Validation of an Integrated Hydrogen Energy Station

Edward C. Heydorn

Air Products and Chemicals, Inc.

20 May 2009

Project ID#
tv_06_heydorn

Overview

Timeline

- Start – 30 Sept. 2001
- End – 31 Mar. 2010
- 85% Complete

Barriers

- H_2 Fueling Infrastructure
- H_2 & Power Coproduction

Budget

- Total project funding
  - DOE share: $5.2 million
  - APCI + Partners share: $5.2 million
- Funding received in FY08 and FY09: $1.265 million

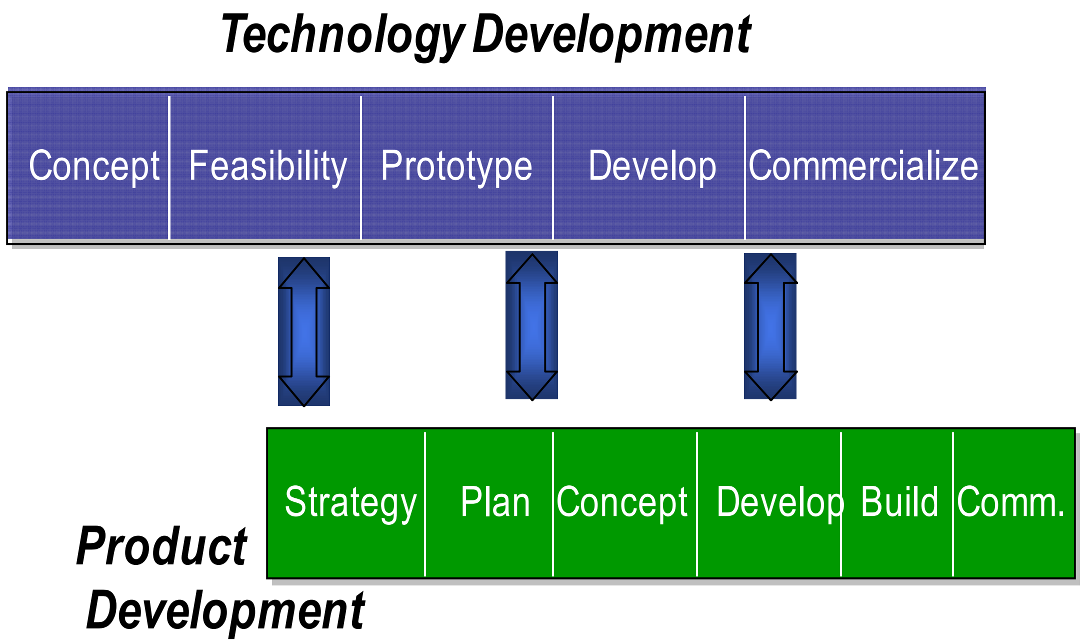
Partners

- FuelCell Energy
  - MCFC, Fuel Prep, WGS
- OCSD – Host Site (CA)
- CA – ARB, AQMD
- U.S. DOD – Army Corps of Eng

Objectives

- **Determine the economic and technical viability of a hydrogen energy station designed to co-produce power and hydrogen**

