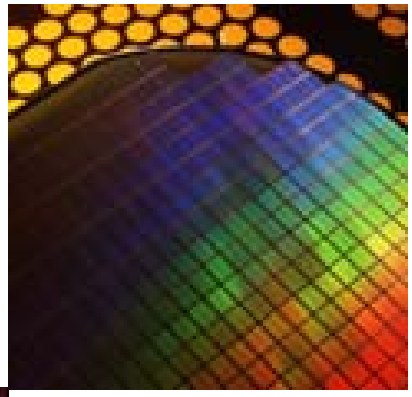
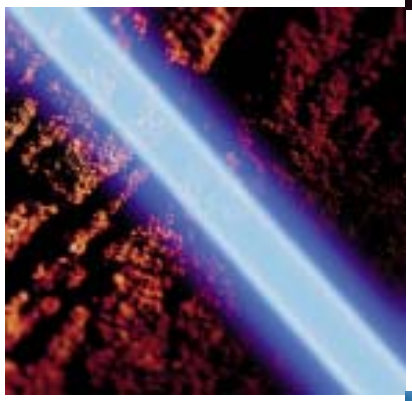
Low Cost Hydrogen Production Platform

Cooperative Agreement: DE-FC36-01GO11004





Timothy M. Aaron

Team

Praxair - Tonawanda, NY
Boothroyd-Dewhurst - Wakefield, RI
Diversified Manufacturing - Lockport, NY

DOE Hydrogen Annual Review Meeting
May 24 - 27, 2004

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Objectives - LCHPP Program

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- **Low Cost On-Site Production of Hydrogen**
  - Existing Technologies (SMR)
  - Transportation & Industrial (1,000 - 5,000 scfh) (2.4 - 12 kg/h)
- **Year in Review**
  - Completed Phase I - 05/03
    - Preliminary Design
    - Economic Models & Business Cases
  - Started Phase II - 10/03
    - Detail Design & Engineering of System
    - Computer Simulations & Modeling
    - System Optimization
    - Component Testing
    - Update of Cost Models

Budget - LCHPP Program

- **Phase I (10/01 - 04/03) - Completed**
  - Total Cost: $341,848
  - Cost Share: 67% - DOE, 33% - Praxair
  - FY2003 Funds (10/02 - 09/03) - $220,643
- **Phase II (10/03 - 05/05) - In Progress**
  - Estimated Cost: $1,989,933
  - Cost Share: 50/50 - DOE/Praxair
  - FY2003 Funds (10/02 - 09/03) - $0
  - FY2004 Estimated Funds (10/03 - 09/04) - $975,000
- **Phase III (06/05 - 12/06)**
  - TBD

Technical Barriers & Targets

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- **DOE Technical Barriers**
  - A. Fuel Processor Capital Costs
  - B. Operation and Maintenance (O&M) Costs
  - C. Feedstock and Water Issues
  - E. Control and Safety
  - Z. Catalysts
  - AB. Hydrogen Separation and Purification
- **DOE Technical Targets (w/o Comp, Storage & Dispensing)**
  - **Cost Targets ($/kg H2)**
    - 2003 - 4.34
    - 2005 - 2.44
    - 2010 - 1.06
  - **Primary Energy Efficiency**
    - 2003 - 62%
    - 2005 - 68%
    - 2010 - 75%

