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TOKYO ELECTRIC POWER COMPANY APPROACH TO FUEL CELL POWER PRODUCTION

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Introduction

Fuel cells, which were first described in the 19th century as a direct power generation method, are currently regarded as being viable. Energetic efforts are continuing mainly in the U.S.A., Japan and Europe to establish fuel cell power as a new technology for residential and commercial sectors. Fuel cells can be classified into the alkali type and the phosphoric acid type, which belong to the 1st generation; the molten carbonate type and the solid oxide type which belong to the next generation. Different components and system configurations are used due to the differences in electrolytes and operating temperatures. From the standpoint of use, they are classified roughly into fuel cells for on-site generation (several hundred kilowatts) and those for distributed generation (several megawatts).

The following describes the Tokyo Electric Power Company's involvement in the development of phosphoric acid, molten carbonate and solid oxide fuel cells. It introduces the company's plan to develop phosphoric acid fuel cells which are considered the most practical at present. An 11 MW plant under construction in Chiba Prefecture is outlined and the themes and trends of the development are reviewed.

Development of fuel cells

Development of phosphoric acid fuel cells

During the latter half of the 1970s, the Tokyo Electric Power Company recognized the importance of research and development (R&D) for distributed power sources located near consumers as well as concentrated large-capacity power sources for stabilizing power supply in the future. As fuel cells are a most promising new power source for this purpose, TEPCO began investigation and research.

In 1980, we introduced a 4500 kW phosphoric acid water-cooling experimental plant (supplied by United Technologies Corporation) from the

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U.S.A., which represented the most advanced technology at the time in this field. The tests were started at the Goi Thermal Power Plant outside of Tokyo, Japan. In April 1983, we succeeded in generating power and continued the tests until December, 1985. Since then, many technological ideas have been acquired and a foothold in the technology for practical use has been established. Table 1 shows the generation performance at the end of the test period.

After thoroughly studying the results of the tests, it was decided to introduce an 11 MW plant from Toshiba (fuel cells were manufactured by International Fuel Cells (IFC)). TEPCO made a significant contribution to the design by conducting a feasibility study, making various improvements in component development. Foundation work began in January 1989, with plans to commence testing in January 1991.

For independent power supplies, TEPCO began to develop a standard atmospheric pressure air-cooled 200 kW-class system in 1986 using Japanese technology. Testing began at the Shin-Tokyo Thermal Power Plant in September, 1987. Subsequently, two 200 kW class systems were imported from IFC in 1988. One was installed and tested in the Shin-Tokyo Thermal Power Plant with the air-cooled system. The other was installed and tested in a building in Shibaura, Tokyo.

Development of next generation type fuel cells

A feasibility study for a molten carbonate fuel cell to be used in a power plant was begun in 1984. Based on the feasibility study results, the

TABLE 1

Operational records of a 4500 kW plant

(1)	Power generation test	
	Test period	April 83 ~ Dec. 85
	Initial power generation	April 83
	Rated power generation	Feb. 84
(2)	Cumulative gross electric power	5428240 kW h
(3)	Cumulative operation practice	
	Power generation	2423 h
	Stand by	464 h
(4)	Maximum continuous power generation	500 h
(5)	Hot times	
	CSA	4233 h
	Reformer	4098 h
	Auxiliary burner	3787 h
	TMS burner	1661 h
(6)	Cycles	
	CSA	50
	Reformer	68

power plant showed great promise, particularly in view of its compatibility with a coal gasification plant. TEPCO then began fundamental research in 1986. Presently, this research is being directed to problems concerning various materials of the fuel cell and its technological characteristics.

Separate investigations and research on a solid oxide fuel cell were begun in 1985. Presently, components are being developed by making a prototype concurrently with investigation and research.

The Tokyo Electric Power Company considers that the next generation of systems can be put to practical use only after development of a phosphoric acid system is realized. That is, use of molten carbonate and solid oxide fuel cells for practical purposes is not possible without sufficient development and experience of a phosphoric acid fuel cell.

Commercialization of phosphoric acid fuel cells

Development policy

Recently, industries, government agencies and universities have shown an increasing interest in cogeneration systems due to their effective energy utilization and cost reduction.

