Validation of an Integrated Hydrogen Energy Station

Edward C. Heydorn
Air Products and Chemicals, Inc.
20 May 2009

Project ID#
tv_06_heydorn

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Overview

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

Barriers
• H₂ Fueling Infrastructure
• H₂ & 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

\[
\begin{align*}
\text{Anode:} & \quad \text{CH}_4 + \text{H}_2\text{O} \rightarrow 4\text{H}_2 + \text{CO}_2 \\
& \quad \text{H}_2 + \text{CO}_3^{=} \rightarrow \text{H}_2\text{O} + \text{CO}_2 + 2e^- \\
& \quad \frac{1}{2} \text{O}_2 + \text{CO}_2 + 2e^- \rightarrow \text{CO}_3^{=}
\end{align*}
\]

Fuel Cleanup

Exhaust

Electrolyte

Cathode

\[
\text{CO}_3^{=} \quad 2e^- \quad \text{Heat Exchangers}
\]

Water-Gas Shift

Air

Compressor

H\text{2} Purification

Electricity

Hydrogen
# Hydrogen Energy Station

## Projected Performance by Phase

<table>
<thead>
<tr>
<th></th>
<th>Units</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall Efficiency</strong></td>
<td>LHV</td>
<td>60%</td>
<td>63%</td>
<td>66%</td>
</tr>
<tr>
<td>(Net Power + ( \text{H}_2 ) Product) / (Fuel)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Power Efficiency</strong></td>
<td>LHV</td>
<td>49%</td>
<td>49%</td>
<td>50%</td>
</tr>
<tr>
<td>Net Power / (Total Fuel – ( \text{H}_2 ) Product)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hydrogen Efficiency</strong></td>
<td>LHV</td>
<td>68%</td>
<td>71%</td>
<td>77%</td>
</tr>
<tr>
<td>(( \text{H}_2 ) Product – Purification Power) / ( \text{H}_2 ) Product</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hydrogen Product</strong></td>
<td>Kg/day</td>
<td>~ 88</td>
<td>~ 125</td>
<td>~ 175</td>
</tr>
<tr>
<td><strong>Net Power w/o &amp; w/ Hydrogen</strong></td>
<td>kW</td>
<td>~ 247 / 207</td>
<td>~ 300 / 250</td>
<td>~ 300 / 250</td>
</tr>
<tr>
<td><strong>Natural Gas Flow</strong></td>
<td>Nm(^3)/hr</td>
<td>~ 55</td>
<td>~ 66</td>
<td>~ 74</td>
</tr>
</tbody>
</table>
Process Improvements during Design Phase

• Improvement in hydrogen purification cycle:
  – Phase 1: 300 psig inlet, 75% H₂ recovery
  – Phase 3: 150 psig inlet, > 85% H₂ recovery

• Patent application filed
## Emissions Performance of DFC® Molten Carbonate Fuel Cell

<table>
<thead>
<tr>
<th></th>
<th>NO$_x$ (lb/MWh)</th>
<th>SO$_x$ (lb/MWh)</th>
<th>CO$_2$ (lb/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average US Fossil Fuel Plant</td>
<td>4.200</td>
<td>9.21</td>
<td>2,017</td>
</tr>
<tr>
<td>Microturbine (60 kW)</td>
<td>0.490</td>
<td>0</td>
<td>1,862</td>
</tr>
<tr>
<td>Small Gas Turbine (250 kW)</td>
<td>0.467</td>
<td>0</td>
<td>1,244</td>
</tr>
<tr>
<td><strong>DFC® Fuel Cell 47% efficiency</strong></td>
<td>0.016</td>
<td>0</td>
<td>967</td>
</tr>
<tr>
<td><strong>DFC® Fuel Cell - CHP 80% efficiency</strong></td>
<td>0.016</td>
<td>0</td>
<td>545</td>
</tr>
</tbody>
</table>

NO$_x$ and SO$_x$ are negligible compared to conventional technologies.
Hydrogen Energy Station Economics (Phase 2)

Fuel Cost, $/MMBTU

Hydrogen Price, $/kg

Power Price
- Near-term equipment costs
  - $0.06/kWh

- Mid-term equipment costs
  - $0.10/kWh
  - $0.06/kWh

- Long-term equipment costs
  - $0.10/kWh
  - $0.06/kWh

Near-term equipment costs
Mid-term equipment costs
Long-term equipment costs
Hydrogen Energy Station Vision

Feedstock Source
- 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

FuelCell Energy
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
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®-H₂-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 – H₂ Purification Skid

- **Step 1:** DFC® Integrated with Anode Exhaust Skid without H₂ purification / export
  - CO shifted to H₂ (<0.5 vol%), H₂ concentration raised from 18% to 29%
  - Purification-ready anode exhaust produced for PSA

- **Step 2:** PSA System Operation
  - H₂ 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
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.