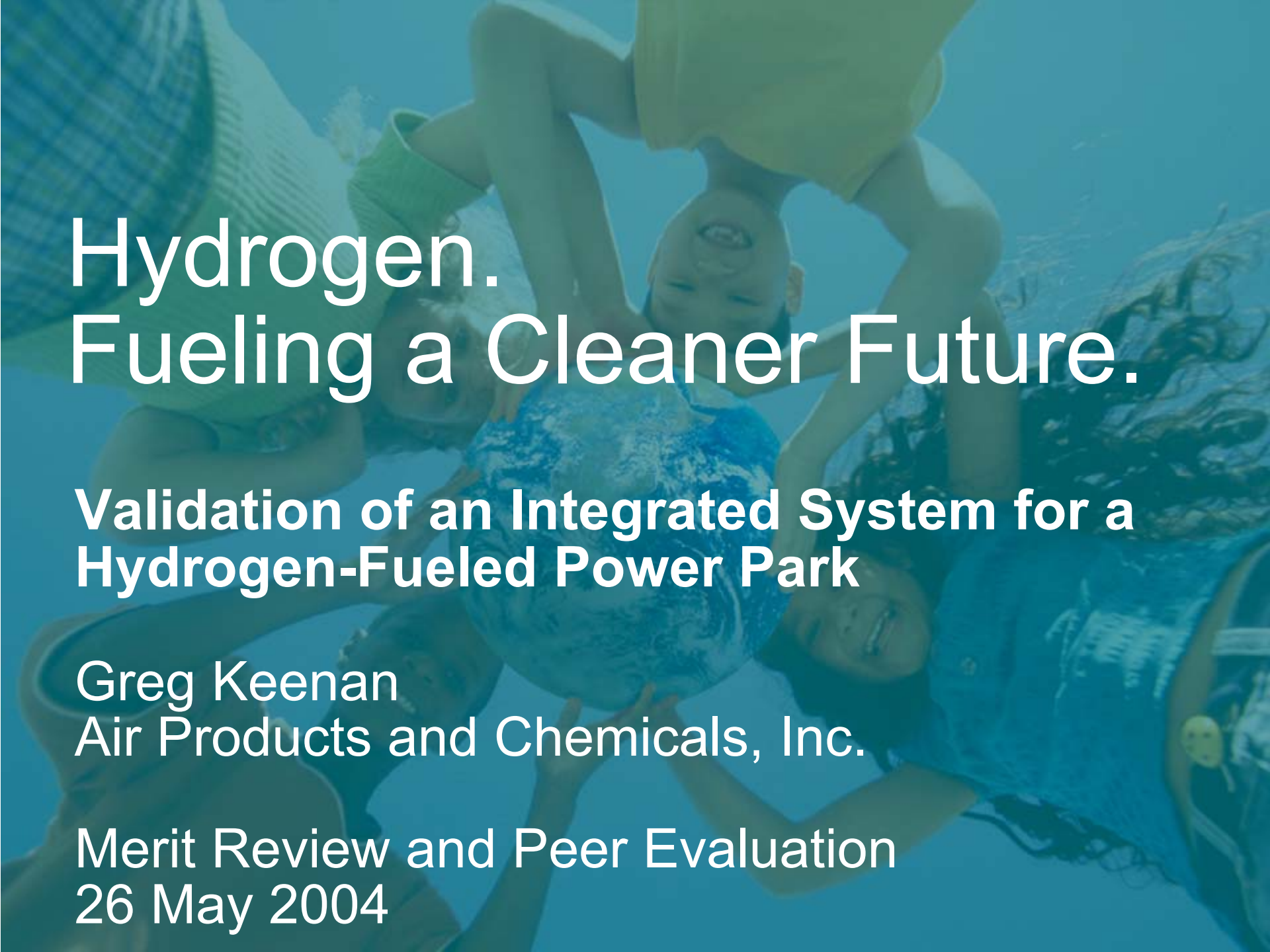
This presentation does not contain any proprietary or confidential information.



Hydrogen. Fueling a Cleaner Future.

