Fuel Cell Development Trends and Future Prospects

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1. Introduction

As we enter the 21st century, it is more urgent than ever to respond to energy and environmental issues, not only within Japan, but on a global scale. The major challenge facing the 21st century is the problem of global warming, and energy problems are themselves environmental problems. When considering the problem of energy, it is important to not be distracted by nearsighted economic factors; we must also consider medium and long-term environmental concerns.

Fuel cells are actively being researched for use as distributed power units and vehicular power sources. Because of their high efficiency and friendliness to the environment, the early adoption of fuel cells as new energy resource in practical applications is anticipated.

Table 1 Types and characteristics of fuel cells

Item \ Type	Phosphoric acid fuel cell (PAFC)	Molten carbonate fuel cell (MCFC)	Solid oxide fuel cell (SOFC)	Polymer electrolyte fuel cell (PEFC)
Electrolyte	Phosphoric acid (H_3PO_4)	Carbonate (Li_2CO_3, K_2CO_3)	Zirconium oxide (ZrO_2)	Proton-exchange membrane
Ion conductor	H^+	CO_3^{2-}	O^{2-}	H^+
Fuel (reactant gas)	H_2	H_2, CO	H_2, CO	H_2
Fuel	Natural gas, LPG, methanol, naphtha, biogas	Natural gas, LPG, methanol, naphtha, coal gas	Natural gas, LPG, methanol, naphtha, coal gas	Natural gas, LPG, methanol, hydrogen
Operating temperature (°C)	170 to 210	600 to 700	900 to 1,000	Room temp. to 100
Power generation efficiency (%)	40 to 45	45 to 60	50 to 60	35 to 60
Development status	Commercialization phase	Demonstration plant, development for practical application	Demonstration plant	Verification testing, development for practical application

Fuel cells are classified into several types according to the type of electrolyte they use. Characteristics of the major types of fuel cells are listed in Table 1. Among the various types, only the phosphoric acid fuel cell for onsite use has reached the commercialization phase.

Fuji Electric began to research and develop alkaline fuel cells (AFCs) in the 1960s. Thereafter, Fuji has researched phosphoric acid fuel cells (PAFCs) since 1973 and polymer electrolyte fuel cells (PEFCs) since 1989. This paper describes the trends and future prospects for PAFCs and PEFCs.

2. Trends and Prospects of Phosphoric Acid Fuel Cell Development

2.1 Development trends

PAFCs utilize an electrolyte and phosphoric acid solution. They operate at a high temperature of approximately 180°C and are well suited for cogeneration systems.

Using hydrocarbon fuel instead of the pure hydrogen-oxygen fuel mixture that was used in the spacecraft power source AFCs, PAFCs began to be developed by the United States in the 1960s for applications on earth. Japan began developing PAFCs in the 1970s. During the development stage, 5 MW and 11 MW PAFCs were operationally verified as an alternative to thermal power generation; however, due to concerns regarding the reliability and economic feasibility of pressurized fuel cells, this did not lead to practical applications. On the other hand, despite their low capacity, 50 kW, 100 kW and 200 kW onsite PAFC systems have a high power generating efficiency of 40 % (low heat value (LHV) standard). These onsite PAFC systems have achieved the initial development goal of a cell life of 40,000 hours (approximately 5 years). The cost, for a single PAFC system, ranges from 450,000 to 600,000 yen per kW, and is economically advantageous when the Japanese national subsidy is applied.

As of the present date of March 2002, Fuji Electric has successfully manufactured 113 power generation systems (101 of which are onsite fuel cell systems), having a capacity of approximately 14,000 kW. In

October 2001, Fuji Electric began selling a second-commercial-type (FP-100F) 100 kW PAFC having a cost of only two-third that of prior models. Basic specifications and the external appearance of the second-commercial-type PAFC are shown in Table 2 and Fig. 1, respectively. In 1998, Fuji began selling a first-commercial-type (FP-100E) 100 kW PAFC that operated with high reliability and a high degree of capacity utilization, and the second-commercial type maintained this high reliability while achieving reduced cost. Future goals include lengthening the time between overhaul maintenance and furthering the cost reduction. Most of the cost of an overhaul is due to the fuel cell stack, and by extending the phosphoric acid lifetime of a cell, the interval between overhaul maintenance will become longer and costs incurred during the life cycle will be reduced. Present development efforts continue to enhance cell materials and improve cooling techniques in order to achieve a phosphoric acid lifetime of 60,000 hours.

