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Japanese fuel cell market projections

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Abstract

The fuel cell is one of the most promising power generation technologies which is able to mitigate the global environmental impact of energy consumption, as well as to improve efficient energy supply. The best approach to the earliest possible commercialization of this attractive technology is (i) to identify its favorable fields of application, (ii) to set a clear target as to when and how much it should be introduced and (iii) to concentrate R&D efforts toward the realization of this target. This paper introduces the prospects for commercialization of the fuel cell power generation technology in Japan, following the above approach.

1. Identification of application fields

The Agency of Industrial Science and Technology (AIST) and NEDO studied the technical and economical aspects of fuel cell systems including a break-even cost analysis in order to identify its favorable application fields.

The break-even cost is defined as investment cost per kW of a new generation technology which can realize the same value of energy cost as the one by the existing competitors. The cost of energy was determined by the equation given below.

$$\text{C.O.E. (yen/kW h)} = \frac{(\text{Investment cost}) \times (\text{carrying charge rate})}{(8760) \times (\text{capacity factor})} + \frac{\text{Fuel cost (yen/Mcal)} \times (0.86)}{(\text{power generating efficiency})}$$

where, capacity factor is the total energy output over a year divided by the product of 8760 h multiplied by the unit capacity.

1.1. Break-even cost of fuel cell systems for utility use

Dispersed power plant (Table 1)

Though fuel cost for a dispersed power plant is comparatively high, owing to its distant location from a large LNG supply base, this type of plant has advantages in saving the investment cost in electric power transmission and substation systems and also in utilizing waste heat. As a typical example, the break-even cost of the plant installed at the site with 15 thousand yen/kW year of transmission and substation credits becomes 220–270 thousand yen/kW, as shown in Fig. 1, when the life of a cell stack can be expected to be 3–5 years. This cost level is in an acceptable range

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TABLE 1

Basic conditions for break-even cost analysis for a dispersed power plant

Common	Capacity factor: 40%
LNG power plant	Investment cost: 210 thousand yen/kW Generating efficiency: 37% Fuel cost: 2.8 yen/Mcal Period of depreciation: 15 years
Fuel cell	Generating efficiency: 43% Fuel cost: 4 yen/Mcal Period of depreciation: 15 years for balance of plant (BOP) Life of cell stack: variable parameter

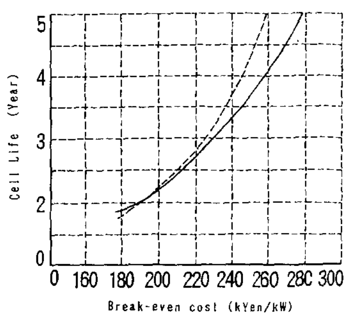

Fig. 1. Result of break-even cost analysis: —— dispersed power plant; - - - on-site co-generation.

for future technology development, which suggests that the phosphoric acid fuel cell (PAFC) is promising for future commercialization for this application.

Large-scale centralized power plant

The break-even cost of a central power plant with approximately 5 years of a fuel cell stack life is about 180 thousand yen/kW. As this cost level is considerably more than that of existing LNG power generating systems with 40% efficiency, the molten carbonate fuel cell (MCFC) system with 50–55% power generating efficiency is preferable for a centralized power plant, where increased efficiency compensates increased capital cost.

Power plant for a detached island

Compared to the existing diesel generators powered by oil, the critical parameter affecting the COE by a fuel cell system is the cost of methanol. But in a reasonable range of the cost, the break-even cost for 3–5 years of cell stack life becomes 250–300 thousand yen/kW, which is also in the applicable range for PAFC.

1.2. Break-even cost of a fuel cell system for on-site co-generation use (Table 2)

The break-even cost of a customer-owned co-generation system by fuel cells in 220–260 thousand yen/kW with 3–5 years of cell stack life, as shown in Fig. 1. The cost analysis suggests that the fuel cell system is extremely promising for application in areas where the demand for heat is large and where the variation in heat and

TABLE 2

Basic conditions of break-even cost analysis for an on-site co-generation plant

Common	Capacity factor: 40% Fuel cost: 4 yen/Mcal Total thermal efficiency: 80%
Gas engine system	Investment cost: 220 thousand yen/kW Generation efficiency: 30% Period of depreciation: 5 years
Fuel cell	Generating efficiency: 38% Period of depreciation: 5 years for BOP Life of cell stack: variable parameter

electricity demand has a similar pattern with time. Good examples are hotels, hospitals and restaurants.

