Present Status of Fuel Cells and Outlook for Development

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1. Introduction

With the Kyoto Protocol taking effect in February 2005, Japan has also been required to make a full-out effort to reduce emissions of CO_2, a greenhouse effect gas. According to the Kyoto Protocol Detailed Program enacted by the Japanese Cabinet in April 2005, the use of fuel cells is predicted to provide approximately 2,200 MW of power by 2010, of which approximately 1,000 MW will be for industrial use. Under these circumstances, Fuji Electric will continue to promote its 100 kW phosphoric acid fuel cells (hereafter referred to as PAFC) that is currently on the market, and aiming to achieve greater market penetration, intends to move ahead with development to reduce cost and expand the range of applications of PAFC. Moreover, since 1989, Fuji Electric has also used technology acquired during PAFC development to develop polymer electrolyte fuel cells (hereafter referred to as PEFC). This paper discusses the present status of PAFC technology, the status of hydrogen supply system development to expand the range of the PAFC applications, and the development status of PEFC technology.

2. Status of Introduction of PAFC Technology

2.1 Delivery record and overview of onsite operation per application

The delivery record of commercial-type fuel cells and their cumulative operating times are listed in Table 1. The first commercial-type PAFC began shipping in 1998, and has been delivered to hospitals, supermarkets, hotels, office buildings, and the like. These fuel cells continue to operate successfully and some have achieved more than 56,000 hours of cumulative operating time. Additionally, a low-cost second commercial-type began shipping in 2001 and this model has achieved more than 30,000 hours of cumulative operating time, while realizing low cost and highly reliable operation. Both the first and second commercial types have a utilization rate of more than 95 %, and realize a high level of durability and reliability.

Table 1 Introduction of commercial-type fuel cells

	Used in	Date delivered	Fuel	Operating time (h)
1st commercial-type fuel cell	Hospital	August 1998	City gas	44,265
	Hotel	March 1999	City gas	56,637
	Commercial institution	March 1999	City gas	Operation ended
	University	April 2000	City gas	41,687
	Office	March 2001	City gas	38,230
	Office	March 2001	City gas	39,541
	Office	July 2000	City gas	42,666
	Office	July 2000	City gas	44,638
	Methane fermentation plant	January 2001	Biogas	Operation ended
2nd commercial-type fuel cell	Training institute	December 2001	City gas	30,311
	Sewer processing plant	March 2002	Biogas	29,780
	Sewer processing plant	March 2002	Biogas	30,080
	Hospital	July 2003	City gas	19,851
	College	October 2003	City gas	11,650
	Exhibition institution	November 2003	City gas	14,666
	Office	January 2004	City gas	13,296
	Hospital	March 2004	City gas	10,557

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An increasing number of fuel cell models have achieved the targeted service life of 40,000 hours (approximately 5 years), and as shown in Table 2, more than 11 models, including the pre-commercial prototypes, have achieved this level of service. In the future, assuming that the operation of these commercial types continues favorably, more and more fuel cell models will surpass 40,000 hours of operation, and by overhauling these models (by replacing their fuel cell stack and apparatus for reforming), an increasing number of fuel cells will achieve even longer service lives.

2.2 Future plans to introduce fuel cells

Based on the success with commercial fuel cells that operate for 40,000 hours, Fuji Electric has improved the fuel cell stack and the reforming apparatus, and since 2005 has been shipping fuel cells capable of operation for 60,000 hours. Scheduled shipments include 1 unit for exhibition, 2 units for use in a hospital, and 4 units for use at a sewer processing plant. Increasing the service life to 60,000 hours (approximately 7.5 years) results in less frequent overhaul work and decreases the equipment recovery cost.

In order to promote more widespread use of fuel cells, Fuji Electric plans to publicize the track record to date of high reliability, and to lower costs further. On the other hand, the range of PAFC applications has expanded because, in addition to city gas, PAFCs can also use renewable energy such as digester gas and biogas.

3. Hydrogen Supply System Using Stationary Fuel Cells

Working to expand the range of fuel cell applications, Fuji Electric has successfully used biogas obtained from fermented raw garbage and sewage digester gas, in addition to city gas, as raw fuel for PAFC. A hydrogen supply system using stationary fuel cells is capable of CHP (combined heat power) while simultaneously producing and supplying highly pure hydrogen, and development of such systems is being advanced to expand the applicable range of fuel cells even further.

3.1 System overview

A hydrogen supply system using stationary fuel cells, such as the 100 kW phosphoric acid fuel cell power generator manufactured and sold by Fuji Electric outputs a portion of the hydrogen-rich reformed gas that is the fuel for power generation, and using a compressor and PSA (pressure swing adsorption), produces highly pure hydrogen of at least 99.99 % purity. In other words, the system generates electrical power and produces highly pure hydrogen.

