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Long-term commitment of Japanese gas utilities to PAFCs and SOFCs

Kiyokazu Matsumoto [a,*], Komei Kasahara [b]

[a] *Fuel Cell Development Department, Osaka Gas Co. Ltd., 5-11-151 Torishima, Konohana, Osaka 554, Japan*
[b] *Fuel Cell R&D Department, Tokyo Gas Co. Ltd., 1-16-25 Shibayra, Tokyo 105, Japan*

Abstract

Tokyo Gas and Osaka Gas have been committed to addressing the energy- and environment-related issues of Japan through promotion of natural gas, an energy friendly to the environment. Being aware of the diversifying market needs (e.g. efficient energy utilization, rising demand for electricity, etc.), active efforts have been made in marketing gas-fired air-conditioning and co-generation systems. In this process, a high priority has also been placed on fuel cells, particularly for realizing their market introduction. Since their participation in the TARGET Program in USA in 1972, the two companies have been involved with the field testing and operation of phosphoric acid fuel cells (PAFCs), whose total capacity has amounted to 12.4 MW. The two companies have played a vital role in promoting and accelerating fuel cell development through the following means: (1) giving incentives to manufacturers through purchase of units and testing, (2) giving feedback on required specifications and technical problems in operation, and (3) verifying and realizing long-term operation utilizing their maintenance techniques. It has been expected that the primary goal of the cumulative operation time of 40 000 h shall be achieved in the near future. Work has also been in progress to develop SOFC. In the joint R&D of a 25-kW solid oxide fuel cell (SOFC) with Westinghouse, the record operation time of 13 000 h has been achieved. Though still twice as much as the average price of competing equipment, the commercialization of PAFCs is close at hand. By utilizing government spending and subsidies for field testing, work will be continued to verify reliability and durability of PAFCs installed at users' sites. These activities have been expected to contribute to realizing economically viable systems and enhance market introduction. The superlative advantages of fuel cells, particularly their environment-friendly qualities, should be best taken advantage of at an appropriate time. In order to achieve smooth introduction of fuel cells into the market, immediate action is seriously needed to re-examine the roles of users, manufacturers, and governments, thereby consolidating the efforts of the parties concerned in the most effective manner. © 1998 Elsevier Science S.A.

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1. Introduction

The debate on environmental issues has raged for some time now. Yet the development of fuel cell technology had been under way well before the environment became an issue. Indeed this tremendous technology was well ahead of its time. Unfortunately, however, the technology which can realize the cost reduction and the reliability has not lived up to expectations as we look back over the past few years. Fuel cells must be commercialized while they still hold such great promise in everyone's mind.

This paper will begin by analyzing the energy situation as well as the business environment of gas companies as a backdrop for understanding exactly why Japanese gas companies have been so enthusiastic about developing fuel cells. Next, it will look into the status of fuel cell operations as well as efforts to develop suitable technologies for fuel cells markets, especially in the phosphoric acid fuel cell (PAFC) and solid oxide fuel cell (SOFC). Finally, the paper will propose measures needed in the very near future in order to commercialize fuel cells.

2. Energy policy in Japan

2.1. Environmental issues

The Third Conference of Parties to the United Nations Framework Convention on Climate Change (COP3) was held in Kyoto, Japan, in December 1997. It is clear that some progress has been made towards shifting from the discussion stage to the implementation stage since the United Nations Conference on the environment in Brazil in

* Corresponding author.

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1992. These environmental issues are inseparable from energy issues, and they have huge impacts on the management of energy companies. One cannot neglect the discussions on the environment issues at these international venues.