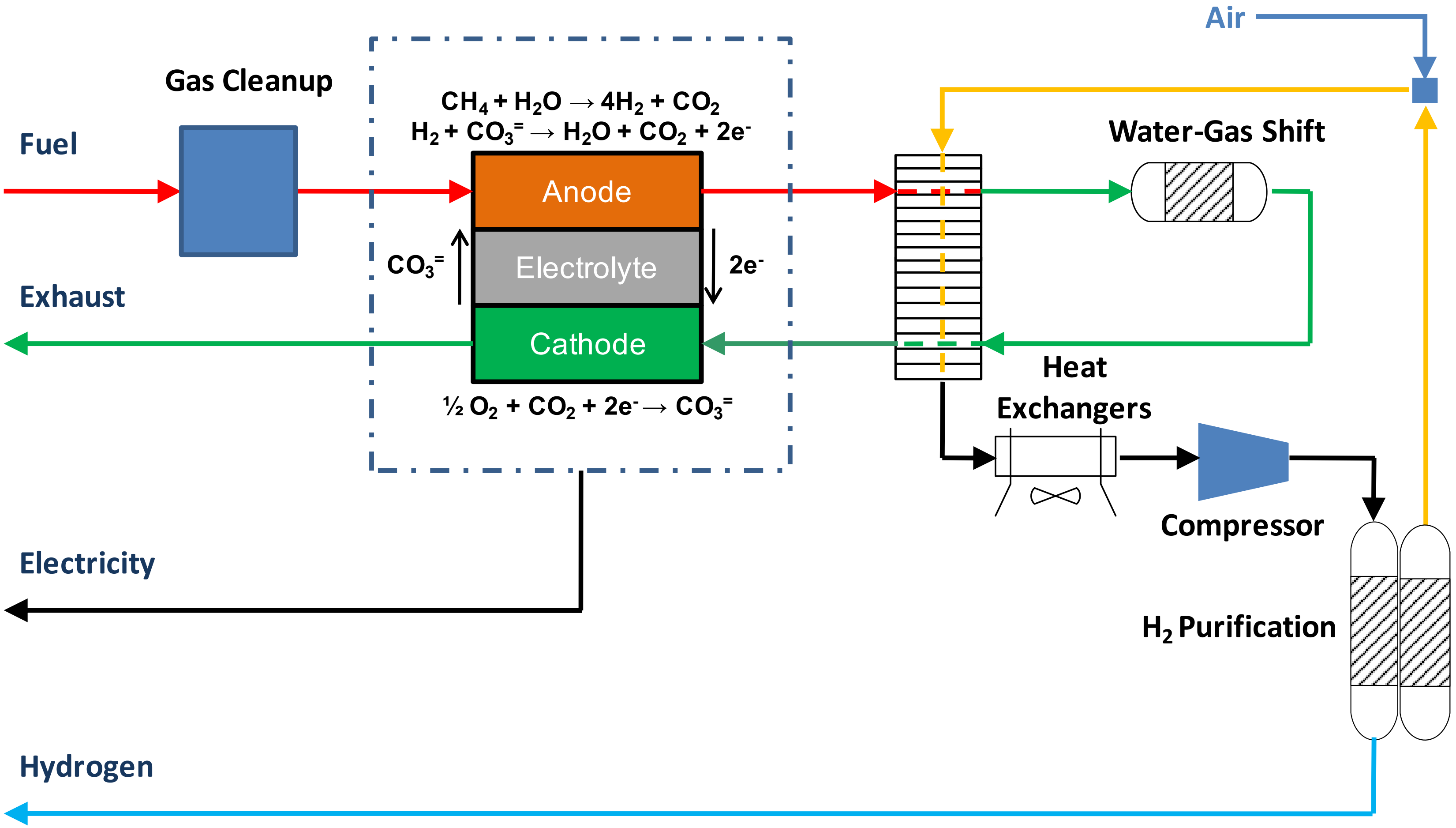
Utilize technology development roadmap to provide deliverables and go/no-go decision points



Approach

- DOE Program defined 4 phases:
  - Phase 1 – Feasibility: Evaluate PEM and HTFC
    - Completed FY04
  - Phase 2 – Preliminary System Design
    - Completed FY06
  - Phase 3 – Detailed Design and Construction
    - Completed March 2009
  - Phase 4 – Operation, Testing, Data Collection
    - Planned for FY09/10

