The Status of Home-Installed SOFC System Development at Osaka Gas

Shuichi Inoue, Fuel Cell Development Dept., Osaka Gas Co., Ltd.
Tadayuki Sogi, Fuel Cell Development Dept., Osaka Gas Co., Ltd.
Katsuki Higaki, Fuel Cell Development Dept., Osaka Gas Co., Ltd.
Shin Iwata, Fuel Cell Development Dept., Osaka Gas Co., Ltd.
Kenichiro Yasuhara, Fuel Cell Development Dept., Osaka Gas Co., Ltd.
Minoru Suzuki, Fuel Cell Development Dept., Osaka Gas Co., Ltd.

1. INTRODUCTION

One advantage of solid oxide fuel cells (SOFCs) is high generation efficiency without requiring expensive materials for production, while another is that their simple configuration allows a compact design, so manufacturing costs could be reduced in the future. These advantages may enable SOFCs to be installed in small residential houses in urban areas, apartment houses and condominiums, opening up a new market which Eco-Will or Ene-Farm cannot easily penetrate.

Osaka Gas recognizes the advantages of SOFC when used as a home-installed CHP system because its environmental compatibility and economic efficiency can be sufficiently maintained even when installed at a household that has only a relatively small heat demand (Figure 1). In 2004, Osaka Gas formed an alliance with Kyocera for joint development of such SOFC systems. In November 2005, we conducted the first SOFC demonstration test in Japan at occupied residential houses using 1-kW class (electric output) SOFC systems, and demonstrated excellent performance in actual operation: generation efficiency of 49% (at the AC transmission end), primary energy saving of 31% and CO_2 emission saving of 45%. In FY2006, we changed the rated electric output from 1 kW to 700 W to suit the residential market, and started developing a smaller model. As a result, the volumetric size of the power generation unit was reduced by 30% from the previous year's model.

From September 2007, we participated in the Demonstrative Research on Solid Oxide Fuel Cell ("SOFC Demonstrative Research") led by the New Energy Foundation (NEF). In FY2007, we tested 20 sets of SOFC systems installed as a trial at occupied houses. The results showed high operating performance and other findings that have helped improve the durability and reliability.

Our system development activities in FY2008 focused on improving durability, reliability, saleability, ease of maintenance, and compactness. Like in FY2007, we continued to participate in the SOFC Demonstration Project. We tested 25 sets of SOFC systems installed as a trial at occupied houses. The following describes the major development considerations, the specifications of the system, and the results of ongoing field tests.

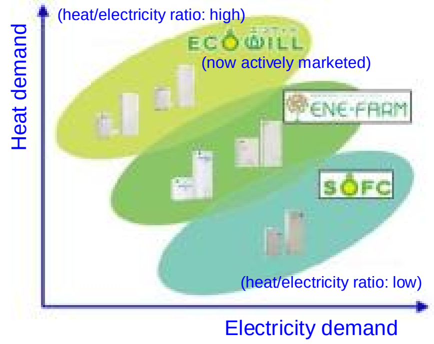

Figure 1 *Market sectors targeted by home-installed CHP systems (conceptual)*

2. SYSTEM DEVELOPMENT

The home-installed SOFC system comprises an SOFC power generation unit and a waste heat recovery unit for water heating and space heating (Figure 2). Table 1 lists the present specifications of each unit. The power generation unit and the waste heat recovery unit are connected by a communication link, and a remote controller for water and space heating by the waste heat recovery unit is used to display information concerning energy saving and troubles with the power generation unit. We have improved the internal structure of each unit to make the system easier to service not only from one direction but also from a diagonal direction. As a result, the system only requires a space 1970 mm wide and 710 mm depth. This is the smallest space required by any home-installed CHP system so far.

