Fuel Cell Power Plants
Renewable and Waste Fuels

DOE-DOD Workshop
Washington, DC.
January 13, 2011

reliable, efficient, ultra-clean
• Premier developer of stationary fuel cell technology — founded in 1969
• Over 50 installations in North America, Europe, and Asia
• Industrial, commercial, utility products
• 300 KW to 50 MW and beyond
Product Line Based on Stack Building Block

- **Cell Package and Stack**

- **Single-Stack Module**

- **Four-Stack Module**

- **DFC300**
  - Single Module Powerplant
  - 300 kW

- **DFC1500**
  - One 4-Stack Module
  - 1.4 MW

- **DFC3000**
  - Two 4-Stack Modules
  - 2.8 MW
Electrical Balance Of Plant (EBOP):
• Converts DC power to grid quality AC power
• Meets IEEE and UL Codes for Safety and Grid Interface

Mechanical Balance Of Plant (MBOP):
• Water and Fuel flow cleanup and preheat
• Air supply, startup heater

Direct Fuel Cell Module:
4-stack Module
Applications

• On-site self generation of combined heat and power
  – Clean Power with natural gas fuel
  – Renewable Power with biofuels

• Grid connected power generation
  – High Efficiency Grid support
  – Renewable Portfolio Standards
Fuels Resources for DFC

- Natural Gas and LNG
- Propane
- Biogas (by Anaerobic Digestion)
  - Municipal Waste Water Treatment
  - Brewery
  - Food and Animal Waste
- Biogasifier derived Fuels
Comparative Electrical Efficiency

**DFC power plants offer the high efficiency**

- **DFC/ERG**: 58 – 70%
- **Direct FuelCell (DFC)**: 47%
- **Natural Gas Engines**: 30 – 42%
- **Small Gas Turbines**: 25 – 35%
- **Micro-turbines**: 25 – 30%
- **Combined Heat & Power (CHP)** applications can have up to 90% total thermal efficiency

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Fuels Diversity and Efficiency

INTEGRATED SYSTEMS IMPROVE EFFICIENCY
- DFC – (47%)
- DFC – CHP (60-80%)
- DFC – ERG (55-60%)
- DFC/T – (55-60%)
- DFC H2 (50-60%)

FUEL RESOURCES
- NATURAL GAS
- PROPANE
- ETHANOL
- WASTE METHANE
- BIOGAS
- COAL GAS

Diversity of Fuels plus High Efficiency - High Sustainability
<table>
<thead>
<tr>
<th></th>
<th>NOX (lb/MWh)</th>
<th>SOX (lb/MWh)</th>
<th>PM-10 (lb/MWh)</th>
<th>CO2 (lb/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average US Grid</td>
<td>3.43</td>
<td>7.9</td>
<td>0.19</td>
<td>1,408</td>
</tr>
<tr>
<td>Average US Fossil Fuel Plant</td>
<td>5.06</td>
<td>11.6</td>
<td>0.27</td>
<td>2,031</td>
</tr>
<tr>
<td>Microturbine (60 kW)</td>
<td>0.44</td>
<td>0.008</td>
<td>.09</td>
<td>1,596</td>
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<tr>
<td>Small Gas Turbine (250 kW)</td>
<td>1.15</td>
<td>0.008</td>
<td>.08</td>
<td>1,494</td>
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<tr>
<td>DFC Fuel Cell 47% efficiency</td>
<td>0.01</td>
<td>0.0001</td>
<td>.00002</td>
<td>980</td>
</tr>
<tr>
<td>DFC Fuel Cell – CHP 80% efficiency</td>
<td>0.006</td>
<td>0.00006</td>
<td>.0001</td>
<td>552</td>
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</tbody>
</table>

Source for non-DFC data: “Model Regulations For The Output Of Specified Air Emissions From Smallerscale Electric Generation Resources Model Rule and Supporting Documentation”, October 15, 2002; The Regulatory Assistance Project report to NREL.
• **More power for given amount of biogas**: Higher efficiency than any other generation at typical digester facility sizes

