Novel Compression and Fueling Apparatus to Meet Hydrogen Vehicle Range Requirements

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Project ID: TVP3

This presentation does not contain any proprietary or confidential information

Overview

- Timeline
  - Project Start 10/2002
  - Contract 5/2004
  - Project End 6/2006 (revised from 2/2006)
  - 90% Complete
- Barriers
  - High cost of hydrogen compression
  - Cost of hydrogen
- Budget
  - Total $690,875
  - DOE Share $345,438
  - APCI Share $345,438
  - 04 Funding $317,606
  - 05 Funding $373,088
  - 06 Funding – Earmark for continued development
- Collaboration
  - Tescom
  - Genesys
  - Weh
  - OPW
  - Walther
  - Spir Star

Objectives

- Primary
  - Develop a process design for a novel compressor to achieve near isothermal compression in a single cylinder with a compression ratio of 140:1
  - Develop mechanical design for novel compressor
  - Select a test hydraulic fluid
  - Machine/Manufacture Compressor parts & components
  - Assemble prototype system and test
  - Demonstrate operation of the system
  - Final report
- Secondary
  - Investigate other fueling components to support 700 barg (10,000 psig) hydrogen fueling

Approach

- Conceptual Design
- Process Design
- Thermodynamic Data
- Fluid Selection and Testing
- Dynamic Modeling
- Component Design, Fabrication, and Testing
- Prototype
  - Site selected and compressor installed
  - Components in hand for test skid
- Long Term Testing
  - Site selection
  - Funding has been granted

