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European opportunities for fuel cell commercialisation

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Abstract

The European electricity market is changing. This paper will look at the background to power generation in Europe and highlight the recent factors which have entered the market to promote change. The 1990s seem to offer great possibilities for fuel cell commercialisation. Awareness of environmental problems has never been greater and there is growing belief that fuel cell technology can contribute to solving some of these problems. Issues which have caused the power industry in Europe to re-think its methods of generation include: concern over increasing carbon dioxide emissions and their contribution to the greenhouse effect; increasing SO_x and NO_x emissions and the damage cause by acid rain; the possibility of adverse effects on health caused by high voltage transmission lines; environmental restrictions to the expansion of hydroelectric schemes; public disenchantment with nuclear power following the Chernobyl accident; avoidance of dependence on imported oil following the Gulf crisis and a desire for fuel flexibility. All these factors are hastening the search for clean, efficient, modular power generators which can be easily sited close to the electricity consumer and operated using a variety of fuels. It is not only the power industry which is changing. A tightening of the legislation concerning emissions from cars is encouraging European auto companies to develop electric vehicles, some of which may be powered by fuel cells. Political changes, such as the opening up of Eastern Europe will also expand the market for low-emission, efficient power plants as attempts are made to develop and clean up that region. Many Europeans organisations are re-awakening their interest, or strengthening their activities, in the area of fuel cells because of the increasing opportunities offered by the European market. While some companies have chosen to buy, test and demonstrate Japanese or American fuel cell stacks with the aim of gaining operational experience and developing European sub-systems, others have chosen to develop their own novel cell technology. This paper will survey the extent of the fuel cell activities in Europe and emphasise the particular markets which fuel cell manufacturers are targeting. Demand for fuel cells in defence and military applications will be the first sector to be commercially viable – European companies such as Siemens, Elenco and VSEL are already marketing AFC or PEM systems for naval and aerospace applications. The small-scale CHP sector is also a likely early market for fuel cell plant. Co-generation fuel cells are of great interest to gas companies like ENAGAS and British Gas looking to promote sales of gas by installing on-site gas-fired generators on their customers' premises. The market for utility scale fuel cell plants is expected to develop later in the decade. The largest demonstration planned for Europe is the 1 MW PAFC for Milan, due to come onstream in 1992. MBB GmbH is considering developing MW-scale MCFC plants with the US company ERC – a 2 MW demonstration is planned for the end of 1993. The potential market for utility fuel cells is large – installation rates could reach 500–1000 MW/year by the turn of the century. Fuel cells will probably not achieve significant use in transport applications in Europe until after the turn of the century unless very stringent emissions legislation for vehicles is introduced. The likely early markets for fuel cells in the transport sector seem

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to be for delivery and fleet vehicles. Examples of European projects in this area include the Amsterdam city bus project which will use Elenco's AFC technology and Siemens' fork lift truck which will incorporate a PEM fuel cell. Fuel cells also link conveniently with renewable energy systems – coupled with an electrolyser a fuel cell can store solar, wind or wave power. The electrolysis process is used to generate hydrogen from water at times of surplus energy while the fuel cell consumes hydrogen fuel when demand for power exceeds supply. The SWB solar hydrogen project in Germany is testing PAFC and AFC stacks in this application. Several problems remain before fuel cell technology can fulfil its maximum potential market. For PAFC there is a need to reduce plant capital costs and to verify lifetimes and reliability. KTI's 25 kW demonstration at Delft and the Milan 1 MW plant will increase European knowledge and experience of PAFC plant operation. For MCFC there are materials problems to be solved and work needs to be carried out on the best way to scale up plants. Projects underway in the Netherlands, Germany, Italy and elsewhere should bring Europe to the forefront of MCFC technology. SOFC requires further study in the area of design configurations and fabrication techniques. Research on these aspects is underway in Denmark, Switzerland, Germany, the Netherlands and the UK. For PEM technology work on reducing precious metal loadings and selecting the best polymer membrane is required – an area in which Johnson Matthey is involved. For all fuel cell technologies there needs to be a greater awareness among power suppliers, consumers, legislators and environmentalists of the advantages that fuel cells can offer. The increase in activity among European organisations in developing, demonstrating, testing and optimising fuel cell systems will encourage a greater awareness of the technology and bring commercialisation closer to reality.

