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FUJI ELECTRIC PHOSPHORIC ACID FUEL CELL ACTIVITIES

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Introduction

Fuji Electric Company (FE) has been engaged in the research and development of fuel cells since 1961. In recent years, we have concentrated on the development and manufacture of phosphoric acid fuel cell (PAFC) targeting mass-production and full commercialization in 1994.

FE's PAFC development can generally be divided into two categories ranging from kilowatt to megawatt range:

(i) stationary PAFC for dispersed power plants, on-site, and cogeneration applications

(ii) transportable PAFC for vehicular and remote site applications

Figure 1 shows a summary of the application of our PAFC plants. Other fuel cell technologies under development at FE are alkaline fuel cell, molten carbonate fuel cell and solid oxide fuel cell.

We are confident that we can help to meet the challenge of the future via the successful development and commercialization of PAFC for both stationary and vehicular applications, and that we can help provide a highly efficient alternative, thus contributing to a cleaner global environment on the Earth.

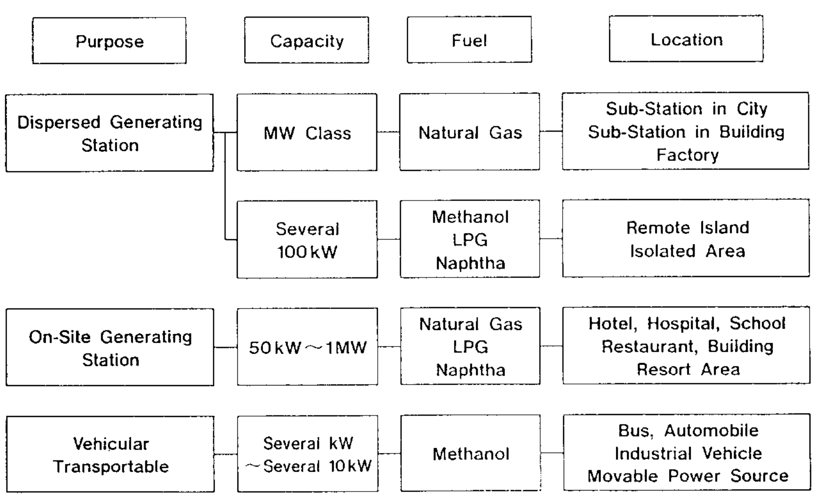

Fig. 1. Application of PAFC plants.

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PAFC for stationary, cogeneration applications

Fuji Electric has accumulated since the late 1970s construction and operation experience of PAFC plants from kW to MW ranges. Now total projected and expected PAFC plants of FE have reached more than 70 projects, 12 000 kW under patronage from both domestic and overseas customers (U.S.A., Europe and South East Asia).

1000 kW PAFC plant (NEDO Project)

The plant was constructed as a dispersed power station for electric utility purposes in the premises of Sakaiko Thermal Power Station of Kansai Electric Power Company, Japan and has been successful as expected. The total accumulated generation hours exceeded 2000 h inclusive of 500 h of non-interrupted operation. The main operation results and recommended performance improvements are shown in Tables 1 and 2, respectively.

The average voltage deterioration rate, about which we are most concerned, is shown in Fig. 2. Real performance data was gained only up to 2000 h but the extrapolated curve to 40 000 h shows the average deterioration will be 2.5 micro V/h. This may be reasonable at the current technology level but it is not satisfactory for the future commercial stage.

TABLE 1

Operation results of 1000 kW PAFC plant (NEDO Project)

Item	Target	Results
Electrical output	1000 kW	1000 kW
Electrical efficiency (HHV)	40%	37.1% (40.87 achievable)
Generating hours	> 1000 h	2045 h (including 705 h non-interrupted)
Reformer operation hours		3614 h
Cold start-up time	4 h	5 h
Load response	25 - 100%/min	±11%/min (125 - 450 kW)
Shutdown time	1 h: normal ⟨1 min: emergency⟩	47 min: normal 10 s: emergency
Environment	NOx < 20 ppm SOx < 0.1 ppm	NOx 10 ppm SOx 0 ppm

TABLE 2

Performance improvements (1000 kW PAFC plant, NEDO Project)[a]

1. More stable and longer operation required
2. Cell performance should be improved
3. Uniform temperature distribution in reformer is necessary (shorter start-up time, quicker load response)
4. Higher efficiency expected

[a]From NEDO's report.