1.3. Other application fields

Although no break-even analysis was performed, the following are expected as potential user fields of fuel cell systems.

Industrial co-generation

Application to the industrial sector is also attractive, for example in the food industry, dyeing industry and elsewhere, where the thermal load remains at a relatively low level, 170 °C or less. In a field which requires a much higher temperature, a MCFC or solid oxide fuel cell (SOFC) should be applied.

Utilization of by-product hydrogen or direct current power

This includes industries such as the ethylene plant which produces hydrogen as a by-product and industries such as the salt electrolysis process plant which uses direct current power.

Transportation application

This group includes electric vehicles such as buses, trucks and delivery vans, driven by a fuel cell system or a hybrid system with storage batteries.

2. Estimation of potential market of PAFC

The most promising and large scale application fields of PAFC in Japan are (i) district heat supply systems and (ii) co-generation systems in large scale buildings.

2.1. Potential market of PAFC for district heat supply systems

In Japan, the present share of a district heat supply business in only 0.5% of the total heat demand in the commercial field, which suggests the possibility for further growth. Potential business sites are the areas specified as urban redevelopment plan areas and new town planning areas where land is used for large-scale housing.

By forecasting total floor area of new buildings and other factors in urban redevelopment plan areas, the annual average potential market of fuel cell systems in the 2000s was estimated as shown in Table 3.

TABLE 3

Potential market of PAFC for district heat supply systems

	Urban redevelopment plan area	New town plan area
No. of areas	544	1065
Total development area (ha)	132000	88000
Estimated total floor area (ha)	1900	1800
Estimated annual heat demand (Tcal)	2200	1800
Potential annual market of fuel cell plants in 2000s (MW/year)	1040	840

TABLE 4

Potential market of PAFC for customer-owned co-generation systems

Capacity of fuel cell system (MW)	1	3	5
Potential demand of fuel cell system (MW/year)	510	220	160

2.2. Potential market of PAFC for customer owned co-generation systems

Another promising market is to introduce medium capacity fuel cell systems (1000 kW or greater), as well as small size systems into individual buildings with a large heat demand throughout the year.

By forecasting the future floor area and other factors of future large buildings, the potential demand was estimated as shown in Table 4.

Thus, the total value of the potential market for large (1000 kW or more) fuel cell systems in the commercial sector was estimated to be approximately 2400 MW/year in the 2000s.

3. Prospect for the introduction of fuel cell systems

MITI published a report on the long-range view of Japan's energy supply and demand in June 1990. The following are the main results of the report.

(a) The elasticity of energy consumption per GNP unit should be reduced from 0.98 of the current value to 0.42 by 2010, by enforcement of a strict energy savings policy.

(b) To achieve this target value and to promote the aggressive utilization of otherwise wasted energy, co-generation systems mainly using fuel cell systems should be expanded from the proposed 50 000 kW to 70 times that figure by 2010.

In parallel, the Committee of Supply and Demand of the Electric Power Industry reviewed a long-range supply and demand of electric power and published a report in June 1990. This report stated:

(a) The promotion of nuclear power generation and the formulation of an optimum power plant mix should be achieved. The positive introduction of dispersed power systems should be carried out with the utilization of new energy technologies such as power generation by fuel cells, solar cells and wind power.

(b) Among the many types of dispersed power systems, the use of the fuel cell in particular is expected to increase in the future. An estimate of fuel cell capacity is listed in Table 5.

These quantitative target values gave a strong promotional impact to both users and manufacturers for the introduction of fuel cells into various fields.

4. Present state of research and development of fuel cell systems

Presently NEDO, Japanese fuel cell industries and users are making every effort to achieve the target given above.

In Japan, a systematic fuel cell national project was started in 1981 as part of a R&D project on large-scale energy saving technology (Moonlight Project) sponsored by the AIST of MITI. NEDO is promoting this project as an implementing agency.

