Ultra Efficient Combined Heat, Hydrogen, and Power System

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FuelCell Energy, Inc.
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Pinakin Patel
FuelCell Energy Inc.
ppatel@fce.com
203-825-6072

U.S. DOE Industrial Distributed Energy Portfolio Review Meeting
Washington, D.C.
June 1-2, 2011
• Leading fuel cell developer for over 40 years
  – MCFC, SOFC, PAFC and PEM (up to 2.8 MW size products)
  – Over 700 million kWh of clean power produced world-wide (>50 installations)
  – Renewable fuels: over two dozen sites with ADG fuel
  – Ultra-clean technology: CARB-2007 certified

• Highly innovative approach to fuel cell development
  – Internal reforming technology (45-50% electrical efficiency)
  – Fuel cell-turbine hybrid system (55-65% electrical eff.)
  – Enabling technologies for hydrogen infrastructure
    • Co-production of renewable H₂ (60-65% eff. w/o CHP)
    • Solid state hydrogen separation and compression
Markets
• 111 MW installed/backlog
  – Korea/Asia: 70 MW
  – California/West Coast: 33 MW
  – Northeast/Canada: 6 MW
  – Europe: 2 MW

• Targeted applications
  – Grid Support: 70 MW
  – **Renewable/Wastewater**: 21 MW
  – Manufacturing: 6 MW
  – Hotels: 2 MW
  – **University** & Hospitals: 5 MW
  – Government: 5 MW
  – Gas Pipeline: 2 MW
Building block approach provides scalability and a common cell/stack component across product lines.
Operation – Carbonate DFC® Technology

HYDROCARBON FUEL (e.g. Natural Gas)

INTERNAL REFORMING

\[ \text{CH}_4 + 2\text{H}_2\text{O} \rightarrow 4\text{H}_2 + \text{CO}_2 \]

ANODE

\[ \text{H}_2 + \text{CO}_3^- \rightarrow \text{H}_2\text{O} + \text{CO}_2 + 2e^- \]

CATALYST

ELECTROLYTE

CATALYST

CATHODE

\[ \frac{1}{2}\text{O}_2 + \text{CO}_2 + 2e^- \rightarrow \text{CO}_3^- \]

Exhaust

25-35% Excess H\_2, CO + CO\_2

AIR + CO\_2

CO\_2

FuelCell Energy
CHHP Technology Demonstration at Orange County Sanitation District (OCSD) Fountain Valley, California

Unit producing over 250 lb/day of renewable H₂ from waste water anaerobic digester gas
Project Team

• FuelCell Energy
  – Pinakin Patel
  – Fred Jahnke
  – Matt Lambrech

• ACuPowder / Abbott Furnace
  – Ed Daver
  – Krishna Patel

• ITP Program Managers
  – Bob Gemmer
  – Jerry Parker
Executive Summary

• Goal – reduce gross utility costs for copper powder manufacturing by up to 25%, energy use by 50%
• Proposed solution - coproduce low cost reducing gas, power and heat on site for reduction of copper powder (CHHP)
• Benefits
  – Ultra efficient on-site generated hydrogen and CO2 mixture replaces currently imported liquid hydrogen and liquid nitrogen and reduces purchased power
  – High value co-products (H2/CO2) make process very competitive
• Status
  – Laboratory testing by manufacturer successful
  – Commercial furnace test equipment being installed
Project Objective

- Demonstrate the use of low cost reducing gas from fuel cell to replace purchased liquid gases
- Maintain high reliability and copper product quality

Concerns

- CO2 replaces N2 currently used and potentially could change product properties
- Risks for integration with existing commercial process
- Uses emerging technology
  - High temperature fuel cell anode exhaust gas recovery
  - Returning furnace off gases to fuel cell
State of the Art

• ACuPowder purchases liquid H2 / N2 for reducing gas to produce over 2 million lbs/month of copper powder
• Power purchased from grid
• Unused H2 in furnace exhaust is vented
Technical Approach

- CHP to CHHP using high temperature DFC® fuel cell
- Recover and condition anode exhaust (H2+CO+CO2+H2O) to produce low cost reducing gas on-site
- Recover furnace exhaust gases for use in fuel cell

- Higher efficiency
- Lower emissions
- Much higher value added with no change in product quality
Technical Approach

• Why believe will be successful
  – Thermodynamics indicate N2 and be replace by CO2 for copper
  – “Endo” gas, a mixture of CO and H2 with some CO2, was used before liquid H2 available
  – Gas produced by fuel cell has H2 content similar to current reducing gas

