construction and testing) in August 2008 with the following criteria:
    - Meeting performance targets as above
    - Demonstrating feasibility of achieving the cost target of \$4.72/kg H_2 (POC design basis)

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  - — MHC skid construction completed and unit shipped to Vancouver
  - — MHC installed and integrated with the reformer
- Future Plans (FY2008)
  - — Performance tests of the integrated POC unit to be completed by early August 2008
  - — GO / NO GO decision regarding the next phase (advanced prototype construction and testing) in August 2008
- FY2009 Plans *(based on GO decision)*
  - Complete design, construction and testing of the advanced prototype unit to validate design improvements
  - Demonstrate that the cost and efficiency targets can be achieved in commercial production of the units