Hydrogen Energy Station

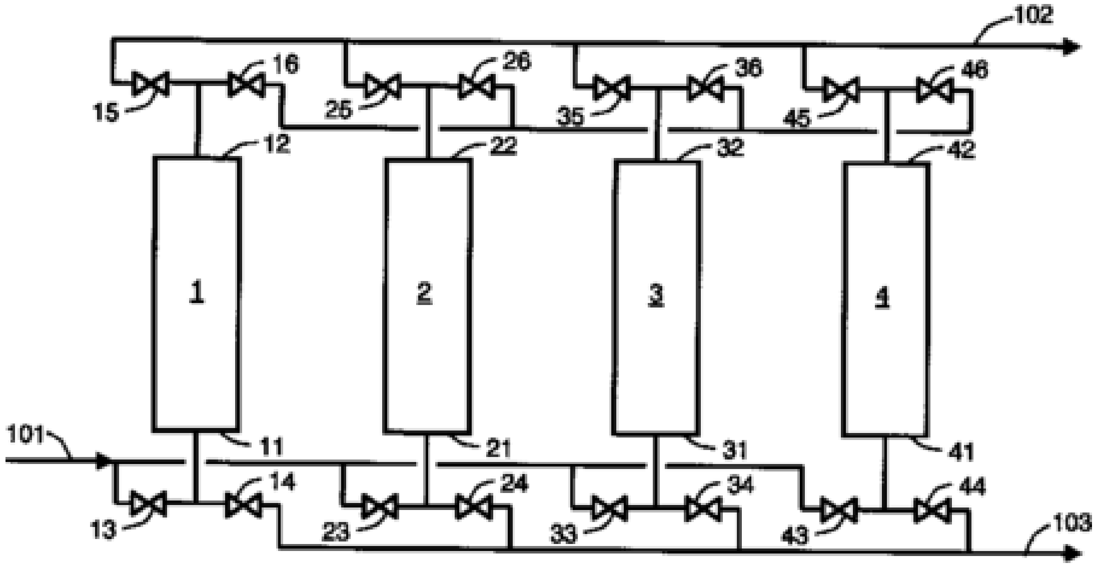


Hydrogen Energy Station Projected Performance by Phase

	Units	Phase 1	Phase 2	**Phase 3**
Overall Efficiency (Net Power + H_2 Product) / (Fuel)	LHV	60%	63%	**66%**
Power Efficiency Net Power / (Total Fuel – H_2 Product)	LHV	49%	49%	**50%**
Hydrogen Efficiency (H_2 Product – Purification Power) / H_2 Product	LHV	68%	71%	**77%**
Hydrogen Product	Kg/day	~ 88	~ 125	**~ 175**
Net Power w/o & w/ Hydrogen	kW	~ 247 / 207	~ 300 / 250	**~ 300 / 250**
Natural Gas Flow	Nm^3/hr	~ 55	~ 66	**~ 74**

Process Improvements during Design Phase

- Improvement in hydrogen purification cycle:
  - Phase 1: 300 psig inlet, 75% H_2 recovery
  - Phase 3: 150 psig inlet, > 85% H_2 recovery
- Patent application filed



