High Temperature Fuel Cells (SOFC) Status

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Special advantages of SOFC

High electrical efficiency
Electrical efficiencies above 50% can be obtained in stand-alone units and above 70% in gas turbine hybrids (based on the energy content of natural gas).

Fuel flexibility
A wide range of fuels, including natural gas, biogas, diesel, LPG, methanol, DME and ethanol, can be used.

Competitive price
In SOFC, no rare or strategic raw materials are used, and the power density is high. Therefore, SOFC is projected to be cost competitive when developed and manufactured in significant quantities.
Many (>25) companies worldwide develop SOFC.

Siemens Westinghouse Power Corporation (SWPC) has so far built the biggest SOFC unit of 250 kW.

The SWPC unit with tubular cells has a relative low power density of 0.6 kWe/litre with a large amount of materials like LaMnO$_3$ and Ni per unit.

This makes the SWPC unit too expensive.

Most developers are therefore pursuing the flat plate bipolar design.
Risø Cell developments Generations

Based on ceramic support  metallic support

1G
LSM+YSZ
YSZ
Ni+YSZ

2G
LSM+YSZ
YSZ
Ni+YSZ

2.5G
LSCF
CGO
YSZ
Ni+YSZ

3G
LSCF
SSZ/CGO
Ni+YSZ/LST
FeCr

1000 °C  850 °C  700 °C  550 °C
1990  2000  2005

temperature

year
SOFC consortium established 2001

- Research & Development
  - cells, few-cell stacks, materials
- Initial cell production
  - for testing, demo and production development
- R&D network
  - EU net work etc.

Risø

- Development, design & system integration
  - stack design, fuel processing, catalysts
- Production & marketing
  - industrial production & marketing
- Commercial net working
  - Sub-suppliers, production partners, sales channels, service & maintenance

Topsøe
2G Anode-supported cell

- **750 - 850°C**
  - Electrochemically active cathode layer, LSM/YSZ, ~20µm
  - Electrolyte, YSZ, ~10µm
  - Electrochemically active anode layer, NiO/YSZ, ~15µm

- **Cheap fabrication**

- **ASR = 0.2 Ω cm² @ 850°C**
  - Anode current collector (support), NiO/YSZ, ~300µm

- Cathode current collector, LSM, ~40µm
Anode supported cell

- Anode support and current collector
- Anode Electrolyte
- Cathode
- Cathode current collector
K_{1C} = 2 \text{ MPa} \sqrt{m}

<table>
<thead>
<tr>
<th>Condition</th>
<th>Modulus of Rupture [MPa]</th>
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<tbody>
<tr>
<td>Oxidized (RT)</td>
<td>270</td>
</tr>
<tr>
<td>Oxidized (800 °C)</td>
<td>220</td>
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<tr>
<td>Reduced (RT)</td>
<td>285</td>
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Cells delivered to EU Partners
Various Designs
850 °C, $i = 1$ A/cm$^2$, synthesis gas, S/C=2, FU: ~75%
Cell Test – 2003: Long Term Stability

**Conditions**
- 75% Fuel Utilization
- Syn-gas; S/C = 2
- 750 °C

**Degradation Rate**
- 0.3 %/1000 hour (at 0.25 A/cm²)
- 12.4 %/1000 hour (at 0.75 A/cm²)
Stack Durability - 5 cell (12 x 12)
800 °C - 20 A

13000 hours + 9 full thermal cycles
5-cell Stack - New MIC with Ceramic Coating

New Alloy (Crofer 22 APU) New Coating ASR 0,5 ohmcm²

Old Alloy (Fe22Cr high Si) Old Coating ASR 1,0 ohmcm²
50 Cell Stack
Thermally self-sustained, 200 W heat loss to Surroundings
35% H₂ + 4% CO + 11%CO₂ + 50% CH₄

Voltage and stack power with mix gas

Av. Cell Voltage (V)

Stack Power (W)

Fuel utilisation (%)

1,02 kW

FU 88%
AVL Stack Test Housing
Thermally Self-sustained Operation
Wärtsilä/HTAS 1 kW Test System
75 Cell Stack (12 x 12 cm²)

September 17, 2004:
1.25 kW
FU = 40%, O/C = 2
In collaboration with Wärtsilä Corporation, Topsoe Fuel Cell A/S (TOFC) is undertaking a 5 kWe proof-of-concept demonstration for a stationary system early 2006. This is planned to be expanded to a 20 kWe alpha prototype by summer 2006 and a 50 kWe beta prototype before the end of 2007.

A 20 kWe CH$_3$OH fueled prototype for sip crew compartments by 2008.

In collaboration with Dantherm Air Handling and others, Topsoe Fuel Cell A/S is planning to complete a 1kWe proof-of-concept micro CHP unit for early 2007.

The strategy is, in collaboration with integrator and end-user partners, to follow up on proof-of-concept units with expanding campaigns of field demonstrations resulting in initial commercial application of micro CHP and APU around year 2010 and distributed generation on the 200+ kWe level around 2012.
Power density
Power density exceeding 2 kWe/litre stack has been demonstrated.

Degradation rate
A 13,000 hour stack testing has shown that the degradation rate is significantly below 1% per 1000 hours. Through new solutions, the degradation has been reduced to <0.5% per 1000 hours.

Fuel utilisation
The TOFC fuel cell stack design has a very high fuel utilisation, more than 90% has been demonstrated.

Mechanical quality
The TOFC fuel cell has, by virtue of its unique composition, an outstanding mechanical strength and flexibility.

Operating temperature
The current operating temperature is 750–800°C, but development of a new generation of metal-supported cells will lower this temperature and further reduce material costs.
TOFC SOFC Demo Unit
The compact TOFC SOFC will probably be suitable for train propulsion.

The size of several MWe is planned to be available after 2012.
Thank you for your attention!

www.risoe.dk

www.topsoefuelcell.com