2.2. Energy demand

The 'Long-term Energy Demand and Supply Outlook' published every few years by Japan's Ministry of International Trade and Industry (MITI) is an important basis for understanding the Japanese energy policy. This is not simply a projection of the country's energy situation, but is an indication of the goals of our energy policy as well. The latest figures were revised in September 1994. As shown in Fig. 1, the target for the total final energy consumption will be 359 million tons of oil-equivalent in the year 2000 and 391 million tons by 2010. However, these targets are not achievable as the actual consumption for 1995 was already 359 million tons. By the same token, the amount of carbon dioxide emissions reached 345 million tons of carbon-equivalent by 1995. Since this is a huge increase over the 320 million tons for 1990, tremendous efforts using all available resources will be needed in order to reach the target of stabilizing this emission at the 1990 level by the year 2000. This is why the Agency for Natural Resources and Energy in the MITI that has control over the Japanese energy policy has begun revising the prospects for long-term energy demand.

2.3. Energy supply

Fig. 2 shows various comparisons such as dependence on energy imports for major countries in 1994 taken from the IEA Energy Balances. Although Japan took drastic steps to reduce its dependence on oil after the first and second oil crises in the 1970s, oil still maintains the largest share (56%) among all primary energy supplies today. Nearly 100% of all oil is imported.

Since nuclear power is considered a domestic energy in energy statistics even though uranium ore is imported,

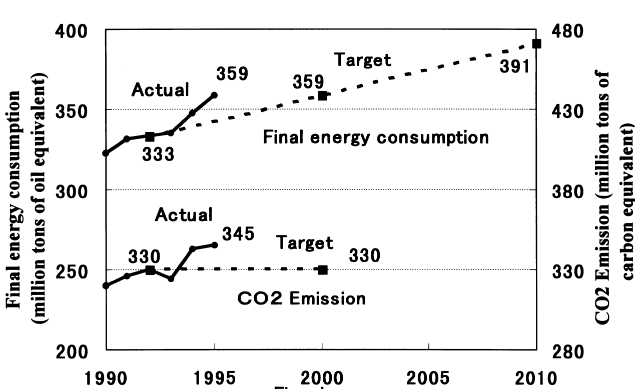

Fig. 1. Final energy consumption and CO_2 emission. Long-term energy demand and supply outlook (MITI) etc.

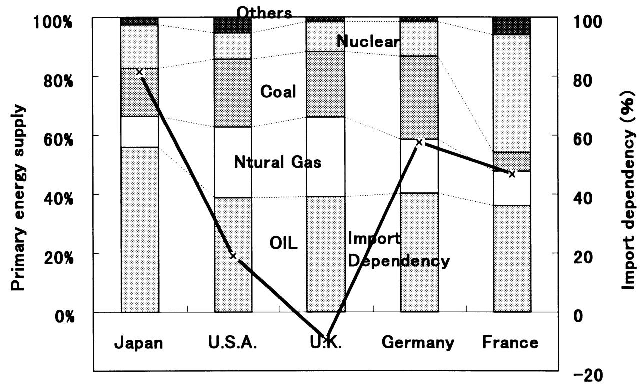

Fig. 2. Primary energy supply and dependence on import. IEA energy balances, 1994.

Japan's dependence on imports in terms of total primary energy supplies is actually 82%. The energy situation in Japan is radically different from that of Europe and North America where they have their own natural resources. The energy policy of Japan promotes natural gas and nuclear power mainly from the standpoint of environment and security of supply.

2.4. Deregulation in the energy industries

The deregulation has been under way in Japan since the 1980s in the communications and transport sectors. In the electric and gas industries, economic regulations are being eased to encourage price competition. The Electric Utility Industry Law was revised in 1995 to eliminate the need for approval from the MITI for entrance into the electricity wholesale market, creating the independent power generation business. Although Japan lags behind the UK and the United States in this area, independent power producers are steadily gaining ground in the Japanese power market.

