NASA Non-Flow-Through PEM Fuel Cell System for Aerospace Applications

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Overview

- Basic PEM Fuel Cell
- NASA PEM Fuel Cell Development History
- Top-level comparison of aerospace fuel cell systems: Flow through vs. Non-Flow-Through (NFT)
- Recent NASA Fuel Cell Development Activities
- Details of NFT Fuel Cell systems
- Testing and Test Results of NFT fuel cell stacks
- Future Activities
- Summary
Major Fuel Cell Types

- ALKALINE FUEL CELL
- PROTON EXCHANGE MEMBRANE FC
- DIRECT METHANOL FC
- PHOSPHORIC ACID FC
- MOLTEN CARBONATE FC
- SOLID OXIDE FC

Fuel Cell Components:
- Anode
- Cathode
- Electrolyte
- Fuel
- Oxygen

Fuel Cell Reactions:
- AFC
- PEMFC
- DMFC
- PAFC
- MCFC
- SOFC

Operating Temperatures:
- AFC: 100°C
- PEMFC: 80°C
- DMFC: 80°C
- PAFC: 200°C
- MCFC: 650°C
- SOFC: 1000°C
Proton Exchange Membrane (PEM)

Fuel Cell Basics

Anode Reaction: \( \text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^- \)

Cathode Reaction: \( \frac{1}{2}\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{O} \)

Net Reaction: \( \text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O} \)
Ideal voltage of 1.23 V/cell from the formation of water
Overview of a Fuel Cell System

External System

Reactant Supply

Fluidics/Mechanicals

Fuel Cell Stack

Electronics Module

Power Conditioning and Start-up Battery

Balance of Plant (BoP)

Hydrogen Gas

Oxygen Gas

Heat

Water/Coolant

Communication Bus

Sensor/Actuator

Power
• NASA initiated PEMFC studies during Shuttle upgrade program in late 1990’s at JSC
  • High DDT&E costs prevented switch from alkaline to PEM, in spite of several technical advantages

• Reusable Launch Vehicle (RLV) program funded initial development of PEMFC technology (2001)
  • A single vendor selected

• RLV transitioned into Next Generation Launch Technology, Space Launch Initiative, and eventually Exploration Technology Development Program, programs (2001-2007)
  • Two vendors selected for Breadboard development
  • One vendor down-selected for Engineering Model development
  • Disadvantages of flow-through PEMFC systems became evident during testing of Engineering Model; balance-of-plant experienced multiple failures (rotating mechanical components)

• Began investigation of “passive” balance-of-plant concepts for flow-through technology (2005)
  • Reactant pumps replaced with injectors/ejectors
  • Mechanical water separators replaced with membrane water separators

• In parallel, began investigation of non-flow-through technology through SBIR program (2005)
  • Single vendor awarded contract
  • Down-selected to non-flow-through technology over flow-through technology; initiated in-house development of balance-of-plant (2008)
Fuel Cell Technology Progression to Simpler Balance-of-Plant

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System-Level Comparison of Flow-Through vs. Non-Flow-Through PEMFC Technology

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Flow-Through</th>
<th>Non-Flow-Through</th>
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<tbody>
<tr>
<td>Efficiency</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Mass</td>
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<tr>
<td>Volume</td>
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<td>✓</td>
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<tr>
<td>Parasitic Power</td>
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<tr>
<td>Reliability</td>
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<td>Reactant Utilization</td>
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<td>Life</td>
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Develop “non-flow-through” proton exchange membrane fuel cell technology to improve system-level mass, volume, reliability, and parasitic power.

Flow-Through components eliminated in Non-Flow-Through system include:
• Pumps or injectors/ejectors for recirculation
• Motorized or passive external water separators

Non-Flow-Through PEMFC technology characterized by dead-ended reactants and internal product water removal
• Tank pressure drives reactant feed; no recirculation
• Water separation occurs through internal cell wicking
Non Flow Through Water Management

- No Moving Parts
- Pure Liquid Water
- No Parasite Power
# NFT Stack Test Results

<table>
<thead>
<tr>
<th>Vendor</th>
<th># Cells</th>
<th>Active Area</th>
<th>Vcc1</th>
<th>Steady State Test2</th>
<th>Load Profile Test3</th>
<th>Separator ΔP4</th>
<th>Max Current Density</th>
<th>Sensitivity</th>
<th>Inert5</th>
<th>Orientation</th>
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<td>Pass</td>
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<td></td>
</tr>
<tr>
<td>A</td>
<td>4</td>
<td>50</td>
<td>0.83</td>
<td>Pass</td>
<td>Pass</td>
<td>8</td>
<td>500</td>
<td>Medium</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>C</td>
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<td>86</td>
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<td>Fail</td>
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<td>400</td>
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</table>

### Notes:

1 = Average Cell Voltage at the Design point of 200 mA/cm²
2 = 200 mA/cm² for 4 hours at design temperature and pressure
3 = NASA Defined 4-hour Load profile ranging from 0 to 500 mA/cm²
4 = Maximum acceptable differential pressure between Oxygen and Water Cavities
5 = Based on vent frequency and vent duration for a normalized by current density and reactant purity
6 = Cell Voltage at start of test - Testing stopped at 1,330 hours due to facility computer failure
Non-Flow-Through PEMFC System Schematic
NFT Fuel Cell Power System vs. FT System

Non-flow-through PEMFC system has a substantially simpler balance-of-plant than conventional flow-through PEMFC system. This offers significant advantages.
Future NFT Fuel Cell Power Systems

Demonstrations
- Carnegie-Mellon Scarab Rover
- NASA MARCO POLO ISRU Lander

Future Tests
- Upgraded Water Separator Technology
- Miniaturized Electrical Packaging
- Integrated Passive Thermal Technology
Summary

• NASA is researching passive NFT PEM fuel cell technologies for primary fuel cell power plants in air-independent applications.

• NFT fuel cell power systems have a higher power density than flow through systems due to both reduced parasitic loads and lower system mass and volume. Reactant storage still dominates system mass/volume considerations.

• NFT fuel cell stack testing has demonstrated equivalent short term performance to flow through stacks. More testing is required to evaluate long-term performance.