• **Good heat to power ratio for digester support**: Fuel cell makes enough heat to support digester operation

• **Avoids generation of NOₓ and other pollutants** from flare or from other generation technologies
## Typical Fuels Composition

<table>
<thead>
<tr>
<th>Composition</th>
<th>Natural Gas</th>
<th>Biogases</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Waste Water</td>
</tr>
<tr>
<td>Methane (Vol%)</td>
<td>80-100</td>
<td>~50-60</td>
</tr>
<tr>
<td>Carbon Dioxide (Vol%)</td>
<td>&lt;3</td>
<td>30-40</td>
</tr>
<tr>
<td>Nitrogen (Vol%)</td>
<td>&lt;3</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Oxygen (Vol%)</td>
<td>&lt;0.2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>H$_2$S, ppm</td>
<td>&lt;0.1</td>
<td>&lt;400</td>
</tr>
<tr>
<td>Non-H$_2$S Sulfur, ppm</td>
<td>&lt;10</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Halogens, ppm</td>
<td>&lt;0.1</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>&lt;0.02</td>
<td>~3</td>
</tr>
</tbody>
</table>
Bio-gas Plants in North America

- Sierra Nevada Brewing Company
- Turlock Irrigation District
- Dublin San Ramon Reclamation District
- Tulare WWTP
- Santa Barbara
- Gills Onions
- Rialto WWTP
- Riverside WWTP
- Eastern Municipal Water District
- Olivera Egg Ranch
- Eastern Municipal Water District
- Orange County Sanitation District

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Tulare CA Wastewater Treatment Plant

- 3 DFC300 Units operating on ADG, provide ~ half of facility load
- 94% Availability from Jan 2008 through Aug 2010
- Recently ordered fourth unit
Site With Power Generation in Excess of ADG Supply
First Site with Automated Fuel Blending
Turlock Irrigation District Waste Water Treatment Facility, Turlock, CA
Ford Motor Company, Ontario Assembly

• Challenge:
  – Cost-effectively dispose of VOC*
  – Reduce emissions in paint operations

• Solution:
  – 300 kW Ultra-Clean 24/7 reliable power running on VOC

• Results:
  Low-cost, low-emissions electricity
  – VOC disposal cost cut in half over ten years

* Volatile Organic Compounds
DFC-ERG High Efficiency Application

- DFC-ERG designed for pipeline letdown operations
  - Byproduct heat warms gas to prevent freezing
  - Energy from pressure letdown fed to turbine
  - Combined electricity delivered to the grid
- Improved economics and lower CO2 emissions
- 2.2MW Toronto plant demonstrating technology and validating value proposition
  - Efficiency greater than 70%
Co-Production of Renewable Hydrogen
Orange County, CA

Orange County Sanitation District (OCSD)

Renewable H₂ Filling Station

ADG fueled DFC-H₂ Production Unit
Unit will produce over 250 lb/day of renewable H₂ from waste water anaerobic digester gas starting in 2010
DFC-H2® Peaker - Complements Smart Grid

Natural Gas or Renewable fuel

Base Load Fuel Cell

Co-Produced Hydrogen

Hydrogen Storage

Load Following Fuel Cell

Electrolyzer

Wind Power

SMART GRID
## Co-Production Capacity of DFC-H2® Power Plants

<table>
<thead>
<tr>
<th></th>
<th>DFC300®</th>
<th>DFC1500®</th>
<th>DFC3000®</th>
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<tbody>
<tr>
<td><strong>Co-product</strong></td>
<td></td>
<td></td>
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<tr>
<td>Power, kW</td>
<td>250</td>
<td>1,000</td>
<td>2,000</td>
</tr>
<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>
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<tr>
<td><strong>Peaker Capacity</strong></td>
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<td></td>
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<tr>
<td>Peak Power (8 hrs/day), kw</td>
<td>500</td>
<td>2,000</td>
<td>4,000</td>
</tr>
<tr>
<td><strong>Refueling Capacity</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Fuel Cell Cars, 0.5 kg/day</td>
<td>300</td>
<td>1,200</td>
<td>2,400</td>
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