In fact, cogeneration installations using gas turbines, gas engines, diesel engines, etc., have markedly increased recently. The Tokyo Electric Power Company believes that fuel cells will become important cogeneration systems in the future due to their efficiency and environmental advantages. This belief is based on test experiments of a 4500 kW plant and a 200 kW air-cooled system.

Fuel cells are classified into an independent supply type and a regional supply type. On the basis of market survey results, a 200 kW class plant and a 10 MW class plant are adequate in size for independent (on-site) supply and regional (distributed) supply, respectively. These two projects will now be discussed.

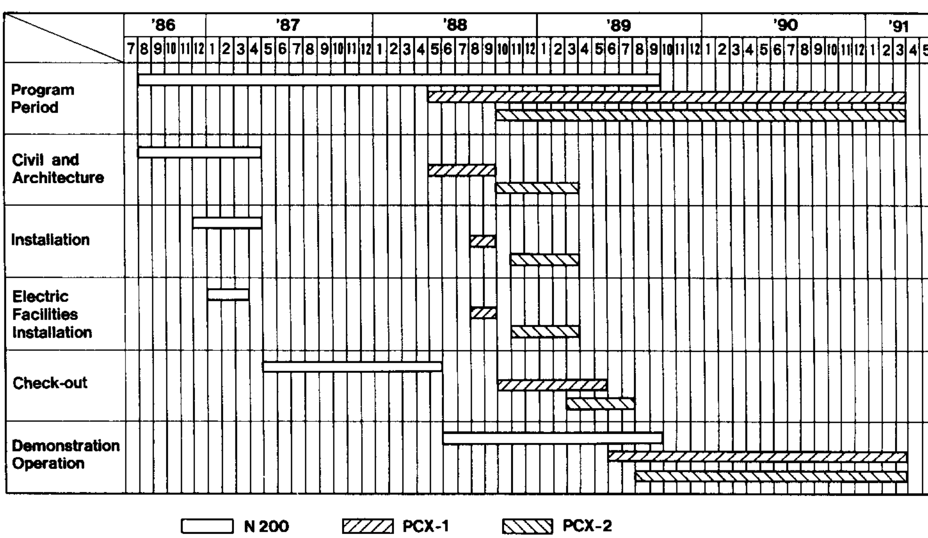
Development of 200 kW system for individual supply

A system for independent supply was installed in hotels, hospitals and other buildings which have a large demand for heat. Presently, the 200 kW air-cooled system, which was developed jointly with the Sanyo Electric Co., and the 200 kW water-cooled system, which was purchased from IFC, are being tested. The air-cooled system and one of the water-cooled systems are being tested in the Shin-Tokyo Thermal Power Plant. The other water-cooled system was installed in the basement of the Kandenko Building located in Shibaura in Tokyo. Plans have been made to investigate the characteristics and reliability of 200 kW class fuel cell power plants and study their suitability for independent power supply. Table 2 shows the specifications of the air-cooled and the water-cooled systems, and Scheme 1 shows the test schedule. Figures 1 and 2 show flow diagrams for these systems, respectively. The following results were obtained from tests of the 200 kW water-cooled fuel cells.

TABLE 2

Specifications of a 200 kW test plant

	Air-cooled (N200)	Water-cooled (PCX)
Rated power (kW (a.c.), gross)	220	200
Output voltage (V (a.c.))	210	210
Minimum power (kW (a.c.), gross)	50	50
Controlled power range (%)	22.7 - 100	25 - 100
Electrical efficiency (% gross, HHV)	35	35 ~ 38
Waste heat recovery rate (%)	40	45
Overall thermal efficiency (%)	75	80 ~ 83
Base fuel	city gas	city gas
Fuel consumption at rated power (Nm^3/h)	60	45 ~ 48
Start-up time (cold, h)	4	5
NOx emission (ppm)	≤30	≤25
Noise level at site boundary (dB)	≤50	≤50



Scheme 1. Test schedule of a 200 kW plant.

(1) Rated generation was achieved (200 kW).

(2) Generation efficiency nearly matched the design efficiency, namely, 35% (transmission end, HHV).

(3) Start up time up to initial load was 3.5 h while the designed value was 5 h (cold start).

(4) Speed of output change was 15 s for 25% - 100%, the target value.

