Novel Compression and Fueling Apparatus to Meet Hydrogen Vehicle Range Requirements

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May 25, 2005

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Project ID: TV6

This presentation does not contain any proprietary or confidential information

Overview

- Timeline
  - Project Start 10/2002
  - Contract 5/2004
  - Project End 2/2006
  - 85% 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
- Collaboration
  - Tescom
  - Genesys
  - Weh
  - OPW
  - Walther
  - Spir Star

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Objectives

- Primary
  - Develope a process design for a novel compressor
  - Develope 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
  - Machining of compressor parts complete
  - New valves developed for 15,000 psig
  - New relief valves being tested and qualified
  - New pressure switch identified
  - New thermocouple wells designed
- Prototype
  - Skid hazard review
  - Components on order for test skid
- Long Term Testing
  - Site selection and funding

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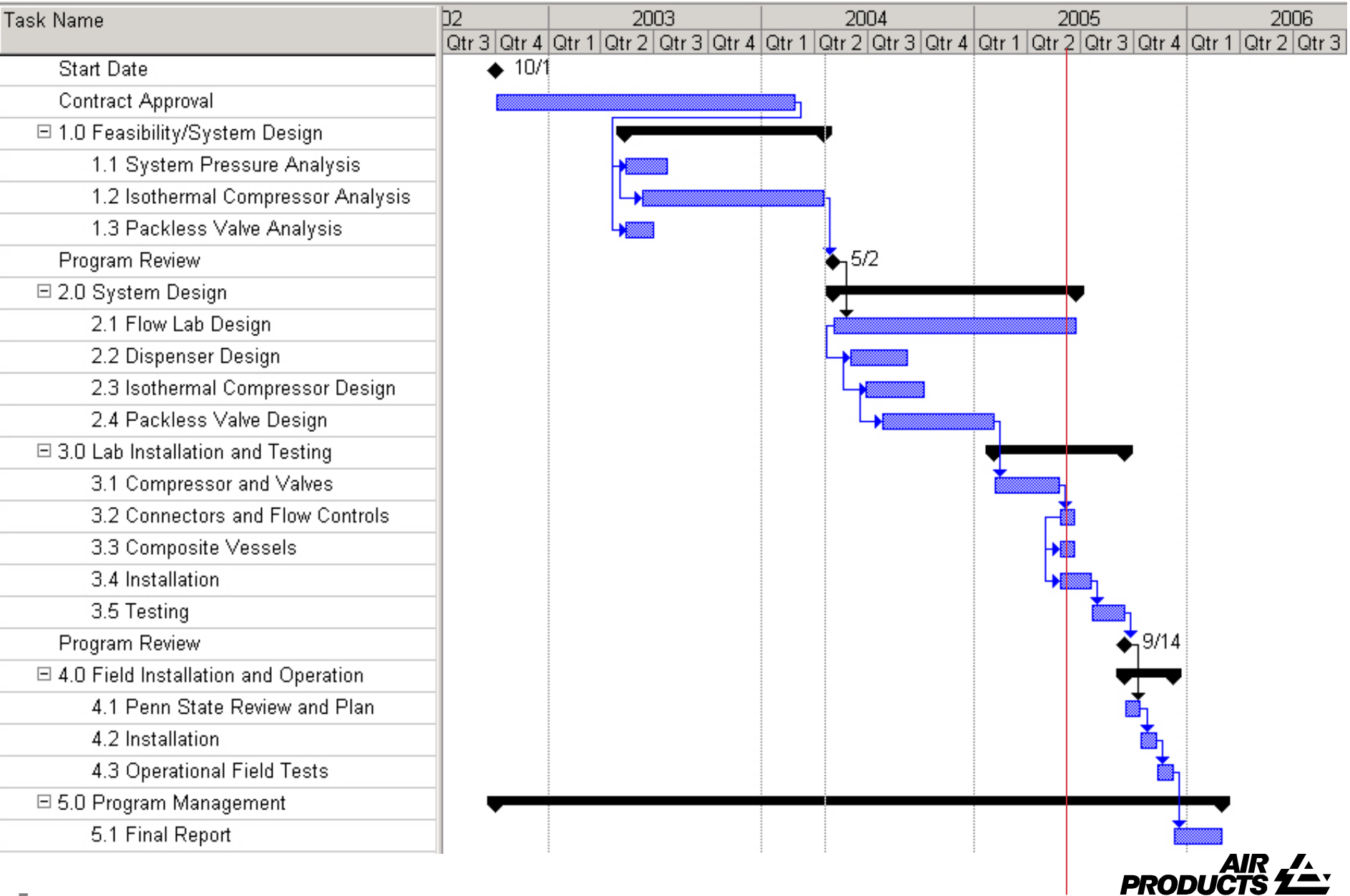
Approach
Design Issues

