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# PRESENT STATUS AND PROSPECTS FOR FUEL CELL TECHNOLOGY

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## 1. FOREWORD

The development and commercialization of fuel cell power plants has recently become a focus of interest worldwide.

Fuel cell technology was first developed in the United States, and then later in Japan. The last few years has also seen the development of such technology in Europe.

The development of phosphoric acid fuel cells (PAFC) has become especially intense:

(1) International Fuel Cells, Inc., U.S.A., has proposed the development of semi-commercial 200 kW and 11,000 kW PAFC power plants, and has approached electric and gas utilities and others, about using them.

(2) In Japan, two 1,000 kW power plants, the main part of the first stage fuel cell development program of the Japanese Government's Moonlight Project, have been completed and put in operation and also several privately sponsored projects have been put into operation.

(3) In Europe, the countries participating in the European Community's fuel cell development project, espesially Holland and Italy, have begun development of PAFC power plants, with the cooperation of the United States and Japan.

(4) Southeast Asian countries have also begun planning the development of PAFC power plants.

One of the main reasons why fuel cells are being investigated by so many countries and companies is their low level of pollution. Unlike thermal power and nuclear power plants, there is no need to locate fuel cell power plants far from the cities they serve. They can be located in suburbs, where the energy available from their exhaust heat can be used more efficiently. The prospect of highly efficient, local power plants has provided impetus to fuel cell development.

The surest way to promote the commercialization of fuel cell power plants is to demonstrate their capabilities and reliability by constructing and operating test plants.

In Japan, two 200 kW PAFC power plants have been constructed, in addition to the two 1,000 kW power plants mentioned above. Furthermore The New Energy Development Organization (NEDO) has planned the demonstration of a system composed of more than ten dispersed, fuel cell power plants for 1990.

Public utilities, and the petroleum and construction industries, are also investigating practical applications of fuel cell power plants. The petroleum industry is doing so in an effort to develop more efficient energy systems, even though fuel cells were originally developed to provide an alternative to petroleum as a source of energy.

The greatest problem confronting the developers of PAFC power plants at this moment is the high cost of such power plants. Fuel cell power plants generally have a modular construction, and their cost cannot be lowered without mass producing their modular components. Of course, this can only be done if there is a market for fuel cell power plants. So, it became very important to find the enough market to reduce the cost to the competitive level.

The Japanese study of second-generation, molten carbonate fuel cell (MCFC) also have been promoting during the first stage of the previously mentioned Moonlight Project, between 1981 and 1986. The second, eight-year stage of that project began in 1987 and has already seen the approval of the construction of MCFC power plants worth 34 billion yen, capable of producing 1,000 kW of power. We believe this project is larger than a similar one planned by the United States Department of Energy. Such projects will give Japan an opportunity to use its economic power to raise the level of world technology.

Third-generation, solid oxide fuel cells (SOFC) are being developed in large scale by the Westinghouse Electric Corp. with the assistance of DOE in the United States. The technology, which has generated worldwide interest, will have to be researched for several years more before it can be said for certain whether it will replace MCFC technology.

Researchers the world over are interested in MCFC and SOFC technology because such fuel cells are more efficient and generate less pollution than PAFC fuel cells. However, it is generally agreed that the commercialization of PAFC will precede that of MCFC and SOFC.

Fuji Electric has been researching fuel cell technology for more than twenty-five years, longer than any other Japanese manufacturer.

As mentioned above, Fuji Electric has developed a 1,000 kW PAFC power plant for NEDO and a 200 kW

PAFC power plant for isolated island use. The company has also manufactured small power plants for Japanese utilities.

We have received numerous inquiries about our PAFC products from foreign companies and have signed several contracts already. And we have the strong confidence in taking the leading position in the field of PAFC development in Japan.

Fuji Electric is the only Japanese manufacturer of alkaline electrolyte fuel cells. We have been developing them for special applications.

## 2. DEVELOPMENT AND COMMERCIALIZATION OF PHOSPHORIC ACID FUEL CELLS

*Table 1* shows all of Fuji Electric's PAFC projects. Since the principal project have been described in print, only an outline of their essential points will be given here.

### 2.1 1,000 kW Power Plant for the Moonlight Project

The 1,000 kW fuel cell power plant was a major component of the first stage of the Japanese Government's Moonlight Project.

Three years was spent developing the technology for the power plant. Site erection of the equipment was begun in early 1985 and test operation in May 1986. The plant was declared fully operational in September 1987.

