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

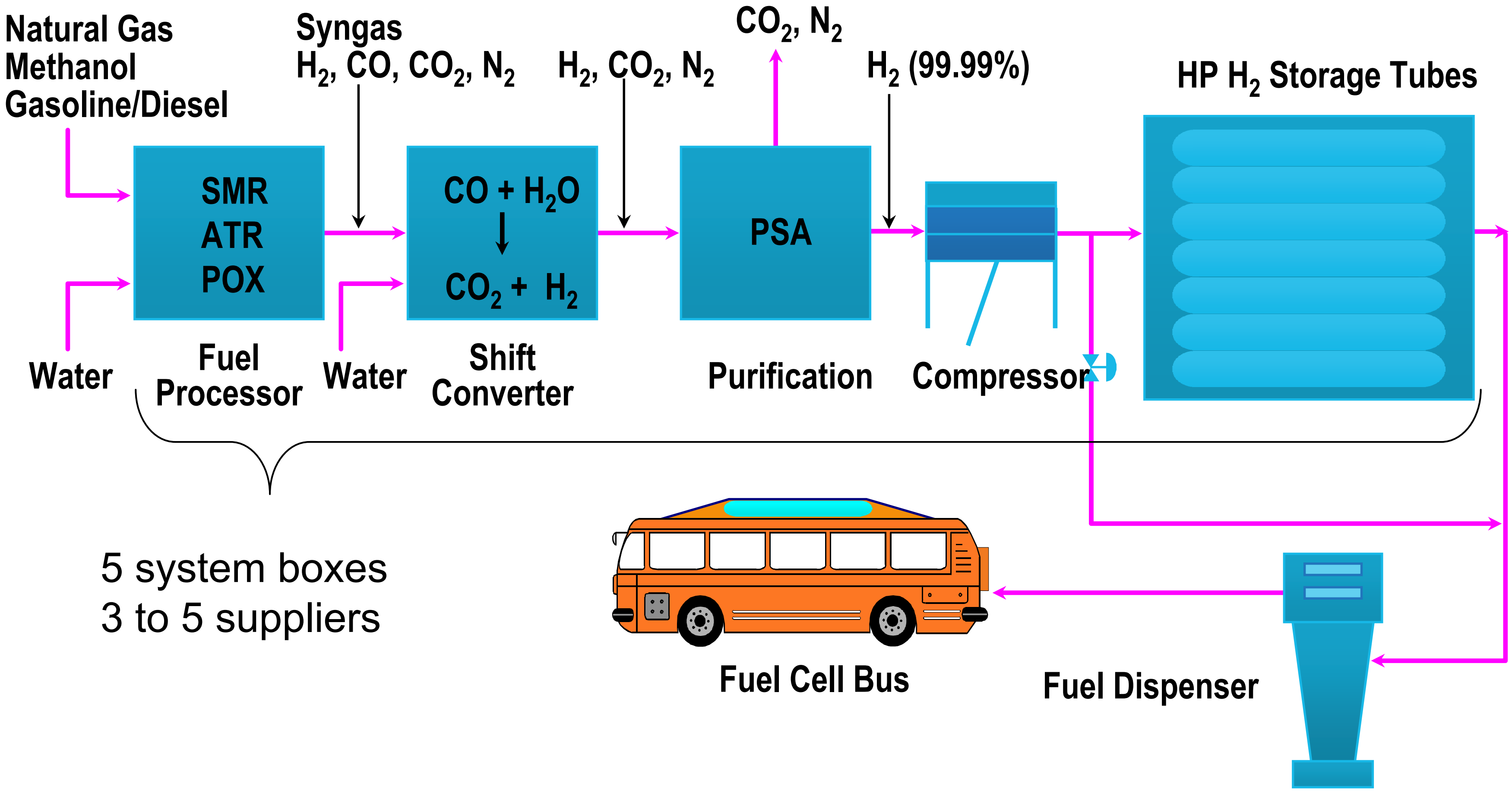
Program Objectives

- 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

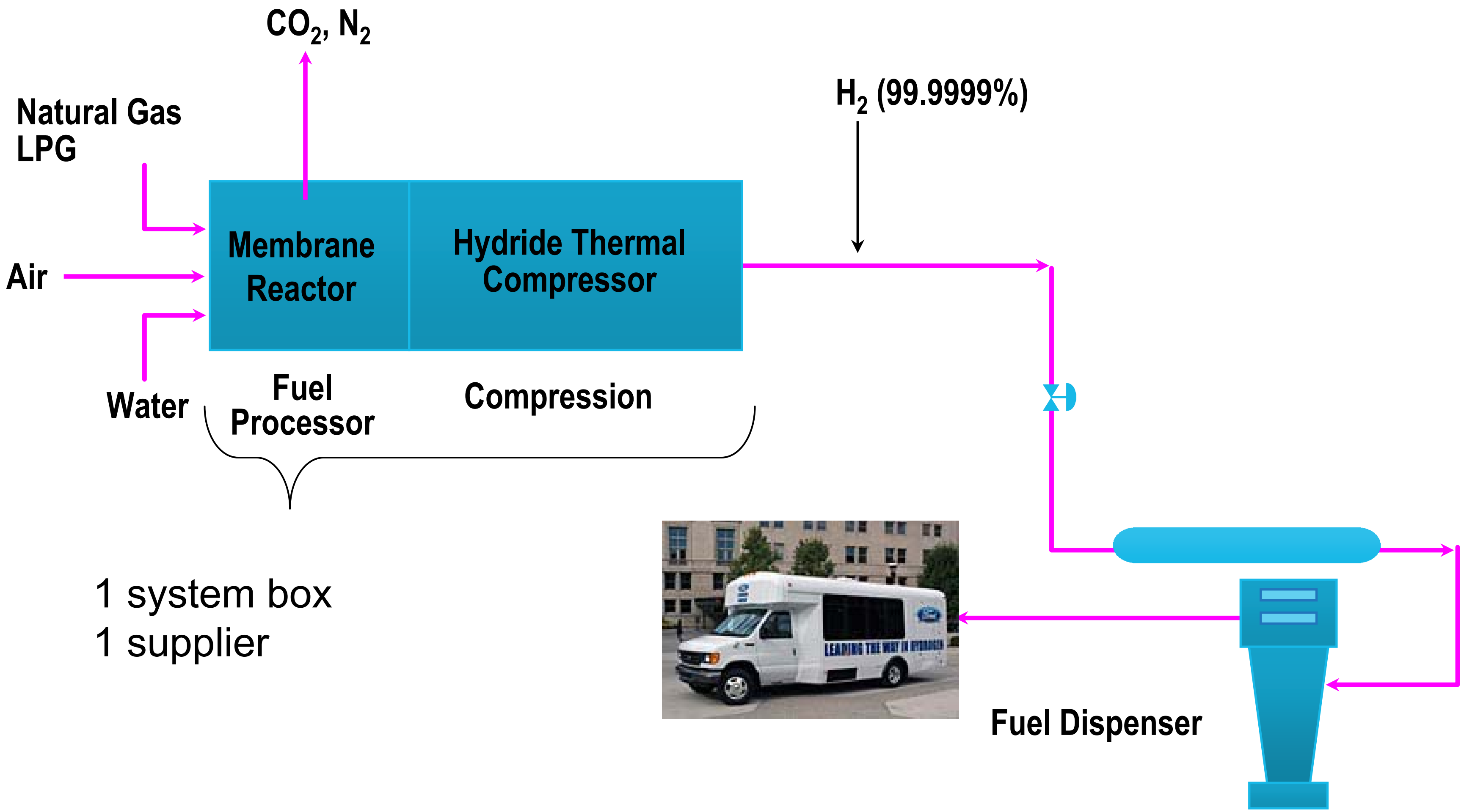
- Integrate the membrane reformer developed by Membrane Reactor Technology (MRT) and the hydride compression system developed by HERA USA in a single package
  - Lower capital cost compared to conventional fuel processors by
    - reduced component count and sub-system complexity
    - tight thermal 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