• Innovations
  – Build on emerging H2 co-production technology
  – Use of waste stream from fuel cell for high value reducing gas
  – Return unused hydrogen and CO2 from furnace to fuel cell to increase efficiency
  – Co-producing inert gas (CO2 replaces N2) as well as hydrogen
  – Low reducing gas production costs (H2 separation not needed)
Transition and Deployment
• Working with major supplier to industry

ACuPowder is source for multiple metal products and alloys (More than 90 years industry experience, >50% market share)

– Antimony, – Graphite, – Phos-Copper,
– Bismuth, – Infiltrants, – P/M
– Brass, – Manganese, Lubricants,
– Bronze, – MnS+, – Silicon,
– Copper, – Nickel, – Silver Flake,
– Copper – Nickel Flake, – Tin and
Alloys, – Nickel Silver, – Tin Alloys..
Transition and Deployment

• Perform study for selecting industry segments to improve manufacturing and energy efficiency using CHHP technology

• ACuPowder parent company can use CHHP system at other facilities

• Joint presentation / paper at MPA (Metal Processing Association) and other industry groups

• Develop business model for disruptive technology
  – Who owns
  – Value proposition

• CHHP technology scale up to megawatt size
Transition and Deployment

Potential Market Readiness

Hydrogen Purity

- Ultra High
- High
- Medium
- Low

Near Term
- Heat Treatment

Mid Term
- Stationary PEM Systems
- Pharmaceutical

Long Term
- Electronics
- Semiconductors
- Fuel Cell Vehicles
- Refinery/Ammonia
- Pharmaceuticals
- Electronics
- Semiconductors
- Fuel Cell Vehicles
- Refinery/Ammonia
Measure of success

Project Addresses Most Important Operating Cost

<table>
<thead>
<tr>
<th>Operating Cost</th>
<th>Range (% of Total)</th>
<th>Guideline (% of Total)</th>
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<tbody>
<tr>
<td>Furnace Depreciation</td>
<td>5% - 15%</td>
<td>10%</td>
</tr>
<tr>
<td>Facility Space Costs</td>
<td>5% - 15%</td>
<td>10%</td>
</tr>
<tr>
<td>Atmosphere &amp; Utilities</td>
<td>40% - 55%</td>
<td>50%</td>
</tr>
<tr>
<td>Operator &amp; Maintenance Labor Costs</td>
<td>5% - 15%</td>
<td>10%</td>
</tr>
<tr>
<td>Inspection &amp; Rework</td>
<td>5% - 20%</td>
<td>8%</td>
</tr>
<tr>
<td>Replacement Parts</td>
<td>10% - 15%</td>
<td>12%</td>
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</tbody>
</table>

100%
Measure of success

• Success criteria
  – Maintain product quality (match properties, satisfy customers)
  – Substantially reduce gross utility costs (up to 25%)
  – Attain ultra high efficiency (60-75% power+ reducing gas)
  – No new emissions of criteria pollutants
Benefits

- 25% Utility Savings (12% operating cost)
  - On-site power, low cost reducing gas, heat
  - Increased competitiveness - Keeps jobs in USA

- Large emissions reductions – Societal benefits

Savings yearly tons

<table>
<thead>
<tr>
<th></th>
<th>Savings from Planned unit (~345 kw)</th>
<th>NOx</th>
<th>SOx</th>
<th>PM-10</th>
<th>CO2</th>
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</thead>
<tbody>
<tr>
<td>Average US Fossil Fuel Plant</td>
<td>7.27</td>
<td></td>
<td></td>
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<tr>
<td>High Temperature Fuel Cell</td>
<td>16.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Fuel Cell with Reducing Gas</td>
<td>0.39</td>
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</table>

Savings for NOx and SOx 25 t/yr at 10,000 $/t = $250,000 emission credit
Commercialization Approach

Commercialization Strategy for Reducing Gas from FuelCell Energy’s DFC® Unit

- H2 Booster
  - Power Booster
    - LT fuel cell
    - Ultra Efficient Power
    - Base Power
    - Base+Peak Power
    - Power and Hydrogen Coproduction
- Optional H2 Purification
  - H2 Power Peaker
    - LT fuel cell
    - Power
  - H2
  - Reducing Gas
  - Metal Treating Industry
    - Power and Reducing Gas Co-production
Commercialization Approach

• Expand commercial DFC® products to include CHHP
• Use technology for multiple markets
  – Industrial H2 market (near term) ($10 billion)
  – Clean distributed power (mid term) (> $100 billion)
  – Backup/Load following power (future)
  – Transportation (future)
• Develop distributor system
  – H2 / Industrial Gas Companies
  – Utilities
• Develop sales options
  – equipment sales
  – over-the-fence supply contracts
Commercialization Approach
Expand commercial DFC® products to include CHHP