Fuji Electric constructed the power plant jointly with Mitsubishi Electric Corp., according to NEDO's specifications. Fuji Electric's scope of supply included the fuel cell stacks (one set of two 260 kW stacks for a total of 520 kW), the fuel processor system, an inverter (500 kVA), and measuring and control systems. The company was also in charge of general plant engineering and overall test operation planning.

*Figure 1* shows the fuel cell stacks Fuji Electric installed at the site. *Figure 2* shows the characteristics voltage distribution for single cells. As shown, single cell voltages at the rated current have an extremely uniform distribution, which speaks well for Fuji Electric's quality control procedures.

*Fig. 1* Appearance of the 260 kW fuel cell stacks (Fuel cell demonstration plant in Sakaiko PS yard of the Kansai Electric Power Co., Inc.)

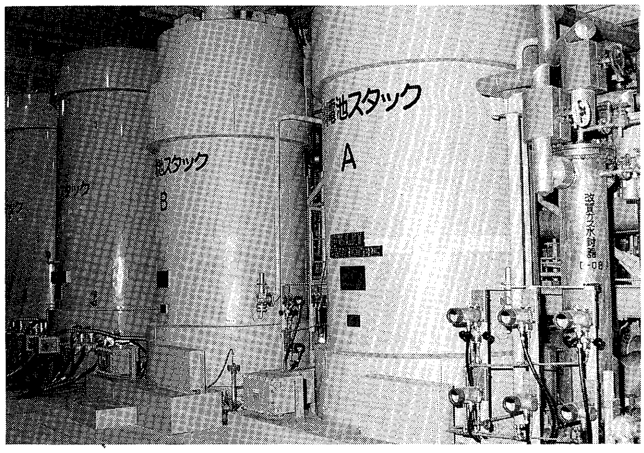



*Fig. 2* Single cell voltage distribution in the 260 kW fuel cell stack (A stack is divided into six blocks. The max., min., and average cell voltages in each block are illustrated.)

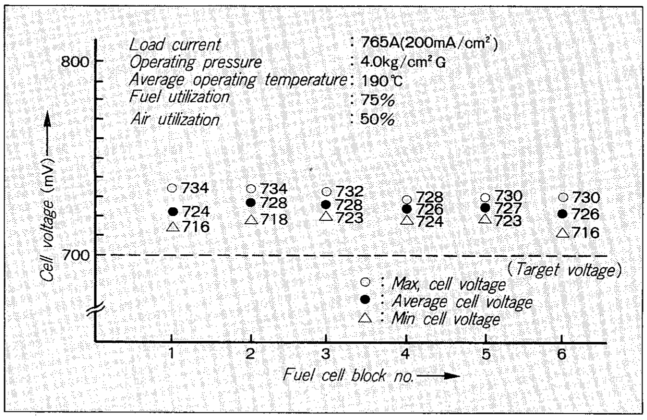



*Table 1* List of PAFC power plants manufactured by Fuji Electric

| | Item | Customer | Output (kW) | Fuel | Operating condition | Date of operation | Remarks |
|---|---|---|---|---|---|---|---|
| Moonlight Project | 1 | NEDO | 1,000 | LNG | Pressurized water-cooled | Sept., 1987 | Location: Sakaiko PS of Kansai Electric Power Co. |
| | 2 | NEDO | 200 | Methanol | Normal pressure water-cooled | Sept., 1989 | Location: Tokashiki Island PS of Okinawa Electric power Co. |
| Separate contract | 3 | Kansai Electric Power Co. | 30 | LNG | Normal pressure air-cooled | Dec., 1982 | Location: Sakaiko PS; removed after 3,500-hour operation |
| | 4 | Tohoku Electric Power Co. | 50 | LNG | Pressurized water-cooled | Mar., 1987 | Location: Niigata thermal PS |
| | 5 | Shikoku Electric Power Co. | 4 | Methanol | Normal pressure air-cooled | July, 1987 | Location: Technical Research Institute |
| | 6 | Hokuriku Electric Power Co. | 4 | Methanol | Normal pressure air-cooled | Apr., 1986 | Location: Mountain hut in Toyama Pref.; making use of hot water (subsidized by NEDO) |
| | 7 | Tokyo Gas Co. | 50 | LNG | Normal pressure water-cooled | Sept., 1989 | Compact design |
| MITI project | 8 | NEDO | 50 | LNG | Normal pressure water-cooled | 1989-1990 | Ten demonstration plants for system interconnected operation |
| Company project | 9 | Several customers | 4 | Methanol | Normal pressure air-cooled | After 1988 | For field tests |

* PAFC stacks other than the above have been supplied to domestic and foreign customers.

