DFC Technology Status

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reliable, efficient, ultra-clean
Distributed Generation

- Distributed generation puts power where it’s needed
- Increases power reliability
- Near zero emissions allow units to be sited almost anywhere – even polluted urban areas
- Reduces need for central generation plants
- Reduces grid congestion and need for new transmission lines
- Distributed generation enables smart grid
- Balances the grid with 24/7 power
- Meets requirements for low carbon technology
- Smaller projects enable faster permitting, financing, and execution

DFC power plant is an enabler for broad distributed generation

600 kW at M&L Commodities
FuelCell Energy

Products

Fuel Cell

Stack

Building block approach provides scalability and a common cell/stack component across product lines

DFC300
Single Module Power plant

DFC1500
Four Module Power plant

DFC3000
Two 4-Stack Modules
DFC Typical Applications

- **Average-Sized Grocery Stores, 300-Bed Hotels**: 300 kW
- **1000-Bed Hotels, Convention Centers, Wastewater Treatment, Food/Beverage**: 1.4 MW
- **300-Bed Hospitals, Manufacturing, Universities**: 2.8 MW
- **Grid Support, RPS**: 10 MW +
DFC power plants offer the highest efficiency of any distributed generation technology.

- **60%**
- **50%**
- **40%**
- **30%**
- **20%**
- **10%**

**Fuel to Electrical Efficiency**

- **Micro-turbines** 25 – 30%
- **Small Gas Turbines** 25 – 35%
- **Natural Gas Engines** 30 – 42%
- **Direct FuelCell (DFC)** 47%
- **DFC-ERG**
  - **DFC/Turbine** 58 – 65%

*MO3262*
### Direct Fuel Cell Emissions Compared to Others

<table>
<thead>
<tr>
<th></th>
<th>CO₂ (lb/MWh)</th>
<th>NOₓ (lb/MWh)</th>
<th>SOₓ (lb/MWh)</th>
<th>PM₁₀ (lb/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average US Fossil Fuel Plant</td>
<td>2031</td>
<td>5.06</td>
<td>11.6</td>
<td>0.27</td>
</tr>
<tr>
<td>Average US Generation</td>
<td>1408</td>
<td>3.4</td>
<td>7.9</td>
<td>0.19</td>
</tr>
<tr>
<td>Typical Small Gas Turbine</td>
<td>1494</td>
<td>1.1</td>
<td>0.008</td>
<td>0.08</td>
</tr>
<tr>
<td>DFC (Baseline products)</td>
<td>980</td>
<td>0.01</td>
<td>0.0001</td>
<td>0.00002</td>
</tr>
<tr>
<td><strong>DFC Potential (at 65% Efficiency)</strong></td>
<td><strong>680</strong></td>
<td><strong>0.007</strong></td>
<td><strong>0.00007</strong></td>
<td><strong>0.00001</strong></td>
</tr>
</tbody>
</table>
DFC: Cleanest Power at the Highest Efficiency

Source for non-DFC data: PAFC data from product brochure; Other data from “Model Regulations For The Output Of Specified Air Emissions From Smaller-scale Electric Generation Resources Model Rule and Supporting Documentation”, October 15, 2002; The Regulatory Assistance Project report to NREL
Both stacks at the Camp Pendleton site met life goals
### Typical Operating Point of a 2.4 MW Power Plant

#### Power Plant Load Rated

<table>
<thead>
<tr>
<th>Metric</th>
<th>Actual</th>
<th>ISO Rated</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Power</td>
<td>2507 kW</td>
<td>2688 kW</td>
</tr>
<tr>
<td>Gross AC Power</td>
<td>2578 kW</td>
<td>2469 kW</td>
</tr>
<tr>
<td>BOP Load</td>
<td>59 kW</td>
<td>53 kW</td>
</tr>
<tr>
<td>Altitude Correction</td>
<td>0 kW</td>
<td>0 kW</td>
</tr>
<tr>
<td>Stack Auto Derate</td>
<td>0 kW</td>
<td>0 kW</td>
</tr>
<tr>
<td>Net AC KW Output</td>
<td>2415 kW</td>
<td>2400 kW</td>
</tr>
</tbody>
</table>

#### System Information:
- ICONICS Version: 11
- PLC Logic Version: 65.0
- Module A Serial Number: B1220-013
- Module B Serial Number: B1220-014

#### Power Plant Location:
- MPC 2, Yuchon, Republic of Korea

#### Module A

<table>
<thead>
<tr>
<th>Stack</th>
<th>DC Voltage</th>
<th>DC Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack AB</td>
<td>623 V</td>
<td>1046 A</td>
</tr>
<tr>
<td>Stack CD</td>
<td>691 V</td>
<td>1092 A</td>
</tr>
<tr>
<td>Average</td>
<td>627 V</td>
<td>1078 A</td>
</tr>
</tbody>
</table>

**Runtime:** 1169 Hrs

#### Module B

<table>
<thead>
<tr>
<th>Stack</th>
<th>DC Voltage</th>
<th>DC Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack AB</td>
<td>625 V</td>
<td>1046 A</td>
</tr>
<tr>
<td>Stack CD</td>
<td>626 V</td>
<td>1024 A</td>
</tr>
<tr>
<td>Average</td>
<td>626 V</td>
<td>1033 A</td>
</tr>
</tbody>
</table>