<table>
<thead>
<tr>
<th>Co-product</th>
<th>DFC300®</th>
<th>DFC1500®</th>
<th>DFC3000®</th>
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<tbody>
<tr>
<td>Power, kW</td>
<td>250</td>
<td>1,000</td>
<td>2,000</td>
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<tr>
<td>Hydrogen, kg/day</td>
<td>125</td>
<td>500</td>
<td>1,000</td>
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<tr>
<td>Heat, mmBtu/hr</td>
<td>0.5</td>
<td>2.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Peaker Capacity</td>
<td></td>
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</tr>
<tr>
<td>Peak Power (8 hrs/day), kw</td>
<td>500</td>
<td>2,000</td>
<td>4,000</td>
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<tr>
<td>Refueling Capacity</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Fork Lifts/FC Cars, 0.5 kg/day</td>
<td>300</td>
<td>1,200</td>
<td>2,400</td>
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Hybrid Power Generation with > 60% Electrical Efficiency for CHP Applications

Use of Waste Fuel in High Efficiency Engine/Turbine
Combined Hydrogen Heat and Power (CHHP) for Micro-Grid Applications

DFC-H2® Peaker Demonstration Project

Plant Features

- **Storage Capacity:** 2.5 MWh (or larger)
- **Energy Storage Medium:** H₂ produced on-site (300 lb/day ~ 2 day storage tank)
- **Peak Power Capacity:** 300 kW for 8 hrs/day
- **Base Load Capacity:** 300 kW (24/7, DFC® 300 unit)
- **Total (base+peak) Capacity:** 600 kW
- **Potential SuperPeak of Peaker:** 300 kW
- **Potential Superpeak Capacity:** 900 kW for 2 hrs
- **Fuel:** Pipeline / Renewable Gas Mixture; optional Biogas (ADG)
- **Emissions related to Peak Power:** nil
- **Emission related to Base Power:** Exceeds CARB Standards

Distributed Generation with waste heat recovery providing over 80% CHHP eff
Combined Cooling Heat and Power (CCHP) Applications

CCHP
Combined Cooling, Heat, Power

Abs Chiller
Cooling

HT Fuel Cell System
Heating

Conventional Generation System
Power

Proposed System
40% fuel savings

FuelCell Energy
Project Management and Budget

- **Key Milestones**
  - Quality testing with low cost reducing gas
    - Laboratory
    - Commercial Furnace (bottled gases)
  - Economic review
  - Installation
  - Operation and Testing

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<th>FY11</th>
<th>FY12</th>
<th>FY13</th>
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<td>DOE Investment</td>
<td>$508,228</td>
<td>$2,275,959</td>
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<tr>
<td>Cost Share</td>
<td>$303,611</td>
<td>$2,895,794</td>
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<tr>
<td>Project Total</td>
<td>$811,838</td>
<td>$5,171,754</td>
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Results and Accomplishments

• The extensive lab test performed in four months of 2011 has revealed that the properties of copper powders using conventional H-N gas mix and FCE gas mix are identical in all respects. *

• The management at ACP is highly optimistic for the completion of both phases of this CHHP project with full installation of commercial FCE in 2012.*

• Completed risk assessment and test plan for testing at larger size in the production furnace using simulated fuel cell gas.

• Completed material and energy balances for different operating scenarios. Economic analysis in progress.

• Rutgers University interested in supporting outreach with NJ State entities for the project.

* manufacturer’s (ACuPowder) statements
Results and Accomplishments

Pre-feasibility Test Done at FCE

Test of Bright Annealing of Oxidized Copper Wire using Reducing Gas from a High Temperature Fuel Cell

Oxidized Copper Wire

Annealed Copper Wire

Reducing Gas Composition

- H2: 21%
- CO: 2%
- CO2: 74%
- H2O: ~3%
Moving Bed Test Results
Current Plant Gas compared to Expected Gas from Fuel Cell

Quality of copper product maintained with low cost reducing gas

Current Gas
Low Cost Gas
Results and Accomplishments

Potential Installation Locations at ACuPowder Site in Union, NJ
Path Forward

• Key Remaining Tasks
  – Commercial Furnace Test
  – Economic Validation
    • Firm up cost with site specific quotes
    • Confirm economics valid with firm costs
  – Install CHHP system
  – Operate and Test
    • Confirm and report performance and cost benefits
  – Implement Commercialization Plan
Thank you

Questions?

Pinakin Patel
Director of Special Systems and Research

ppatel@fce.com
203-825-6072

WWW.FuelCellEnergy.com