- 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
  - Breakaway and fuel nozzle (Walther, OPW, and Weh)
  - Fueling codes

Safety

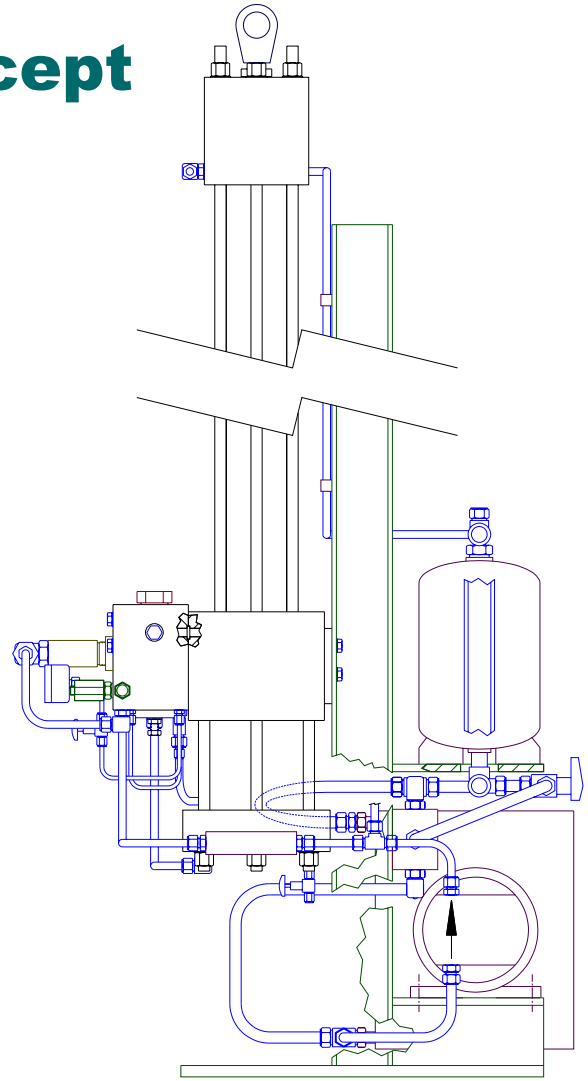
- Air Products Hydrogen Experience
  - Over 12,000 fills (75-100/week)
  - 10 fuel stations installed last year (32 total, 12 in construction)
  - Industrial hydrogen (30+ years, 55% merchant market share, 1000 gaseous/500 liquid customers, pipelines, purification/separation, reformers, electrolysis)
- Our fueling systems have undergone rigorous third party independent safety reviews
  - ABS Consulting – Singapore
  - 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
Start Date
Contract Approval
1.0 Feasibility/System Design
1.1 System Pressure Analysis
1.2 Isothermal Compressor Analysis
1.3 Packless Valve Analysis
Program Review
2.0 System Design
2.1 Flow Lab Design
2.2 Dispenser Design
2.3 Isothermal Compressor Design
2.4 Packless Valve Design
3.0 Lab Installation and Testing
3.1 Compressor and Valves
3.2 Connectors and Flow Controls
3.3 Composite Vessels
3.4 Installation
3.5 Testing
Program Review
4.0 Field Installation and Operation
4.1 Penn State Review and Plan
4.2 Installation
4.3 Operational Field Tests
5.0 Program Management
5.1 Final Report
10/1
5/2
9/14

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)
- **Liquid Pump:** Inherently lubricates all dynamic seals
- **Dynamic Gas Seals Eliminated:** No gas seals to atmosphere
- **Issues:** fluid carryover, level control



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)