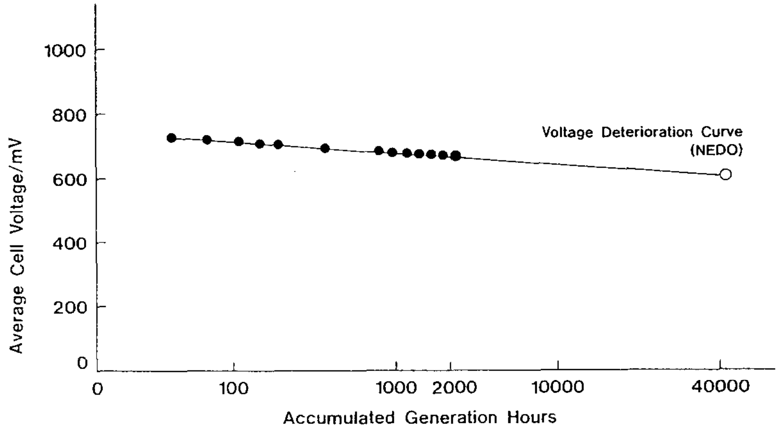

Fig. 2. Average voltage deterioration rate (1000 kW PAFC plant).

After completing the demonstration operation, the plant was dismantled and key components such as the fuel cell stack, reformer, turbo compressor etc. were examined in great detail.

Based on the design and operational experiences of the 1000 kW plant, NEDO and electric utility companies in Japan are planning to construct larger capacity dispersed PAFC power stations with the cooperation of manufacturers.

200 kW PAFC plant for a remote island (NEDO Project)

The purpose of this plant is to demonstrate the feasibility of a PAFC plant as the power supply system on a remote island. The plant has been operated at full power in our factory and will be shipped to the site (Tokashiki Island, one of the most southern islands in Japan, Okinawa Electric Power Company) in the middle of September 1989. The plant is expected to begin operation at the site from the beginning of October 1989.

To meet the special conditions in this remote island, the plant uses methanol as its primary fuel and operates in parallel with diesel generators.

Table 3 shows the key specification of the plant and Fig. 3 shows a view of the plant under construction.

50 kW PAFC plant for electric utility companies

We have been operating a 50 kW pressurized PAFC plant for Tohoku Electric Power Company (one of our electric companies which supplies electric power to the northern area of Japan) since March 1987 with good performance. LNG is used as the primary fuel for the first phase operation and LPG in the second phase.

The total operation time exceeded 8000 h as of the end of August 1989 (including 1000 hours unmanned non-interrupted operation and also including 590 h operation with LPG), which is the longest operation record

TABLE 3

Key specification of PAFC plant for remote island (NEDO Project)

Purpose	generating station in a remote island
Type	water-cooled PAFC
Output	200 kW (sending end)
Efficiency	>37% (HHV) (sending end)
Construction	packaged type (outdoor use)
Fuel	methanol
Working pressure	atmosphere
Minimum load	20%
Start-up time	<3 h (cold start)
Load response time	30 s for 20 - 100% load, instantaneous for ±20%
Voltage distortion	<3% total
Operation mode	independent and/or grid connected, self-start, self-synchronized
Weight	<20 t (as package)
Footprint	<0.2 m^2/kW (as package)

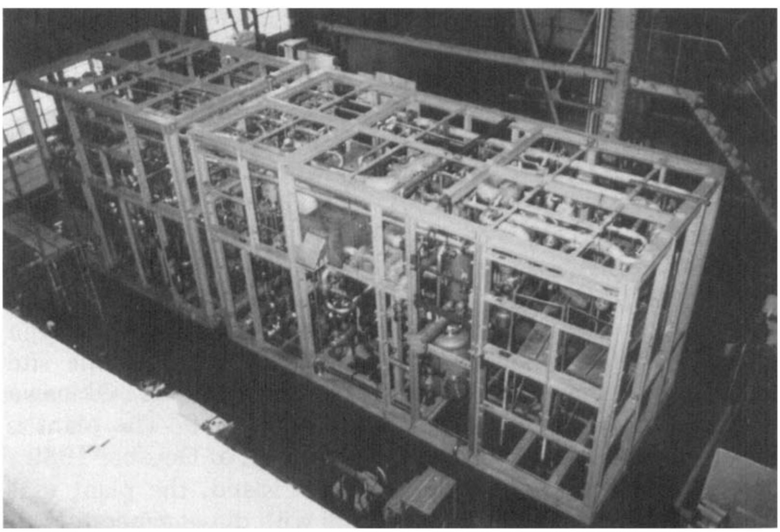

Fig. 3. General view of 200 kW PAFC plant for remote island (under construction) (NEDO Project).

of pressurized PAFC systems in the world. The success of LPG reforming should be noted also as the first experience in Japan.

Table 4 shows the key specifications and operation record of the plant.

50 kW PAFC for gas utility companies

The 50 kW plant for the Tokyo Gas Company is now being tested, in FE's facility very satisfactorily, and will begin operation at the site from the beginning of October 1989.