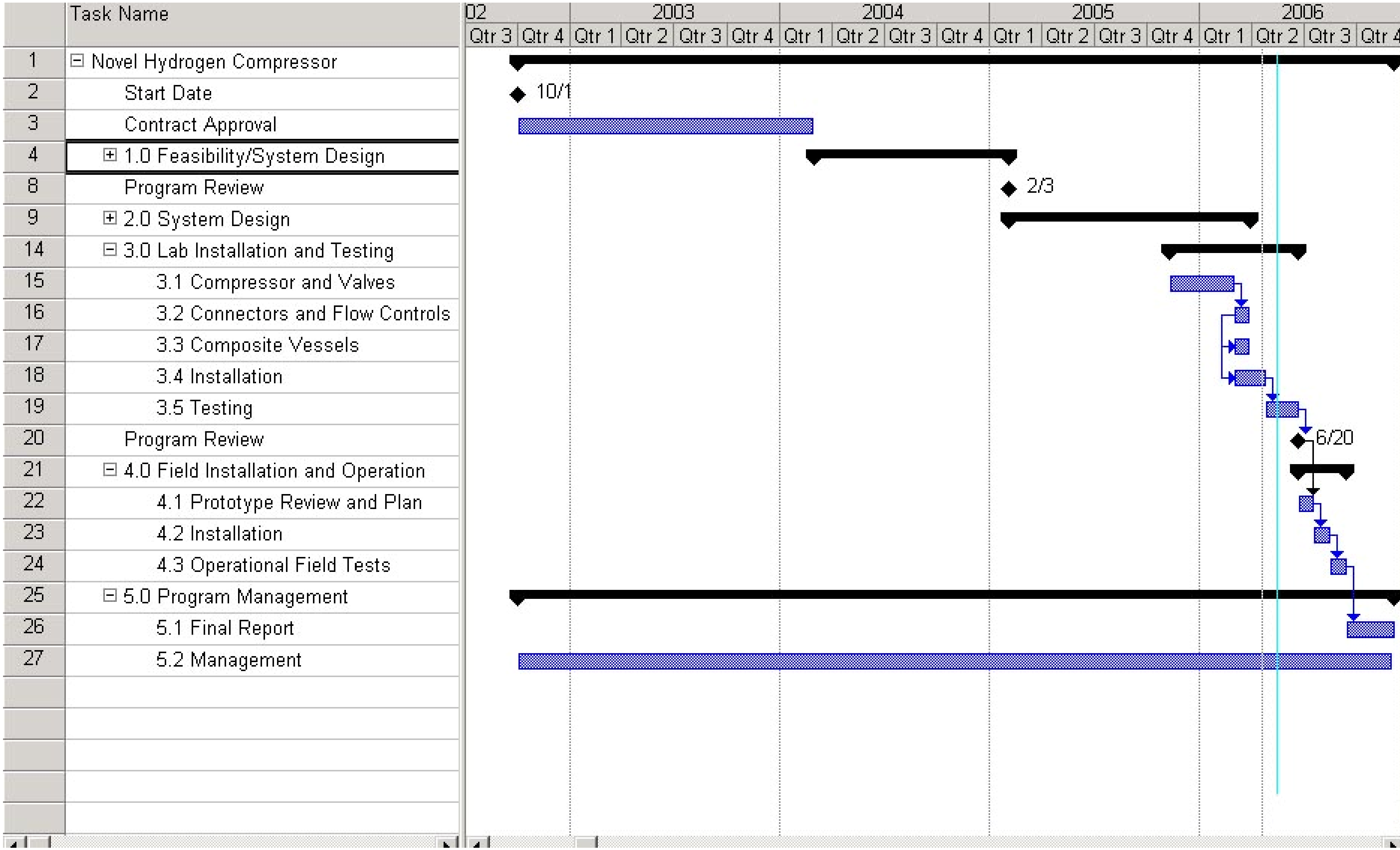
Approach
Design Issues

- Compressor
  - Isothermal (~50 Deg F rise)
  - High pressure (~14,000 psig)
  - Single stage
  - Low cost
- Fueling Station
  - Lower the delivered cost of hydrogen
  - Composite vessels (ASME approval)
    - Lined steel vessels are $110,000/ft3 at 15000 psig
    - Alternate materials suitable for high pressure hydrogen service are high cost and difficult to machine.
  - Breakaway and fuel nozzle (Walther, OPW, and Weh)
  - Fueling codes

Safety

- Air Products Hydrogen Experience
  - Over 20,000 fills (75-100/week)
  - 8 fuel stations installed last year (40 total, 10 in construction)
  - Industrial hydrogen (30+ years, 55% merchant market share, 1000 gaseous/500 liquid customers, pipelines, purification/separation, reformers, electrolysis)
- Our fueling systems have undergone rigorous third party independent safety reviews
  - ABS Consulting – Singapore
  - BP – PHSER review
  - NASA - White Sands, NM
  - KHK/JHPGSL – Kagoshima, Japan
  - International Refinery Services – Singapore
  - Beijing Government – FSR Permitting
  - KGSL – Seoul, Korea
  - UL and Metlabs

Timeline



Task Name
02
2003
2004
2005
2006
Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4
1 Novel Hydrogen Compressor
2 Start Date
3 Contract Approval
4 1.0 Feasibility/System Design
8 Program Review
9 2.0 System Design
14 3.0 Lab Installation and Testing
15 3.1 Compressor and Valves
16 3.2 Connectors and Flow Controls
17 3.3 Composite Vessels
18 3.4 Installation
19 3.5 Testing
20 Program Review
21 4.0 Field Installation and Operation
22 4.1 Prototype Review and Plan
23 4.2 Installation
24 4.3 Operational Field Tests
25 5.0 Program Management
26 5.1 Final Report
27 5.2 Management
10/1
2/3
6/20

Technical Accomplishments
Novel Compressor – Basic Concept

- **Isothermal:** Gas cooled during compression (50 ºF rise)
- **Single Stage:** Liquid piston permits high pressure ratio by elimination of piston to cylinder clearance and temperature concerns (140:1 compression ratio).
- **Simple Fabrication:** No exotic materials or sophisticated machining.
- **Liquid Pump:** Inherently lubricates all dynamic seals, off the shelf pump
- **Small Footprint:** 3’x4’x7’
- **No External Cooling:** Radiator on hydraulic loop is all that is needed
- **Dynamic Gas Seals Eliminated:** No gas seals to atmosphere
- **Level Control:** Density control
- **Potential Issues:** Fluid carryover, high pressure storage vessels, intensifier seal wear