Figure 2 *Overview of our home-installed SOFC-based CHP system*

Table 1 *Specifications of the units*

SOFC-based power generation unit

Manufacturer	Kyocera Co., Ltd.
External dimensions	960 × 540 × 350 mm
Weight	91 kg
Rated output	700 W
Rated generation efficiency	45% (LHV)
Rated efficiency of waste heat recovery	40% (LHV)
Operation mode	Continuous and load-following

Waste heat recovery unit

Manufacturer		Chofu Seisakusho Co., Ltd.
External dimensions		1700 × 700 × 300 mm
Weight		89 kg
Hot water tank capacity		70 L
Water heating capacity		41.9 kW (Type 24 rating)
Water heating capacity	80°C	17.4 kW
	60°C	8.4 kW

① SOFC-based power generation unit

The electric output is variable between 10 W and 700 W in load-following operation. The generation efficiency at the rated output is 45% (LHV) at the AC transmission end, and the efficiency of waste heat recovery is 40% (LHV). These figures demonstrate the very high efficiency of the system. Eco-Will and Ene-Farm require some learning about the operation before achieving the maximum energy saving. With an SOFC system, however, electrical load-following is the most efficient operation mode in view of the partial load efficiency characteristics and energy losses from intermittent operation. This eliminates the need for any complex learning operation.

② Waste heat recovery unit for water heating and space heating

The waste heat from the SOFC is used for heating water in a 70-L hot water tank, to meet the hot water demand including for baths. Since electrical load-following is the most efficient operation mode as mentioned above, power generation must be continued even when the maximum thermal energy is stored in the hot water tank. Therefore, the waste heat recovery unit for water heating and space heating contains a radiator of the optimal size to meet the thermal output of the power generation unit.

3. HIGHER DURABILITY

As a home-installed gas appliance, the SOFC-based CHP system must have a service life of at least 10 years. The cell stack and auxiliary components must both be highly durable. We repeated the cycle of verification and improvement by parallel execution of accelerated aging tests for materials, cell stack durability tests under various conditions and evaluation of the system as a whole. Prior to achieving the 10-year durability goal, we are now working on attaining 5-year durability.

4. FIELD TEST RESULTS

The purpose of the SOFC Demonstrative Research from FY2007 is to collect demonstration operation data under actual load conditions to assess the latest technological developments, identify technological issues, and clarify the future technological challenges. In November 2007, at the first meeting for presenting results from the SOFC Demonstration Project, NEF reported that the project had shown that the SOFC system could save energy even at a site with relatively small heat demand.

Figure 3 shows an example of daily operation data from an SOFC system installed at a site with relatively small load. The data includes the electrical load to the system, the system's electric output, and the amount of heat stored in the hot water tank. The data demonstrates quick responses of electric output to changes in the electrical load. In this example, the mean daily electrical load was 535 W while the mean electric output was 437 W. In spite of prolonged operation under partially loaded condition, the mean generation efficiency was as high as 38.1% (LHV) at the AC transmission end and the efficiency of waste heat recovery was as high as 41.7% (LHV). However, the efficiency of waste heat utilization was lower at 27.7% (LHV) due to losses caused by radiation from the piping, from the hot water tank, and from the radiator. The primary energy saving ratio was 20% while the CO_2 emission reduction ratio was 38%. These results demonstrate that the system substantially reduces CO_2 emissions even when operating under a relatively small load

Table 2 summarizes operation data from sites at which an SOFC system was installed from August to December 2008. As shown, the load level differed greatly among the sites, by a factor of approximately three between the site with the largest electrical load and that with the smallest. Nevertheless, the variation in the primary energy saving ratio remained approximately 13–29%, while the CO_2 emission reduction rate was approximately 34–45%. Thus, the SOFC system demonstrated its high operation performance at sites with various load levels. Figure 4 shows the change of SOFC operation efficiency at Sites 1-10 covered by our demonstration activities in FY2008. As shown, the SOFC systems continued to perform well with only a minor drop in generation efficiency, suggesting that durability was significantly improved compared with FY2007. Some of the systems installed for the SOFC Demonstration Project activities in FY2007 still continue to operate, and their running time had exceeded 11,000 hours by March 2009.