Approach

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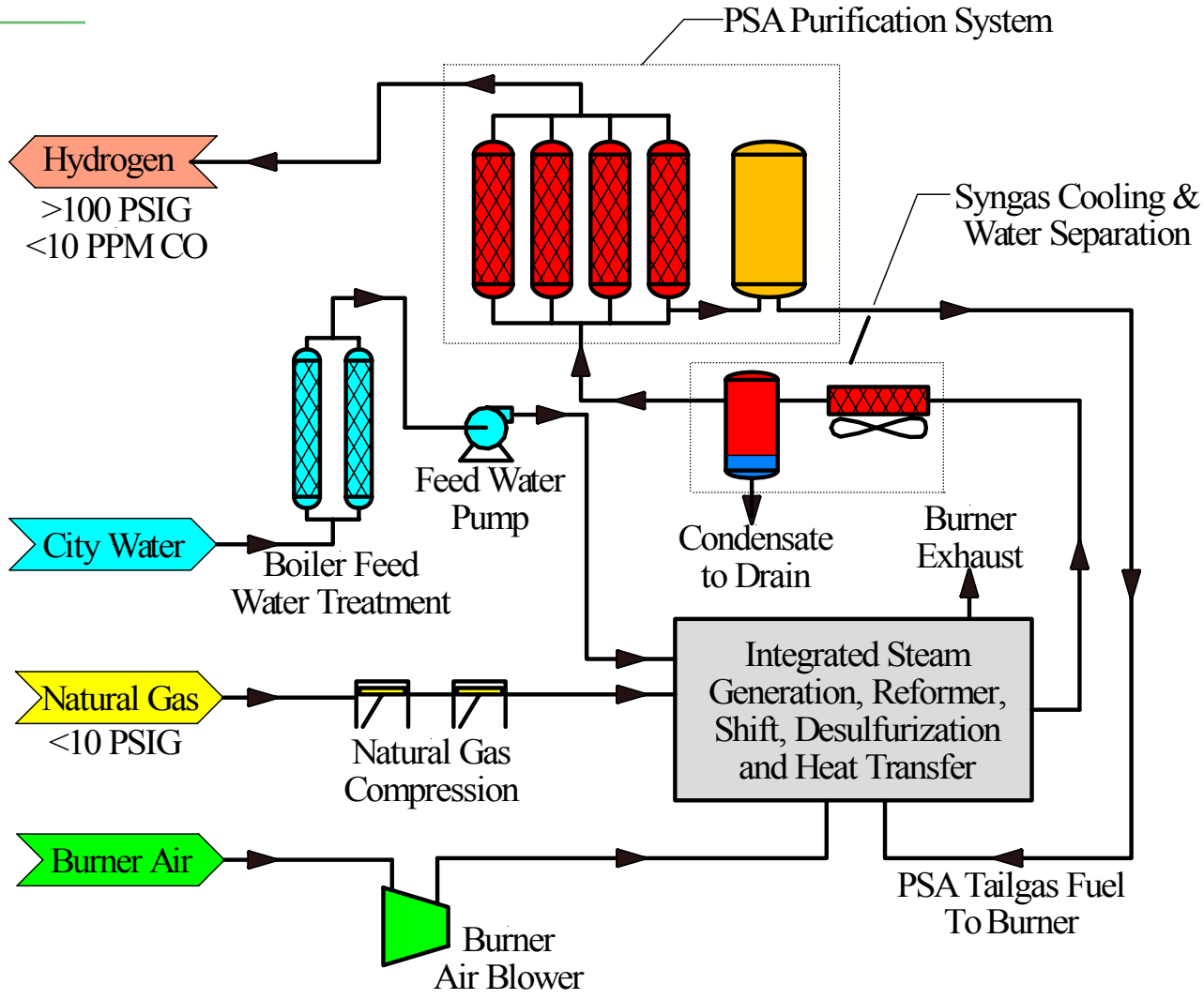
- **Develop Small SMR Based Hydrogen System**
  - Phase I (Completed)
    - Preliminary Design & Techno-Economic Study
  - Phase II (10/03 - 05/05)
    - Detail Design & Optimization
      - Increase System Efficiency
      - Lower Capital Cost
      - Comply/Develop Safety & Design Standards
    - Component Modeling & Testing
    - Catalyst Analysis
    - Economic Model Updates
  - Phase III (06/05 - 12/06)
    - Prototype System