Patents Pending

many typical machinery issues eliminated by liquid piston

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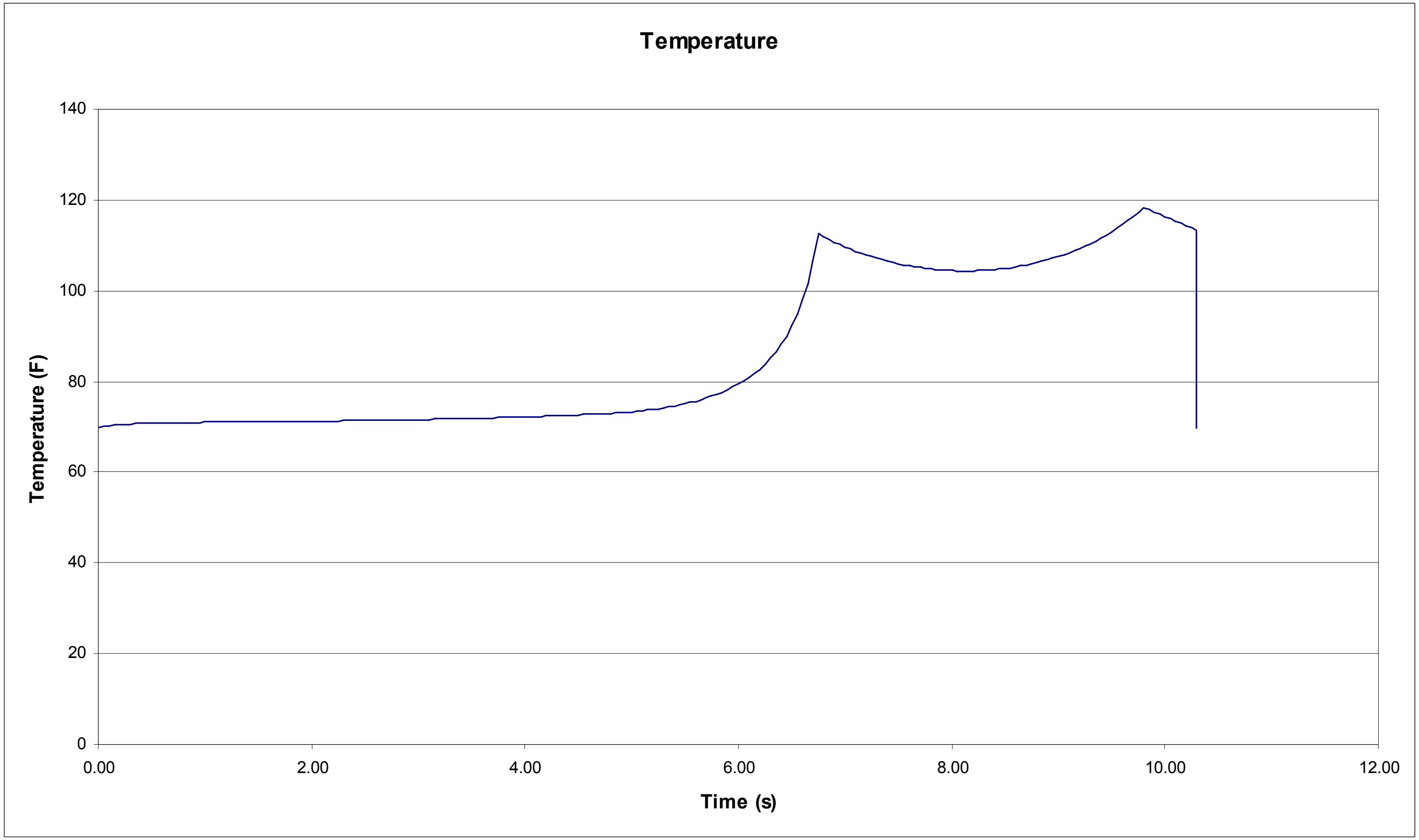
Technical Accomplishments Existing Technology

- Diaphragm Compressor
  - Metal diaphragm separates gas from oil
  - 300 deg F temperature rise
  - 20:1 standard compression ratio
  - Up to 350 barg is bolted, higher pressure requires bootstrap
- Hydraulic Intensifier
  - Floating piston with rings separates gas from oil
  - 300 deg F temperature rise
  - 8:1 standard compression ratio
  - Smaller cylinder allows higher discharge pressures (long stroke at low RPM)

