Integrated Hydrogen Production, Purification and Compression System

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Project ID# PD8

This presentation does not contain any proprietary or confidential information
Overview

Timeline
- Project start date - April 1, 2005
- Project end date - March 31, 2008
- Key Milestones
  > Techno-economic study - 9/05
  > Proof-of-concept prototype - 9/06
  > Advanced prototype - 11/07
  > Final report - 3/08

Barriers addressed
- Cost reduction of distributed hydrogen production from natural gas and renewable liquids
- DOE delivered H2 cost target: $1.50/gge H2* in 2010
  * Being revised by DOE

Budget
- Total project funding - $3,840,009
  - DOE share - $2,854,202
  - BOC/MRT/HERA share - $985,807
- Funding received in FY04 - none
- Funding for FY05 - $330,410

Partners
- Key partners: MRT and HERA USA
- Other collaboration/interactions:
  - Safety experts
  - Product certification experts

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Program Objectives

• To demonstrate a low-cost option for producing FCV quality hydrogen that can be adopted to meet the ultimate DOE cost and efficiency targets for distributed production of hydrogen

• Develop a hydrocarbon fuel processor system that directly produces high pressure, high-purity hydrogen from a single integrated unit
  – Verify cost and performance targets for the prototype development stages based on techno-economic analysis and develop a plan to address safety issues
  – Build and experimentally test a Proof of Concept (POC) integrated reformer/Metal Hydride (MH) compressor system
  – Build and demonstrate an Advanced Prototype (AP) system at a commercial site
  – Complete final product design capable of achieving DOE 2010 H2 cost and performance targets
Approach

• Integrate the membrane reformer developed by Membrane Reactor Technology (MRT) and the hydride compression system developed by HERA USA in a single package
  – Lower capital cost compared to conventional fuel processors by
    ➢ reduced component count and sub-system complexity
    ➢ tight thermal integration of all reactions/processes in a single package
    ➢ integrated, thermal MH compression without rotating machinery, which results in high reliability and low maintenance
  – High efficiency achieved by
    ➢ directly producing high-purity hydrogen using high temperature, H2 selective membranes
    ➢ improved heat and mass transfer due to inherent advantages of fluidized catalyst bed design
    ➢ 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
Current Forecourt Fueling Station Scenario

Natural Gas
Methanol
Gasoline/Diesel

Syngas
H₂, CO, CO₂, N₂

SMR
ATR
POX

CO + H₂O
CO₂ + H₂

Shift Converter

Psa

CO₂, N₂

H₂ (99.99%)

Compressor

Fuel Dispenser

Fuel Cell Bus

5 system boxes
3 to 5 suppliers
Forecourt Fueling with Proposed System

- Natural Gas
- LPG
- Air
- Water
- CO₂, N₂

Membrane Reactor → Hydride Thermal Compressor

Compression

1 system box
1 supplier

Fuel Processor

H₂ (99.9999%)

Fuel Dispenser

- BOC

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Membrane Reactor Configuration

- Fluidized bed reactor
  - Well-mixed catalyst particles; uniform temperature
- Thermodynamic equilibrium shift of reforming and shift reactions
- Oxidant added to supply part or all of the energy needed for reforming
- Hydrogen withdrawn with vacuum to increase production
Membrane Reactor Technology Status

- Core technologies in reactor and membrane areas covered by patents
- Fluidized catalyst development complete
- Extensive knowledge / experience with Pd alloys and fabrication / operation of foil and deposited membranes in the 5 - 50 micron range
- Pilot manufacturing system for membrane module in place and operational
- Proof-Of-Concept (POC) scale testing of FBMR technology completed last year with Alpha test unit

Alpha Unit
- Located at NRC facility in Vancouver, BC
- Validation of membrane reactor at 15Nm3/hr scale
- Successful operation with custom-developed mechanical vacuum pump
Basics of Hydride Compression

Thermal Compression with Metal Hydride Alloys

- Hydrides are materials that store hydrogen
- The pressure of the hydrogen is a function of temperature
- A modest increase in temperature results in a large increase in pressure
- Compression energy can be provided by hot water, rather than electrical power
- High compression ratios are achieved by staging alloys with increasing plateau pressures
Principle of Hydride Compressor

Thermal Compression with Metal Hydride Alloys

- Hydride Beds are heated to compress the hydrogen, then cooled to accept the next volume of hydrogen.

