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Preliminary evaluation of fuel cells

Nils Arild Ringheim

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TECHNICAL REPORT

SINTEF Energy Research

Address: NO-7465 Trondheim, NORWAY
Reception: Sem Sælands vei 11
Telephone: +47 73 59 72 00
Telefax: +47 73 59 72 50

http://www.energy.sintef.no

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CONTRIBUTOR(S)

Nils Arild Ringheim

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RESULT (summary)

This report makes a short overview of common fuel cell technologies and their main properties. In addition, a status regarding stationary and transportation applications for different fuel cell types is given. To some extent, a comparison between different fuel cell technologies regarding their suitability for specific applications is done.

Fuel cells are electrochemical devices that convert the chemical energy of a fuel directly into electric energy. An often used classification of fuel cells are based on operating temperature:
Low temperature cells:
- AFC (Alkaline fuel cell)
- PEMFC (Proton exchange membrane fuel cell)
- DMFC (Direct methanol fuel cell)

High temperature fuel cells
- PAFC (Phosphoric acid fuel cell)
- SOFC (Solid oxide fuel cell)
- MCFC (Molten carbonate fuel cell)

The low temperature fuel cells are characterized by quick start-up time compared to high temperature cells. However, catalysts are needed in order to speed up the electrode process of the low temperature alternatives. Especially for the PEMFC and DMFC, these catalysts are expensive and susceptible to impurities in the fuel. The AFC is sensitive to CO_2 impurities in the fuel due to possible reaction with electrolyte into solid carbonate.

The high temperature fuel cells have flexibility to use more types of fuels and inexpensive catalysts, as the reactions involving breaking of carbon to carbon bonds in larger hydrocarbons occur much faster at higher temperatures. However, the high temperature enhances corrosion and breakdown of cell components. High temperature fuel cells are well suited for cogeneration applications, increasing the overall efficiency of the fuel cell system. Some high temperature systems also combine the use of fuel cell and gas turbine, maximizing the electrical output from the total fuel input. Both MCFC and SOFC are candidates, but SOFC systems are regarded as near time products. Efficiencies in the range of 60 to 75 MW are expected.

KEYWORDS

SELECTED BY AUTHOR(S)		
	Fuel cells	Overview
	Application	Comparison

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1 SUMMARY

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A summary of some important fuel cell characteristics is given in the table below.