Technical Accomplishments
Cylinder Pressure and Temperature



~ 50ºF temperature rise for 140:1 compression ratio

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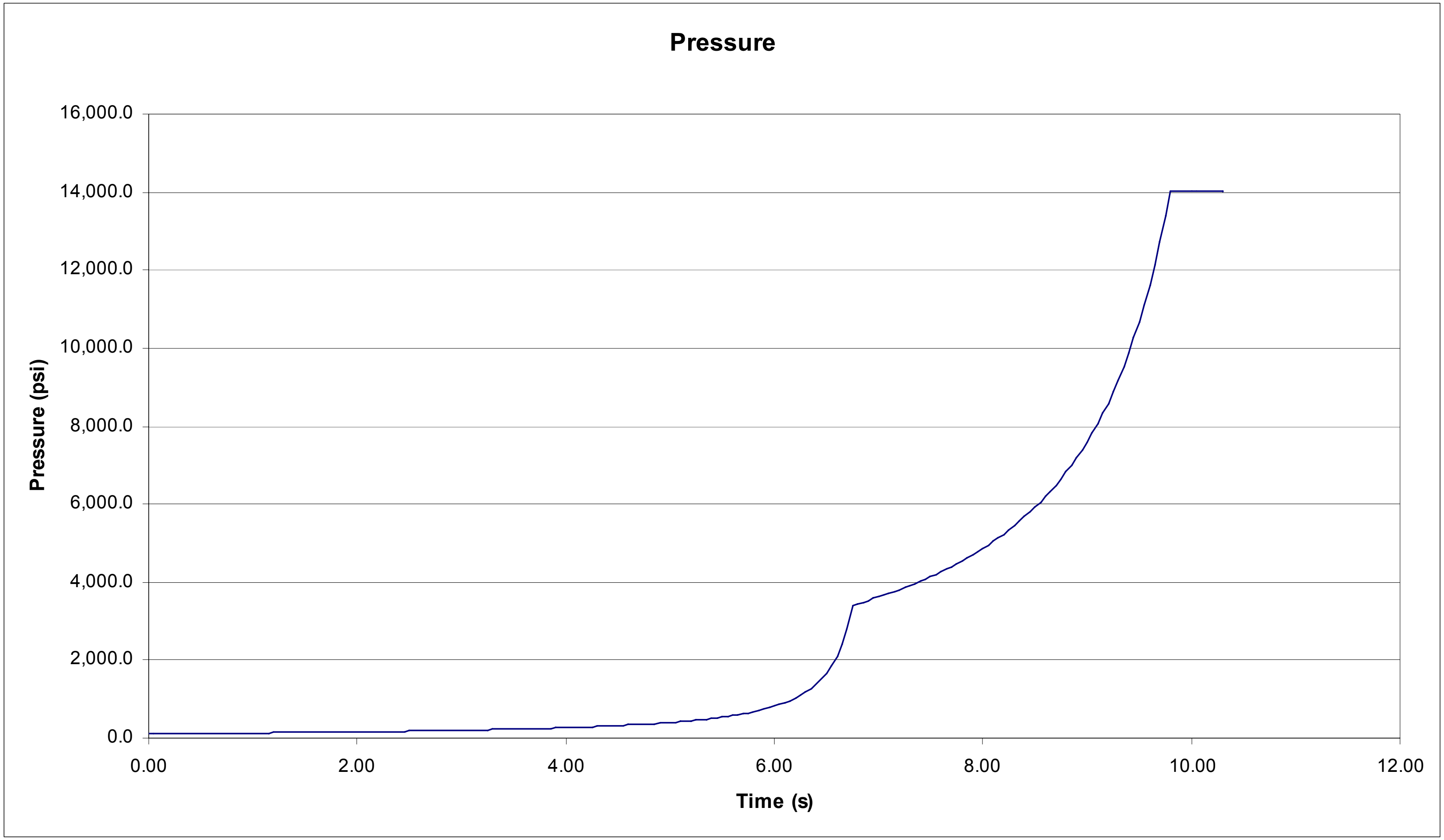
Technical Accomplishments
Cylinder Pressure and Temperature



Technical Accomplishments
Dynamic Simulation Results

- **Identified key operational issues and design parameters:**
  - **Surface area requirements in heat exchanger and heat transfer coefficients for near isothermal operation**
  - **Liquid inventory management needs (pressure/flow regulation)**
- **Quantitative results on potential sources of inefficiency:**
  - **Hydraulic intensifier friction**
  - **Circuit DPs**
  - **Hydrogen solubility in compression fluid**
  - **Heat transfer limits and design of heat exchanger**
- **Process sensitivities to the following parameters studied:**
  - **Initial accumulator gas volume**
  - **Pump flow**
  - **Hydraulic intensifier flow**
  - **Valve flow coefficients**

novel H_2 compressor unit is feasible

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Technical Accomplishments
Pressure Analysis

