Development of a Renewable Hydrogen Energy Station

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“Delivering Renewable Hydrogen – A Focus on Near-Term Applications”
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Presentation Outline

• Hydrogen Energy Station Technology Overview
• Process Description
• Performance and Economic Parameters
• Proposed Demonstration on Renewable Feedstock
• Status of Shop Validation Test
• Conclusion
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
Hydrogen Energy Station Concept

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

- Air Products Cooperative Agreement with U.S. DOE (30 September 2001) 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
    • Ongoing
Hydrogen Energy Station

\[ \text{Anode} \]
\[ \text{Electrolyte} \]
\[ \text{Cathode} \]

\[ \text{Fuel} \]
\[ \text{Exhaust} \]
\[ \text{Electricity} \]
\[ \text{Hydrogen} \]

\[ \text{Gas Cleanup} \]

\[ \text{CH}_4 + H_2O \rightarrow 4H_2 + CO_2 \]
\[ H_2 + CO_3^{=} \rightarrow H_2O + CO_2 + 2e^- \]

\[ \frac{1}{2} O_2 + CO_2 + 2e^- \rightarrow CO_3^{=} \]

\[ \text{Air} \]

\[ \text{Compressor} \]
\[ \text{H}_2 \text{ Purification} \]

\[ \text{After-Gas Shift} \]

\[ \text{Heat Exchangers} \]
## 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>66%</td>
<td>66%</td>
</tr>
<tr>
<td><em>(Net Power + H2 Product) / (Fuel)</em></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><em>Net Power / (Total Fuel – H2 Product)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hydrogen Efficiency</strong></td>
<td>LHV</td>
<td>68%</td>
<td>68%</td>
<td>77%</td>
</tr>
<tr>
<td><em>(H2 Product – Purification Power) / H2 Product</em></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>~ 175</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 / 243</td>
<td>~ 300 / 250</td>
</tr>
<tr>
<td><strong>Natural Gas Flow</strong></td>
<td>Nm3/hr</td>
<td>~ 55</td>
<td>~ 74</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

US20080223213A1
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>DFC Fuel Cell 47% efficiency</td>
<td>0.016</td>
<td>0</td>
<td>967</td>
</tr>
<tr>
<td>DFC Fuel Cell – CHP 80% efficiency</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

Power Price
- $0.06/kWh
- $0.10/kWh
- $0.06/kWh
- $0.10/kWh

Fuel Cost, $/MMBTU

Hydrogen Price, $/kg

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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
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
Hydrogen Energy Station Shop Validation Test – DFC® System

All DFC®-H₂-PSA Equipment Installed and Commissioned

- 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
- Fuel cell with water-gas shift in operation > 6,000 hours

Hydrogen Ready Fuel Cell Module

Mechanical Balance of Plant (MBOP)
Fountain Valley Renewable Hydrogen Station

Tri-Generation Results

- Produced 5 to 10 lb/hr hydrogen with > 200 kW electricity
- Estimated hydrogen recovery at 80 to 85%
- Product purity <0.2 ppm CO; <2 ppm CO2
- Operation with simulated digester gas feed
- PSA operating map developed (cycle time vs. feed rate)
- Implemented automated integration/deintegration

FuelCell Energy
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
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