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Journal of Power Sources 61 (1996) 125-127

JOURNAL OF POWER SOURCES

Critical issues and future prospects for solid polymer fuel cells

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Abstract

A review of the state-of-the-art of solid polymer fuel cell (SPFC) development is given. The international activities focus on cell performance and stack design, materials research and gas processing, depending on the application. The fastest progress is being made with respect to fuel cell development for transportation, but the specific advantages of SPFC make the system interesting for residential power supply systems, for on-site power production and also for small, portable power supplies.

Keywords: Solid polymer fuel cells; Germany

1. Introduction

Solid polymer fuel cells (SPFCs) exhibit many advantages for application in the low- and medium-power range. As R&D is still going on, the potential of SPFC technology is not finally defined. Most of the advantages are directly connected to the use of the solid polymer electrolyte which makes the SPFC a robust fuel cell with simple design being insensitive to pressure differences and simple to operate. High power densities can be attained and a quite long lifetime has been demonstrated, nearly independent of operation conditions. The potential for cost reduction is still very high. On the basis of today's level of 5000 to 30 000 US $/kW the cost must be reduced in order to be adequate, for example, even for electric cars. In the context of transportation, the question of fuels is discussed. The use of fuels other than hydrogen means high complexity of gas processing.

For stationary applications, the main restriction is the low temperature of the off-heat due to the low operation temperature, usually at 80 °C.

In this paper, the prospects of SPFCs are discussed in relation to the various applications, specifying different research programmes of national and international projects.

2. SPFC for transportation application

2.1. International activities

Batteries in electric vehicles, buses as well as passenger cars could be replaced by SPFCs. The targets for this application are summarized in Table 1.

Table 1
Targets of the SPFC development for automotive applications

Power density	0.5-1.25 kW/kg
	0.4-1 kW/l
Efficiency	48-60%
Lifetime	2500 h or 8-10 year
Cycles	300-2000/year
Start-up time	2-10 s
Cost: stack	US $30/kW
Cost: system	US $60/kW

Initiated by the California Clean Air Act and attracted by the future market oppertunities, a great number of car manufacturers seek to realize the goals listed above. In recent years, SPFC developing R&D groups have been founded. Their main activities are given in Table 2.

2.2. German SPFC project

The German project for SPFC development started in March 1994. The target is 'the demonstration of basic technologies necessary for low-cost series production of SPFC power drives'. To achieve this goal, a power density of more than 0.4 W/cm^2, a platinum loading lower than 0.2 mg/cm^2, a membrane as cheap as 35 US $/m^2 in a pilot production and new catalysts for gas processing — especially for methanol as fuel — are some of the main requirements. The operation of component demonstration systems will prove to be sucessfull at the end of a four-year period. The two main leading companies are Daimler-Benz and Siemens. BASF and Degussa have joined Daimler-Benz for the development of catalysts; Hoechst and Heraeus cooperate with Siemens

PII S0378-7753(96)02348-8

Table 2
Companies working on the SPFC development for automotive application

	Cell and stack	System	Partners
a) *Canada, USA*			
Allied signal	x		Chrysler
Ballard Power Systems	x	x	Daimler Benz, General Motors
Energy partners	x	x	Ford
H-Power	x		Ford
IFC	x		Ford
Mechanical Technology	x		Ford
b) *Japan*			
Honda	x	x	
Mazda		x	Ballard
Nissan	x		
Toyota Motor	x	x	
c) *Europe*			
Ansaldo		x	DeNora
Daimler-Benz	x	x	Ballard
DeNora	x		
PSA	x	x	
Renault		x	DeNora
Siemens	x	x	
Volvo/Renault		x	

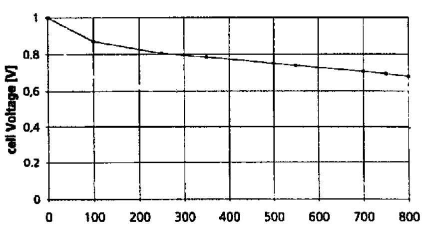

Fig. 1. Current–voltage data of SPFCs operated with H_2/air at 1.6 bar and 80 °C, 0.13 mg catalyst/cm^2 on the anode side. Data: Daimler–Benz, catalyst: Degussa.

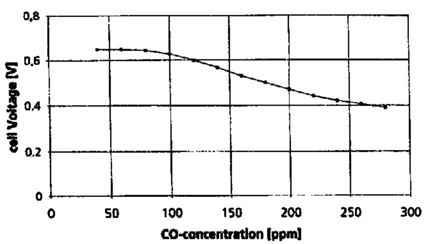

Fig. 2. CO content in reformate as the anode fuel vs. cell voltage at a constant load of 0.9 A/cm^2 at 80 °C and 1.6 bar. Data: Daimler–Benz, catalyst: Degussa.

Objective:
- development of lower cost membranes (target: 50.-DM/m²)
- development of better processible membranes

Status:
- Hoechst has access to high performance polymers with excellent thermal and chemical stability
- introduction of specific groups renders ionic conductivity without loss in stability properties
- preliminary experiments are promising

Fig. 3. Targets and status of the Hoechst project.