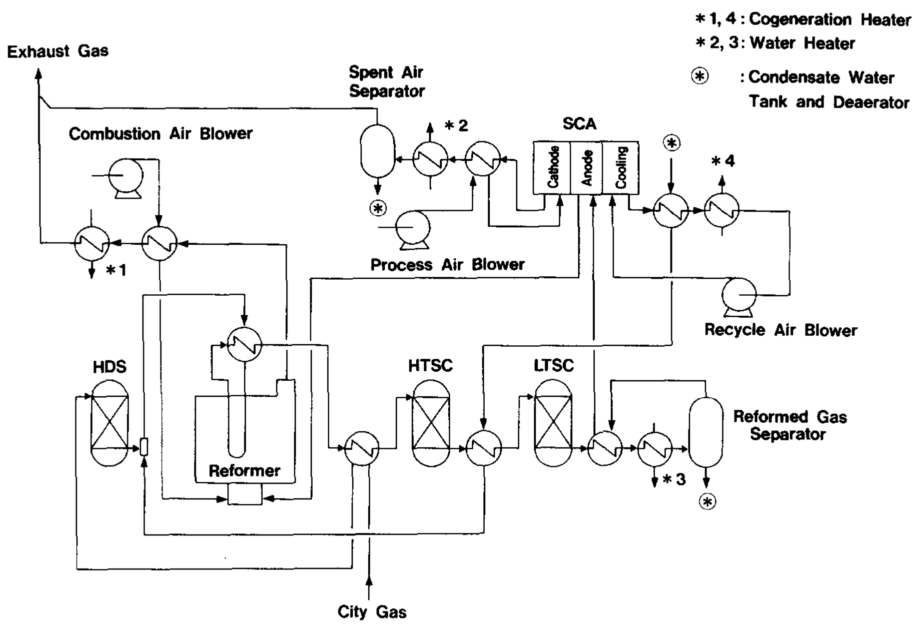


Fig. 1. System flow of an air-cooled type 200 kW plant.

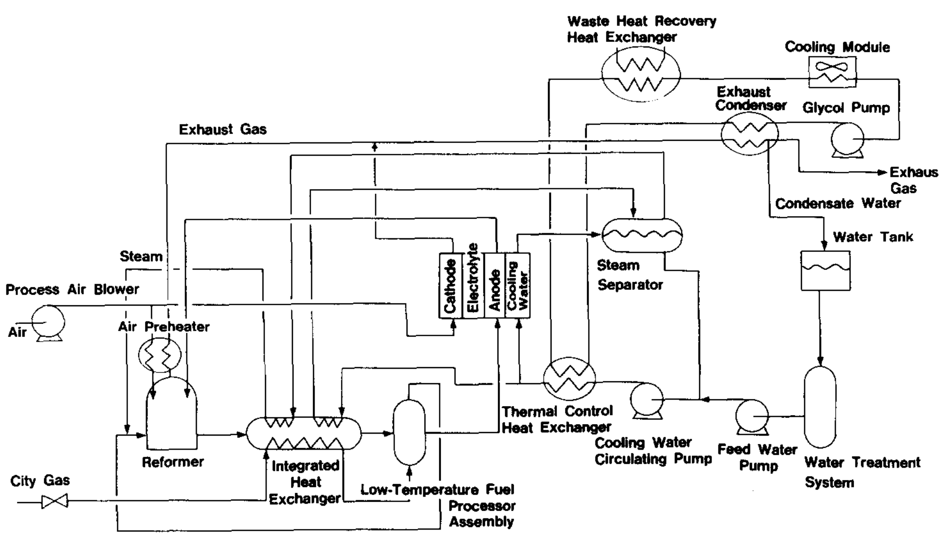


Fig. 2. System flow of a water-cooled type 200 kW plant.

(5) Harmonic voltage distortion was about 1.2% during the rated operation while the designed value was below 3% (overall).

(6) Environmental characteristics were extremely good. NOx, SOx and dust levels were below the detection limits at the exhaust tower outlet.

Development of 11 MW system for regional supply

TEPCO began construction of an 11 MW test plant at the Goi Thermal Power Plant in order to develop a regional supply system which could be constructed in urban redevelopment sites and other areas having a large energy demand. This is the world's largest fuel cell plant and was developed jointly with the Toshiba Corporation and the IFC Corporation, on the basis of the 4500 kW experimental plant test results. The Tokyo Electric Power Company hopes to obtain information regarding development of a commercial system through this experiment. The plan of the 11 MW experiment plant is described below.

