STATUS OF SOFC DEVELOPMENT IN EUROPE

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ABSTRACT

An overview will be given of the SOFC R&D programmes which are carried out in Europe. This will include industrial and national activities in European countries such as Denmark, Germany, Italy, Netherlands, and Norway. Further, the activities within R&D programmes of the European Community and their links with national and industrial programmes will be highlighted. Both basic R&D and development of prototypes will be discussed.

1. STATE OF THE ART, PROBLEMS AND FUTURE LINES OF RESEARCH

SOFC's have a number of advantages which are related to the high operating temperature of around 1000°C:

- The possibility of internal reforming of natural gas can lead to a considerable cost reduction due to the fact that an external reformer is not required;
- The fact that SOFC can deliver waste heat at temperatures of around 800-900°C is very interesting for cogeneration applications in industry;
- If the SOFC is optimized for electricity production, high temperature waste heat can be used in a combined cycle. In the long term, such systems may be expected to achieve efficiencies for electricity production of 65-70%.

The SOFC technology has the advantage that much of the know-how can also be used for other applications:

- A reversed SOFC can be used as a high temperature electrolyser which may lead to energy savings of 30-40% as compared to conventional electrolyzers;
- The SOFC's can be used as chemical reactors for oxidation processes, to produce chemical compounds (e.g. partial oxidation of methane to produce methanol).
The SOFC has a number of advantages which I would like to discuss by comparing the SOFC with the Molten Carbonate Fuel Cell (MCFC), which in terms of energy efficiency, operating temperature and fields of applications is similar. For SOFC corrosion is, contrary to the MCFC, not a serious problem; even 15 years ago, SOFC cells obtained life times of 50,000 hours at BBC in Germany. Another advantage as compared with MCFC, is the fact that the SOFC does not have problems with the electrolyte management. The current density of SOFC, which already is 2 to 4 times higher than for MCFC, still has much potential for further improvement; this is an important route for cost reduction of SOFC. Finally the problems connected with internal reforming of methane in SOFC may be easier to solve than for MCFC.

SOFC's however also have a number of serious drawbacks. The brittleness of the ceramic components is a major barrier for scaling up to MW size SOFC power plants. For PAFC and MCFC, the standard cell size lies around 0.5 to 1 m², whereas the typical cell size of SOFC does not exceed 0.1 to 0.2 m² due to the brittleness of the ceramic components. Although the higher current density of SOFC may compensate for the smaller cell size, it is crucial, in view of scaling up and of cost reduction, to find ways to increase the cell surface of SOFC. As compared to the tubular SOFC concepts, where the cell surface can only be increased in one direction, flat plate cells have the advantage that they can be increased in two directions. The present operating temperature of 1050°C for SOFC leads to a high cost for the auxiliary parts such as heat exchangers, piping etc. Considerable cost reductions can be obtained for a SOFC which operates at lower temperatures (850-900°C). To that end R&D should be aimed at electrolytes which allow acceptable current densities at these temperatures. Recently encouraging results have been obtained by RISØ, Denmark and ECN, Netherlands. Another problem is the high polarization losses at these temperatures; a major R&D effort should be made to cope with this problem.

Of the two major applications for SOFC, electricity production only and cogeneration, the last option may well be very important. In particular in Europe there is a tendency towards a more decentralized electricity production. This is due to an increasing number of regulations in European countries which require the use of waste heat produced during electricity production to improve the overall efficiency of electricity and heat production and to reduce overall pollution emission. Another important development is the increased possibility for small electricity producers, such as cogeneration in industry, to get free access to transmission lines. Finally, in industrial cogeneration there is a increasing tendency to give priority to heat requirements of the company; electricity is thus produced as a function of the heat requirements. The above mentioned developments may, in the long term, lead to a largely decentralized electricity production where cogeneration plays a major role and where large power plants fill the gap between the electricity demand and supply. Presently-used cogeneration systems such as diesel engines and combined cycles can deliver heat up to 100-150°C; gas turbines which can deliver heat above 150°C are generally not available below sizes of 1 MW. SOFC and MCFC clearly fill a gap in industrial cogeneration where temperatures
between 150 and 900°C are required at sizes below 1 MW. For industrial cogeneration the high temperature heat of SOFC is a major asset due to the fact that the ratio of the use of electricity and heat industry is much smaller than one, and a high efficiency for electricity production is not the first priority for this application of SOFC. Cost reduction on the other hand should have a high priority.

2. THE ROLE OF THE CEC IN THE EUROPEAN SOFC RESEARCH

SOFC R&D in Europe is carried out in different national, industrial and CEC programmes. Although CEC funding for SOFC R&D in Europe forms only a relatively small part of the overall funding, CEC programmes play an important role in bringing about a collaboration and information exchange between most of the SOFC programmes in Europe. Due to the condition that a project should have several partners from different EC member states, each CEC project on the average consists of four to five partners and in the six ongoing CEC projects around 30 organizations participate which are also involved in national and industrial SOFC activities. Regular CEC SOFC contractor meetings assure a continuous contact and information exchange between major SOFC groups in Europe.