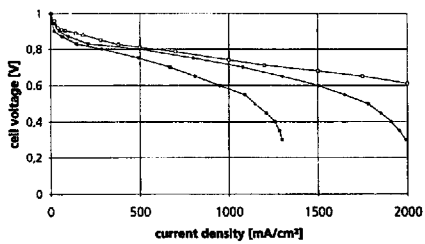

Fig. 4. Current–voltage data obtained with several membranes during operation with H_2/O_2 at a gas pressure of 2 bar, 80 °C and a platinum loading of 4 mg/cm^2. (□) DOW membrane; (♦) Hoechst membrane, and (■) Nafion 117.

for the development of membranes and catalysts. A number of German research institutes are under contract for these companies: DLR, FhG-ISE, ISET, KFA Jülich, MPI Stuttgart and ZSW. The budget of this project being subsidized to 50% by the German Ministry of Education, Research and Technology (BMBF) is more than 33 million US $.

The first results of the research groups are promising, the new electrochemical catalysts show good performance at low platinum loading, even being operated with air as the oxidant. The current–voltage data are given in Fig. 1.

As methanol is chosen the fuel for transportation, operation with reformate instead of hydrogen is also being investigated. The influence of a certain CO amount in the reformate on the catalyst, and thereby on the performance of the fuel cell, has been examined. The results of these measurements are shown in Fig. 2.

A second very important, main route of development is devoted to the replacement of expensive perflourinated membrane materials by new polymers. This ambitious aim is being pursued by the company Hoechst, see Fig. 3.

The third example shows the vast potential for improving the power density. At optimal operation conditions, the targeted power density is exceeded in experiments carried out by Siemens, see Fig. 4.

Also presented by Siemens, the reduction of the noble metal loading of the electrodes from 4 mg/cm^2 as presented above to 0.25 mg/cm^2 does not affect the performance significantly.

3. Choice of fuel for fuel cell-driven vehicles

In addition to the development of a suitable fuel cell for automotive application, the problems connected with the sup-

Table 3
Fuels for automotive applications

Fuels	Companies
Methanol	General Motors, Toyota, Daimler-Benz, VW, CJB/Rover, Ansaldo, Haldor Topsoe, VSEL
Hydrogen	Chrysler, Ford, Ballard, Honda, Mazda, Daimler Benz, Renault, Volvo, Ansaldo
Gasoline, ethanol, natural gas	A.D. Little, Hydrogen Burner Technology

Table 4
Targets for on-site applications of SPFCs

Power density	0.3 kW/kg or 0.5 kW/l
Efficiency	55–65% stack or 40–45% system
Lifetime	40000 h, 15–20 years
Cycles	10–100/year
Start-up time	5–60 min
Fuel	Natural gas
Cost	US $400/kW stack or US $800/kW system

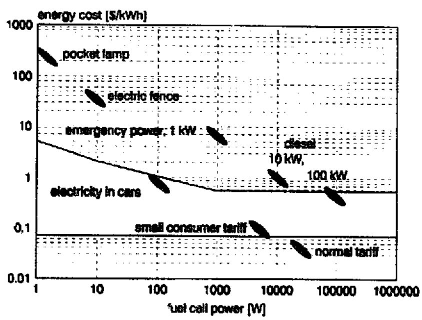

Fig. 5. Different electricity-supply markets for SPFC penetration; cost: US $1500–2500/kW, and lifetime: 40000–10000 h.

ply of fuel must be solved. At present, the experts discuss (i) the best fuel to obtain a reduced volume and weight of the storage tank, (ii) the fuel processing unit, and (iii) an easy filling process. In Table 3, the fuels for automotive applications are given.

4. On-site SPFC

For stationary applications, the targets are different and much easier to fulfil than the requirements for automotive applications. The lifetime of the complete power supply system is an additional, more crucial issue. The respective values for on-site power production are given in Table 4.

For on-site fuel cell development, the number of companies involved is much smaller. But the progress made for automotive applications of course will also promote the stationary application. The companies definitely interested in on-site fuel cell development in the power range from 100–500 kW, are Ballard, Fuji Electric, Mitsubishi Heavy Industries, and Toshiba. In Europe, there are unfortunately no activities in that field at all. Even less is the interest in small decentralized power supply units, fuel cells with a power between 1 and 10 kW. There is a programme going on in the USA, called 'Residential fuel cell systems'. A syndicate consisting of EPRI, various utilities and Polydyne intends to develop a system comprising a 2 kW fuel cell and a 6 kWh battery. 200 units will be manufactured for a unit price of US $6250. Sanyo Electric, Japan, is concerned with fuel cell development for residents.

In Japan, R&D with respect to SPFC development only started not before 1989, but the success is convincing. Eight companies reached the state-of-the-art within this short period of time, fuel cell stacks with a power of several kW have been demonstrated.

5. Summary

The actual situation of SPFC is characterized by a large budget available for R&D and demonstration projects. In 1995, 110 Mio US $ (estimated) have been spent, approximately 60% thereof for automotive fuel cell development, 25% for special purposes like military projects and space missions, and 15% for on-site fuel cell development in the commercial scale. Critical issues for future improvement are to reduce the cost of materials and manufacturing processes and to find a solution for the kind of fuel and fuel processing. Especially efficient CO elimination constitutes a critical issue.

The market for power supply units in the small and medium power range is huge as depicted in Fig. 5; the acceptable price level strongly depends on application. For certain niche markets, back-up power sources like batteries or diesel engines with a tremendeous price for electrical energy per kWh are used up to now. A substitution by fuel cells seems to be an attractive option as soon as commercial, handy and reliable systems become commercially available.