<table>
<tr><th>Fuel cell system</th><th>Electrolyte</th><th>Operating temperature [°C]</th><th>Efficiency [%]</th><th>Fuel</th><th>Reforming</th><th>Oxidant</th><th>Impurity</th><th>Current density [mA/cm²]</th><th>Power density [mW/cm²] (present | future)</th><th>Lifetime [hour] (projected)</th><th>Scale</th><th>Applications</th></tr>
<tr><td>PAFC
Phosphoric acid fuel cell</td><td>Concentrated phosphoric acid (H_3PO_4)</td><td>200 [1]
190 [2]
160-200 [4]</td><td>40-50
40 [4]</td><td>Hydrogen, natural gas, methanol [4]</td><td>External</td><td>Oxygen, air</td><td>CO, H_2S [4]</td><td></td><td>200 | 250 [4] 1)</td><td>>40000 [4]</td><td>200 kW – 10 MW [2] 100 kW – 5 MW [4]</td><td>Small utility (cogeneration units (heat 60-120 °C))</td></tr>
<tr><td>PEMFC
Proton exchange membrane fuel cell</td><td>Polymer</td><td>80
80-90 [4]</td><td>40-50
45 [4]</td><td>Hydrogen, methanol [4]</td><td>External</td><td>Oxygen, air</td><td>CO, H_2S [4]</td><td>1000 (@ 0,7 V) [2] 2)</td><td>350 | >600 [4]</td><td>>40000 [4]
20000 [12]</td><td>1 kW – 1 MW [4]
100W – 10 MW [2]</td><td>Mobile applications, small utility, military, space missions</td></tr>
<tr><td>SOFC
Solid oxide fuel cell</td><td>Ceramic (solid electrolyte)</td><td>900-1000 [1]
1000 [2]
800-1000 [4]</td><td>50-60 [1]
>60 [2]
>50 [4]</td><td>Hydrogen, natural gas, coal [4]</td><td>External, internal</td><td>Oxygen, air</td><td>H_2S [4]</td><td></td><td>240 | 300 [4]</td><td>>40000 [4]</td><td>100 kW – 100 MW [4] >100 MW [2]</td><td>Utility (cogeneration units, power plants)</td></tr>
<tr><td>AFC
Alkaline fuel cell</td><td>KOH/H_2O</td><td>80 [1]
80-200 [2]
60-90 [4]</td><td>40-60 [1]
40-50 [2]
40 [4]</td><td>Pure hydrogen [4]</td><td>N/A</td><td>Pure oxygen</td><td>CO_2 [4]
CO, CH_4, H_2S</td><td>200 | 400 [18]
(@0,67 V)</td><td>100-200 | >300 [4]</td><td>>10000 [4]
10000 [12]</td><td>10 – 100 kW [4]
100 W – 20 kW [2]</td><td>Aerospace, military, stationary</td></tr>
<tr><td>MCFC
Molten carbonate fuel cell</td><td>Molten salt (Li and K carbonate)</td><td>650 [2]
660 [4]</td><td>50-60 [1]
>60 [2]
50-75 [4]</td><td>Hydrogen, natural gas, coal [4]</td><td>External, internal</td><td>Carbon dioxide, oxygen, air</td><td>S, H_2S, HCl, HBr, HF... [4]</td><td></td><td>100 | >200 [4]</td><td>>40000 [4]</td><td>1 – 100 MW [4]
>100 MW [2]</td><td>Utility (cogeneration units, power plants)</td></tr>
<tr><td>DMFC [3]
Direct methanol fuel cell</td><td>Polymer</td><td>50-90 [3]
60 [21]</td><td>40 [1], 30 [4]
45 [21]
(increase with higher temp.)</td><td>Methanol [4]</td><td>Internal</td><td>Oxygen, air</td><td></td><td></td><td>40 | >100 [4]
240 | - [23]</td><td>>10000 [4]</td><td>1 – 100 kW [4]</td><td>Military</td></tr>
</table>

1) Projected power density: 0,12 kW/kg and 0,16 kW/L [4]
2) Power density: 1 kW/l [2]

PAFC is the only fuel cell technology, which offers a commercial product for stationary applications. (ONSI P25: 200 kW_{el}, 205 $kW_{thermal}$). Several hundreds test sites exists around the world, and the recorded operation experience is considerable. The PAFC has, however, low current and power densities, resulting in large size and weight and less suitable for automotive applications.

AFC was first used in space applications several decays ago, but no commercial product exists yet. Several demonstration projects exist based on a 5 KW unit, manufactured by the European company ZeTek.

Present R&D funding of PEMFC is considerable, i.a. because it has been regarded as a promising candidate for automotive vehicles. Several demonstration sites exist, mostly on automobiles, but also some on stationary applications (Ballard: 250 kW_{el}).

The SOFC is primarily discussed for stationary applications. Two prototypes are built from Siemens Westinghouse today (one 110 kW_{el} and 64 kW_{th}, one 220 kW_{el} SOFC combined with a gas turbine) using a tubular technology. Other manufacturers are exploiting planar technology as well, but no demonstration sites exist yet.

A demonstration unit of a stationary MCFC exist (260 kW_{el}) produced by a European consortium. In addition, MCFC field test sites exist in USA (e.g. one 2000 kW_{el} by Energy Research Corporation).

The DMFC might be a promising candidate for automotive applications, but its development lies 5-10 years behind the PEMFC.

As a general comment to fuel cells, the technology is still quite expensive compared to alternative technologies. In addition, little or no information can be found on the dynamic behaviour of fuel cells in literature. Therefore, it is difficult to predict the need for possible parallel energy storages, converter characteristics etc. depending on the different load characteristics.