(1) Test items

The test aim at verifying the suitability of a phosphoric acid fuel cell as a distributed urban power source by studying the following items: (i) demonstration of a power and heat supply system, (ii) verification of plant operation performance, (iii) major component verification performance, including the fuel cells and reformer, (iv) establishment of reliable operation technology targeting automatic operation, (v) confirmation of favorable environmental characteristics.

(2) Brief description of plant

This plant is based on PC23, which was developed by the IFC Corporation and the Toshiba Corporation as a standard system for the American market. We adopted new improvements in the major components, such as the cells, reformer, turbo compressor and the inverter, on the basis of accumulated experience from the 4500 kW plant. Efforts were made to attain high reliability by testing the plant components separately at full scale in advance and by making improvements where problems occurred. The specifications were reviewed and partly changed so as to ensure compatibility with site conditions in Japan. Tables 3 and 4 show the planned performances and the specification of the principal machinery, respectively; Fig. 3 shows the system flow sheet and main characteristics. The efficiency and the capacity of cell stacks were increased by utilizing fuel cells having a large area, higher temperature and pressure operation than the earlier 4.5 MW plant. The heat load conditions of the reformer were made less severe and the NOx level was decreased by introducing exhaust gas combustion and adopting a bottom combustion burner. Circuits of the inverter were simplified by installing a large-capacity GTO. The quality and the quantity of recovered heat and the recovery cost were analyzed. Three locations which can recover heat economically were selected. Data on the range of effective utilization of waste heat and operation characteristics will be obtained.

As the adjacent area has no large demand for heat, it is planned to discharge the recovered heat by exchanging it to sea water in the future.

TABLE 3
Planned performance of an 11 MW plant

Rated power at 66 kV utility grid	11 MW (a.c.)
Output voltage	66 kV
Minimum power	0 MW
Controlled power range	30 - 100%
Controlled VAR range	—11 to +11 MVA
Electrical efficiency based on fuel HHV at utility grid	41.1%
Waste heat recovery rate based on fuel HHV	31.6%
Overall thermal efficiency (HHV)	72.7%
Base fuel	liquefied natural gas
Fuel consumption at rated power	2100 Nm^3/h
Start-up time (cold/hot)	6/2.5 h
NOx emission	$\leqslant$ 10 ppm
Noise level at site boundary	$\leqslant$ 55 dB (A)

TABLE 4
Specifications of 11 MW principal machinery

Machinery	Item	Specifications
(1) Cell stack assemby	cell stack arrangement	6(series) × 3(parallel)
	unit cell dimension	100 cm × 100 cm
Full size stack	unit cell output	670 kW
2000 h operation	operating pressure	7.4 kg/cm^2 g
	operating temperature	207 °C
(2) Reformer	reformer tube material, number	superalloys, 54
Full size simulator	operating pressure	approx. 10 kg/cm^2 g
Burner characteristics	combustion method	spent air mixing
Temperature distribution		lower portion burner
(3) Turbocompressor	type	generalized design lateral, 2 shafts
Full size model	arrangement	2 stage series with intercooler
Start-up operation characteristics	lubrication	oil
	start-up	air injection to compressor blade
Burner characteristics	delivery pressure	approx. 8 kg/cm^2 g
(4) Inverter	capacity	11800 kV A
Full size inverter, reactor	bridge number	3 pair × 18 poles
Transformer, controller	power device, number device	GTO thyristor, 36
Operation characteristics	device rated value	5000 V × 2500 A
	control signal transmission	optical fiber
	exciting method	self exciting
(5) Waste heat recovery	waste heat recovery rate	
	(HHV, gross)	41.3%
	(HHV, net)	31.6%
	heat recovery facility	CSA cooling water cooler
		fuel gas cooler
		cathode spent air cooler