Validation of an Integrated System for a Hydrogen-Fueled Power Park

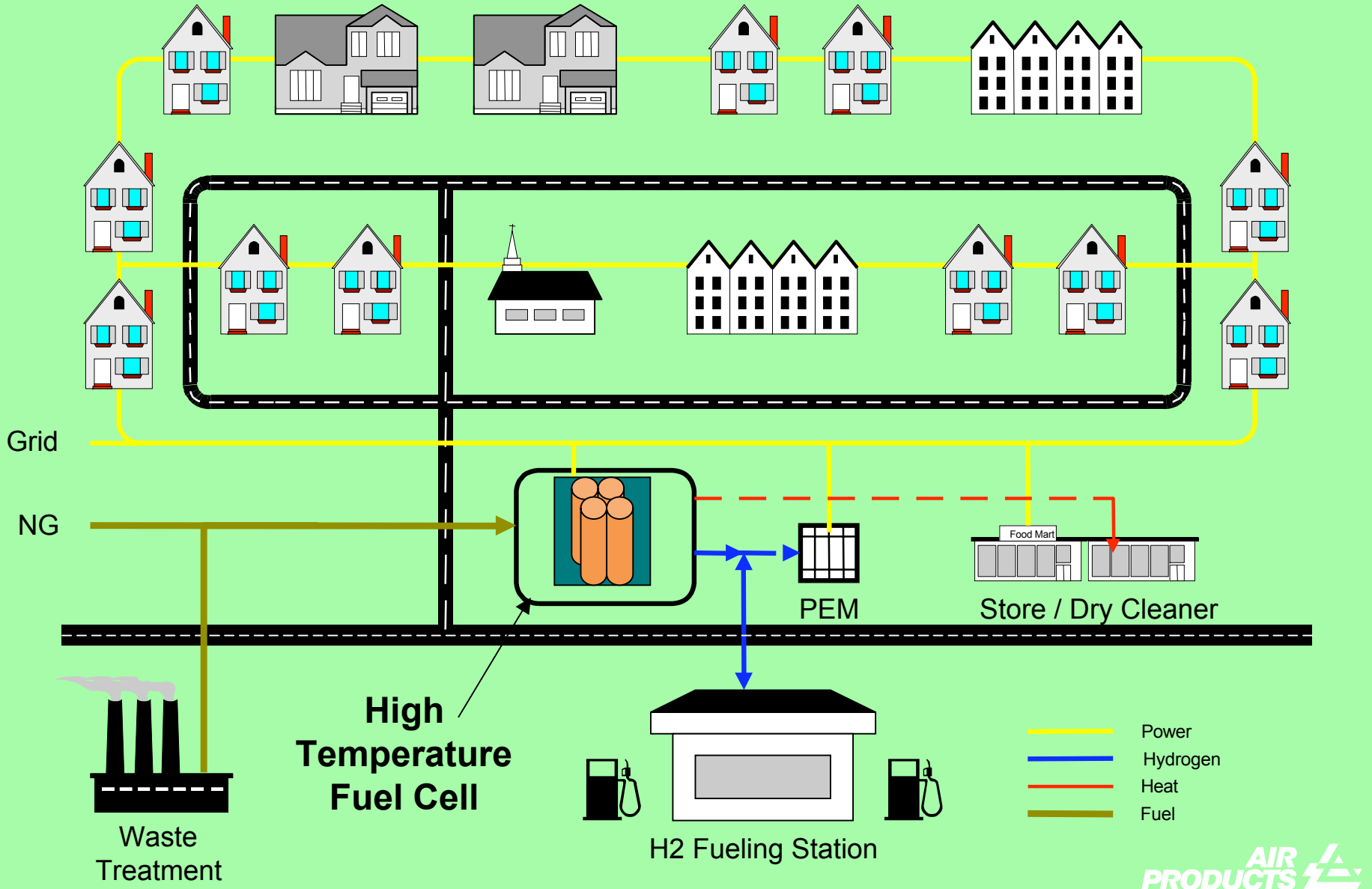
Greg Keenan
Air Products and Chemicals, Inc.