There are currently 10 power companies throughout Japan, and six of these companies opened the first power bids in the country last year. For the total of 2.65 GW offered by power companies, the bids from individual companies reached four times the offer at 10.81 GW. Table 1 shows the bid results for the power companies. Although oil and steel companies were generally successful bidders, Osaka Gas made a successful bid to supply Kansai Electric

Table 1

First power bids in Japan (unit: megawatts)

Electric Power Co.	Plan	Offer by IPP	Successful bid	
Tokyo	1000	3860	1100	Petrochemical etc.
Kansai	1000	3580	1123	Osaka Gas etc.
Chubu	200	1150	270	
Kyushu	200	1025	274	Steel company etc.
Tohoku	155	850	180	Steel company etc.
Hokkaido	100	345	100	Steel company etc.
Total	2655	10813	3047	

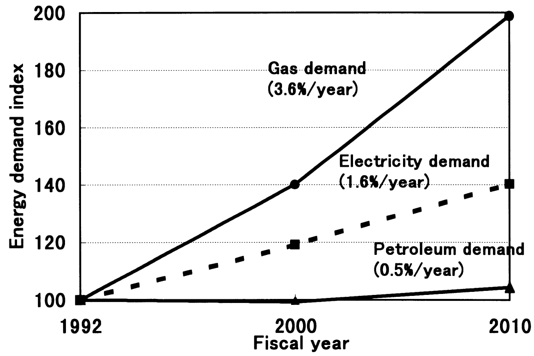

Fig. 3. Growth of final energy consumption toward 2010. Long-term energy demand and supply outlook (MITI).

Power Company Limited and plans to start operating a combined cycle power generating plant based on natural gas by the year 2002.

2.5. Summary of efforts to solve energy issues

To summarize the above, the energy issues facing Japan today are (1) environmental issues, (2) stable energy supply, (3) maintaining economic growth while somehow preventing an energy demand explosion and (4) cost reductions brought about by deregulation in energy markets.

Japanese gas companies are aggressively tackling these issues as each contain issues that have a direct impact on the companies. Next, let us examine efforts on the part of gas companies that are related to energy issues.

3. Gas companies and energy issues

3.1. Japanese gas industry

The structure of the energy industry varies from country to country. In Japan, we have a very large number of gas companies totaling 244. The number of households supplied with gas is nearly 24 million which comprise about half of the total in the country. Total gas sales stand at about 21 billion m^3. Despite the large number of gas companies, Tokyo Gas and Osaka Gas combined supply over half the Japanese market in terms of sales volume and the number of households supplied. Of the total number of households supplied by gas companies, Tokyo Gas accounts for about 34% while Osaka Gas supplies about 24%. In terms of sales, Tokyo Gas earns 37% while Osaka Gas earns 32% of the domestic market, which means the two companies together cover about 70% of the entire gas market.

Nearly 75% of the gas is derived from natural gas imported as liquefied natural gas (LNG) from mainly Asian-Pacific countries such as Malaysia, Indonesia, Australia, etc. The domestic production of natural gas supplies barely 5%, while the remaining 95% is imported. Japan has 20 LNG receiving terminals that annually import a total of 40 million tons of LNG used for gas distribution and power generation. Despite this, a pipeline network connecting major consumption areas has yet to be built.

Gas demand for co-generation is on the rise. Fig. 3 shows the growth in secondary energy in the Prospects for Long-term Energy Demand mentioned earlier. Unlike the demand growth for oil that will level off at an annual rate of 0.5% and electric power that will level off at an annual rate of 1.6%, the demand for gas is expected to see higher growth at an annual rate of 3.6% until the year 2010.

3.2. Gas companies activities in upstream and downstream

At the upstream end of corporate activities, such as resources procurement, Japanese gas companies are implementing a broad range of activities embracing both global environmental and energy security issues such as (1) promotion of natural gas as energy friendly to the environment, (2) long-term LNG purchasing agreements with gas producing countries and (3) research and development of coal gasification and converting methane gas hydrates as alternative energy resources.

At the downstream end, Japanese gas companies keep close relationships with end users as distributors rather than transporters. In particular, we have realized a steady growth of gas demand through customer-oriented marketing, such as proposing gas utilization applications fit for individual customer needs. Specific efforts in the downstream sector include (1) developing residential gas equipment, (2) developing and proposing energy-saving equipment including gas-fired air conditioners while providing our customers with consultations on energy saving and (3) making proposals to businesses for installation of co-generation systems for efficient energy utilization.