3. PAST, ONGOING AND FUTURE SOFC R&D IN EUROPE

In the past extensive SOFC research was carried out in Germany by BBC, with financial support of the German government. This research was terminated in 1977 because the market potential for SOFC at that time seemed rather low. Dornier carried out R&D on high temperature electrolyser, a technology which is closely related to SOFC; in 1987 a 2 kW tubular high temperature electrolyser was constructed.

In 1987 the European Community started a two year exploratory SOFC R&D programme to investigate different SOFC structures taking into account technical feasibility, the possibilities for cost reduction, potential for cheap mass production such as extrusion and tapecasting etc. The aim of this two year programme was to carry out exploratory research on four types of SOFC with different structures: two advanced multichannel "honeycomb" SOFC reactors made by extrusion and tapecasting respectively and two flat plate SOFC units with metallic and ceramic bipolar plates respectively. For each type 10-20 W units have been constructed and tested. SOFC research on the "honeycomb" concepts in the CEC programme was stopped after 1989; the development of the two flat plate concepts was continued. In the exploratory programme several market and system studies were carried out which led to the conclusion that the first market opportunities for SOFC can be expected for industrial cogeneration with 200 kWel SOFC plants. A development plan was made for the CEC SOFC programme with the following targets:
1993: two 1 kW SOFC units built according to different concepts; 
1995: one 20 kW SOFC unit; 
1997: one 200 kW SOFC unit.

CEC SOFC research after 1989 aimed at demonstrating the technical feasibility of two 1 kW SOFC units built according to two different concepts:

A project carried out by Siemens-Germany, ECN-Netherlands and Imperial College and GEC from the UK is developing a flat plate SOFC with metallic bipolar plates and with a multiple cell array (See Fig. 1). Small stacks of 100 W with multiple array cells have been successfully tested; a 1 kW SOFC unit is foreseen in 1993. Work on a 20 kW SOFC plant, which is expected to be operational in 1995, has already started. Basic research in this project on the improvement of the electrolyte led to current densities of 1 A/cm² at 0.7 V with a temperature of 935°C.

A second project carried out by British Gas, ICI (UK), Risø (Denmark) and TNO (Netherlands) is aiming for a 1 kW SOFC with a structure which is a mixture of tubular and flat plate concepts (see Fig. 2). This project ran into a number of technical problems and did not reach its objectives; in view of the interesting concept, research is continued to prove its feasibility.

In addition to the above two projects, research was also continued on the development of a flat plate SOFC unit with ceramic bipolar plates. Although work on this topic by Imperial College was terminated due to technical problems, it will be taken up in 1993 by Dornier (Germany) and Cookson (UK). This project will aim for kW size SOFC units.

Two projects deal with SOFC materials research. The main objective is the development of new materials, in particular electrodes, which will allow the operation of SOFC at 850°C instead of the present operating temperature of 1050°C. This is expected to lead to a strong cost reduction due to the fact that at 850°C less costly materials can be used for auxiliary equipment such as heat exchangers, piping, etc. The results of these projects will be used by the three more applied SOFC projects. The basic material research projects are carried out by Risø, Denmark with 6 partners and INPG, France with 4 partners.

The total cost of CEC SOFC projects for a three year period is around $18 million of which the CEC contributes 50%, the other 50% being funded by contractors or national programmes.

In the German national SOFC programme, complementary funds are made available for the above-mentioned projects of Siemens and Dornier. Basic materials research is carried out by a number of organizations of which the research centre in Julich is the most important group. The budget of the German SOFC programme in 1992 was around $5 million.

National SOFC efforts in the Netherlands are carried out by ECN and TNO which participate in CEC projects led by Siemens and British Gas respectively.
In Denmark, a joint Danish SOFC programme was launched in 1990 with a budget of $7 million for the period 1990-1992. The Danish programme is aimed at the development of technical know-how on fabricating cells and stacks (bipolar flat plate) and at more basic materials research for the understanding of SOFC processes and improvement of SOFC performance. In the framework of this programme, basic research on conventional electrolytes led to current densities of 1 A/cm².

In Italy and the UK, limited SOFC activities are going on.

Apart from the SOFC activities in the European Community, SOFC research is carried out in Switzerland and Norway.

In Switzerland, Sulzer in collaboration with Ceramatec Inc. is developing the Heat Exchanger Integrated Stack (HEXIS) concept for SOFC. A 1 kW SOFC is expected to be operational by the end of 1993. In 1992, $1.3 million was made available for this project by the Swiss Government.

Finally, in Norway, two major SOFC programmes exist. A project of Statol (1993-1995), with a budget of $3 million per year, is aiming at a 5-10 kW planar SOFC plant in 1995. Another consortium, with SI, Norsk Hydro, Elkem (Ceramatec Inc.), Saga and Sintef, is carrying out a 3 year research programme (1991-1994) which should lead to a 3-4 kW unit in 1994. For this programme, around $7 million is available for the three year period.