LCHPP - Skid Process Flow



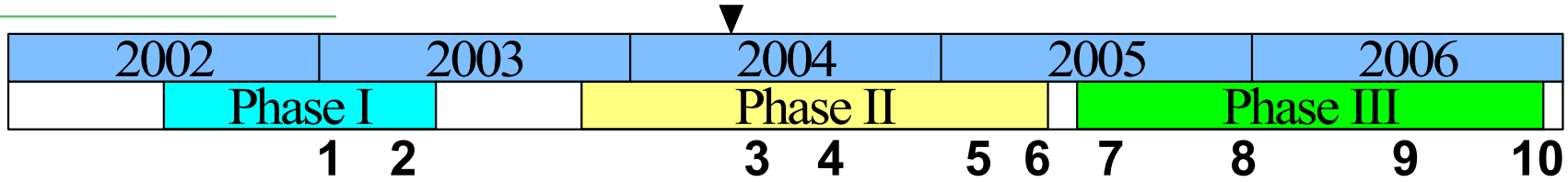
High Temperature Component

- **Functions**
  - Natural Gas Pre-Heat
  - Desulfurization
  - Reforming
  - Water-Gas Shift Reactor
  - Steam Generation & Superheat
  - Combustion
  - Air/Exhaust/Process Heat Exchange
  - Syngas Cooling
- **Design**
  - DFMA
  - Highly Integrated
  - Welded Construction

Safety

- **Design Safety**
  - Risk Analysis Completed in Phase I
  - Full HAZOP Review of System Will be Performed
  - All Applicable Standards Will Be Followed
    - NEC
    - NFPA
    - ISO
    - Praxair Design Standards & Procedures
  - Member of ISO Technical Committee 197 - WG 9
    - ISO 16110-1 & 2: Hydrogen generators using fuel processing technologies
      - Part 1: Safety
      - Part 2: Performance

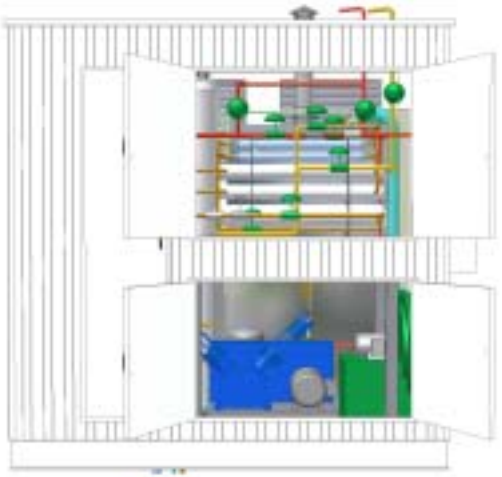
Project Timeline



- **Phase I - Preliminary Design**
  1. Preliminary Component & System Design
  2. Techno-Economic Study
- **Phase II - Detail Design & Optimization**
  3. Detail Design & Computer Models
  4. Construct Test Apparatus
  5. Component Testing
  6. Update System Design and Economic Models
- **Phase III - Prototype System**
  7. Complete Prototype Design
  8. Build Prototype System
  9. Verify System Performance & Update Economics
  10. Commercialize System

Phase I Review - System Design

- Safety
- Compact, Single Skid
- Easily Installed
- Welded Construction
- Highly Integrated



Technical Progress (04/03 - 04/04)

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- **Phase I Completed**
  - Preferred Design Chosen
  - Report & Phase II Proposal
- **Phase II (Started 10/03)**
  - Detail Design of System
    - Process & Instrumentation Diagram
    - Process Computer Simulations
    - Startup, Operating & Shutdown
    - Material Selection & Mechanical Stress Models
    - Component Modeling & Testing
    - Component Test Plan
    - Design of Test Apparatus
    - Catalyst Modeling & Testing

Technical Accomplishments

PRAXAIR

- **Design**
  - Completed Detail Design of High Temp Component
    - Drawings
    - Process Models
  - Optimized System
    - Reduced Mass of System
    - Reduced Parts & Assembly Complexity
    - Increased Thermal Efficiency
      - Increased Primary Energy Efficiency
      - Reduced Product Cost