TABLE 4

Key specification and operation record of 50 kW PAFC plant (for Tohoku Electric Power Company)

Type	pressurized, water-cooled PAFC
Output	50 kW (sending end)
Fuel	natural gas, LPG
Working pressure	2.0 kg/cm^2 A
Working temperature	190 °C
Cell area	3600 cm^2 class
Hydrogen utilization factor	80%
Air utilization factor	55%
Operation hours	8000 h (at end of Aug. 1989) (world's longest operation of a pressurized PAFC plant)
Fuel	LNG/LPG (first LPG operation in Japan)
Grid connection	first connected operation with distribution networks in Japan
Exhausted NOx	6 ppm

TABLE 5

Key specification of 50 kW PAFC on-site plant

Purpose	on-site co-generation
Type	water-cooled PAFC
Output	50 kW (sending end)
Electrical efficiency	40% (LHV) (sending end)
Total efficiency	80% (LHV)
Construction	packaged type (indoor/outdoor)
Fuel	town gas (LNG) (13 A)
Working pressure	atmosphere
Range of output	0 ~ 100%
Start-up time	<4 h
Voltage distortion	<5% total
Operation mode	independent and/or grid connected
NOx	<10 ppm (O_2: 7%)
Weight	<5 ton
Footprint	<0.11 m^2/kW (L: 3.1 m, W: 1.75 m, H: 2.2 m)

This plant is very compact and will serve as the precursor for future commercialization. Grid connected as well as independent power operations are possible. The key specification and outer view of this on-site plant are shown in Table 5 and Fig. 4 respectively.

Recently three major gas utility companies in Japan jointly requested Fuji to supply nine 50 kW plants before 1991 and seven 100 kW plants by 1993. The Japanese Government also intends, beginning in 1990, to demonstrate 10 to 16 sets of 50 kW PAFC plants, grid-connected in conjunction with solar and wind power systems.

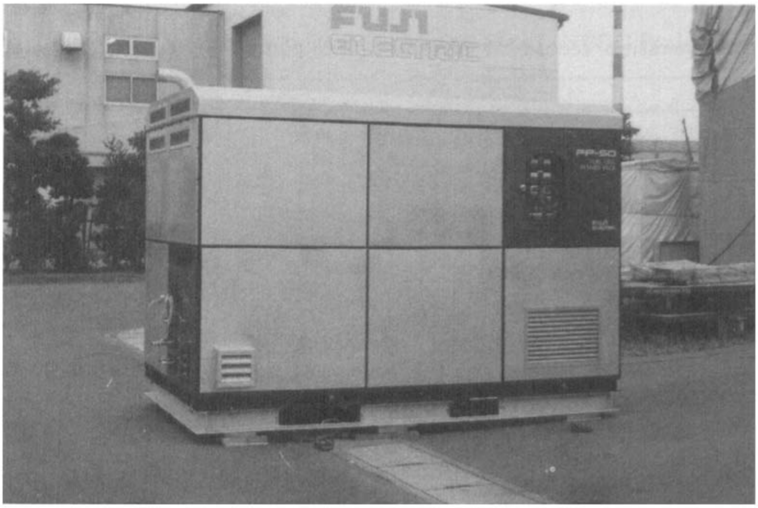

Fig. 4. Outer view of 50 kW PAFC plant for cogeneration.

TABLE 6

50 kW on-site PAFC plant-order list

Item	Customers	Quantity	Delivery
1	Tokyo Gas	1	1989
2	NEDO, Kansai Electric Power, Rokko Island	>10	1990 - 1992
3	EGAT (Thailand) ODA Project[a]	1	1991
4	Europe	1	1990
5	Tokyo Gas	4	1990 - 1991
6	Osaka Gas	4	1990 - 1991
7	Toho Gas	1	1991
	Natural gas	Ambient pressure	Water cooling

[a]ODA: Official Development Assistance.

Table 6 shows the list of 50 kW PAFC on-site plants for which we have received orders.

Fuji is now offering the current type 50 kW plants to several potential customers in Europe, U.S.A. and also South East Asia markets.

General purpose small capacity PAFC

Many of our customers have expressed interest in using fuel cells in various new applications. We have already supplied several 4 kW methanol reforming, normal pressure and air-cooled portable fuel cell units. It is very difficult for such small capacity PAFC plants to be economically competitive with other conventional systems unless some new innovative technologies are applied.

PAFC for vehicular applications

In 1983 Fuji Electric and Engelhard Corporation, which had developed a substantial amount of expertise in PAFC technology, entered into a co-operative agreement to develop PAFC power packs for forklift truck application. Several prototypes were developed and tested. Currently, Fuji Electric has full responsibility for commercializing fuel cell powered forklifts since Engelhard's management decided to terminate their fuel cell program.