*Table 2* Operation test results of the fuel processing system

| | Target values | | | | Test results | | | |
|---|---|---|---|---|---|---|---|---|
| Load (%) | 25 | 50 | 75 | 100 | 25 | 50 | 75 | 90 |
| Reformed gas volume ($Nm^3/h$) | 250 | 491 | 750 | 1,024 | 250 | 489 | 751 | 915 |
| Residual $CH_4$ (vol%) | 2.0 or less | | | | 0.5 | 1.38 | 2.31 | 2.61 |
| Residual $CO_2$ (vol%) | 1.0 or less | | | | 0.11 | 0.13 | 0.15 | 0.14 |
| $H_2$ (vol%) | 77 or more | | | | 77.83 | 78.10 | 77.04 | 77.72 |
| Unused reformate volume ($Nm^3/h$) | 90 | 200 | 330 | 490 | 72.3 | 167 | 350 | 440 |

*Table 2* shows the test results obtained for the fuel processing system during test operations. The results demonstrate the system's planned performance characteristics.

The power plant has been inspected by Ministry of International Trade and Industry officials on April, 1988 and then be operated to obtain data for the design of future power plants.

### 2.2 200 kW Power Plant for the Moonlight Project

This power plant was proposed in 1986 as a step in the development of methanol reformate fuel cell power plants for isolated islands.

The main features of the power plant are:

(1) A capability of operating in parallel with the existing diesel generating system.
(2) A fuel processing system that uses catalytic combustion, to allow easy load-following performance.
(3) Integrated electrodes, like those shown in *Fig. 3*.

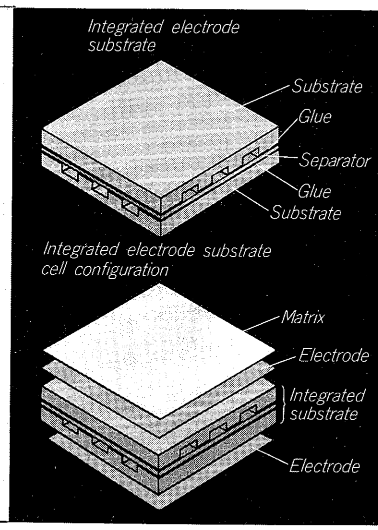
The main purpose of this research is to develop a high-load follow-up methanol processing technology that will allow the quick response to the load changes characteristics of island power supplies, and to develop highly efficient stacks and systems with an integrated electrode configuration.

### 2.3 Separate Contracts with Electric Power Companies

Fuji Electric has had or has now contracts with

(1) The Kansai Electric Power Co., Inc., for a 30 kW natural gas reformate, normal pressure, air-cooled fuel cell at that company's Sakaiko Power Station. (The fuel cell was put in operation in 1982, operated for 3,500 hours for one year and taken out of operation.)
(2) The Tohoku Electric Power Co., Inc., for a 50 kW natural gas reformate, pressurized, water-cooled fuel cell at that company's Niigata Thermal Power Station. (The fuel cell was put in operation in 1987 and is now undergoing operational test very satisfactorily.)
(3) The Hokuriku Electric Power Co., Inc., for a 4 kW methanol reformate, normal pressure, air-cooled fuel cell. (The fuel cell was put in operation in 1986 and is now serving as a backup power supply for a solar cell power system in a mountain hut in Toyama Prefecture, Japan. The fuel cell's development costs were paid by NEDO.)

*Fig. 3* Concept of integrated electrode substrate cell configuration




(4) The Shikoku Electric Power Co., Inc., for a 4 kW methanol reformate, normal pressure, air-cooled fuel cell at that company's Technical Research Institute. (The fuel cell was put in operation in 1987 and is now undergoing operational tests.)

The 50 kW power plant we installed in the Niigata Thermal Power Station of the Tohoku Electric Power Co. established a record for successful operation in its first year of service, from October 1985 to October 1986. It has been operated unmanned continuously for 650 hours, and is showing the accumulating operation of more than 4,000 hours.

The 4 kW plant we installed for the Shikoku Electric Power Co. was developed as a model emergency power supply for distribution systems. It has been designed to respond quickly to sudden system load changes.