LCHPP - System Cost Model Parameters

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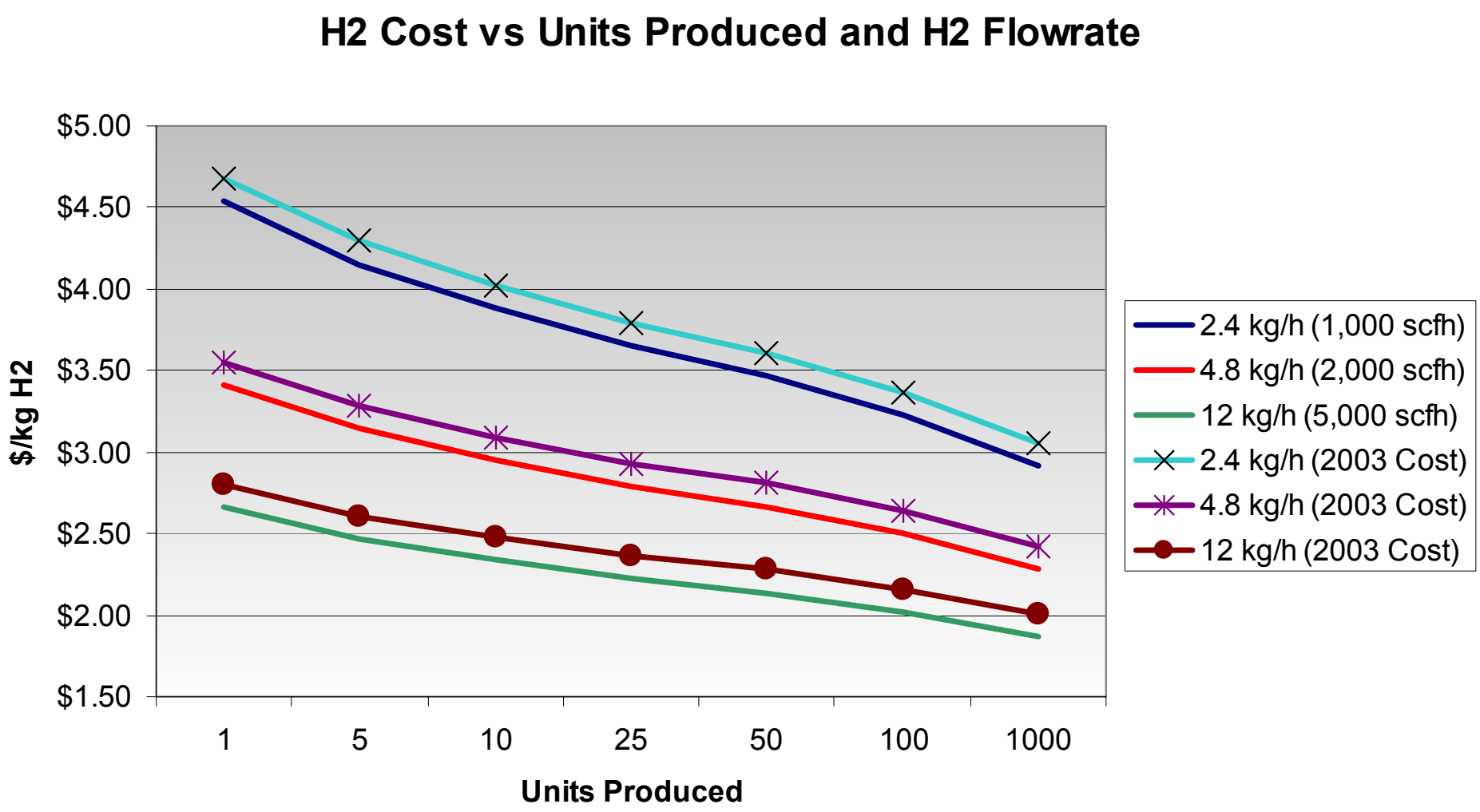
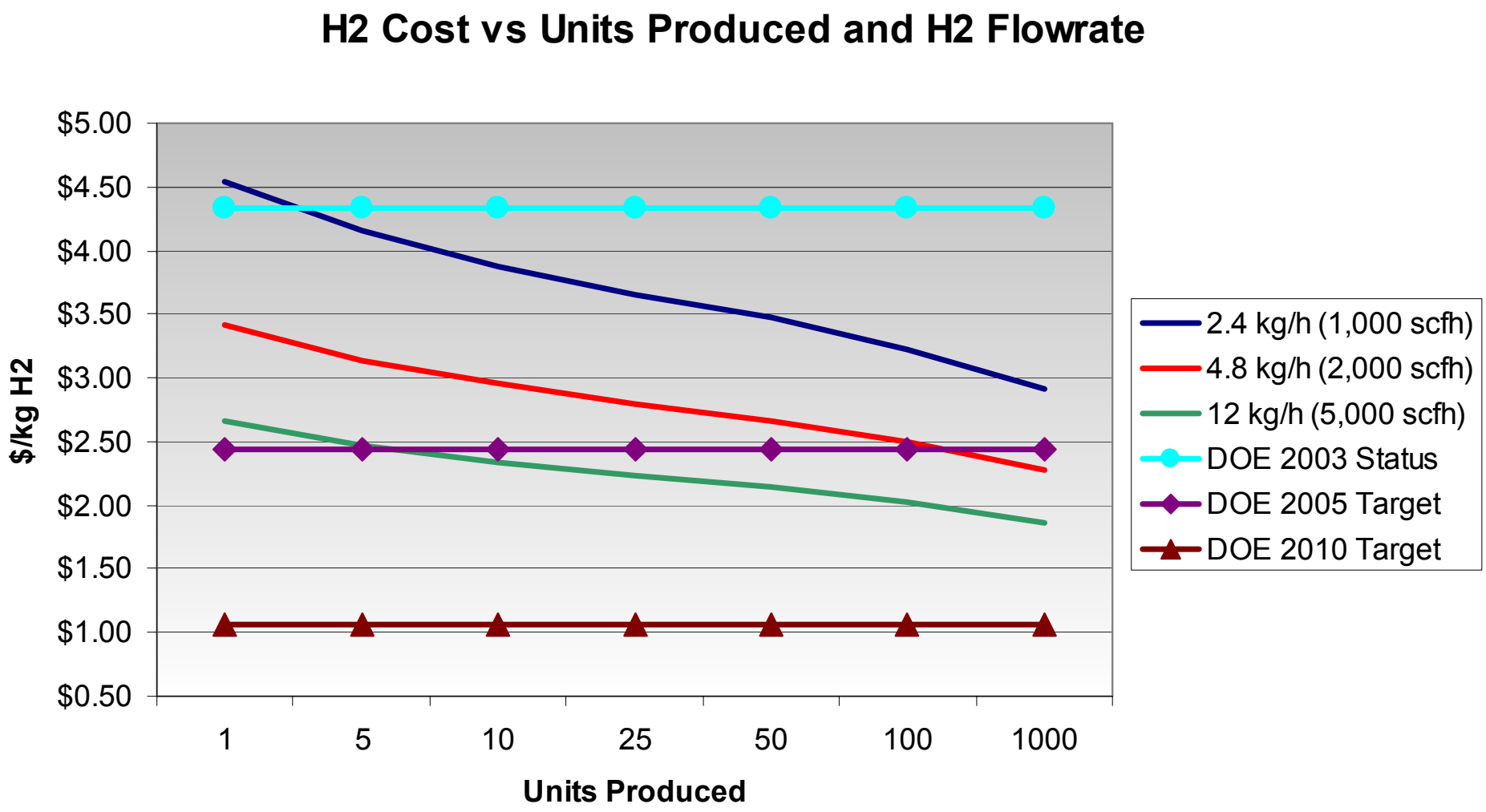
Cost Model Assumptions