Merit Review and Peer Evaluation
26 May 2004

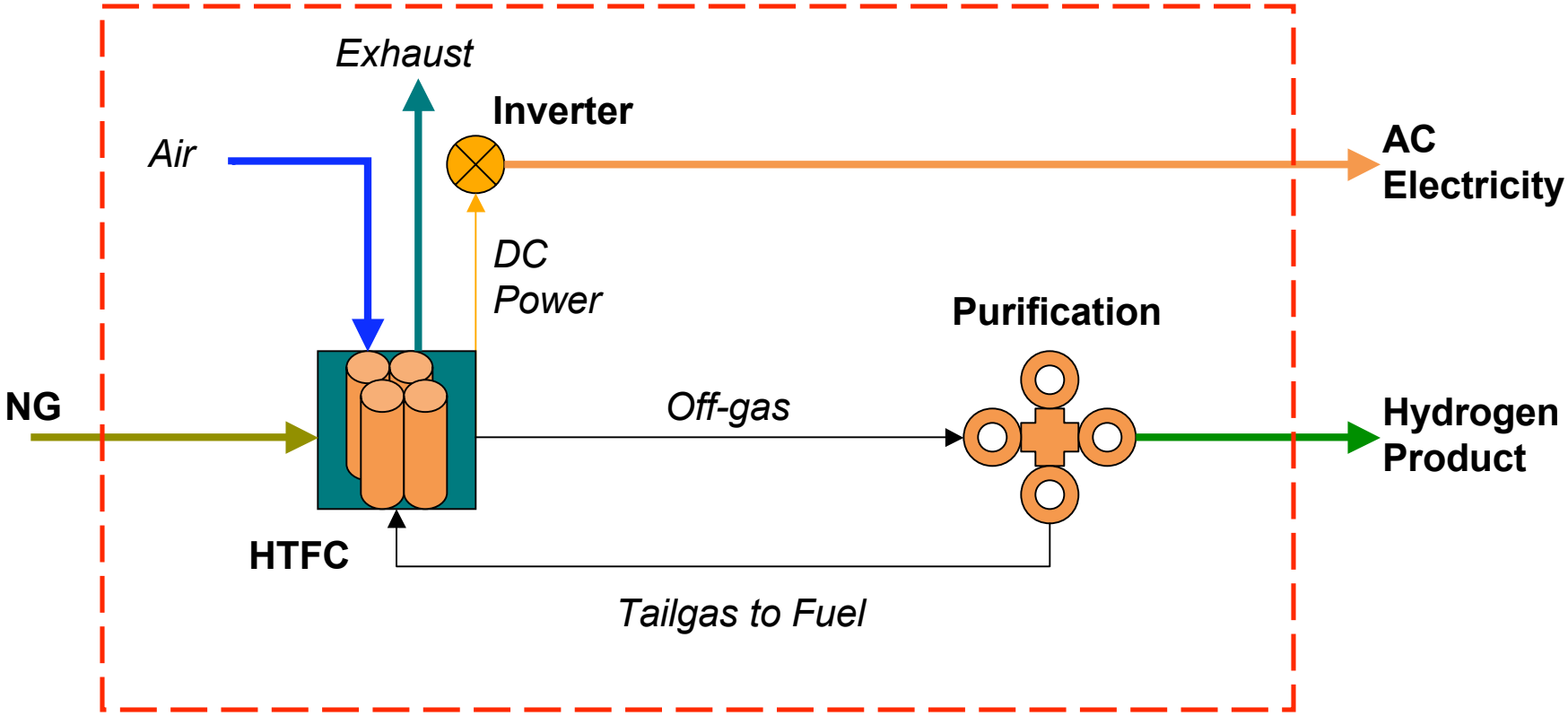
Objectives (FY04)- Phase 1B

- Complete a feasibility, technical, and economic analysis to determine the optimal fuel cell system for the co-production of power and hydrogen from natural gas (energy park)
  - Reformer / PEM System
  - High Temperature Fuel Cell (HTFC)
- Optimize the system for lowest total energy price
- Develop a cost estimate to demonstrate a prototype natural gas based energy park at a suitable site

PowerPark Concept



High Temperature Fuel Cell (HTFC) Co-production

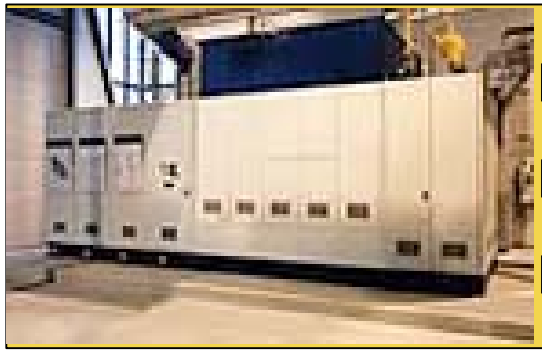


Potential Co-Production Efficiency (LHV): 55 - 60%

Benefits of HTFC Co-Production

- High efficiency
- Low emissions
- Potential to use waste hydrocarbons as energy source
- Multiple product slate (power, hydrogen, & heat)
  - Improves capital utilization
  - More flexible pricing options- 2 or 3 Levers
- Fuel cell / fuel cell hybrid option
  - Efficient cycle – (potential for > 60%)
  - No turbine- potential for higher reliability and less maintenance

Distributed Power and Hydrogen for Industry...