Table 2 Standard specifications of a 100 kW phosphoric acid fuel cell power unit

Item	Description
Rated output (power transmitting side)	100 kW
Rated voltage	200 V (210 V, 220 V)
Power generation thermal efficiency	40 % (for rated output, power transmitting side, LHV)
Overall thermal efficiency	87 % (for rated output, power transmitting side, LHV)
Exhaust emission	NOx : 5 ppm or less SOx , dust concentration : below detectable limit
Higher harmonics	Total current distortion : 5 % or less Distortion of each current harmonic : 3 % or less
Fuel consumption	22 Nm^3/h (Town gas 13A)
Thermal output	High temperature water : 90°C/85°C (Return) 180 MJ/h Lower temperature water : 50°C/45°C (Return) 243 MJ/h
Fuel type	Town gas 13 A, low pressure
Operation system/mode	Fully automated, linked to the utility system
Main dimensions	2.2 m (W) × 3.8 m (L) × 2.5 m (H)
Mass	10 t

Fig.1 External appearance of a 100 kW PAFC

In this era of heightened environmental awareness, sewer digester gas and biogas, formed from methane fermented raw refuse or industrial wastewater, have been used as fuel in actual PAFC applications. In this case, unlike cogeneration that uses town gas as fuel, the fuel for PAFCs is nearly free of cost. Also, differing from the case of a fuel cell power generation system that uses town gas as fuel, technology is being developed to improve techniques for processing impurities in biogas or to improve methods to control fluctuations in the quantity of biogas generated. Because a fuel cell power generation system contains a built-in inverter, it is therefore able to continue supplying electrical power to critical loads even when utility power is interrupted. Power utilization is being leveraged to expand the range of applications for PAFCs.

2.2 Future prospects

As stated above, of the various types of fuel cells, only the onsite-use PAFC has achieved a level of technical and economic feasibility suitable for commercialization. Future advances such as cost reductions enabled by further technical development, expanded use of biogas or sewer digester gas as fuel, and a wider field of applications such as supplying power to critical loads, are expected to steadily pave the way for bringing PAFCs to market. Japanese national policies to promote the introduction of fuel cell power generation systems include subsidies (subsidy percentage of 50 % for a municipality and 33 % for the private sector) as specified by the Special Law for Promoting New Energy Utilization and the Taxation System for Promoting Investment to Improve Energy Demand and Supply.

PEFCs are being actively researched and developed, and because they are suited for power generation systems having smaller capacity than a PAFC, and have a low waste heat temperature level, PEFCs are expected to coexist with PAFCs in the future, with each being used in fields where they are best suited.

3. Trends and Prospects of PEFC Development

3.1 Development trends

PEFCs employing polymer ion-exchange membranes as electrolytes were used to power the Gemini spacecraft, but they were subsequently replaced as the main spacecraft power source by AFCs, which had superior performance. During the 1980s, the performance of ion-exchange membranes was improved and the application of fuel cell power generation systems as vehicular power sources was studied. Since the late 1990s, there has been a dramatic increase in activity regarding the research and development of fuel cells.

PEFCs have a low reaction temperature of approximately 80°C above room temperature and can potentially use inexpensive materials. If mass-produced as vehicular power sources, a large drop in price is expected. Because fossil fuels are predicted to be depleted by the year 2030, and also because of the problem of global warming, fuel cells that use hydrogen fuel are thought to be ideal for use as vehicular power sources. Eyeing the California state law requiring zero emission vehicles (ZEVs) by 2003, automakers are accelerating their development efforts.

Meanwhile, unrelated to the above vehicular use, a great many manufacturers have developed power units as transportable and distributed power sources, ranging in capacity from several hundred watts to several kilowatts, and are aiming to introduce home-use cogeneration systems by 2005.

The Ministry of Economy, Trade and Industry (METI) has positioned fuel cells as a key technology for next generation energy and environmental preservation. In December 1999, as a step toward the practical application and popularization of PEFCs, the Research Committee for Household Application of Fuel Cells was established as a private research panel of the Director-General of the Agency of Natural Resources and Energy, and the Committee issued a report in January 2001. In August 2001, the Committee prepared a strategy for the development of utilization technology for PEFCs and hydrogen energy. The scenario for promoting practical applications and widespread use consists of three phases: ① a base arrangement and technology verification phase (from year 2000 to 2005), ② a market entry phase (from year 2005 to 2010), and ③ a diffusion phase (beginning in 2010). The targeted adoption quantities are 50,000 Fuel Cell Vehicles (FCVs) and approximately 2,100 MW of stationary fuel cell system capacity by 2010, and approximately 5 million FCVs and approximately 10,000 MW of stationary fuel cell system capacity by 2020.