Table 2 PAFC units having cumulative operating time of at least 40,000 hours

Cumulative operating time (h)	No. of units
40,000 to less than 45,000	9
45,000 to less than 50,000	0
50,000 or greater	2
Total	11

Development of this system was commissioned by Tokyo Gas Co., Ltd, and Fuji Electric designed and manufactured a phosphoric acid fuel cell power generator and a reformer outlet gas cooler (also functioning as a buffer tank) for removing excess moisture from the reformed gas that is output, and is also responsible for control of the entire system. Figure 1 shows the skeletal structure of the system.

3.2 Development overview

Development of this system began in the latter half of 2003, aiming for a product launch date in 2006.

(1) 2003: Assessment and implementation of basic design

Under the condition of not requiring changes to the main equipment of an existing fuel cell system, we assessed the quantity of reformed gas that could be output to the power generator. As the results of this basic assessment, the relation between the output flow rate of reformed gas and the generated power output are shown in Fig. 2.

Fig.1 Configuration of hydrogen supply system using stationary fuel cells

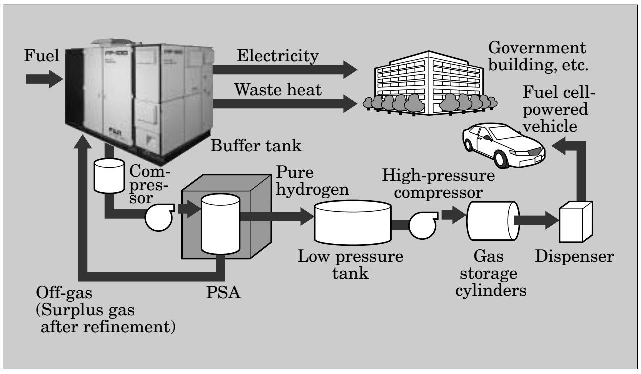
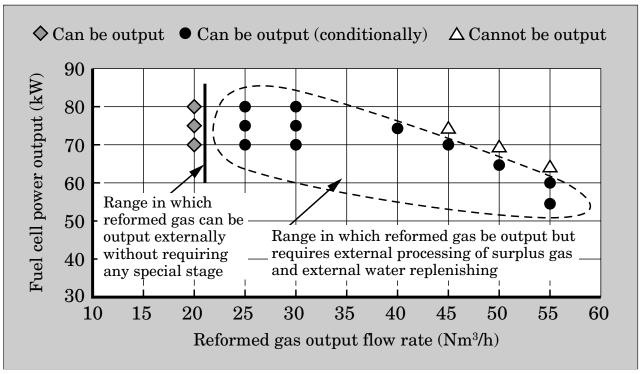


Fig.2 Reformed gas output flow rate



(2) 2004: Detailed design and modification of existing equipment

We modified existing equipment for the purpose of outputting reformed gas, and designed, manufactured and installed a reformer outlet gas cooler and a control system.

(3) 2005: Assessment of commercial equipment specs

We assessed commercial specifications based on the results of verification testing and experimental results.

Based on the assessment of the basic design, the goal was established to develop small capacity (8.5 Nm^3/h) and large capacity (20 Nm^3/h) systems capable of producing and supplying highly pure hydrogen. The corresponding capacities of these systems are as follows.

Small capacity supply: Capable of supplying sufficient hydrogen for 5 fuel cell-powered vehicles per day (1 bus per day)

Large capacity supply: Capable of supplying sufficient hydrogen for 12 fuel cell-powered vehicles per day (2 to 3 buses per day)

The hydrogen production and supply capabilities of 8.5 Nm^3/h and 20 Nm^3/h correspond to reformed gas output quantities of 20 Nm^3/h and 50 Nm^3/h, respectively.

3.3 Anticipated effects

In the near future, the arrival of an era in which hydrogen is used as a fuel is highly anticipated. At that time, it is predicted that highly pure hydrogen will be produced and supplied at low cost to end-users. Recent development efforts aim to serve as a bridge to that era of full-scale usage of hydrogen fuel, and the following types of effects are anticipated.

(1) Even in cases where the production and supply of highly pure hydrogen is not needed, the system can operate as a CHP plant and contribute, as a constantly high-efficiency system, to reducing the load on the environment.

(2) During late night hours and other times when the power load decreases, the excess capacity for producing reformed gas can be used to produce hydrogen, thereby contributing to an improved utilization rate of the equipment.