Introduction

In 1985, Johnson Matthey (UK) and TESI (Italy) worked together on a study sponsored by the European Commission which evaluated the potential market for phosphoric acid fuel cells for power generation in EEC countries [1]. The aim of this paper is to update the 1985 study by identifying the major changes which have taken place in the European electricity market in the last 5–6 years; by reviewing the surge of interest in fuel cell projects in Europe and describing the market sectors currently being targeted by fuel cell manufacturers.

Many of the changes that have taken place in the last five years in Europe tend to favour the installation of fuel cells. The public's increased environmental awareness, which is causing greater constraints to be placed on power producers, together with the recent commitment by fuel cell manufacturers to produce units on a commercial scale have given us good reason to be more optimistic about the prospects for fuel cells in Europe than we were in 1985.

Background to power generation in Europe

EEC market

Electric power capacity in the EEC grew rapidly during the 1970s, from 220 to 350 GW, an average growth of almost 5% per year. Nuclear capacity more than quadrupled during the period, rising from an embryonic 8 GW in 1970 to reach 34 GW by the end of the decade [2].

In the first half of the 1980s, as everyone became more aware of the need to conserve energy, the rate of growth in capacity slowed. Between 1980 and 1986, EEC capacity increased by 70 GW to 420 GW, an average growth of 3% per year. Once again the nuclear sector showed fasted growth; 54 GW of the 70 GW new capacity was nuclear and the majority of the new nuclear plants were sited in France and Germany.

Since 1986, the rate of growth of new capacity has slowed yet further; for the 12 EEC countries it has grown at a moderate 1–2% per year. EEC capacity now stands at around 440 GW, comprising roughly 60% conventional thermal, 20% hydroelectric and 20% nuclear power stations.

Elsewhere in Europe

Outside the EEC similar growth patterns have been seen. For both non-EEC member countries and Eastern European countries the average growth in capacity was between 5 and 6% per year in the 1970s, about 3% per year in the early 1980s falling to between 2% and 3% per year in the latter half of the last decade.

Forecasts for growth in capacity

The European Commission has made forecasts of the need for new capacity to the year 2010. Depending on the scenario chosen, capacity is expected to rise by between 30 and 190 MW in the 20 years to 2010, averaging 0.3% to 1.8% growth per year. Capacity growth rates are therefore never expected to achieve the rates seen in the 1970s and early 1980s [3]. In Eastern Europe there is a greater need for increased power; capacity is expected to increase by about 32 GW in the period to 2000, a growth rate of about 2% per year [4].

We are therefore about to enter a period of much slower growth in demand for new generating capacity in Europe. Where does this leave the market potential for new generating technologies such as fuel cells?

Replacement plant

Despite lower growth in total capacity, there is expected to be substantial demand for new power plant in Europe. Many of the new generators will be required to replace existing plants which are due for retirement rather than to build up capacity. Forecasts show that demand for replacement capacity in the EEC will total 62 GW in the period 1991–2000 and 75 GW between 2001–2010; almost as much as the most optimistic forecast of new capacity demand [1].

Constraints of power producers

The options available to power supply companies to meet the demand for new and replacement capacity in Europe are becoming increasingly limited, as the examples below show.

Limits to nuclear plant expansion

The Chernobyl nuclear accident profoundly affected the sentiment towards nuclear power in Europe. Following the accident in 1986 several European countries held referenda on the future of their nuclear power programmes.

In Italy a referendum held in 1987 resulted in the halting of the nuclear programme and in Germany opinion has also swung away from nuclear power, partly as a result of the Chernobyl accident compounded by the Transnuklear scandal. A new nuclear plant which opened in Austria in 1980 was immediately mothballed as a result of an anti-nuclear referendum in that country and following Chernobyl the plant was dismantled. The Netherlands has ordered two PWRs prior to Chernobyl, but since the accident these plans have also been mothballed. Sweden has perhaps the most difficult task ahead; following a referendum the country decided to phase out totally nuclear power by 2010.

Limits to expansion of hydroelectric plant

Norway, which relies largely on hydroelectric power, has found problems with capacity expansion. Virtually all new schemes have been the subject of intense wrangling and power producers are considering increasing their use of North Sea gas for power generation instead. Sweden has set legislation stating that its 'wild' rivers cannot be exploited for hydroelectric power. Spain, another country where hydroelectric power is important, has found it is running out of suitable sites, while in Austria, plans for a 360 MW hydroelectric plant on the Danube have now been abandoned.