US20080223213A1

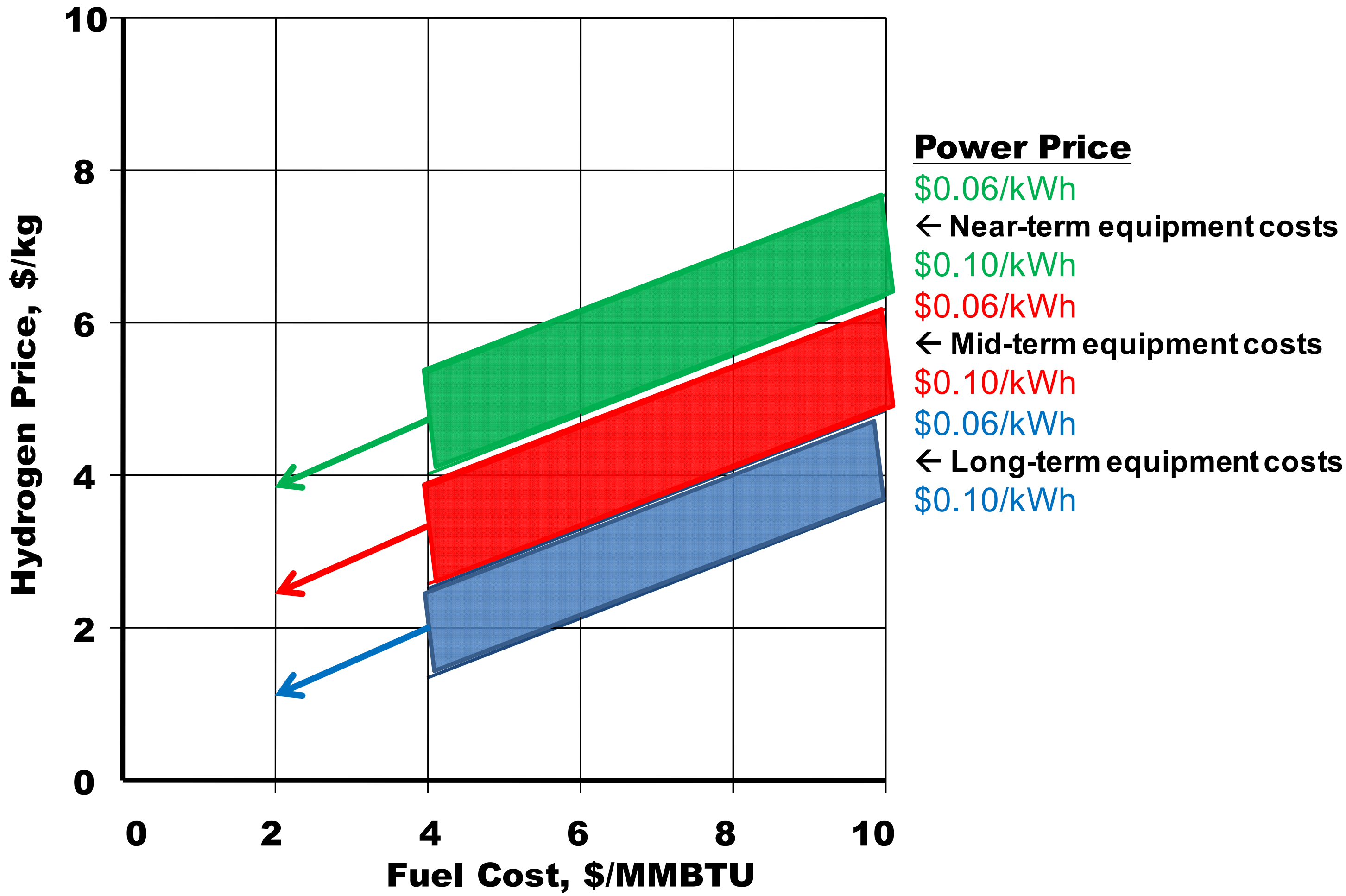
AIR PRODUCTS

Emissions Performance of DFC® Molten Carbonate Fuel Cell

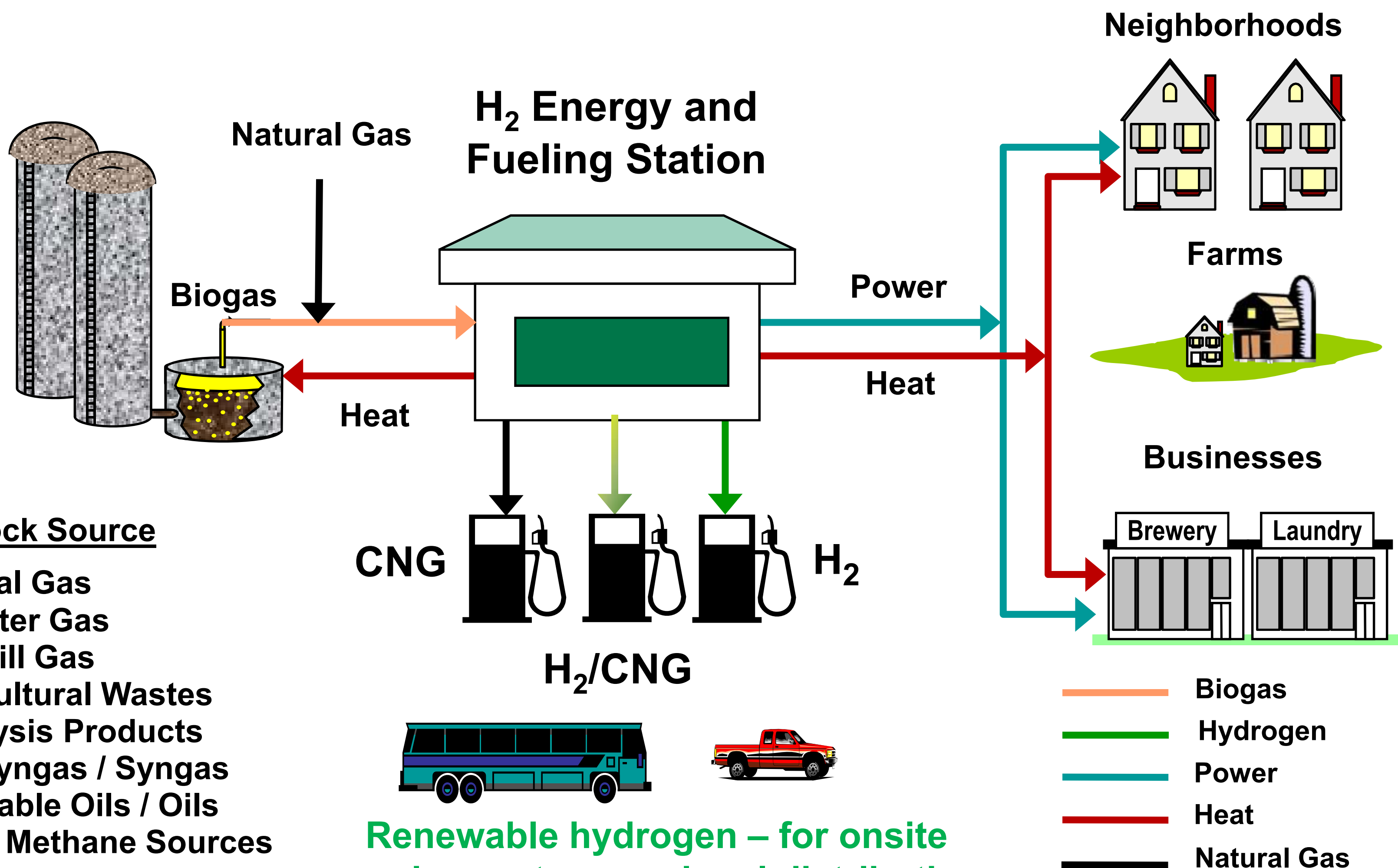
	NO_x (lb/MWh)	SO_x (lb/MWh)	CO_2 (lb/MWh)
Average US Fossil Fuel Plant	4.200	9.21	2,017
Microturbine (60 kW)	0.490	0	1,862
Small Gas Turbine (250 kW)	0.467	0	1,244
DFC® Fuel Cell 47% efficiency	**0.016**	**0**	**967**
DFC® Fuel Cell - CHP 80% efficiency	**0.016**	**0**	**545**