- Automotive OEM's are pursuing 700 barg fueling to achieve US norm of 300 mile range.
- Fast fill (~ 4-6 minutes) is the method with the highest commercial potential.
- Cascade fueling is the most often used method of achieving a low cost, fast fill. This is not possible at 700 barg with steel storage cylinders due to cost and hydrogen embrittlement concerns.
- To achieve full fills, cascade filling requires a minimum of 25% overpressure to counter vehicle tank heating.
- Fast fill to 700 barg will require cooling of the hydrogen and communications between the vehicle and dispenser.
- ASME and Air Products requirements for relief valves (set at vessel MAWP) impose a maximum operating pressure of 90% of MAWP.

(700 Barg * 125%) / 90% = 972 Barg MAWP (14100 psig)

System pressure requirement is 14100 psig MAWP

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Technical Accomplishments
Cost / Efficiency

	Today	Novel Compressor Prototype	Novel Compressor "Product" (10 per year)
Cost	**$1.00**	**$.40 - $.50**	**$.25 - $.30**
Efficiency		In principle, will require less power. Testing to determine.	

Flow = 70 scfh H2
Pin = 100 psig
Pout = 14,000 psig

Technical Accomplishments
Dispenser Update

- Dispensers have been updated to include a breakaway and nozzle shield.
- New HMI touchscreen allows use of a single panel for control and display.
- Class I Division 1, Group B design for dispenser.
- Control panel is separate enclosure rated for Class I Division 2, Group B.
- Dispenser components upgraded to 15,000 psig MAWP (700 barg).
- Fueling hose with 6:1 safety factor.
- New remote data acquistion system is being piloted (e-Ram).

Future Work

- Long term operational test.
- Determine overall costs.
- Determine feasibility of future use.
- Identify barriers and other work needed for 700 barg fueling.
- Final Report

Summary

Relevance: Develop a compressor that enables 700 barg fueling by lowering the cost of hydrogen.

Approach: Design a compressor that can dramaticallly lower the cost, maintenance, and power requirements for fueling.

Accomplishments: Developed a 700 barg dispensing system. Compressor is built and undergoing testing.

Collaborations: Work with industry leaders and develop required hardware to support 700 barg fueling.

Future: Continued testing and installation into a fueling station.

Interactions/Collaborations

- Air Products and Chemicals, Inc.
  - Future Energy Solutions
  - Advanced Systems Machinery
  - Advanced Controls
  - Cryomachinery
  - Dynamic Modeling
  - Corporate Safety
- Tescom
- Spir Star
- Barksdale
- Ashcroft
- Weh
- OPW
- Walther

tell me more

www.airproducts.com

Response to 2005 Reviewer’s Comments

- **Potential hurdles not identified.**

  We are working to identify the potential hurdles to compressor operation. A test plan will be executed to check each portion of the system prior to full operation.

Publications and Presentations

- May 2003 – DOE Peer Review
- May 2004 – DOE Peer Review
- May 2005 – DOE Peer Review

Issues

- Determined that the original Krytox oil could react with hydrogen. Switched to a mineral oil that is much lower cost and will act as a better lubricant.
- Identified some problem materials (17-4 ph steel) used for trim on some valves. Identified an alternate heat treatment to repair the items, if they have not been in hydrogen service.
- Will investigate other fluids and absorption vessels. There is potential for vapor carryover of the mineral oil.
- Need to monitor the intensifier seal rings for wear and check coalescer for wear products.
- Medium pressure component lead times have gone to 4x normal due to Hurricane Katrina and the rebuilding effort.

Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

Drawing air into the compressor suction and compressing into the high pressure hydrogen storage vessels. Given the correct conditions, this could result in a high pressure flammable gas mix. Deflagration or detonation of this mixture could result in failure of the vessels.

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Hydrogen Safety

- Our approach to deal with this hazard is:

  We have completed a Level of Protection Analysis that takes all physical and operating conditions into consideration to determine the probability of the event occurring. We also utilize a low pressure switch on the compressor inlet (hard-wired to PLC power). This pressure switch is functionally tested every quarter.

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