### 2.4 A Contract with a Gas Company

Fuji Electric is now manufacturing a 50 kW natural gas reformate, normal pressure, water-cooled fuel cell power unit for Tokyo Gas Co., Ltd., for delivery in 1989. The most remarkable feature of the power unit is its compact design, which we believe will become the semi-commercial co-generation plants.

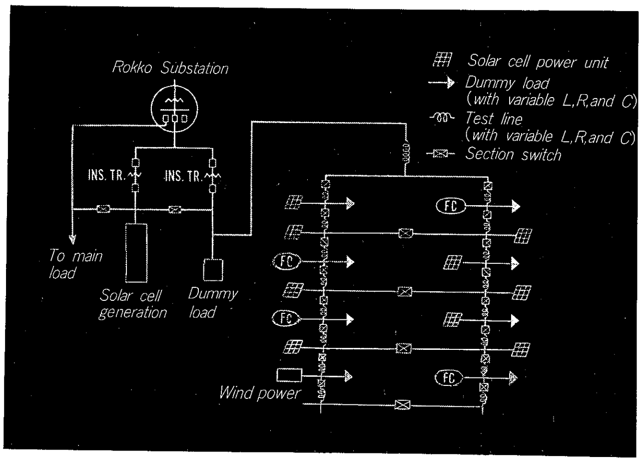
The fuel cell power unit has been designed to be able to connect to the grid network and also to operate as stand-alone plant.

### 2.5 System Interconnection

In 1987 the Public Utilities Department of the Agency of Natural Resources and Energy of MITI proposed a plan research on the interconnection of various types of new power generating systems. Demonstrations of interconnected systems are scheduled to begin from 1990.

According to the Public Utilities Department's proposal, power supplies such as solar and fuel cells and

*Fig. 4* Conceptual diagram for the system interconnection demonstration




windmills will be connected in one power system, and their and the system's performance evaluated. The successful interconnection of such power supplies is regarded as an important step on the way to integrated power systems.

The proposal calls for the installation of ten 50 kW, one 100 kW and two 200 kW fuel cell power plants. Fuji Electric will have the responsibility of manufacturing the fuel cells for the ten 50 kW power plants.

The power supplies specified in the Public Utilities Department's proposal will be integrated with the Rokko Island test system of the Kansai Electric Power Co. After field tests have been completed satisfactorily, the power supplies will be integrated with the Kansai Electric Power Co.'s distribution system to supply electricity to their customers.

*Figure 4* shows a conceptual diagram of the proposed integrated system.

### 2.6 General Purpose Small-capacity Fuel Cells

Many of Fuji Electric's customers other than public utilities have expressed an interest in using fuel cells in their new applications. To satisfy the needs of some of those customers, we have already begun manufacturing a 4 kW methanol reformate, normal pressure, air-cooled, portable fuel cell unit.

## 3. DEVELOPMENT OF MOLTEN CARBONATE FUEL CELLS

The development of MCFC was included in the first stage fuel cell development program of the previously mentioned Moonlight Project. The first stage program was completed in six years, with the development of elementary technology and evaluation of the performance of 10 kW fuel cell stacks.

The second stage fuel cell development program, which began in 1987, included a project to construct 1,000 kW MCFC power plants. Thirty-four billion yen was budgeted for this construction. The second stage program includes also the development of materials and systems, as well as fuel cell stacks. Public and private organizations were brought together in the MCFC Research Union during the second stage program.

Fuji Electric cooperated with the Central Research Institute of the Electric Power Industry to test and evaluate fuel cells and stacks from 1981, and began developing large electrolytic plates for NEDO from 1984. A method of making paper is used to develop electrolytic plate manufacturing technology.

The experience gained from this research allowed the company to manufacture a pilot 24-cell stack with an electrode area of 2,500 $cm^2$ (375 A, 18.9 V and 7 kW) in 1987. The performance characteristics of the stack were superior to the target characteristics specified by the Moonlight Project.

The two main features of Fuji Electric's stack technology are

(1) The application of paper making technology to electrolytic plate manufacturing, which allows the construction of heat cycle resistant, inexpensive, large plates.
(2) A hybrid type manifold, with an inner part for fuel and an outer part for air.

Satisfactory electrolytic plates must retain their stregnth when subjected to high temperatures, maintain the liquid electrolyte in a stable state, be able to withstand heat cycles, be inexpensive and have a long service life.