4.1. PAFC project

NEDO completed the PAFC project with a 1 MW power plant for utility power and a 200 kW system project for on-site use in fiscal year 1990. In the 200 kW project, NEDO developed two types of PAFC system, one for a remote island and the other for commercial use, and carried out demonstration tests of both systems. Main system performance results are shown in Table 6.

200 kW System for remote island sites

This system is for all-electric power generation. It was installed on a small island to supply electricity to local customers. Net generation efficiency (HHV) attained 39.7%, the world record for an unpressurized PAFC plant.

200 kW System for commercial use

Another NEDO 200 kW system is intended for co-generation use, and was installed at a city hotel to demonstrate its practical features. High-grade heat (170 °C steam) could be recovered and utilized for the air-conditioning system for guest rooms, which was the first successful demonstration of this technology for the PAFC. Hot water of 70 °C was also supplied.

High-efficiency turbo-compressor

A turbo-compressor for a 5 MW class plant with an efficiency of 74.2% was developed by applying new technologies such as air-bearings, three-dimensional impellers and a high speed rotor.

TABLE 5

Target value of introduction of fuel cells

	Year	
	2000	2010
Commercial use	900 MW	2800 MW
Industrial use	300 MW	2400 MW
Utility use	1050 MW	5000 MW
Total	2250 MW	10700 MW

TABLE 6

Performance of 200 kW PAFC plants

Items	Detached island use	Co-generation use
Fuel	methanol	city gas
Net a.c. output (kW)	202	200
Net generating efficiency (HHV) (%)	39.7	36.0
Total thermal efficiency (HHV) (%)		80.2
Temperature of recovered heat (°C)		170, 70
Total operation hours (h)[a]	8499	11567
Load following	instant. for 20%	instant. for 20%
No_x (ppm)	2 (O_2=7%)	4 (O_2=7%)

[a]Up to Aug. 15, 1991.

4.2. MCFC project

At present, the second-stage plan of the development of a 1000 kW class pilot plant and operational test is being conducted. In order to achieve this target by 1997, a 100 kW class cell stack, peripheral equipment and system technology is to be developed and assessed at a mid-term interval in FY 1993.

Development of large capacity cell stacks

Large capacity cells with an electrode area of 1 m^2 were developed successfully using the following two types of cells.

Multiple type. This is a large, square cell consisting of 4 small cells with total electrode area of 1.2 m^2. By using 22 cells, a 25 kW class stack was developed in FY 1989 which reached an output of 28.3 kW, the world's highest to date. Following this, a 25 kW class cell stack for pressurized operation was developed in FY 1990 and its performance in pressurized operation was confirmed.

The development of a 100 kW class cell stack for pressurized operation will start in 1991.

Rectangular type. This is a large cell, of rectangular shape with electrodes of 560 mm × 1800 mm, the world's largest for a single cell. By using 10 cells, a 10 kW class stack was developed, and an operational test was carried out during FY 1989 and 1990. After a 50 kW class cell stack for atmospheric pressure operation is developed and tested in 1991, a 100 kW class cell stack for pressurized operation is to be developed by FY 1993.

Internal reforming type. The electrode area of these cells was expanded to 5000 cm^2 class in FY 1989, a prototype of a 3 kW class stack was developed by stacking these cells, and operational performance was evaluated. Total operating period was 5070 h. A 5 kW sub-scale stack (900 cm^2 × 50 cells) was then developed to study key issues such as heat balance and other problems associated with a tall stack.

A 30 kW class cell stack for atmospheric pressure operation is to be developed in FY 1992.

BOP technology development

Peripheral equipment and plant operational control technology used for the 1 MW class pilot plant are being developed alongside cell stacks. The main items for development are control technology for gas recycling, a MC scrubber, a high temperature blower, catalytic combustion reformers for MCFC, a heat recovery steam generator, a turbine compressor and other equipment.

Improvements in BOP and control technologies, as well as 100 kW class cell stacks will be put on test at the Akagi Stack and System Square of the Technological Research Association of MCF Generation Systems. ASSS was opened in autumn of 1990.

4.3. SOFC project

In 1989, NEDO started a three-year R&D project to develop basic fabrication technologies using five different approaches for four planar and one tubular SOFC. The project is to be completed at the end of fiscal year 1991.