- Power - $0.05 $/kWh
- Natural Gas - $4.00 $/MMBtu, HHV
- Water - $2.50 per 1,000 Gallon
- Capital Recovery Factor - 15% Return, 15 Yr Life
- On-Stream Factor - 80%
- Contingency - 10%
- M&R - 3% of Capital
- Site Labor
  - 15% @ 1 Unit ===> 2% @ 1000 Units

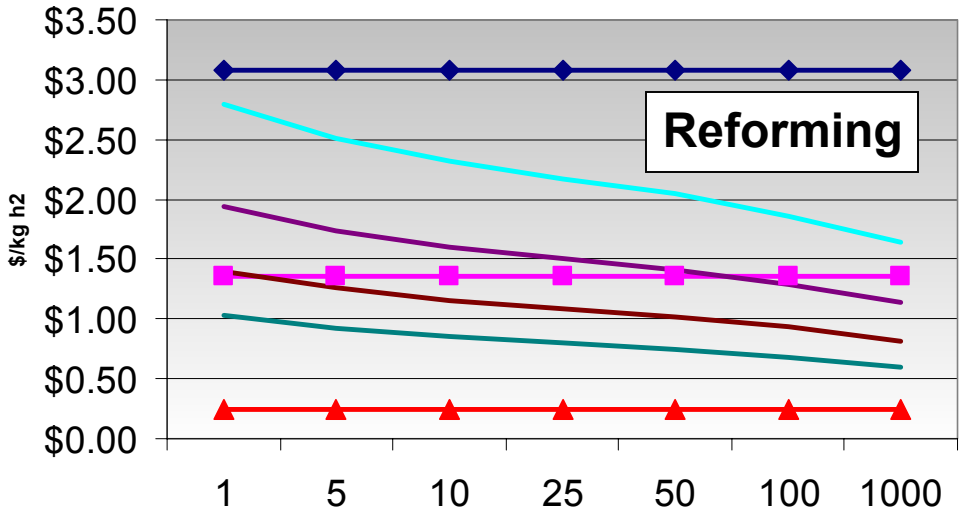
Technical Accomplishments / Cost of Hydrogen

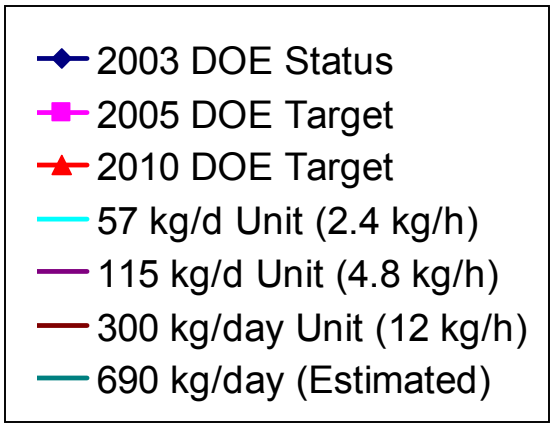


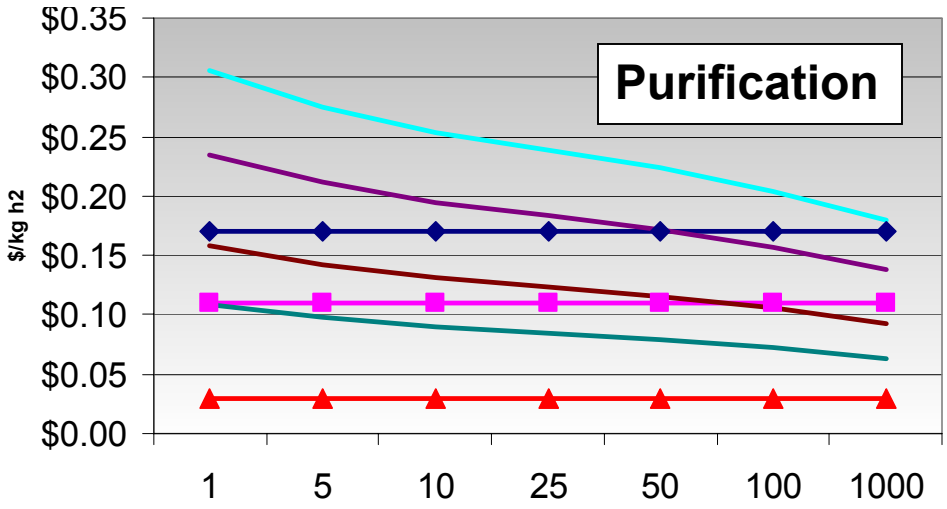
Technical Accomplishments / DOE Program Goals