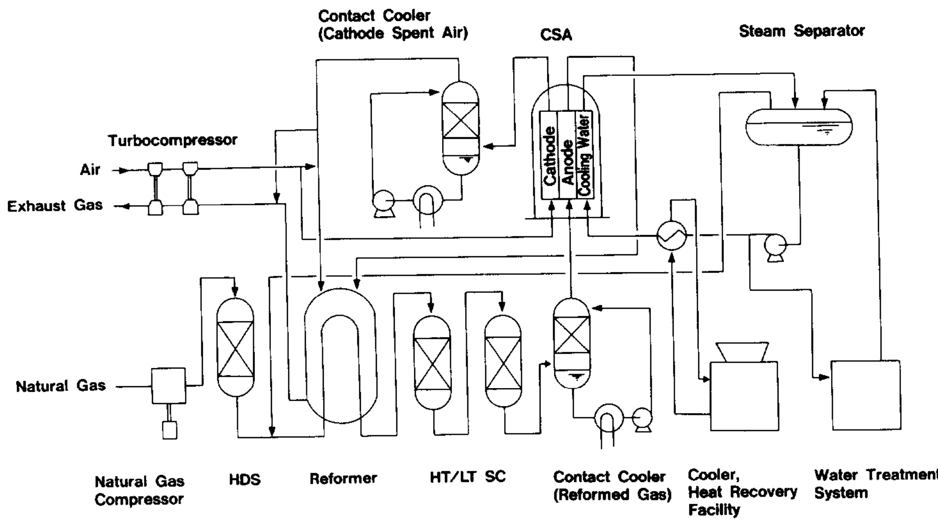
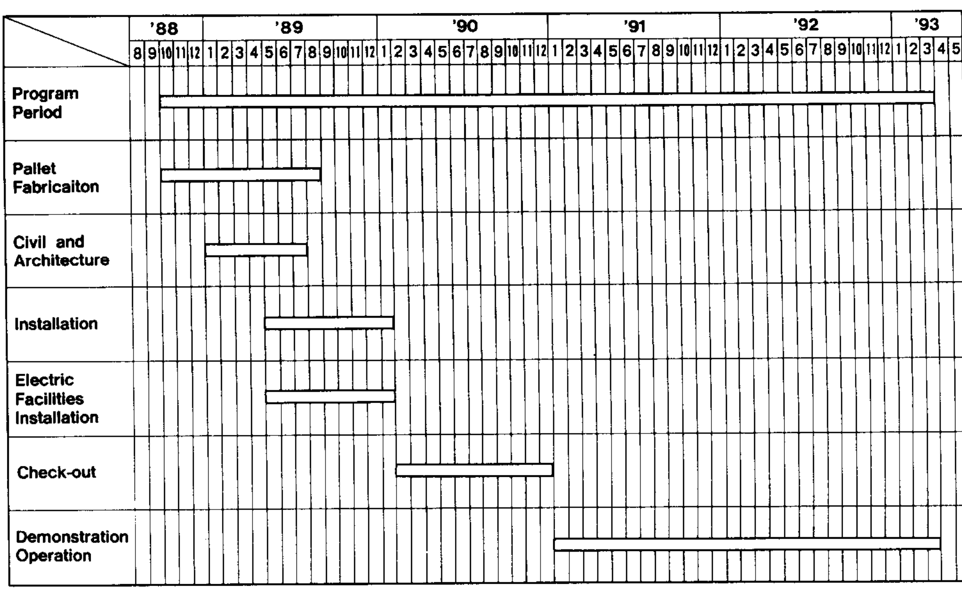


Fig. 3. System flow of an 11 MW plant.



Scheme 2. Test schedule of an 11 MW plant.

(3) Schedule (Scheme 2)

The Tokyo Electric Power Company began this construction project in July 1988, through site preparation, with the civil engineering work starting on January 20th, 1989. Toshiba's Keihin Plant began production of pallets (a pallet is a unit which has built-in machinery process vessels and pipes) in October 1988. Pallets produced at the plant will be site-installed and connected with pipes to complete the plant. Construction work for machinery and pallet installation will be carried out throughout the year. PAC (Process and Control) tests will be started in February 1990. An approximate 2-year test period will begin in January 1991.

Commercialization obstacles

In order to commercialize a new technology, it must be both technologically and economically sound. A fuel cell has the following characteristics: (i) improvement of operation reliability, (ii) compactness of system (footprint reduction), (iii) reduction of construction costs. The inherent characteristics of a fuel cell for regional supply will be discussed later with reference to the 11 MW plant, which is now under construction.

Operation reliability

The reliability of the cell itself must be raised. In small laboratory tests using simulated gas, the cell exceeded 40 000 h in some cases. According to field tests, the record of a GRI plan (40 kW) is 15 000 h and that of a MW class system is about 2500 h.