Constraints on conventional thermal plant

The two prime concerns over expanding conventional thermal capacity are the emissions of oxides of nitrogen and sulfur, precursors to acid rain, and increased emissions of carbon dioxide, a greenhouse gas. Concern about acid rain is strong in Northern Europe, particularly Sweden and Germany, where damage has been caused to forests and lakes.

In Germany there is strong pressure from the Green movement which is accusing utility companies of being technically conservative and retrograde in their environmental attitudes. Germany has legislated to reduce its carbon dioxide emissions by 25% by the year 2000. Sweden has also set strict targets to limit greenhouse gas emissions.

Options for new capacity

Such constraints on expansion are forcing the power industry in Europe to re-think its methods of generation. Solutions all seem to point in the same direction – to highly efficient, clean, modular power stations which can be sited close to the users of power and are fuelled by clean fuels such as natural gas. Combined heat and power schemes are attracting a great deal of interest because of their high overall efficiency, and consequent potential for saving energy and for reducing greenhouse gas emissions.

Fuel cell power plants meet all these criteria and have caused many European organisations to re-awaken their interest, or strengthen their activities, in this area of technology.

European fuel cell projects (Table 1)

Two complementary strategies have developed for European companies wishing to commercialise fuel cells. One approach is to buy, test and demonstrate Japanese or American fuel cell stacks. The other is to develop European stack and component technology.

Fuel cell trials and demonstrations

Several European companies are taking the opportunity to gain operational experience with fuel cell systems. Some of these projects involve integrating European fuel cell plant components with American or Japanese stack technology.

The largest demonstration planned in Europe at present is the 1 MW phosphoric acid fuel cell (PAFC) in Milan, due to come onstream in 1992. Part of the Volta

TABLE 1

Current European fuel cell activity

Organisation	Type	Markets	Project description
Elenco NV (Belgium)	AFC	space defence traction	14 kW unit developed for VW van; currently developing 70 kW unit for Amsterdam bus project
Haldor Topsoe (Denmark)	PAFC MCFC SOFC	utility	developing reformer technology with US and Japanese companies
Naturgas Syd (Denmark)	PAFC	on-site	ordered 200 kW unit from IFC (USA)
Sonderjyllands Hojspandingsvark (Denmark)	PAFC	on-site	ordered 200 kW unit from IFC (USA)
Elkraft (Denmark)	MCFC	utility	installed 7 kW unit from ERC (USA)
Riso National Laboratory (Denmark)	SOFC		materials selection for 1 kW unit; working with university partners
Helsinki University (Finland)	AFC		catalyst research
Neste Oy (Finland)	MCFC SOFC	utility	design study of 40 MW high temperature plant
Asea Brown Boveri (Germany/ Switzerland)	SOFC	on-site	1 kW stack under development
Messerschmitt Boelkow Blohm (Germany)	MCFC	utility	planning 2 MW/y. pilot production facility with ERC (USA)
Dornier GmbH (Germany)	SOFC	utility	Single cell testing – developing kW units
Siemens (Germany)	SOFC AFC PEM	utility naval space	developing 1 kW SOFC stacks (1993); 6 kW AFC units developed for space shuttle and submarines
Solar Wasserstoff Bayern (Germany)	AFC PAFC	energy storage	testing 80 kW Fuji PAFC and 6 kW Siemens AFC in solar hydrogen project
Project Volta (Italy)	PAFC	utility	demonstrating 1 MW PAFC stack from IFC (USA)
	MCFC	utility	stack testing planned using IGT (USA) cells
	SOFC	utility	basis research
	PEM	traction	10 kW stack development
KTI (Netherlands)	PAFC	on-site	demonstrating 25 kW Fuji units with KTI reformer technology
Dutch MCFC programme (Netherlands)	MCFC	utility	cell design, 1 kW stack construction, internal reforming research

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TABLE 1 (*continued*)