NEDO is planning to start a new six-year SOFC project during the next fiscal year, whose main objectives are the development of 10 kW SOFC modules, internal reforming technology, among others.

4.4. New project on PAFC

After the success of the PAFC project under the Moonlight project, NEDO is about to start a new project to promote commercialization of the PAFC during 1991.

Target of the project is to develop 5 MW pressurized and 1 MW unpressurized plants and to perform demonstration tests of both until 1996. To promote this project, a new PAFC research association was founded by nine power companies, the Central Research Institute of the Electric Power Industry and four gas companies.

4.5. R&D activities in private sector

In addition to the national projects, research and development of various types of fuel cells is actively being promoted in the private sector.

For the PAFC for example, Tokyo Electric Power Company started the operation of the world's largest plant (11 MW) in 1991, and Tokyo Gas, Osaka Gas and Toho Gas Company started a commercialization program for 50 and 100 kW systems of packaged type. Products resulting from this project are expected to be put on the market in 1993.

Kansai Electric Power Company is about to install a 25 kW Westinghouse SOFC module jointly with Osaka Gas and Tokyo Gas to assess its performance as a power source for utilities. KEPCO is also developing a 100 kW class MCFC stack of the indirectly internal reforming type.

5. Commercialization program and critical issues to perform the program

In the author's opinion, the commercialization program of fuel cell systems in Japan within the period 2000 to 2100 may be summarized as shown in Fig. 2.

Success in the commercialization of a fuel cell generation technology depends on how to resolve the key issues described below.

(1) The improvement cost in performance ratio:

Further acceleration of technology development and field experience at demonstration plants should be performed to create attractive products which can compete with existing technologies. The most important issues are:

(a) Cost reduction

The target is 250 thousand yen/kW. Key strategies are to improve the performance of cell stacks, reformers, heat exchangers and inverters, and thus make them more

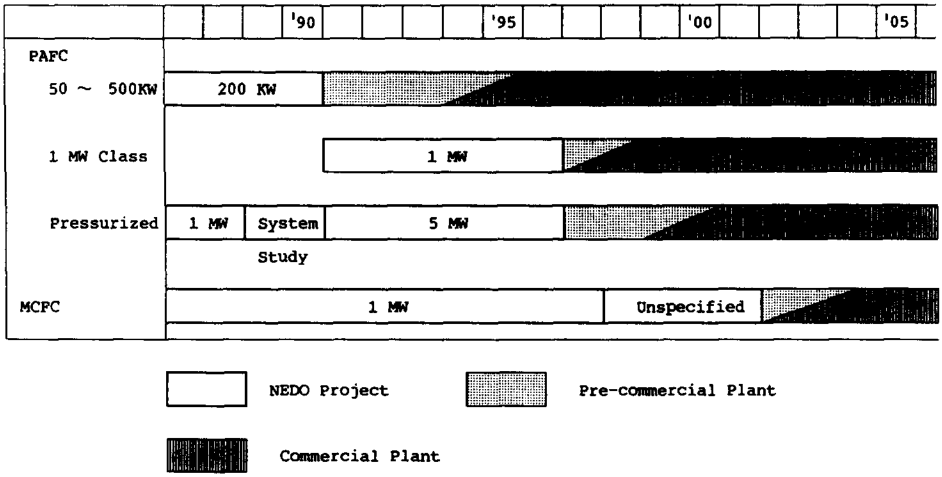

Fig. 2. Fuel cell commercialization program.

compact. The optimization and standardization of the system structure, automated plant assembly and of the quality control process are also important.

(b) Improvement of reliability

(2) The improvement in the environment for easier social acceptance of fuel cell systems

This includes items supported by the national government and other public organizations, as follows:

(a) to give incentives to users through model projects, low interest loans, preferential tax systems, etc.

(b) to develop systematically the infrastructure, including the fuel supply network and heat energy distribution network.

Activities for better understanding of the important features of fuel cell systems by users are also necessary.

Conclusions

NEDO will actively continue its contribution to a full scale commercialization of fuel cell systems in Japan and also abroad by combining government policy and private sector's vitality and also by promoting international cooperation activities through the Implementing Agreement on Advances Fuel Cells prepared by IEA and others.