(3) Because both electric power and heat can be supplied, economical operation is anticipated, with a low-cost hydrogen supply provided even during the initial introduction stage and permitting early recovery of invested capital.

(4) By installing and using stationary fuel cells as CHP equipment before introducing them into fuel cell-powered vehicles, at the future time when fuel cell-powered vehicles are eventually introduced, an additional hydrogen supply system part may be installed to provide the necessary hydrogen supply.

4. PEFC Development

Fuji Electric became involved in the development of a polymer electrolyte fuel cell stack in 1989, and since 2002, has been advancing the development of a 1 kW-class polymer electrolyte fuel cell system. Using first and second prototypes, a stationary home-use system was demonstrated and its problems identified, optimal capacity was assessed, and basic data was accumulated and evaluated so as to implement successive improvements. The operating status of a third PEFC prototype created in 2004, the operating status of PEFC verification testing in Mie Prefecture (known as the PEFC field testing in Mie Prefecture), and an overview of a fourth PEFC prototype developed in 2005 are described below.

4.1 Operating status of third PEFC prototype

The method of manufacturing the MEA (membrane electrode assembly) for the PEFC stack has been optimized, and a cell of improved durability and reliability has been used in this third generation prototype. Figure 3 shows the operating status of the third PEFC prototype, and Fig. 4 shows the operating status (as of July 2005) of an evaluation-use PEFC stack having the same specifications as the third PEFC prototype. The third PEFC prototype has accumulated 5,500 hours of operation as a power generator. The

Fig.3 Operating status of third PEFC prototype stack for evaluation

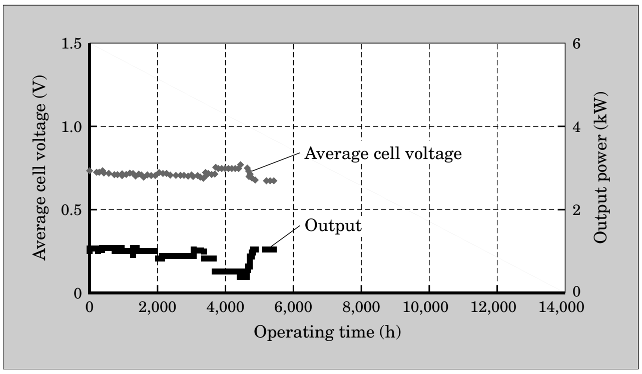
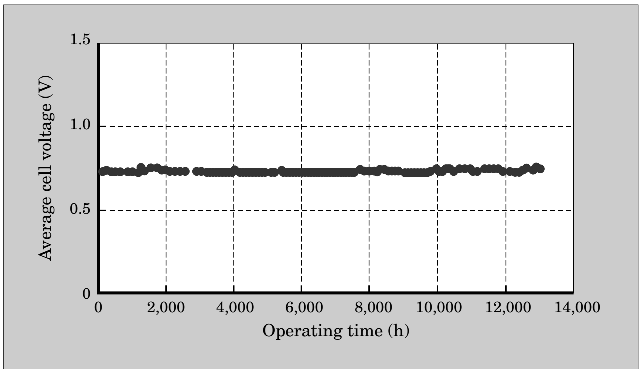


Fig.4 Operating status of PEFC prototype stack for evaluation



PEFC stack, having operated for 12,700 hours, surpassed the targeted value (showing a voltage drop of not more than 2 μV/h), and verified the improved effect of the cells.

4.2 Operating status of Mie prefecture field-test PEFCs

Receiving assistance from the Fuel Cell Verification Testing Business run by Mie Prefecture, as well as Yokkaichi City and Suzuka City of Mie Prefecture, PEFC field tests were begun in April 2005 at the two sites of Yokkaichi City and Suzuka City.

Figure 5 shows an onsite installation in Yokkaichi City, and Fig. 6 shows an installation in Suzuka City. The Yokkaichi City field-test PEFC is installed at a convenience store (the Takahama-cho, Yokkaichi City branch of the "Family Mart" convenience store chain) and the hot water generated is supplied to a local home-visit bathing service. The Suzuka City field-test PEFC is installed at a typical home (the official residence of the Suzuka National College of Technology), and is used to supply electricity and hot water to the residence. Figures. 7 and 8 show the operating status at Yokkaichi City and at Suzuka City, respectively. As of September 30, 2005, the respective operating times are approximately 3,600 hours and