4. Fuel cell development by gas companies

4.1. Expectations for fuel cells

Japanese gas companies are exerting aggressive efforts for promoting gas-fired air conditioning and co-generation systems under the current trends of (1) rising demand for electric power, (2) the need to reduce peak power demand, and (3) maximizing efficiency of energy utilization.

Gas-fired air-conditioning reached the total capacity of 5.5 million refrigeration tons by March of 1995 and co-generation using gas 1.28 million kW by March of 1996. Both gas-fired air conditioning and co-generation systems are expected to double in their installed capacity within the next five years. At the same time, Japanese gas companies have maintained their hopes on fuel cells and invested heavily in fuel cell development. With the expected mounting pressures for higher power generating efficiency and lower NO_x emissions, it is crucial to commercialize fuel cells as quickly as possible.

Table 2

Field test sites by Tokyo Gas

No.	Site	Manufacturer and model	kW	Start of operation	Operation time (h) (Jun. 1997)
1	Akabane Building	Fuji Electric	50	Jan. 1995	6042
2	Itabasi Ecopolis Center	Fuji Electric	50	Mar. 1995	18141
3	Riverside Sumida	Fuji Electric	100	Jun. 1994	13609
4	Tokyo Gas Tamachi	ONSI PC25A	200	Nov. 1992	30646
5	Tokyo Gas Tamachi	ONSI PC25A	200	Dec. 1993	20533
6	Tokyo Gas Tamachi	ONSI PC25A	200	Oct. 1993	22546
7	Tokyo East 21	ONSI PC25A	200	Nov. 1992	31750
8	Tokyo Gas Sodegaura Factory	ONSI PC25A	200	Jun. 1993	27699
9	Tokyo Gas Senju	ONSI PC25A	200	Dec. 1992	30939
10	Tokyo Gas Shinjuku	ONSI PC25A	200	Mar. 1994	18907
11	Tachikawa Toshi Center	ONSI PC25A	200	Sep. 1994	18853
12	Tachikawa Toshi Center	ONSI PC25A	200	Sep. 1994	22494
13	Tokyo Environment Research Center	ONSI PC25A	200	May 1995	15977
14	Tokyo Misono Waterworks	ONSI PC25C	200	May 1996	8088
15	Tokyo Gas Tamachi	ONSI PC25C	200	Jun. 1996	7362
16	Tokyo Gas Tamachi	ONSI PC25C	200	Jun. 1996	277
17	Tokyo Gas Sodegaura Factory	ONSI PC25C	200	Dec. 1996	2026

4.2. Phosphoric acid fuel cells

4.2.1. Fuel cell operating performance

Tokyo Gas and Osaka Gas have conducted research on PAFCs for 25 years since they first participated in the Target Program in the United States in 1972. Total capacity of fuel cells tested to date by the two companies reached 12.4 MW; 4 MW for Tokyo Gas, 7.4 MW for Osaka Gas, and 1 MW for the PAFC research group run jointly by the two companies. The cumulative number of units reached a total of 87