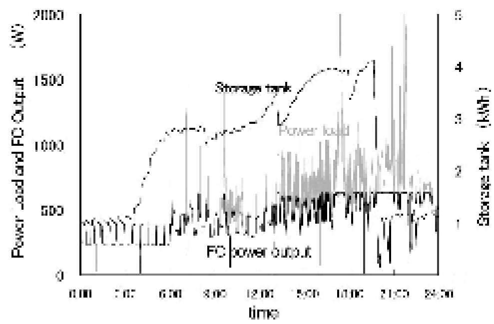

Figure 3 *Example of daily system operation data (one day in December)*

Table 2 *Summary of field test data*

Operation data for the period up to the end of December 2008

Site No.	Power generation hours	Electricity demand	Hot water demand	Percentage of SOFC-covered electricity demand	Mean electric output	Mean generation efficiency	Mean efficiency of waste heat recovery	Primary energy saving ratio	Amount of primary energy saved	CO_2 emission reduction ratio	Amount of CO_2 emissions saved
	hr	kWh/day	kWh/day	%	W	%HHV	%HHV	%	MJ/month	%	kg/month
H20-1	3,387	16.6	7.5	68	480	35.1	37.5	17.3	713	37	102
H20-2	3,239	19.8	13.4	60	483	35.9	37.1	19.8	557	39	119
H20-3	2,894	24.0	10.3	60	595	38.3	37.7	21.4	1,248	40	149
H20-4	2,674	15.5	8.8	74	483	36.1	36.5	19.3	833	38	113
H20-5	2,686	20.5	4.1	66	568	37.9	37.2	13.0	603	35	112
H20-6	2,551	35.5	14.6	44	646	39.4	36.6	28.5	1,693	45	178
H20-7	2,446	31.7	15.6	47	608	39.2	37.5	28.6	1,561	45	166
H20-8	2,072	27.8	12.2	54	617	37.5	40.0	19.9	1,162	39	148
H20-9	1,852	17.4	9.0	59	428	34.7	38.8	19.2	641	38	95
H20-10	1,775	12.4	10.7	82	431	34.9	38.3	22.2	931	40	111
H20-11	775	19.4	16.2	66	538	33.8	39.5	23.4	1,264	41	144
H20-12	1,111	13.2	10.2	78	424	31.5	35.6	15.2	608	34	93
H20-13	1,039	19.5	12.3	67	545	35.8	39.4	20.8	1,057	39	133
H20-15	679	14.6	7.0	81	500	35.7	38.4	16.3	743	36	114
H20-16	373	30.2	17.6	48	606	37.4	39.3	26.7	1,684	43	173
H20-17	398	13.8	16.2	76	440	34.7	39.5	23.3	1,005	40	114
H20-24	1,272	14.0	15.4	71	408	32.7	37.8	16.8	757	36	97

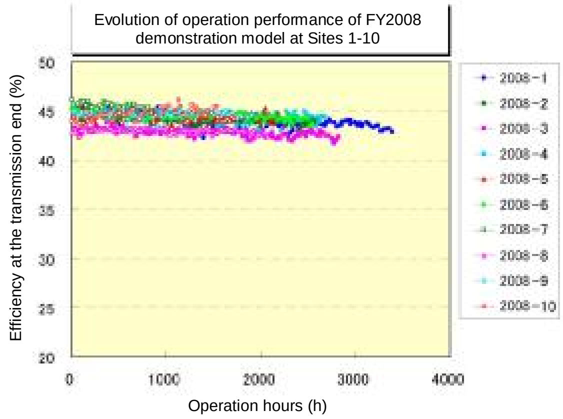

Figure 4 *Evolution of operation efficiency of FY2008 demonstration model at Sites 1-10*

5. FURTHER ACTIVITIES

Development efforts so far have made the system more compact, nearly perfected the design of the power generation unit and the waste heat recovery unit, and steadily raised the long-term durability and reliability of the power generation unit. Since Toyota Motor Corporation and Aishin Seiki Co., Ltd. joined the team in the second half of FY2008, four companies are now collaborating on the project. The integration of technologies and know-how developed by each company is expected to accelerate the development of home-installed SOFC-based CHP systems. We aim to complete the project in the early 2010s.

References:

1) Kenichiro Yasuhara et al., *The Status of Home-Installed SOFC System Development at Osaka Gas* [in Japanese], City Gas Symposium (2008)

2) M. Suzuki, T. Sogi, K. Higaki, T. Ono, N. Takahashi, K. Shimazu and T. Shigehisa, *Development of SOFC Residential Cogeneration System at Osaka Gas and Kyocera*, Proceedings of the 10th International Symposium on SOFC (2007)

3) Yoshitaka Kayahara, *A Report on Fuel Cell System Installation Status* [in Japanese], The 71st SOFC Study Meeting (2008)