**Runtime:** 1169 Hrs
4.8 MW Fuel Cell – Pohang, Korea
• 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 NO$_x$ and other pollutants from flare or from other generation technologies
1 MW Municipal Wastewater Treatment Plant
First Site with Online Fuel Switching
First SubMW Digester Gas Project, Running on Biogas from Beer Production
Sierra Nevada Brewery

Site with Power Generation in excess of ADG Supply
First Site with Automated Fuel Blending
MW and Sub-MW DFC®
Worldwide Installations
Markets

- 95 MW installed/backlog
  - Japan/Korea: 72 MW
  - California/West Coast: 15 MW
  - Northeast/Canada: 5 MW
  - Europe: 2 MW

- Targeted applications
  - Grid Support: 69 MW
  - Renewable/Wastewater: 9 MW
  - Manufacturing: 7 MW
  - Hotels: 3 MW
  - University & Hospitals: 2 MW
  - Government: 3 MW
  - DFC-ERG: 2 MW
• Production and delivery capabilities meet current demand
• State-of-the-art manufacturing in Torrington, CT
• 70 MW capacity
• Production rate of 30 MW/year
• Strong supply chain in place
• Expansion plan to achieve 150 MW capacity
• DFC-ERG provides heat for natural gas pipeline letdown operations
  – Byproduct heat warms gas to prevent freezing as pressure is let down from transcontinental pipelines to local lines
  – Excess electricity sold to the grid
• Improved economics and lower carbon emissions due to ~60% electrical efficiency
• First site commissioned in Toronto
• Four sites pending under Connecticut RPS program
• Market opportunity estimated at 250-350 MW in Toronto, California and the Northeast U.S.
Products Under Development: DFC/T Fuel Cell Turbine Hybrid System

- Fuel cell waste heat drives unfired turbine
- Electrical efficiency increased from 47% to 58-60%
- Field tested in DFC300 based subMW system
- Commercial product being designed based on DFC3000, 3.4 MW rating
  - First unit approved under CT Project 100

Billings, MT field test
Products Under Development: Electricity and Hydrogen Co-production

- **Electricity and Hydrogen Co-production**
- **H₂ Purification**
- **A/E Cooing**
- **DFC300**
- **E-BOP**
- **M-BOP**

- kWs to electric load
- Heat to buildings thermal load
- **H₂ to refueling station or industrial user**
• Exhaust from fossil fuel plant used as DFC oxidant
• CO₂ from fossil fuel plant transferred and concentrated for efficient sequestration
• Produces additional power, unlike other carbon capture concepts
DFC system has shown excellent performance in separation of carbon dioxide, in the study of various types of coal fueled power plants.

<table>
<thead>
<tr>
<th>PLANT TYPE</th>
<th>Net Power</th>
<th>CO2 to Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MW</td>
<td>lbs/MWhr</td>
</tr>
<tr>
<td>w/o DFC</td>
<td>with DFC</td>
<td>w/o DFC</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Pulverized Coal (PC) Steam Plant</td>
<td>200</td>
<td>341</td>
</tr>
<tr>
<td>ACFB Steam Plant</td>
<td>200</td>
<td>353</td>
</tr>
<tr>
<td>IGCC Plant</td>
<td>200</td>
<td>327</td>
</tr>
</tbody>
</table>

DFC provides additional power

> 90% CO₂ separation from the greenhouse gas (per unit energy produced)

* Preliminary results prior to input from fuel cell test results
• 300 kW, 1.4 MW, and 2.8 MW size products for CHP applications
• Product performance expanding markets
• Customers/applications providing repeatable order flow – Asia, California, Connecticut
• RPS and South Korean markets creating multi-MW volume (84% of the installed and backlog volume in Asia). 
• Established manufacturing capability to meet current and future demand
• Cost reduction and volume on path to profitability

Pohang, Korea
Direct FuelCell Attributes

- Higher electrical efficiency than competing technologies (approaching 50% in simple cycle distributed generation applications)
- Fuel flexible (NG, biogas, propane, coal-bed methane, and methanol)
- Modular
  - Easily siteable at load centers (simple connections to grid and fuel infrastructure)
  - Near-zero NO\textsubscript{x}, SO\textsubscript{x} and low CO\textsubscript{2} emissions as well as quiet operation
  - Reliable, 24/7 power
- High grade waste heat for combined heat & power (CHP; overall efficiency can achieve 90%)
- Competitive advantage on renewable biogas over other technologies
- Enabler for transformational technologies
  - High efficiency (58-65%) combined cycle systems in small size range (DFC/T)
  - Co-production of electricity and hydrogen (DFC-H\textsubscript{2})
  - Co-production of electricity from coal and CO\textsubscript{2} separation
  - High efficiency energy (>60%) recovery generation (DFC-ERG) system
Current DFC Products

Cell Package and Stack

Single-Stack Module

DFC300
Single Module Power Plant

DFC1500A
Four Module Power Plant

DFC1500B
One 4-Stack Module

DFC3000: Two 4-Stack Modules

DFC300
Single Module Power Plant

Four-Stack Module

DFC1500A
Four Module Power Plant
Direct Fuel Cell Efficiency Comparison with Competition

Average U.S. Fossil Fuel Plant = 33%
• Production and delivery capabilities meet current demand
• State-of-the-art manufacturing in Torrington, CT
• 70 MW/yr capacity
  – Current production rate 30 MW/year
• Strong supply chain in place
• Expansion plan to achieve 150 MW capacity