Table 3

Field test sites by Osaka Gas

No.	Site	Manufacturer and model	kW	Start of operation	Operation time (h) (Jun. 1997)
1	Osaka Gas Torishima	Fuji Electric	50	Apr. 1992	11619
2	Hankyu Railway Main Office	Fuji Electric	50	Mar. 1993	26284
3	Hankyu Railway Main Office	Fuji Electric	50	Mar. 1993	29308
4	UN Environment Plan Build.	Fuji Electric	50	Sep. 1993	26748
5	RITE	Fuji Electric	50	Oct. 1993	27678
6	Coop Himeji-shirahama	Fuji Electric	100	May 1993	29069
7	NEXT 21	Fuji Electric	100	Sep. 1993	26665
8	Micalbore Sanda	Fuji Electric	100	Dec. 1993	24812
9	Osaka Gas Himeji Factory	Fuji Electric	100	Jan. 1994	12056
10	Osaka Gas Torishima	ONSI PC25A	200	Jun. 1992	25798
11	Osaka Gas Torishima	ONSI PC25A	200	Nov. 1992	24361
12	Osaka Gas Torishima	ONSI PC25A	200	Feb. 1993	26825
13	Umeda Center Building	ONSI PC25A	200	Oct. 1994	36236
14	Sumitomo Chemist Factory	ONSI PC25A	200	Jun. 1993	26127
15	Otsu Tire Factory	ONSI PC25A	200	Jun. 1993	30074
16	Matsushita Electric Works	ONSI PC25A	200	Dec. 1993	25844
17	Osaka Red-cross Hospital	ONSI PC25A	200	Oct. 1994	20789
18	Osaka Gas Torishima	ONSI PC25C	200	Mar. 1996	8926
19	Osaka Gas Torishima	ONSI PC25C	200	Oct. 1996	2666
20	Kyoto Research Park	ONSI PC25C	200	Mar. 1993	2248
21	NTT Kansai Network Center	ONSI PC25C	200	Mar. 1997	2190
22	Osaka Gas Torishima	ONSI PC25C	200	Apr. 1997	462
23	Osaka Gas Torishima	Toshiba	200	Jul. 1994	15599
24	Nisshin Steel Sakai Factory	Toshiba	200	Jun. 1995	15106
25	Osaka NTT Hospital	Toshiba	200	Jul. 1996	7504
26	Kirin Beer Kyoto Factory	Mitsubishi	200	Sep. 1995	12334
27	Kirin Beer Kyoto Factory	Mitsubishi	200	Sep. 1995	12116
28	Ajia Trade Center Building	Fuji Electric	500	Mar. 1994	8873
29	Ajia Trade Center Building	Fuji Electric	500	Mar. 1994	14653

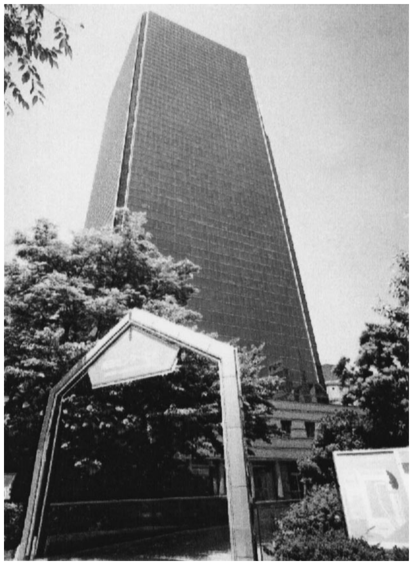

Fig. 4. Umeda Center Building (37 000 h operation).

units, comprising 34 for Tokyo Gas, 52 for Osaka Gas and one for the research group. The total number of PAFCs that are currently operational is 47 units; 17 for Tokyo Gas, 29 for Osaka Gas and 1 for the research group. Table 2 shows operational PAFCs for Tokyo Gas, while Table 3 shows those for Osaka Gas.

While fuel cell manufacturers have production expertise, gas companies have fuel cell operation expertise as well as maintenance techniques that are superior to that of manufacturers. The fuel cells run by the gas companies have operating experience exceeding 37 000 h and have records for continuous, uninterrupted operation exceeding a full year.

Fig. 4 shows a photograph of the Umeda Center Building, an office building in Osaka where Osaka Gas installed a PC25A. The system is interconnected to the commercial power network, and it utilizes waste heat for water heating. Since it became operational in October 1992, the system has exceeded the operating time of 37 000 h and is currently extending the record for the longest operating time in Japan. There is great anticipation that the system will soon surpass the 40 000 h set as the development target for fuel cell technology. Furthermore, Tokyo Gas is currently running three fuel cells and Osaka Gas one fuel cell that have topped the 30 000 h mark.

Fig. 5 shows a photograph of Tokyo Metropolitan Research Institute for Environmental Protection where Tokyo Gas installed a PC25A. The system is interconnected to the grid and utilizes waste heat for water heating and air conditioning. It has reached 9478 continuous operating hours, i.e. continuous, uninterrupted operation for over a year. Tokyo Gas has also installed a PC25A in East 21, an office building which houses a hotel and offices. This unit also has about 9500 continuous operating hours. And finally, a 100-kW unit of Fuji Electric that Osaka Gas installed in Next 21, a futuristic multi-family experimental housing project, has achieved about 7000 continuous operating hours.