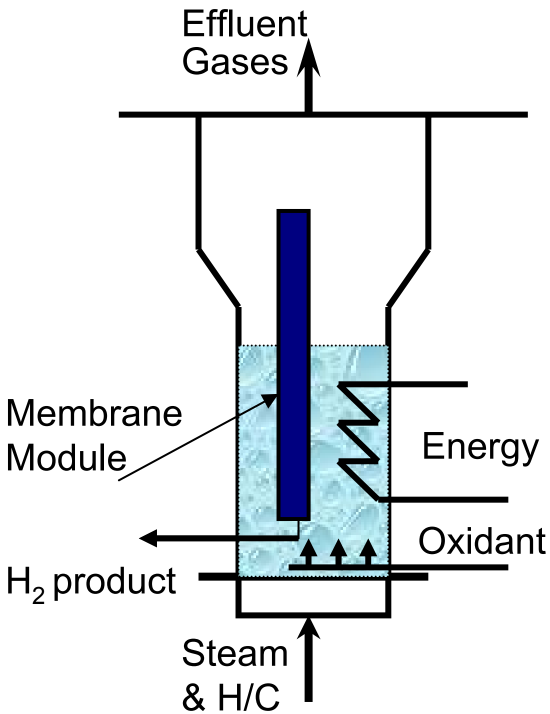
5 system boxes
3 to 5 suppliers

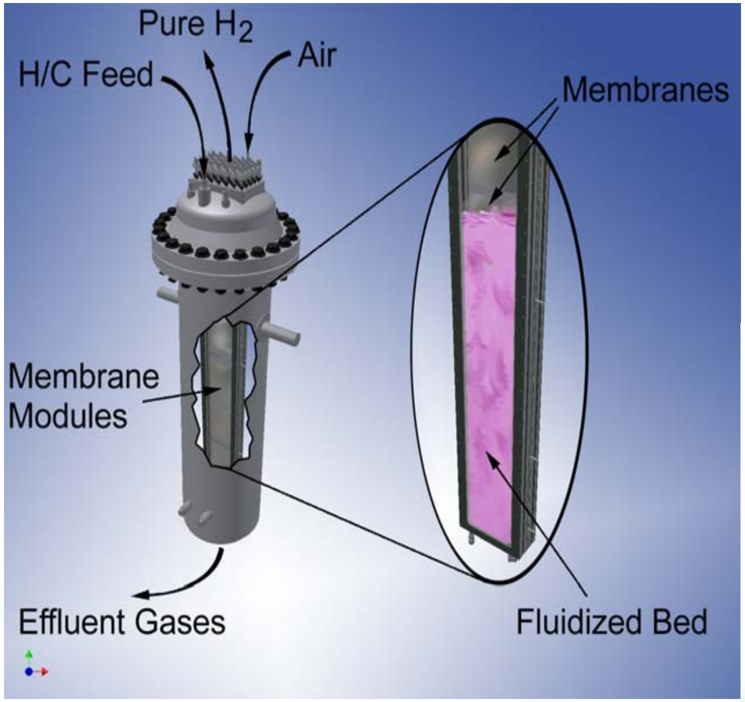
Forecourt Fueling with Proposed System



1 system box
1 supplier

Membrane Reactor Configuration





Typical membrane module

- 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