NO_x and SO_x are negligible compared to conventional technologies

Hydrogen Energy Station Economics (Phase 2)



Hydrogen Energy Station Vision



<u>**Feedstock Source**</u>

- Natural Gas
- Digester Gas
- Landfill Gas
- Agricultural Wastes
- Pyrolysis Products
- Bio-Syngas / Syngas
- Vegetable Oils / Oils
- Other Methane Sources

Renewable hydrogen – for onsite requirements or regional distribution

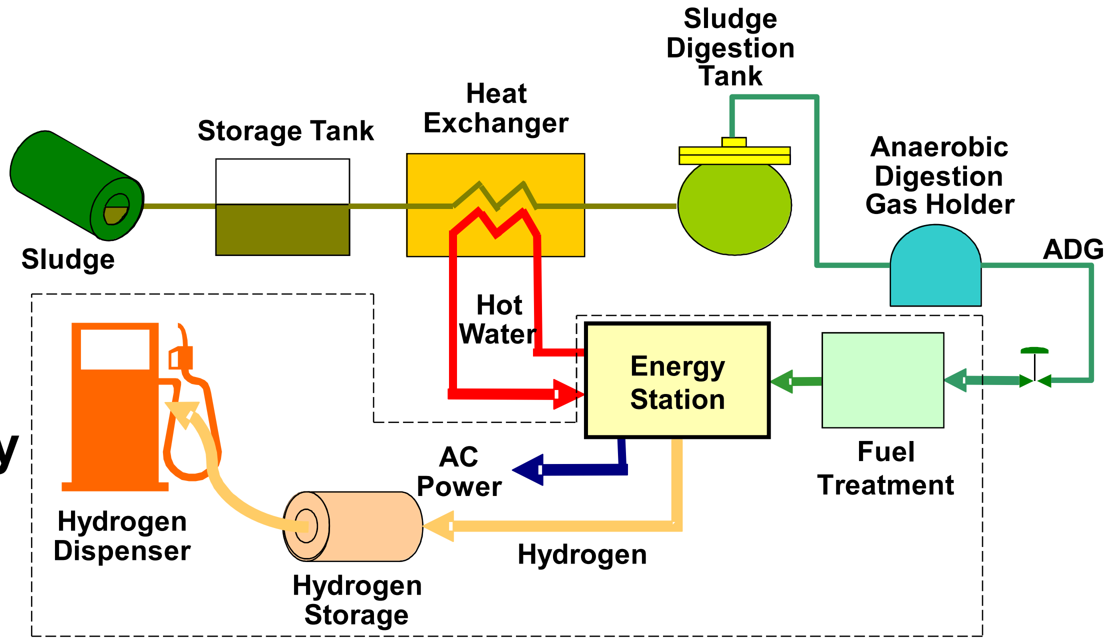
Demonstration of Hydrogen Energy Station Vision