Heat cycle resistance is especially important when an MCFC power plant is connected to power systems, and is forced to cope with frequent load changes, such as start-ups and shut-downs. Soft electrolytic plates with a high heat-cycle resistance and superior electrolyte retention characteristics can be manufactured with Fuji Electric's paper making method. The equipment costs of the method are low and its productivity high.

In Fuji Electric's paper making method, lithium aluminate ($LiALO_2$) powder, pulp and a coagulating agent are mixed in water, made into paper, dried and burned to form pores to retain the electrolyte.

The results of a heat cycle test of a single 200 $cm^2$ cell with electrolytic plates made of Fuji Electric's paper technology showed no deterioration after 25 heat cycles, which is excellent.

The hybrid manifold supplies fuel through the internal manifold and air through the external manifold. It was designed to enlarge the effective area of the electrolytic plates while maintaining the gas imperviousness of the fuel passage.

The purpose of manifold is to distribute gas uniformly to cell stacks. The external manifold, which has its cover outside the fuel cell, distributes gas uniformly to fuel cell stacks. This type of manifold has been adopted by the United Technologies Crop. and Energy Research Corporation.

The internal manifold, which has passages for supplying gas in the electrodes, has been tested by the General Electric Co.

Fuji Electric has succeeded in developing a small, single fuel cell with a voltage of 0.80 V (150 $mA/cm^2$) and an effective electrode area of 200 $cm^2$. The fuel cell has been operated continuously for 2,500 hours.

The company has also succeeded in developing a fuel cell with a voltage of 0.79 V with a 24-cell stack (7 kW output) and an enlarged electrode area of 2,500 $cm^2$.

We intend to further improve our paper making method and, so, the quality of our electrolytic paper and plates. We also intend to improve our hybrid manifolds. Such improvements should allows us to build commercial fuel cell power plants with capacities of more than of 1,000 kW.

## 4. ALKALINE FUEL CELLS

Though alkaline fuel cells have been developed mainly in Europe, the use of pure hydrogen and oxygen in such fuel cells has discouraged research of them in Japan. But alkaline fuel cells have many excellent characteristics. They can be operated at low temperatures, start instantaneously at room temperature and are more efficient than PAFC.

In 1972 Fuji Electric developed a 10 kW power unit with an alkaline fuel cell, and operated it for thousands of hours at a current density of 100 $mA/cm^2$. At the time, it was the largest such power unit in Japan.

In 1978 we developed a hydrogen-oxygen type alkaline fuel cell for the Japanese Government's Sunshine Project, and in 1981 a hydrogen-air type fuel cell for the Moonlight Project.

Since 1985 the company has developed substitutes for battery units for CVCF emergency power supplies. The substitutes, which have features of alkaline fuel cells, have been proved satisfactory in two years of field tests.

The main specification of the battery substitutes is that they should be able to supply 7.5 kW of electric power for about ten minutes with cylinders of hydrogen and oxygen. The substitutes are used to supply power uninterruptedly to computers when their main power supplies fail. This application makes use of alkaline fuel cells ability to start instantaneously.

Alkaline fuel cells can also be used in portable power supplies for construction sites, when pure hydrogen and oxygen are available. Fuji Electric is now developing an air cooled, hydrogen-oxygen fuel cell unit for use at such sites. The fuel cell unit is light, compact and has a simplified structure.

Alkaline fuel cell material costs are lower than those for other types of fuel cells. If such cells can be produced in quantity, their manufacturing costs can be reduced to the level where the prices of alkaline fuel cells should be competitive with those of batteries in CVCF power suppliers.

European countries are conducting experiments with alkaline fuel cells in buses. The experiments are being conducted in an effort to combat pollution in cities. We are looking forward to seeing their results when they are concluded.

## 5. FORECAST

The promotion of commercial PAFC and the development of MCFC have generated interest in fuel cells. Fuel cells are now being developed in the United States, Europe, Japan and Southeast Asia.

A provisional proposal by IFC of the United States for semi-commercial 11,000 kW and 200 kW PAFC power plants suggests that cost problems are no longer an insurmountable obstacle to the construction of such power plants. This is significant because cost has been thought as the major obstacle to the construction of PAFC power plants.

Japanese mass production technology is the most advanced in the world, therefore Japanese manufacturers will, no doubt, begin the commercial production of PAFC if we could find enough market.

European companies will probably continue to configure their own systems combined with imported PAFC fuel cell stacks from the United States or Japan.

We, Fuji Electric, intend to develop small capacity PAFC power plants, and to reduce the overall cost of fuel cell systems by expanding the market for them.