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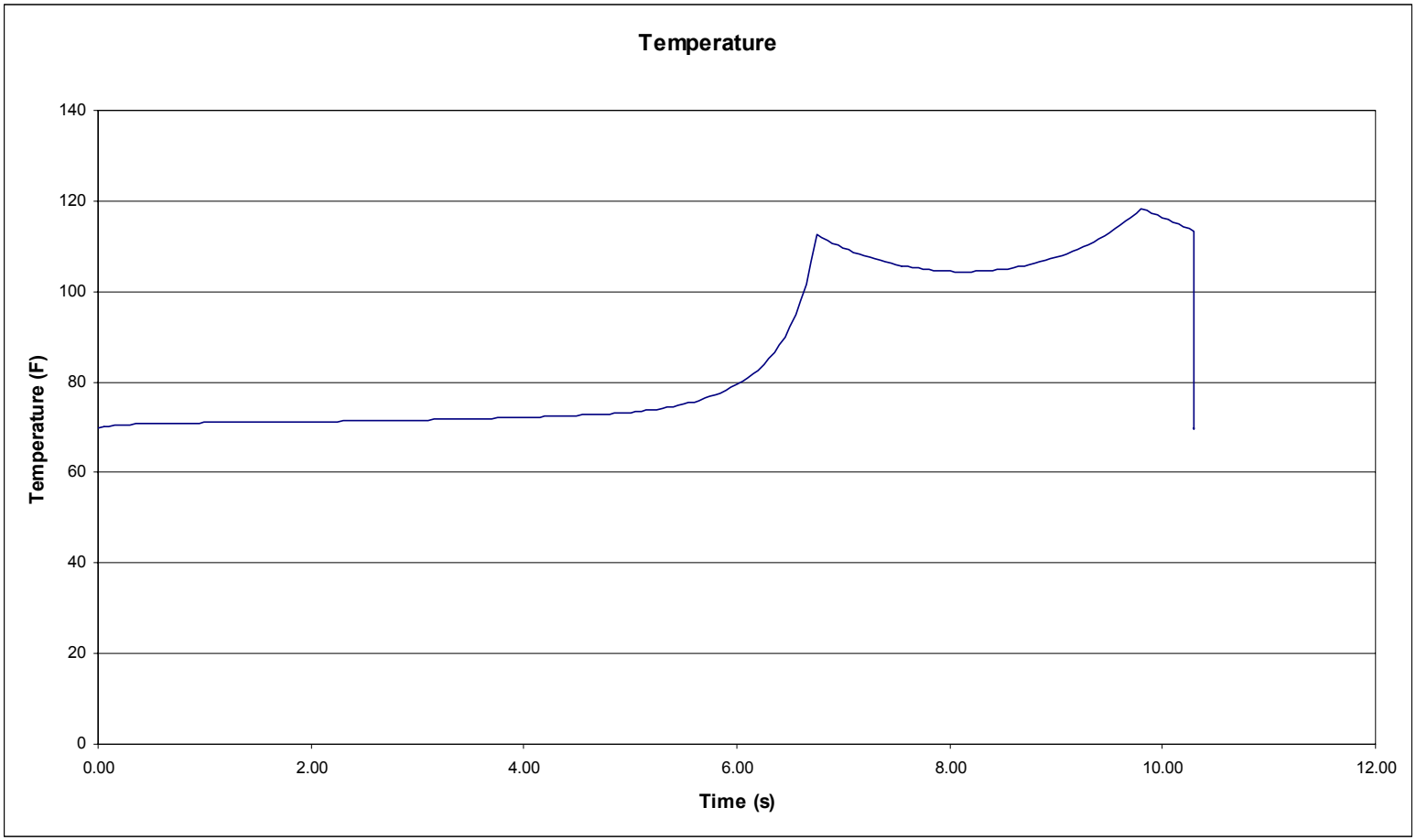
Technical Accomplishments
Cylinder Pressure and Temperature



