PAFC History and Successes

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Manager Product Development
AGENDA

Company overview and history

System description and applications

Failure modes and life analysis

Summary
UNITED TECHNOLOGIES CORPORATION

Revenues: $58.7 billion (2008)

Commercial & Residential Building Systems, Aerospace & Transportation, Industrial systems

- UTC Power
- Carrier
- Hamilton Sundstrand
- Sikorsky
- UTC Fire & Security
- Otis
- Research Center
- Pratt & Whitney

18th largest U.S. manufacturer (2009 list, Industry Week)
37th largest U.S. corporation (2009 list, Fortune)
61st largest publicly held manufacturer in the world (2009 list, Industry Week)
UTC POWER

Markets

Transportation fuel cells

Space & defense fuel cells

Stationary fuel cells

Global sales

5 continents
19 countries
PURECELL® FUEL CELL SYSTEM

Stationary fuel cell history

- 1970 – 1975
  - 4 kW - PAFC
  - 12 kW - PAFC

- 1976
  - 1 MW - PAFC

- 1978
  - 4.5 MW - PAFC

- 1984
  - 11 MW - PAFC

  - 200 kW - PAFC

- 1991
  - 200 kW - PAFC

- 1992 – Present
  - 200 kW - PAFC

- 2001 – 2005
  - 150 kW PEM

- 2002 – Present
  - 5 kW H2 PEM

- 2009
  - 400 kW

$290 MM from DOE for PAFC*
Main focus areas: Durability & CHP

PURECELL® FUEL CELL SYSTEM
Worldwide fuel cell deployment and experience

Over 260 systems installed across 19 countries on 5 continents
More than 8.7 million hours of operation
More than 1.4 billion kWh of electricity generation

Fleet Leader
65,615 hrs
Toshiba
Houston, TX

59,456 hrs
Hospital
Bocholt, Germany

58,307 hrs
Casino
Uncasville, CT

56,630 hrs
District Heating works
Halle, Germany

54,694 hrs
Huis Ten Bosch
Sasebo, Japan

62,165 hrs
Central Park Police Station
New York City, NY
PURECELL® FUEL CELL SYSTEM
Flexible fuel cell application and varied experience

Assured Power
- First National Bank of Omaha
  - Nebraska

On-Line Emergency Power
- Verizon Communications
  - New York

Green CHP Power
- Whole Foods Market
  - Connecticut

Renewable Fuel (ADG)
- Wastewater treatment plants
  - New York, New York

Indoor CHP Power
- Mohegan Sun Resort & Casino
  - Connecticut

Off-Grid Power
- Central Park Police Station
  - New York
Purecell® Fuel Cell System
Three main sections – fuel processor, stacks, & power conditioner

**Fuel Processor**
Converts fuel to hydrogen

**Fuel Cell Stack**
Generates DC electricity

**Internal heat exchanger provides:**
1.50MM BTU/hr @ 60C, or
0.68MM BTU/hr @ 121C with balance at 60C

**Fuel Input**
98.9 Nm³/hr natural gas

**Electric Output:**
400 kW, 480 V, 60 Hz
400 kW, 400 V, 50 Hz

**Power Conditioner**
Converts DC power to high quality AC power

UTC Power
A United Technologies Company
PURECELL® FUEL CELL SYSTEM

Cell stack assembly

Repeat assembly

8 cells per substack
34 substacks per CSA

Molded carbon Teflon® composite for bipolar plates and coolers

Carbon substrates coated with catalyst layers

Cell active area = 0.5 m²
FPS converts fuel into a hydrogen-rich, sulfur-free, gas for CSA

CSA provides required heat for the endothermic fuel processing steam reforming
**PURECELL® FUEL CELL SYSTEM**

Mohegan Sun facility

Fuel

- **Power**: 200 kW
- **HG Heat**: 88 kW (250°F / 121°C)
- **LG Heat**: 132 kW (140°F / 60°C)

**Maximum Efficiency**

\[
\text{Efficiency} = \left( \frac{200 + 88 + 132}{494} \right) = 85\%
\]

Efficient use of high grade and low grade heat

Customer needs heating all year long

Effective integration
PURECELL® FUEL CELL SYSTEM

Failure modes

Failure

- Acid loss
  - Advanced cell designs for acid management
  - Non plugging cooler designs

- Lower voltage limit

- Cooler plugging

- Steady state decay
  - Best in class alloy catalysts

- Start stop decay
  - System mitigation and best in class catalyst supports

- Contamination
  - Ammonia scrubber or advanced FPS catalyst
Understanding of acid movement fundamentals is the key enabler for product performance
Fleet decay performance

Performance at 200 kW

Performance band due to operational and site characteristics
Analysis of field operated components demonstrates catalyst agglomeration

New

43,000 hr

ECA: 50 m²/g
Average diameter: 4.5nm

ECA: 6.5 m²/g
Average diameter: 19.9 nm

ECA=Electrochemical area
Modeling accounts for catalyst decay mechanisms
Good model correlation with field data out to 60,000+ hours
**Approach**
Collaborative designs

Supply chain module sourcing

<table>
<thead>
<tr>
<th>Life (years) / Power (kW)</th>
<th>Model 200</th>
<th>Model 400</th>
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</thead>
<tbody>
<tr>
<td>5 / 200</td>
<td>10 / 400</td>
<td></td>
</tr>
<tr>
<td>Weight (lb)</td>
<td>40,000</td>
<td>60,000</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>48.4 (9.5’ x 10’ x 18’)</td>
<td>66.2 (8.5’ x 10’ x 27.5’)</td>
</tr>
<tr>
<td>Power density (kW/m³)</td>
<td>3.9</td>
<td>6.0</td>
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DISTRIBUTION OF U.S. GRID RATES
2007 and 2010 (projected) commercial rates

2010 Projected Commercial Electric Rates
2007 Commercial Electric Rates

US Average
PAFC offers high durability and total efficiency

Durability performance is driven by fundamentals based modeling and post tear down analysis correlation

PAFC has been a technical success in many market segments and applications

Next generation 400 kW powerplant leverages sound technology to close gaps to true commercialization

However, first cost is still a challenge.....