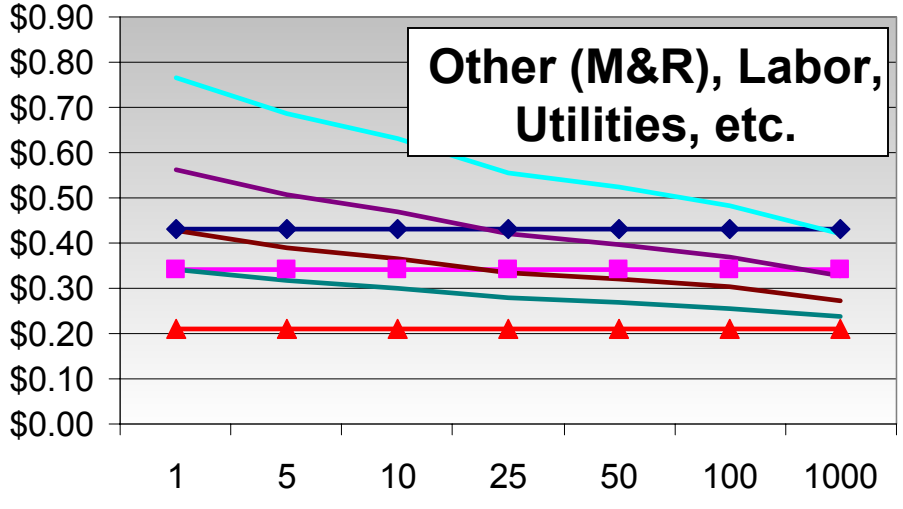


Technical Accomplishments / DOE Program Goals (H2 Cost vs. Units Produced)









LCHPP - Future Work

PRAXAIR

- **Verification of Results to Date**
  - Modeling & Simulations
    - Heat Transfer
    - Fluid Dynamics
    - Reaction Kinetics
    - Burner Design
  - Testing
    - Components
    - Catalysts
    - Water Treatment
    - Etc.
  - Maintain / Reduce Cost of Product
    - DFMA Techniques
    - Material Selection
    - Process Optimization

Phase II Cooperative Efforts

- **Praxair**
  - Overall Lead
- **Boothroyd-Dewhurst**
  - System Optimization
  - Cost Reduction / Estimating
- **Diversified Manufacturing**
  - Manufacturing
  - Prototype Development
- **Computer Modeling**
  - Reformer / Shift Design
  - Burner Design
  - Heat Transfer
- **Catalyst Supplier**

LCHPP - Interactions & Collaborations

PRAXAIR

- **Society of Automotive Engineers (SAE)**
  - Paper & Presentation (October 2003)
    - DFMA Approach to Reducing the Cost of Hydrogen Produced from Natural Gas
- **The 2003 Hydrogen Production & Storage Forum (Washington, D.C.)**
  - Presentation & Roundtable Discussion (December 2003)
    - Using DFMA to Reduce the Cost of Hydrogen from Small Steam Methane Reformer Based Systems
- **ISO Technical Committee 197 - WG 9 (Member)**
    - ISO 16110-1 & 2: Hydrogen generators using fuel processing technologies

2003 Reviewers' Comments

- **Project would benefit if Compression, Storage & Dispensing Included in Scope of design**
  - Praxair/DOE Projects With This Scope
    - GEERC
    - LAX Fueling Station
    - These Projects are being monitored & assessed for Integration potential
- **Does not address Codes & Standards Issues**
  - Member of ISO committee related to applicable Standard
  - Praxair has Representation on many Standards Committees related to hydrogen production & plant citing
- **Techno-Economic Study should be done only after system concept has been proved**
  - Economic model is relatively easy and cost effective to develop and results in an understanding of the system potential. Proof of concept requires a test program and significant resources that would not be expended if economics did not warrant the development effort.

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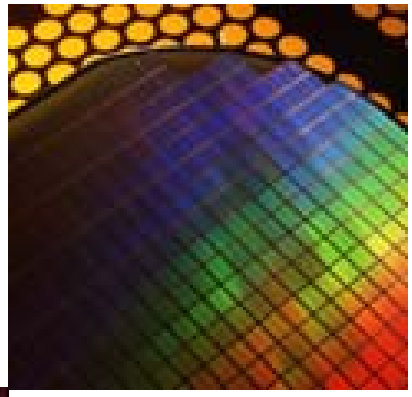

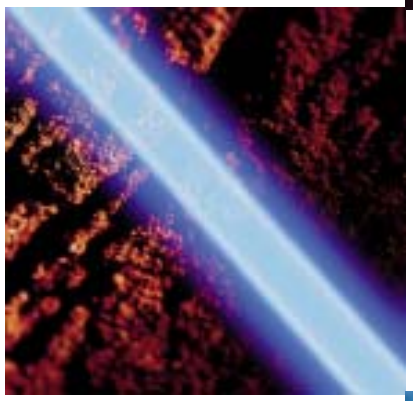

Questions?

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