~ 50ºF temperature rise for 140:1 compression ratio

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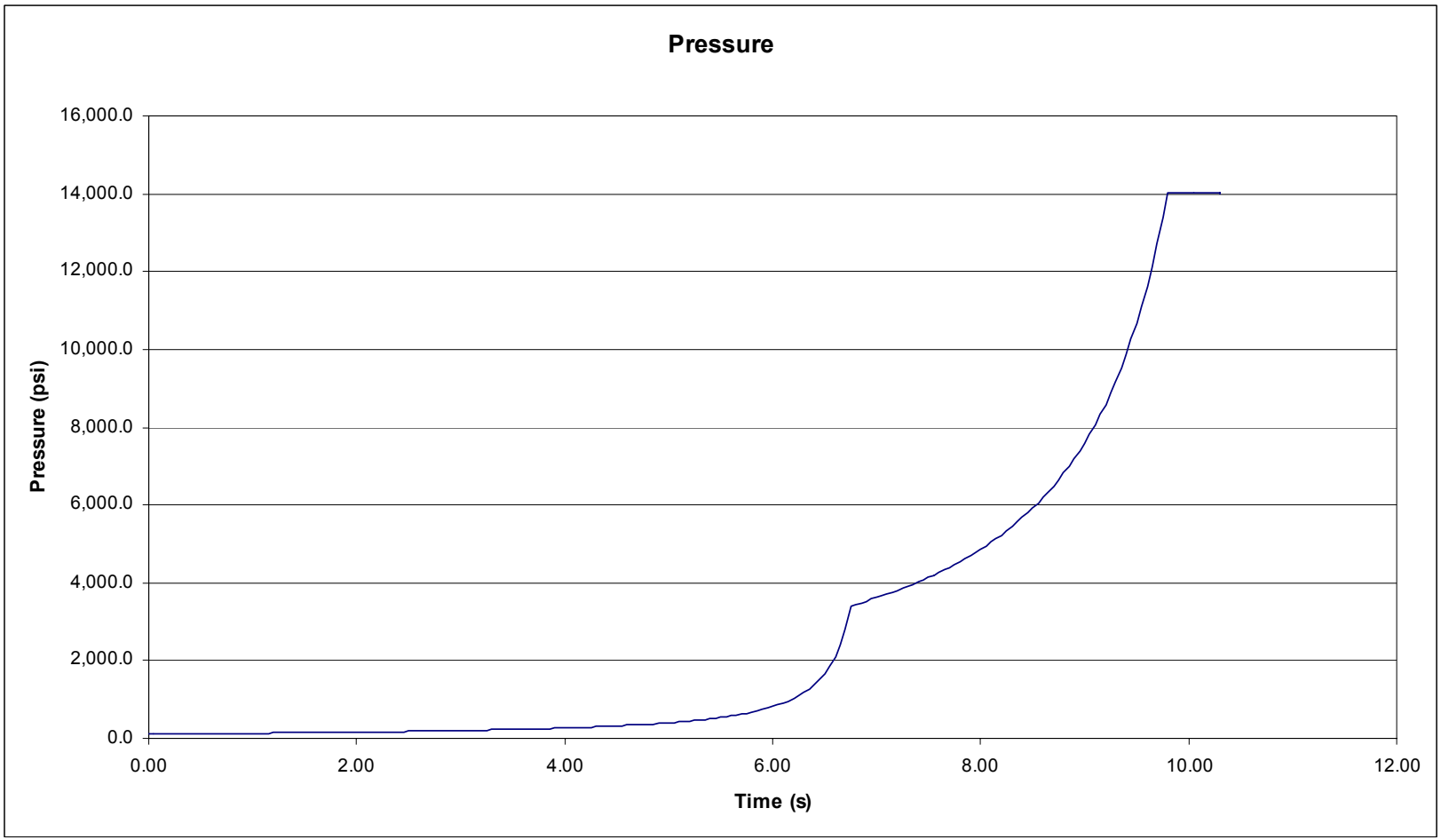
Technical Accomplishments
Cylinder Pressure and Temperature



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Technical Accomplishments
Dyanamic 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.
- 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.
- 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
Fueling Apparatus

- Air Products has developed hydrogen fueling systems up to 700 barg (10,000 psig).
  - Valves
    - Manual
    - Actuated
    - Pressure Control
  - Flexible Hose
  - Tubing
  - Fittings and Adapters
  - Controller
  - Packaging

Most components available today for 700 barg fueling

Responses to Questions

- What fluid is used for a the compressor?
  - Krytox Fluorocarbon Oil
  - Patents are submitted and contract with DOE and DEP are now signed

Future Work

- Assemble and Test.
- Determine overall costs.
- Determine feasibility of future use.
- Long term prototype testing, if warranted.
- Final Report

Interactions/Collaborations

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

Questions?

Thank you

tell me more

www.airproducts.com

Publications and Presentations

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

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.

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.