Cell life must be at least 40 000 h and preferably more than 60 000 h for purposes of commercial use.

On the other hand, the service life of the reformer is another factor in achieving high reliability. The need for compactness and rapid load following is required to offset the severe increase of the reformer's heat load change. This has been the principal cuase of plant problems.

Compactness

The 11 MW plant now being constructed is about 0.3 m^2/kW, and is larger than that of present competitive technologies. The footprint should be as small as possible to meet the requirements of cogeneration systems being planned for urban areas. This is an important factor, particularly in Japan, where land prices are high. Our target for commercialization is 0.1 m^2/kW in the case of a 10 MW class plant.

Construction cost

In the case of the 10 MW plant, the current construction cost is approximately 1 million yen/kW, which is still higher than that of existing systems. It should be lowered to 200 - 300 thousand yen/kW (in consideration of the merits of the fuel cell). The merits of fuel cells include lower NOx levels, greater thermal efficiency, lower transmission and distribution costs, and reduced transmission loss due to the vicinity of the consumers. Some reports on the future forecast of fuel cell costs indicate that their competitive strength in costs can be increased sufficiently by the establishment of a mass production factory. The largest reduction cost factor is the fuel cell modules which currently account for 50% of the total plant costs. It is predicted that the manufactured cost of the cells can be lowered to almost 1/10 by technological improvements and mass production.

Measures for solving problems and future prospects

Greater efforts must be made to solve the problems discussed in the preceding section. The Tokyo Electric Power Company is considering the following steps for attaining these targets.

Simplification of system

The performance and reliability of individual machinery and the plant by testing the 11 MW plant will need to be confirmed. The system will be simplified by eliminating the sensors which are incorporated for diagnostic purposes. Other simplification measures include eliminating redundant machinery, reducing the pallet size and simplifying the system on the assumption of attaining fully automatic/unmanned operation. Plant space can be reduced by adopting a hierarchical structure, by installing a reformer and cells in the basement level and by rationally reducing maintenance space.

Promotion of technological development

In parallel with the tests, development of the following component technologies will be promoted to attain greater compactness and to reduce costs. For example, TEPCO will increase the capacity of the stack and improve its durability by increasing the cell's power density and developing a large area cell. Also, performance of the reformer will be raised by improving catalyst performance, heat transfer method, etc. The inverter bridges and d.c. circuits will be improved and other improvements made on electrical machinery. The low temperature carbon monoxide reactor will be eliminated, efficiency of the turbo compressor will be raised and failure diagnosis technologies will be developed.

Operation of semi-commercial plant

TEPCO plans to design an improved plant on the basis of the aforementioned improvements, and will confirm that these technologies are suitable for the purposes of commercial use. TEPCO will also establish operational technologies, including the applicability to a power heat supply system, and will construct and operate the plant according to its design conditions.

Efforts for mass production

The last step is mass production. At this stage, the construction costs can be lowered considerably by a mechanization/automation process, mastery/standardization of operations, and by cost reduction of materials and machinery through bulk purchase. In other words, the achievement of mass production is the key to commercialization. Naturally, fuel cell demand must increase to enable mass production. This is difficult to achieve by the efforts of only one company or one country. International cooperation is essential. Learning from the past PC 23 Project, the American Public Power Association (APPA) recently announced a NOMO (Notice of Market Opportunity), which requests cell makers to promote commercialization of phosphoric acid fuel cells for distributed installation. Cooperation between makers and users as proposed in this report is essential. In addition to these technological efforts, administrative cooperation is also necessary. For example, the related legal regulations must be improved, tax credits must be given and long-term low interest loans must be provided.

Conclusions

The development of fuel cell power generation, which is expected to become a distributed power source in the future by using phosphoric acid fuel cells, has been discussed. There are many problems still to be worked out for commercialization of fuel cells. These include the development of individual components, such as cells and reformers, the optimization and tests of an integrated system, the improvement of manufacturing technology for cost reduction, and the promotion of mass production by increasing fuel cell demand. A multi-lateral approach is necessary in order to overcome these difficulties and to successfully realize phosphoric acid fuel cell power generation. There is also an urgent need to grasp the current situation accurately and to device an overall strategy. Cooperation among different industries and countries is a prerequisite.