Siemens Westinghouse

Electricity

Hydrogen

High Grade Heat

Distributed Power and Hydrogen for Consumers…

FuelCell Energy DFC-300

Power

Heat

The Plaza at PPL Center, Allentown

H2

Budget

- Total Project Budget:
  - $1.391 MM
- Cost Sharing:
  - DOE - $0.695 MM
  - APCI and Partners – balance.
- FY2004 Funding
  - $ $100 k Obligated by DOE

Technical Barriers and Targets

- DOE Technical Barriers
  - Technical Validation (Section 3.5.4.2 of HFCIT Program Report), Task #4.
    - B. Storage
    - C. H_2 Refueling Infrastructure
    - I. Hydrogen and Electricity Coproduction
- DOE Targets
  - H_2 Production (Table 3.1.2 of HFCIT Program Report), Task #3.
    - Cost of H_2:
      - $3/kg 2005
      - $1.50/kg 2010

Approach: Co-production Analysis

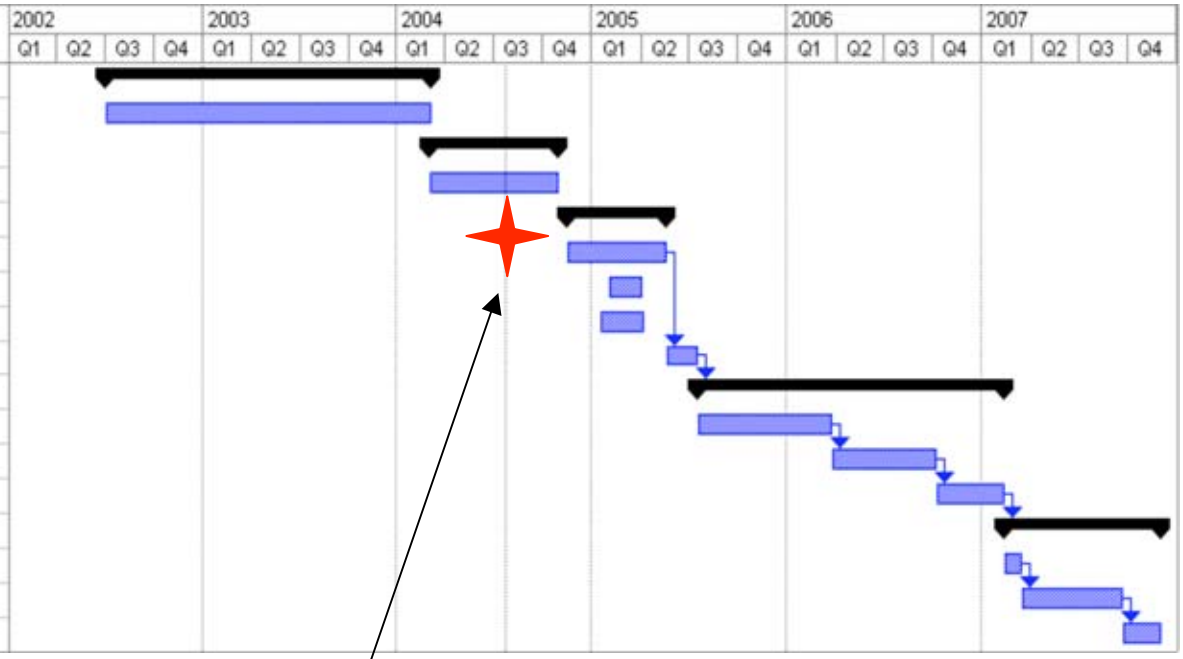
- **Phase 1B- Process and Economic Analysis**
  - **3 HTFC technologies evaluated**
    - 2 Solid Oxide Fuel Cells (2 different geometries)
    - 1 Molten Carbonate Fuel Cell
  - **Each HTFC technology was matched with the appropriate purification technology selected by Air Products**
- **HTFC Vendors Provided:**
  - Fuel Cell Performance Projections
  - Fuel Cell Cost Projections
  - Flow Diagrams
  - Process Data
- **Air Products Provided:**
  - Purification design, performance and cost projections
  - Overall process and economic analysis