  [There are parallel beds, not shown here, which operate out of phase]

- High Pressures are achieved with Multiple stages using alloys with progressively elevated plateau pressures
HERA Hydride Compressor Technology Status

- Ergenics (now HERA USA) held initial patents on hydride compressors
- HERA has been supplying metal hydride hydrogen compressors for a broad range of applications for over twenty years
- Current technology demonstrated to 550 bar (8000 psi) output pressure and 200 slpm (12 m3/hr) flow rate
- Technology ready for product standardization and its commercialization is an essential part of HERA’s business plan
- Technology development funded by the DOE Hydrogen and Fuel Cells Program over the 1999-2004 period (focused on impurity tolerance)
- Second generation compressor design in progress
  - Modular design; elevated temp. operation
  - Larger capacity (1560 Nm3/hr); higher pressure (345 bar)
Key Challenges to be Addressed

Membrane Reactor
- Optimization of membrane cost vs. performance / lifetime
- Development of lower cost mechanical design of system

Hydride Compressor
- Optimization of the efficiency of the hydride heat exchangers
- Integration of low cost, high temperature heat source
- Standardization of the staging elements (for flow rates & pressures)

Integrated System
- Full heat source integration between membrane reactor and hydride compressor
- Smooth operation of reformer with the cyclic operation of the compressor
Work Plan

• Task 1 – Techno-economic evaluation (Apr – Sept. 05)
  – Review / revise overall system requirements
  – Evaluate integration options and select the most promising scheme
  – Detailed design of Integrated reformer / compressor components
  – Economic analysis of Integrated system
  – Deliverable: Completion of techno-economic analysis report
    ▶ Recommendations for the POC construction and testing (Task 2)

• Task 2 – Proof of Concept prototype (Oct. 05 – Sept. 06)
  – Fabrication / assembly / testing
  – Deliverable: Report summarizing POC test results

• Task 3 – Advanced Prototype unit (Oct. 06 – Nov. 07)
  – Design / fabrication / assembly / testing / report

• Task 4 – Develop concept for mass production (Dec. 07 – Mar. 08)
  – Deliverable: Report providing final design to meet DOE targets
Schematic of the Integrated System

• Evaluating SMR vs. ATR options and various equipment configurations
• Excess heat from reformer section used for hydride regeneration
Technical Accomplishments/Progress/Results

- Project kick-off meeting held with DOE personnel
- Project organization / decision making process defined
- Reformer/compressor integration being progressed
  - Preliminary designs developed
  - Integration options being reviewed
  - Modeling, simulation and optimization in progress
  - Economic analysis framework based on H2A
- Project Safety Review process being defined
Thank You!

Questions?
Project Management

• BOC will provide overall project management by leveraging
  – Experience in operating industrial hydrogen plants and developing customer solutions around these plants
  – In-depth knowledge of process integration and of customer needs
  – Culture of collaboration and team work to obtain results
• Team formed with technical and business representatives from BOC, MRT and HERA
  – Individual tasks will be led by area experts with participation from others
  – Regular meetings to review progress and make decisions
• BOC will coordinate communication with DOE with input from MRT and HERA
  – Submission of technical reports
  – Management of budget, invoicing, disbursement
• Upon successful completion of project BOC is committed to facilitate commercialization of the integrated system
Safety Planning

• The most significant hydrogen hazard associated with this project is:
  – Fire or explosion due to exposure of hydrogen-containing combustible gases to air and/or heat sources

• Our approach to deal with this hazard consists of the following:
  – Rigorous procedures developed by the team for this type of project will be used. These include Technical Risk Assessment, Process Safety Review and HAZOP
  – System design will incorporate safety shutdown protocols for all potential critical identified
  – Project team is educated and trained on hydrogen safety and access to test equipment will be limited to trained personnel

• Other related activities will be leveraged
  – BOC actively participates in various Codes & Standards committees
  – BOC has significant experience with H2 refueling station projects