Organisation	Type	Markets	Project description
TNO/Univ Delft (Netherlands)	SOFC		materials development
NOVEM/Univ Twente (Netherlands)	SOFC		materials development
Norsk Hydro (Norway)	PAFC	on-site	testing 400 kW Westinghouse (US) plant
ENAGAS (Spain)	PAFC	on-site	testing 50 kW Fuji plant
Hydro Electrica Espanola (Spain)	MCFC	utility	200 kW stack development planned for 1994
Sydkraft (Sweden)	PAFC	on-site	purchasing 200 kW unit from IFC (USA) and 50 kW unit form Fuji (Japan)
Vattenfall (Sweden)	PAFC	on-site	purchasing unit from Fuji (Japan) for test
Royal Institute of Technology (Sweden)	AFC MCFC	traction on-site utility	catalyst research IR catalyst research
British Gas (UK)	MCFC SOFC	on-site	laboratory research
Johnson Matthey (UK)	PAFC PEM		electrocatalyst research and production
VSEL/CJBD (UK)	PEM	naval space	investigation and marketing Ballard (Canada) units
GEC Alsthom (UK)	SOFC	utility	systems engineering
ICI (UK)	SOFC		ceramic research

Project, the plant will comprise a stack from International Fuel Cells (USA) and a reformer from Haldor Topsoe (Denmark). The plant, designed by Ansaldo (Italy), is to be erected in a former Pirelli type factory in the centre of Milan and will be operated by the Milan Energy Municipal, AEM.

International Fuel Cells is the plant supplier for several smaller European fuel cell demonstrations. We believe that at least six of IFC's 200 kW combined heat and power units have been ordered by European gas or electric utilities for delivery in 1992 or 1993. Plants are destined for Germany, Sweden and Denmark.

Last year in Japan, Fuji Electric set up a production line to produce on-site fuel cells of 50–200 kW capacity. Several orders for these plants have been received from European companies. Four 25 kW Fuji units form part of the European Commission's phosphoric acid programme — two units are to be tested in the Netherlands and two in Italy. Additionally at least four 50 kW units are thought to have been sold to companies in Sweden, Spain and Italy and these are due for delivery either in 1991 or 1992. The Solar Wasserstoff Bayern (SWB) solar hydrogen project in Bavaria, Germany has just started to operate an 80 kW Fuji stack coupled with a reformer built by KTI (Holland) with the intention of verifying the feasibility of using fuel cells linked to electrolysers to store solar energy.

Westinghouse is to carry out a demonstration of its phosphoric acid fuel cell technology in Europe. In conjunction with Norsk Hydro, the company plans to set up a 400 kW PAFC in a chlorine plant. Operating on waste hydrogen produced by the chlor–alkali cell, and generating d.c. current for use in the electrolysis process, the fuel cell will need no reformer or inverter.

All the above projects incorporate phosphoric acid technology. Other types of fuel cell are also being demonstrated in Europe. For instance the Danish utility company, Elkraft, is testing a 7 kW molten carbonate fuel cell (MCFC) supplied by Energy Research Corp (ERC) of America and is considering either a 100 kW or a 2 MW demonstration next. SWB has installed a 6 kW alkaline cell manufactured by Siemens at its plant. Messerschmitt Boelkow Blohm (MBB) GmbH (Germany) is planning a 2 MW MCFC demonstration for the end of 1993 using stack technology from ERC.

Should all these projects come to fruition, fuel cells will represent about 5 MW of installed capacity in Europe by 1994.

European stack development programme

Europe has projects underway to develop alkaline (AFC), molten carbonate (MCFC) and solid oxide (SOFC) fuel cells and proton exchange membrane (PEM) technology.

Elenco, the Dutch/Belgian consortium, has concentrated on developing AFC for aerospace and transport applications. The company's largest unit to date is a 70 kW module designed to power a bus. Siemens has a long history of interest in AFC and is currently developing units for the European space shuttle and for submarines.

Europe is showing great interest in MCFC development. The Dutch National Project was set up with help from the USA (from the Institute of Gas Technology, the Illinois Institute of Technology and the Electric Power Research Institute). The programme, managed by ECN, the Netherlands Energy Research Foundation, is seeking to optimise cell design and improve internal reforming technology. The Italians have a similar strategy for MCFC development whereby American MCFC stack technology is to be acquired and improved. They intend to study both internal and external reforming, improving durability and manufacturing techniques.

MBB (Germany), which owns 13% of ERC, recently announced that it intends to establish a 2 MW/year pilot facility for MCFC production. The Spanish announced their MCFC development plans in 1989. Led by Hydro Electrica Espanola, the plan aims to develop and operate a 200 kW system by 1994. MCFC research is also underway at the Royal Institute of Technology in Sweden.

Most of the research work on MCFC aims to find solutions to the materials problems that remain to be solved. There are also investigations on manufacturing techniques and the best way to scale up plants.