In a quarter of a century since development work first began on PAFCs, fuel cells have logged nearly 40 000 h operating experience and long-term uninterrupted operation, and have thus demonstrated the excellent reliability of the cells.

4.2.2. Contribution of gas companies to PAFC development

Japanese gas companies have played a vital role in promoting fuel cell development.

1. They gave incentives to manufacturers through purchase of fuel cells. Purchasing and operating a large number of fuel cells led to further development by manufacturers.
2. They ascertained the cause of malfunctions on site and pushed for improvements. They gave feedback on required specifications and technical problems in operation.
3. They demonstrated the potential for long-term operation using their superior maintenance techniques.

The results of these efforts have brought fuel cell technologies closer to commercialization.

4.3. Solid oxide fuel cells

Great strides are being made toward developing SOFCs that offer higher power generating efficiency. In 1997, Tokyo Gas and Osaka Gas set a world record for long-term operation surpassing 13 000 h with a 25-kW SOFC co-generation system that had tubular cells made by Westinghouse. Table 4 shows the main specifications and experimental results for the unit. SOFCs will be the next generation of fuel cells after PAFCs because they offer various features outlined below:

1. simple cell structures because they use solid rather than liquid electrolyte;

Fig. 5. Tokyo Metropolitan Research Institute (9500 h continuous operation).

Table 4

Summary of 25-kW SOFC co-generation system

Specification	
Cell	AES (576 cells)
Fuel	Natural gas
Pressure	Atmospheric
Fuel utilization	85%
Operating result	
Operating period	Mar. 1995–Feb. 1997
Cumulative generating time	13194 h
Longest continuous time	6499 h
Electricity power output	25 kW DC
Steam output	4.7 kWt (9 kg/cm^2 G)
Voltage degradation rate	$<$0.1%/1000 h
Startup/cooldown	11/11 times
Availability	$>$90%

2. higher power generating efficiency above 50%; and
3. a higher operating temperature that provides high-grade heat that can be used for generating power with a steam turbine and for air conditioning using absorption-type chillers.

Improving materials for the tubular cells developed in the present study will significantly improve the heat-cycle resistance and durability of the cells. Minimum voltage drop was observed in cells during operation, and steam extracted at pressure higher than 8 kg/cm^2 was also demonstrated.

Tokyo Gas and Osaka Gas are also conducting independent research on planar-type SOFCs. They will be focusing more on the electrical aspect in the future in order to achieve a suitable balance between heat and electricity required in the market for fuel cell. Meanwhile the demand for systems such as SOFCs that offer higher power generating efficiency will undoubtedly grow.

4.4. Development investment

Large amounts of capital and R&D personnel are needed to develop fuel cells. The resources that Tokyo Gas and Osaka Gas invested in fuel cell developments have been about 20 billion yen in investment costs and about 400 man-years in R&D personnel. Investment costs include about 95% for PAFCs and 5% for SOFCs.

The government has also provided support for private development efforts and has invested heavily in developing and field testing a variety of fuel cells with their interest in the country's major energy policy of promoting R&D on energy saving and new energy technologies. About 38% of the national budget for fuel cells goes to PAFCs, while 56% goes to molten carbonate fuel cells (MCFCs) that are being promoted by the power industry. A mere 4% of the budget goes to SOFCs, but financial support for SOFCs is expected to increase in the very near future. The remainder is for polymer electrolyte fuel cells (PEFCs).

5. Outlook

5.1. Government support

PAFCs have taken yet another step forward. The MITI will again provide grants for field testing of PAFCs starting this year. Japanese gas companies plan to take advantage of these grants to install new fuel cells at end-users' sites for demonstrations of reliability and durability. They will continue to evaluate operation of 200-kW PC25Cs made by ONSI and Toshiba as well as new 50–100-kW systems of Fuji Electric which feature an improved cell.