Fuji Electric began researching and developing PEFCs in 1989, at the time when the potential for enhancing the performance of polymer electrolytes became feasible. With the goal of building a high-efficiency power generation system that runs on hydrogen fuel, Fuji Electric developed a stack module having an output capacity of several kilowatts. Thereafter, Fuji Electric worked to improve cell reliability and to miniaturize the size of the cell stack, and performed run-time evaluation testing for more than 15,000 hours with a 1 kW-class stack (Fig. 2) running on hydrogen fuel. Since 2000, Fuji Electric has built a prototype of a 1 kW-class power generation system that runs on town gas fuel, has performed continuous operation testing for approximately 3,000 hours as well as other tests including start/stop testing, and has performed an evaluation of the system as a PEFC power system. Figure 3 shows the external appearance of the 1 kW-class PEFC power generation systems and a hot water tank. Power generation systems including reformers and inverters are well suited to the technology acquired during PAFC development. Through the process of prototyping and evaluating 1 kW-class power generation systems, Fuji Electric has been able to identify potential problems, estimate cost reductions, and investigate suitable applications for PEFC power generation systems.

Fig.2 1 kW class PEFC stack

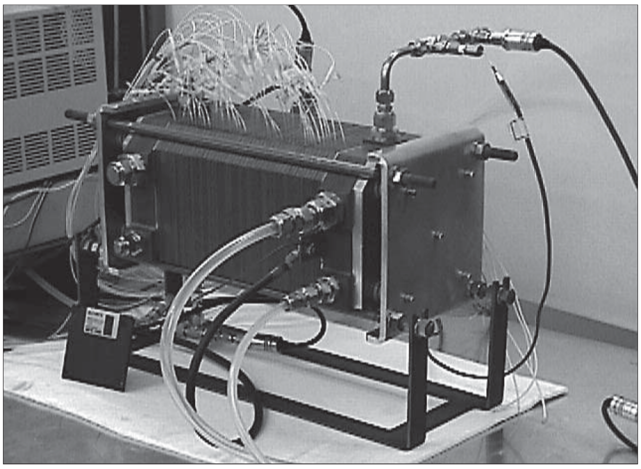

Fig.3 1 kW class PEFC power generation system and hot water tank

3.2 Future prospects

The development of PEFC power systems has been accelerated for vehicular and home-use applications. Due to the differences in the fields for application, it is believed that performance and cost specifications will also differ. The selection of an appropriate fuel is an issue for vehicular applications, and at the moment, pure hydrogen fuel appears likely to be the main choice. On the other hand, home-use and stationary fuel cell systems use fuels such as town gas or liquefied petroleum gas (LPG), which have been used as the fuel in conventional cogeneration applications. There is a need to develop reformers compatible with this fuel and fuel cells compatible with reformed gas. Although it is possible for vehicular and stationary fuel cell systems to use the same material for the separator in the main fuel cell unit, the cell unit design (especially the electrode) differs according to whether hydrogen or reformed gas will be used, and therefore these power generation systems require different types development. Furthermore, in addition to home-use applications, it will be necessary to examine other suitable applications such as industrial applications that leverage the special features of stationary PEFC power systems.

Under present conditions there is not much to say about the cost of PEFC power systems, but it will be necessary to decrease the cost to less than that of existing PAFC power systems before the demonstration device introduction phase that is slated for year 2005.

4. Conclusion

Among the fuel cells for which early applications are promising, the development trends and future prospects have been described for PAFC and PEFC technology, which is being developed by Fuji Electric as key technology for the 21st century.

By positioning fuel cells as a key component in the fields of energy and the environment, Fuji Electric will continue to promote the commercialization of PAFCs and to accelerate the development of PEFCs.

The authors wish to thank the Japanese government and all other affiliated parties for their guidance and cooperation through these many years of development. We are also deeply indebted to each user who actively adopted this fuel cell technology. In the future, we request your continued understanding and support for the introduction and technical development of this fuel cell technology.

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