Fig.5 Onsite installation of field-test PEFC in Yokkaichi City

Fig.6 Onsite installation of field-test PEFC in Suzuka City

Fig.7 Operating status of PEFC field test in Yokkaichi City

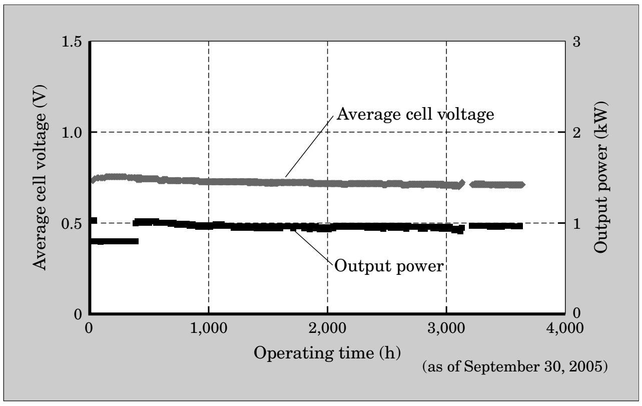


Fig.8 Operating status of PEFC field test in Suzuka City

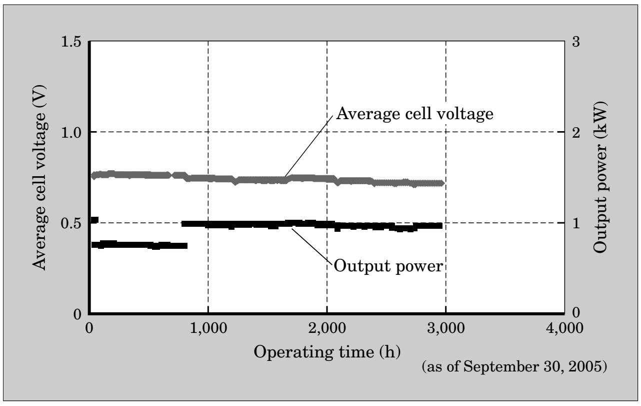
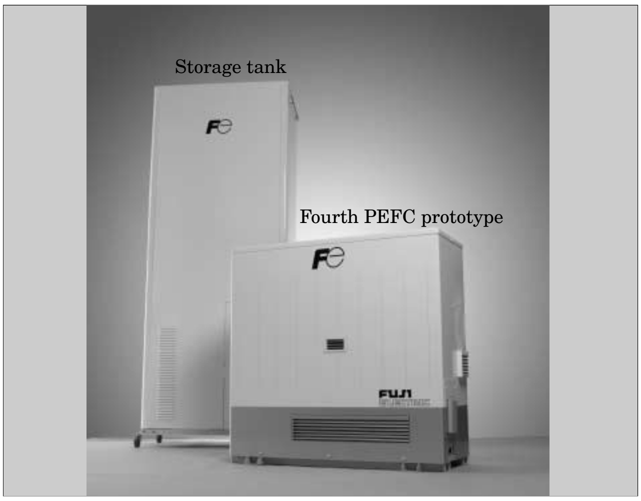


Table 3 Specifications of fourth PEFC prototype

Output power	1 kW (AC power transmitting side)
Electrical connection	1 phase, 3 wires 200 V AC
Electrical efficiency	35 % (for rated output, LHV)
Thermal output	Approx. 60°C
Heat recovery	51 % (for rated output, LHV)
Fuel	City gas (13 A)
Operation	Fully automatic
Main dimensions (width, height, depth)	910×895×360 (mm)

Fig.9 Appearance of fourth PEFC prototype



3,000 hours.

4.3 Development status of fourth PEFC prototype

At present, Fuji Electric is moving ahead with production and evaluation of a fourth PEFC prototype stack that aims to realize a dramatic reduction in cost. The basic specifications and the appearance of the fourth prototype are shown in Table 3 and Fig. 9, respectively. The specifications aim to improve the power generating efficiency and the overall thermal efficiency, while eliminating the need for nitrogen for purging during start up and shut down. In the future, Fuji Electric plans to initiate an internal evaluation of the fourth PEFC prototype, and then to verify its reliability and durability during continuous operation and start-stop operation. Fuji Electric also intends to advance development that enhances durability and targets mass production, and to accelerate PEFC commercialization.

5. Conclusion

Hydrogen is an energy-yielding substance that does not emit carbon dioxide when used, and because it can be produced from non-fossil fuels, hydrogen-derived energy is also preferred from the standpoint of energy security. In order to realize a hydrogen fuel-using society, the early widespread adoption of the key technology of fuel cells desired. To contribute to the advent of this hydrogen fuel-using society, Fuji Electric intends to position fuel cells as a key component in the energy and environment fields, and to strive to expand the usage of phosphoric acid fuel cells and to strengthen efforts to develop polymer electrolyte fuel cells.

The authors wish to thank the relevant organizations and each user for their guidance and cooperation thus far, and requests their continued understanding and support in the future.