This year the Japanese government enacted the Law Concerning the Promotion of the Use of New Energy. Despite high hopes for new energies, the share of new energies in primary energy supply has not increased. As such, the government aims to create a favorable cycle that will promote commercialization and, subsequently, lower initial costs by providing support in order to accelerate introduction of new energies.

Fuel cells are positioned as one of the new energy systems under this law. If reliability and durability can be verified in the field tests mentioned earlier, users of fuel cells can receive government assistance under the new legislation. This makes it imperative that we move steadily, but quickly on reliability demonstrations, and that we create a scenario where we are ready to promote commercialization after some installations of fuel cell systems at users' sites assisted by governmental grants under this law. This is a scenario where fuel cells prove their economic viability without government assistance.

5.2. Strategy for developing fuel cell markets

There are a variety of different fuel cells, such as PAFCs, SOFCs, MCFCs and PEFCs. Fig. 6 shows the target of these fuel cells, their power generating efficiency and their anticipated market.

Despite nearly a quarter of a century of development work, fuel cell technology has yet to be perfected. First there is growing pressure to commercialize PAFCs which, among others, is at a stage close to commercialization. We can no longer be allowed to be complacent in technological developments as there is mounting pressure for full realization of the potential of fuel cells. While steps are being taken to develop fuel cells, great strides are also being made in the development of gas engines that are the main competitors for fuel cells in the co-generation market. The power generating efficiency of miller cycle gas engines will achieve nearly some 40% equivalent to that of PAFCs. Every effort will have to be made to improve the economic viability and power generating efficiency of PAFCs if we are to take advantage of the market opportunities of these fuel cells.

SOFCs hold great promise in terms of a large-scale power generating stations. SOFCs with their higher power gener-

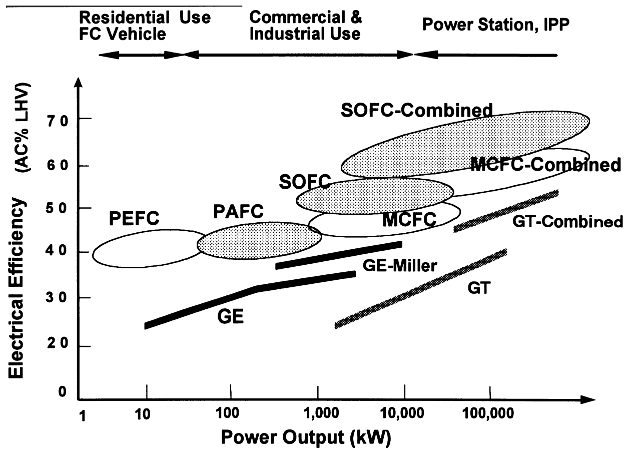

Fig. 6. Market of fuel cells (electrical efficiency and power output).

ating efficiency and high waste heat temperatures are ideally suited for industrial co-generation users as well as independent power producers. As boundaries among energy industries (power, gas, oil, etc.) continue to become less demarcated, gas companies should explore new business opportunities including IPP and other businesses. From a long-term standpoint, SOFC is one of our research targets for large-scale power generating systems.

Another important area of research will be the application of PEFCs and other fuel cells to small-scale residential and commercial markets.

5.3. Conclusions

The climate towards deregulation in recent years is starting to have an impact on energy companies and their businesses. We cannot afford to squander this opportunity to introduce environmentally friendly technologies. The time for discussion is past, and now is the time to focus on demonstrating the quality of these technologies and to tap the market opportunities offered. Users, manufacturers and governments around the world must re-examine their roles to promote the commercialization of fuel cells.

Fuel cell development demands large sums of money and a significant amount of time. It is an enormous task for a single entity. The development process must begin with refining fuel cells through cooperation among users, manufacturers and governments so that we can establish technologies, reduce costs and develop markets which enjoy the full benefits of PAFCs. Success with this technology will open up new opportunities for other superior technologies that follow, including SOFCs.