SOFC technology is another area of European research interest — there are no less than ten organisations involved in six European countries. Work is being carried out into design configurations and fabrication techniques. Companies involved include Brown Boveri Corp., Dornier and Siemens in Germany, Asea Brown Boveri in Switzerland, TNO and Novem in Holland and ICI and GEC in the UK. Academic institutions researching SOFC include the Universities of Delft and Twente in Holland and Imperial College in the UK. Some basic research on solid oxide is also being carried out under the Project Volta programme in Italy. SOFC, with its high temperature operation and potential for high conversion efficiency, is considered to be an 'advanced' or 'second generation' fuel cell technology which is unlikely to reach the market until after the turn of the century.

PEMFC stack development is underway in Germany, Italy and the UK at companies which include Dornier, Siemens, De Nora and Johnson Matthey.

Markets for fuel cells in Europe

It is interesting to note the range of applications being targeted by fuel cell manufacturers. As different applications demand different features from their generators it seems that the various fuel cell technologies, rather than competing with one another, could find complementary markets.

Defence and aerospace

The market for fuel cells in defence and aerospace applications is expected to be the first to become commercially viable. European companies such as Siemens, Elenco and VSEL are already marketing AFC and PEM systems to military and aerospace customers such as the European Space Agency and various naval establishments. Markets such as this, although usually lucrative, are not expected to amount to more than a few MW per year in Europe.

Small-scale combined heat and power

The small-scale CHP sector has been targeted by Japanese and American fuel cell manufacturers such as Fuji Electric and IFC. Commercial products are already on offer. Generators with an electrical output of between 50 and 200 kW are appropriately sized to supply power and heat for buildings such as blocks of flats, hospitals, hotels and leisure centres and old peoples' homes, in fact anywhere which requires significant heat and hot water as well as electricity. A study of the UK market for small-scale CHP plants [5] has shown a potential market of 320 MW installed capacity by 1995, at over 4000 sites (from a base of 7 MW installed at 170 sites in 1987).

After 1995, when fuel cell producers expect that fuel cells will be able to compete in price with other types of on-site generator, fuel cells should be able to take a large share of the on-site market, due to their attributes of low maintenance, reliability and quietness. Gas companies are expected to be the main customers for on-site units. Companies such as ENAGAS and British Gas have already shown interest in installing fuel cells on their customers' premises. We forecast that installation rates for on-site fuel cells in Europe could reach 100 MW/year by the turn of the century.

Utility markets

For the reasons outlined earlier, fuel cell technology could solve some of the problems facing electric utility companies which need to expand or replace capacity. It appears that the goal of most fuel cell developers is to produce power plants in the capacity range 2–50 MW to meet the market for dispersed power plant or incremental increases in capacity at existing power station sites.

This market is not expected to develop until later in the 1990s, as wide-scale demonstration of MW-scale fuel cells has only just begun. However, the potential market is huge. If fuel cells take only 5% of the market for new and replacement plant by the turn of the century, installation rates could reach between 400 and 800 MW per year. PAFC, MCFC and SOFC may all take a share of the utility market, but PAFC is certain to have the major share in this decade, and probably in the next as well.

Transport

Fuel cells will probably not achieve significant use in transport applications in Europe until after the turn of the century unless very stringent emissions legislation for vehicles is introduced. The likely early markets for fuel cells in the transport sector seem to be for delivery and fleet vehicles. Examples of European projects in this area include the Amsterdam city bus project which will use Elenco's AFC technology and Siemens' fork lift truck which will incorporate a PEM fuel cell.

Renewable energy

Fuel cells can also be linked conveniently with renewable energy systems – coupled with an electrolyser a fuel cell can store solar, wind or wave power. The electrolysis process is used to generate hydrogen from water at times of surplus energy while the fuel cell consumes hydrogen when demand for power exceeds supply. The SWB solar hydrogen project in Germany is testing PAFC and AFC in this application.

Conclusions

There are good reasons to be optimistic about the prospects for fuel cell commercialisation in Europe. Growing environmental pressures on electricity producers, coupled with the recent availability of commercial fuel cell plants, has raised awareness of fuel cell technology in Europe to an unprecedented level.

The growth in interest has been translated into action. The last five years have seen a significant increase in activity among European organisation in developing, demonstrating, testing and optimising fuel cell systems. The projects described in this paper will not only contribute to overcoming the technical problems that remain to be solved, but will also increase the awareness of fuel cell technology by power suppliers and legislators and thereby bring commercialisation even closer to reality.

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