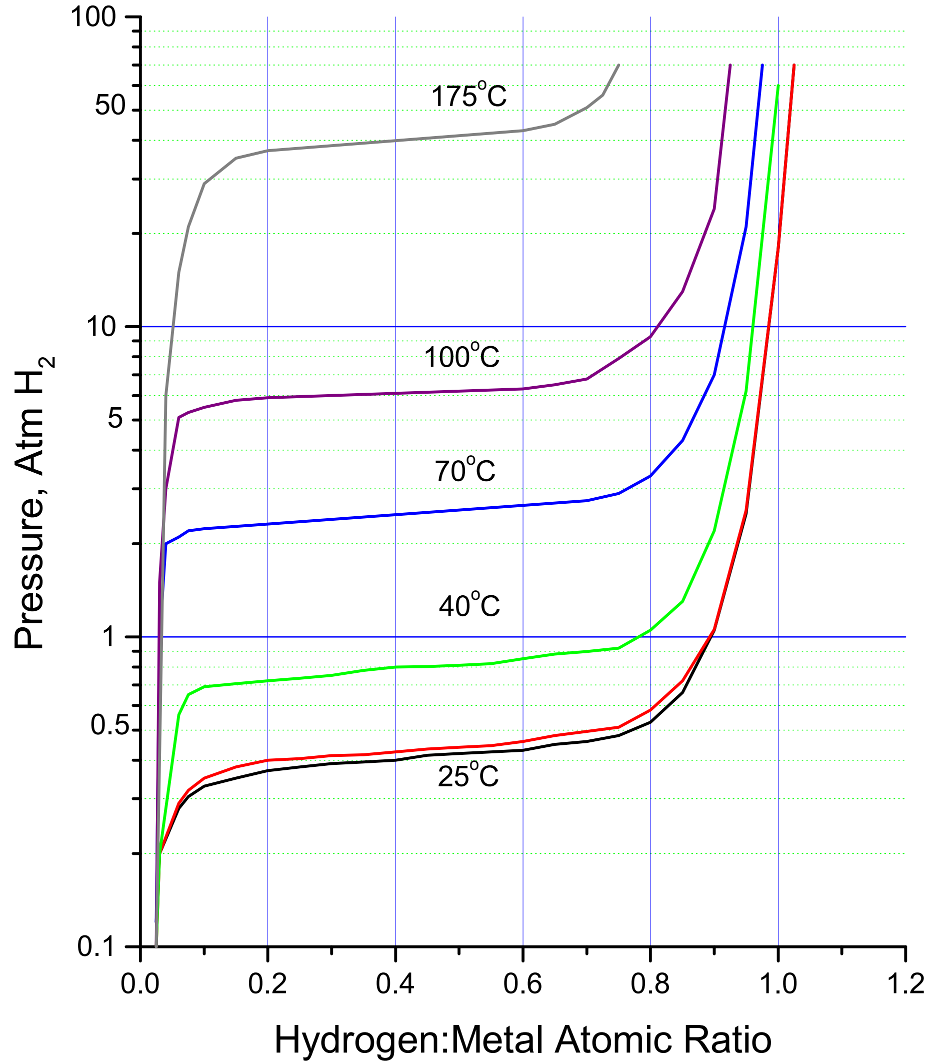
Alpha Unit

- 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

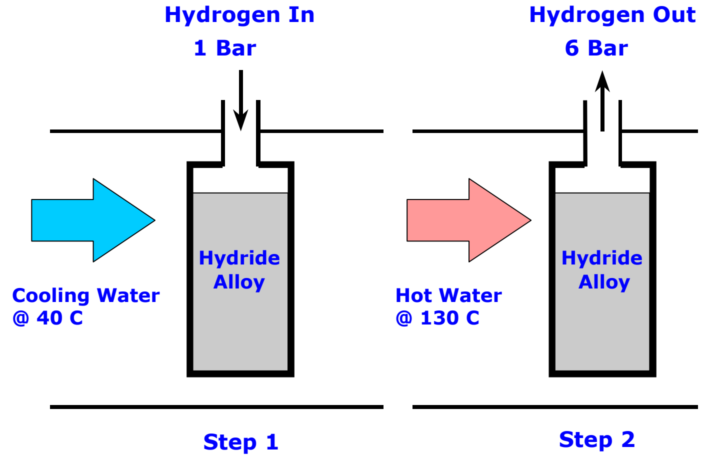


Principle of Hydride Compressor

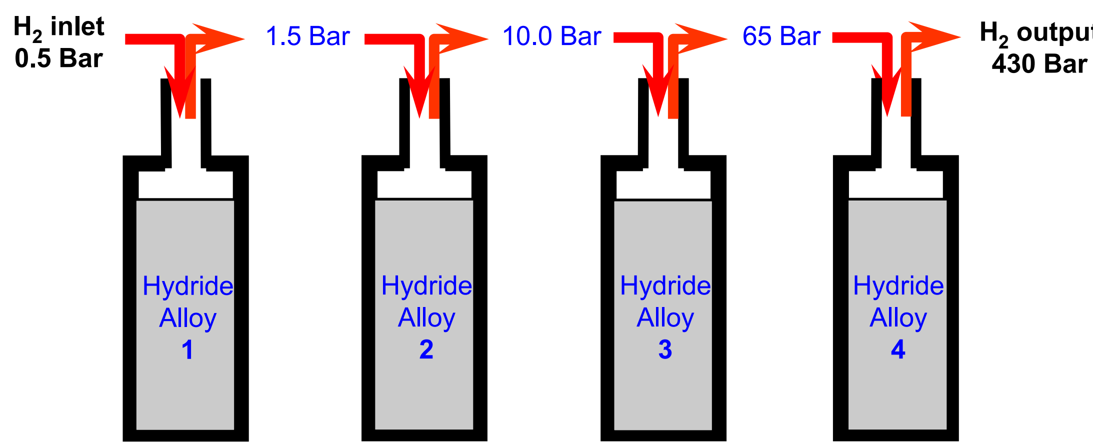
Thermal Compression with Metal Hydride Alloys

- 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]