The development and engineering of the Fuji Electric PAFC power pack for forklift trucks are essentially complete. In order to penetrate into the potentially large market for such trucks in the U.S.A. and Europe we need to substantially reduce the production cost of our product. Our current forklift program goal is just that: cost reduction.

It is our belief that the initial commercialization of PAFC product(s) for vehicular applications, where the unit size of the fuel cell required is larger, and/or where there is a definite need for the injection of a new technology, can succeed.

For bus application where a 50 kW unit is called for (*versus* 5 kW for forklift truck), we feel that the cost goal can be met. In addition, the environmental regulations mandated for 1991 and 1994 in the U.S. offer the opportunity to introduce a 'clean' technology.

Finally, since Fuji's PAFC is methanol-fed, it will help to reduce the country's dependency on foreign oil in the future. We at Fuji Electric believe these forces provide a strong impetus to PAFC development and commercialization.

U.S. Department of Energy (DOE) bus project

Fuji Electric has committed several million dollars towards the development of a forklift PAFC system. The basic technology and experience gained in our forklift development has served as the basic design of the DOE bus power system. This is a very compact, liquid-cooled stack design, fuel cell–battery hybrid propulsion system, which has been developed and demonstrated through the operation of the forklift power pack; it could be applied to the PAFC bus system without any major modification. Therefore, minimal research and development are required to convert the forklift design to buses. The merit of the liquid cooling technology is summarized in Fig. 5. The probability of success is quite high.

The DOE bus project is composed of 4 phases, that is,

Phase 1 (1987 - 89): proof of feasibility for fuel cell/battery subsystem
Phase 2 (1989 - 91): proof of concept for fuel cell/battery subsystem
Phase 3 (1991 - 92): test-bed bus evaluation
Phase 4 (1992 -): prototype bus testing

For phase 1, the half size 25 kW brassboard including chopper has been shipped to Chrysler Pentastar Electronics, which is responsible for the fuel cell–battery hybrid propulsion system for the bus, after having satisfactory

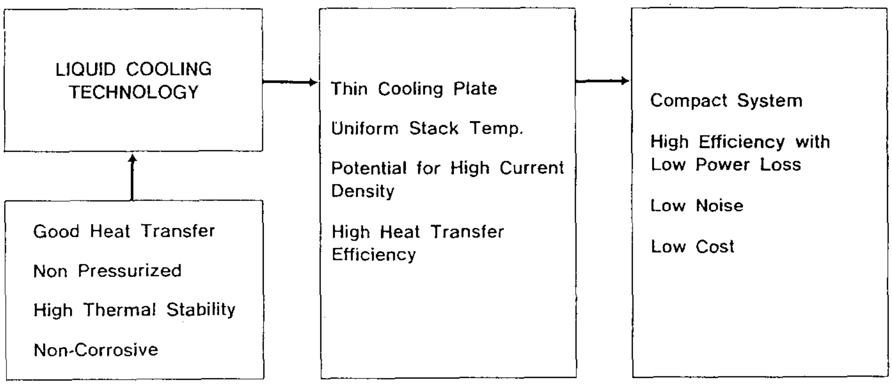

Fig. 5. Features of Fuji fuel cell technology for fuel cell bus system.

TABLE 7

Key specifications for 50 kW fuel cell system

Items	Phase I	Phase II
Configuration	brassboard	onboard
Net output	22.5 kW	50 kW
System efficiency	36% (LHV) (excluding auxiliary power)	38% (LHV) (including auxiliary power)
Chopper		
Efficiency	90%	95%
Frequency	1.3 kHz	10 kHz
Auxiliary power	utility power	battery power
Cold start-up time	45 min	25 min
Standby to full power (0% to 100%)	7 min	3 min
Interface	analog	digital

approved tests at Fuji's Chiba Factory. The plant has begun combined testing with the peaking battery at Chrysler since the middle of July 1989.

Table 7 shows the comparison of the 25 kW brassboard plant and the 50 kW full size.

The overall combined tests of fuel cell and battery hybrid system at Chrysler Pentastar Electronics will last until the end of December 1989 and we are expecting successfully to enter into phase 2 of the program where 3 sets of 50 kW PAFC plants will be manufactured and tested.

Conclusions

Our commercialization plan for stationary and vehicular PAFC has been highlighted. Our goal is to make PAFC a commercial reality, with appropriate cost and benefit trade-offs to users. We believe that environmental and energy concerns will be critical to PAFC's success in the coming years, and that a most attractive market for PAFC in the future lies in the U.S., especially in Southern California, Japan and European countries.

Collaborative efforts between foreign organizations and Fuji are necessary to promote and demonstrate fuel cell applications, as efficient and environmentally superior alternatives, for a cleaner Earth.