- DOE Program – Natural Gas Feed
- Potential Host Site Identified - OCSD
  - Orange County Sanitation District, Fountain Valley, CA
  - Municipal Wastewater Treatment
  - Existing CNG Refueling Station
  - Ability to Achieve Production of both Renewable Hydrogen and Electricity
  - Renewable Hydrogen Available for Use

Proposal to California Air Resources Board (June 2008)

Fountain Valley Station

- 100 kg/day capacity, renewable hydrogen supply
- 350 and 700 bar fueling capability
- Host site: Orange County Sanitation District
- Anaerobic digestion of municipal wastewater



- Hydrogen production using Hydrogen Energy Station
- Anticipated onstream December 2009
- Funding for fuel treatment and fueling station from DOE California Hydrogen Infrastructure Program (Cooperative Agreement No. DE-FC36-05GO85026)

Hydrogen Energy Station Shop Validation Test – DFC® System

All DFC®-H_2-PSA Equipment Installed and Commissioned

Hydrogen Ready Fuel Cell Module

- Verified operability of hydrogen-ready DFC®300
- Developed procedures for start-up, shut-down and off-normal events
- Achieved stable operation at various loads up to 200 kW-net AC

Mechanical Balance of Plant (MBOP)

Hydrogen Energy Station Shop Validation Test – H_2 Purification Skid

Anode Exhaust Processing and H_2 Purification System

- **Step 1: DFC® Integrated with Anode Exhaust Skid without H_2 purification / export**
  - CO shifted to H_2 (<0.5 vol%), H_2 concentration raised from 18% to 29%
  - Purification-ready anode exhaust produced for PSA
- **Step 2: PSA System Operation**
  - H_2 Production at 50% load
  - In progress (3/09): validation of emergency shutdown and de-integration protocols

Shop Validation Test – Next Steps

- Operation on Natural Gas
  - Grid-connect and grid-independent operation
  - Validate different operating modes- all electric to full co-production
  - Vary hydrogen co-production (turn-down capability)
  - Verify quality of hydrogen produced by PSA
  - Verify emissions benefits

- Operation on Simulated Digester Gas

- Obtain Data for Field Operation and Analysis

Future Work

- Operation of Hydrogen Energy Station – Lessons learned from shop test, field trial
- Validation of process economics
- Following DOE Program:
  - Product development activities – Process improvements for second generation system
  - Scale-up based on existing fuel cell products –
    - DFC®1500 – 400 to 500 kg/day hydrogen plus 1.0 to 1.2 MW
    - DFC®3000 – 800 to 1,000 kg/day hydrogen plus 2.0 to 2.4 MW

DFC®300

DFC®1500

Summary

- Determine the economic and technical viability of a hydrogen energy station designed to co-produce power and hydrogen
  - Concept defined – FuelCell Energy's molten carbonate fuel cell plus Air Products' hydrogen purification system
  - Design and fabrication of demonstration unit completed
  - Shop test at FuelCell Energy's facilities in Danbury, CT
  - Plans for demonstration operation on renewable feedstock at Orange Co. Sanitation District, Fountain Valley, CA
    - Hydrogen refueling station under DOE's California Hydrogen Infrastructure Project
    - Other funding: California Air Resources Board, South Coast Air Quality Management District
  - Validate process economics based on system performance

Thank you

tell me more
www.airproducts.com

Acknowledgement & Disclaimers

This material is based upon work supported by the Department of Energy (Energy Efficiency and Renewable Energy) under Award Number DE-FC36-01GO11087. This presentation was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

AIR PRODUCTS