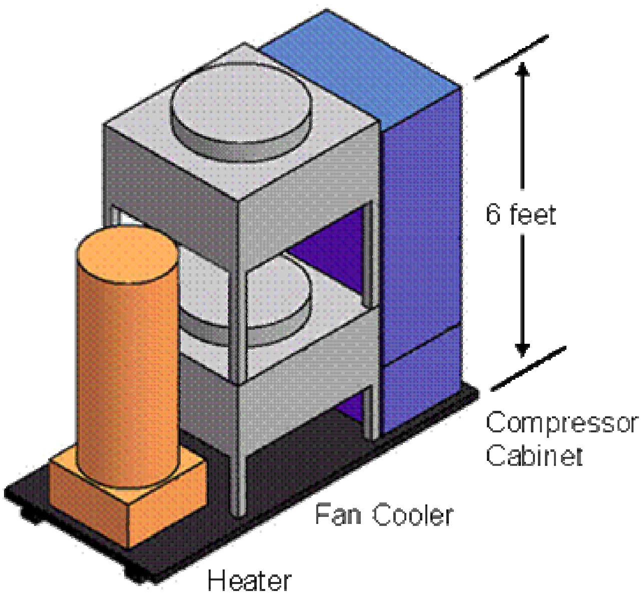


- High Pressures are achieved with Multiple stages using alloys with progressively elevated plateau pressures



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)

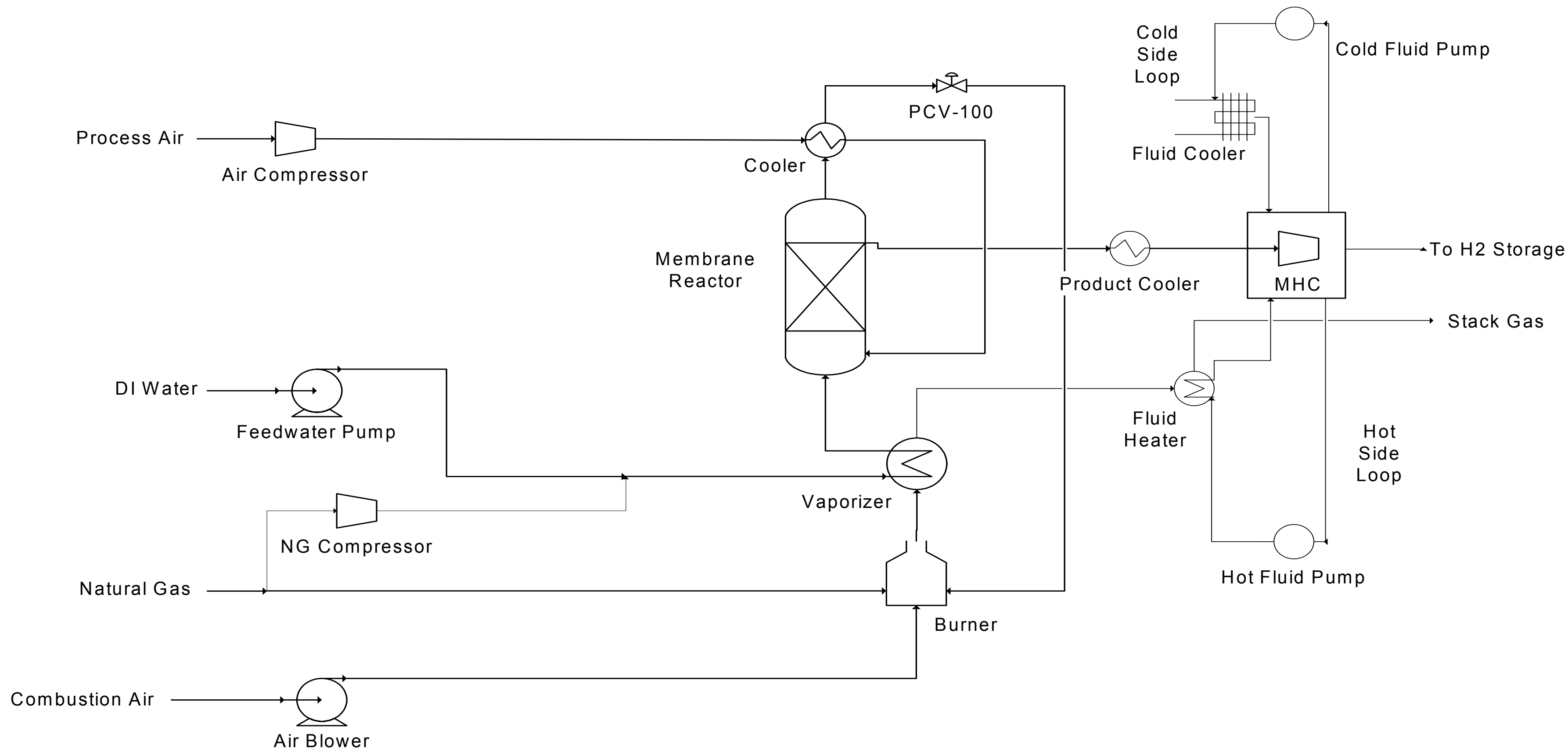
Integrated System

- 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