Safety Reviews and Training

- APCI has >40 years experience in safe design, construction, & operation of H_2 plants.
- Leader in Management of Change, Near Miss Reporting, and Quantified Risk Assessment Procedures
- PHR: Phase 2
- HAZOP: Phase 3
- All applicable industry codes will be followed
- APCI participates in SAE, ICC, ISO, HFPA, IETC, and EIHP2 committees

Project Timeline

ID	Task Name
1	**Phase 1A - Power Park Study**
2	Techical and Economic Study of PEM Power Park
3	**Phase 1B - Power Park Study**
4	Technical and Economic Study of HTFC Power Park
5	**Phase 2 - Prelim Design, Testing, Site Selection**
6	Engineering Deliverables (Specs, Costs, etc)
7	Site Selection
8	Lab Testing
9	Go / No Go Mtg
10	**Phase 3 - Detailed Design, Construction**
11	Detailed Design
12	Procurement and Equipment Fabrication
13	Site Preparation Construction
14	**Phase 4 - Start-Up, Operation, Testing, Data**
15	Commissioning and Start-Up
16	Operation, Testing, and Data Collections
17	Analysis and Final Report



Today: APCI & DOE Go- No-Go Decision

Phase 1A Conclusions- FY03

- **Small Reformer/PEM System (w/ current PEM technology)**
  - Low commercial potential for distributed continuous power generation with natural gas as a feedstock.
  - Don't recommend a Phase II demonstration with PEM
- **PEM Niche Market Opportunities: Pipeline/Offgas (Back-up)**
  - Economic in limited geographic region
  - Potential in non-attainment areas (low emissions)
  - Low noise
  - Spinning reserve
- **Co-production of Power and Hydrogen using High Temperature Fuel Cells**
  - High temperature fuel cells have greater potential than PEM for distributed power
    - Energy Station- Co-production of Hydrogen and Power
    - Distributed Generation- Hybrid Fuel Cell Cycle
  - Recommend further review- Phase 1B

Phase 1B Conclusions- FY04

- **High temperature fuel cells configured to co-produce hydrogen have the ability to meet the DOE hydrogen targets as specified in the multi year plan while producing power for less than 0.10 $/kW**
- **Both molten carbonate and solid oxide fuel cells can be designed for co-production**
  - Co-production efficiencies were similar- 55%-60% (LHV)
  - Both have the potential to meet the DOE targets while producing power for less than 0.10 $/kW
- **Engineering development required for co-production**
  - Recovering and conditioning off-gas
  - Purification of hydrogen
  - System integration
  - Optimization of co-produced products
- **Recommend proceeding with engineering development, design, and demonstration of the economic viability of a combined electric power and hydrogen production application**

HTFC Co-Production Economics

	2005	2010	2015
Hydrogen, kg/day*	690	690	690
Net Electricity, kw	>1.5 MW	>1.5 MW	> 1.5 MW
HTFC Cost, $/kW AC w/o H2	2250	1200	800
Natural Gas Costs, $/mmbtu*	4.00	4.00	4.00
Production Volume, units/year*	100	100	100
Fueling Utilization*	90%	90%	90%
Capital Factor*	0.11	0.11	0.11
Base Energy Price			
Hydrogen Price, $/kg	2.97	2.15	1.88
Power Price, $/kwh	0.07	0.05	0.05
Fueling Scenario			
Hydrogen at the Pump, $/kg*	3.00	1.50	1.50
Station Allocation, $/kg*			
Compression, $/kg H2*	-0.29	-0.24	-0.24
Storage & Dispensing, $/kg H2*	-0.19	-0.11	-0.11
Hydrogen Production Price, $/kg	2.52	1.15	1.15
Power Price, $/kwh	0.08	0.07	0.06

*Assumptions from the DOE Multi-Year Research, Development and Demonstration Plan, Table 3.1.2, page 3- 10, Draft 6/3/03.

Future Work: Required Engineering Development

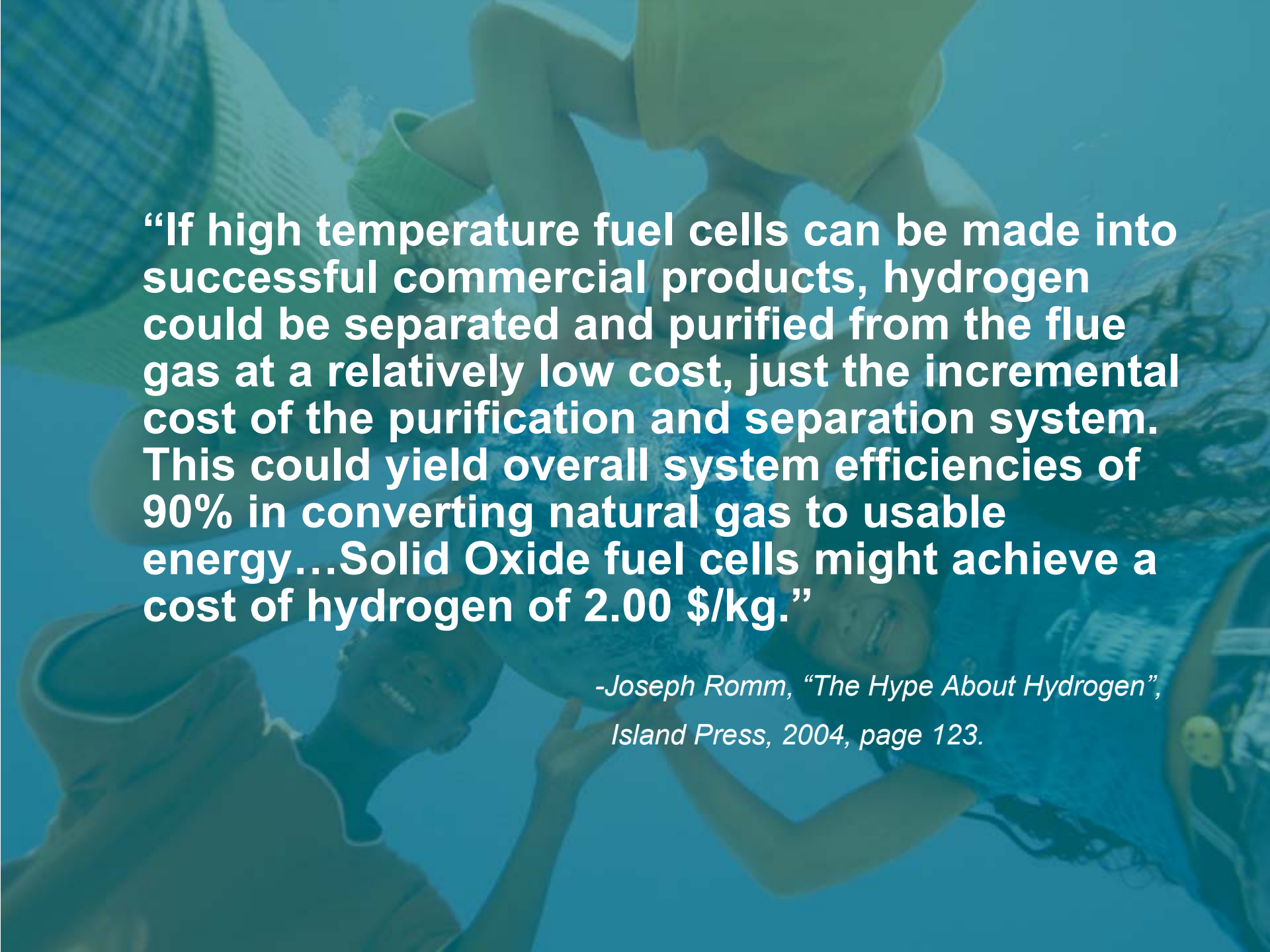
- HTFC modifications to recover off-gas
- Off-gas conditioning
- Hydrogen purification
- System integration
- Steady state vs. dynamic response
- Optimization of co-produced products

Development work applicable to both MCFC and SOFC

Proposed Forward Program

- **Develop and demonstrate the technical and economical viability of a HTFC co-production system.**

- **Program Forward**
  - HTFC Partner Selection
  - Phase 2: Preliminary Design, Engineering Development, Firm Bid Estimate, and Site Selection
  - **DOE/APCI GO / No-GO**
  - Phase 3: Detailed Design and Construction
  - Phase 4: Operation, Testing, Data Collection



“If high temperature fuel cells can be made into successful commercial products, hydrogen could be separated and purified from the flue gas at a relatively low cost, just the incremental cost of the purification and separation system. This could yield overall system efficiencies of 90% in converting natural gas to usable energy…Solid Oxide fuel cells might achieve a cost of hydrogen of 2.00 $/kg.”

-Joseph Romm, “The Hype About Hydrogen”, Island Press, 2004, page 123.

Thank you

Special Thanks to:

DOE- Chris Bordeaux, Sig Gronich

Air Products- Todd Carlson, Dave Guro, Rick Klippstein