REPORT ON DEVELOPMENT STATUS OF NEXT-GENERATION MODEL OF "ENEFARM" FUEL CELL FOR RESIDENTIAL USE

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1. INTRODUCTION

Tokyo Gas Co., Ltd. has been conducting a joint development project since 2003 with Matsushita Electric Industrial Co., Ltd. and Ebara Ballard Corporation, and succeeded in developing the world's first 1-kW class fuel cell cogeneration system for residential houses in February 2005, which was released under the brand name "LIFUEL." Tokyo Gas then participated in a large-scale demonstration project organized by the New Energy Foundation (NEF), making LIFUEL available to the market on a limited scale, and had installed 450 LIFUEL units by December 2007. By the end of FY2008, the company plans to release the next-generation model, named ENEFARM, which will feature major improvements that have resulted from addressing the challenges and operation data revealed by the demonstration project. The three main improvements are higher durability, higher reliability and lower cost, which, together with other improvements, will make this new model even more attractive.

This paper reports on the installation and operation of LIFUEL as part of the large-scale demonstration project and describes the development status of the next-generation model.

2. SPECIFICATIONS AND OPERATION RECORD OF THE PRESENT MODEL

(a) Manufactured by Matsushita Electric Industrial Co., Ltd. (b) Manufactured by Ebara Ballard Corporation

Figure 1 *Installation of the present model*

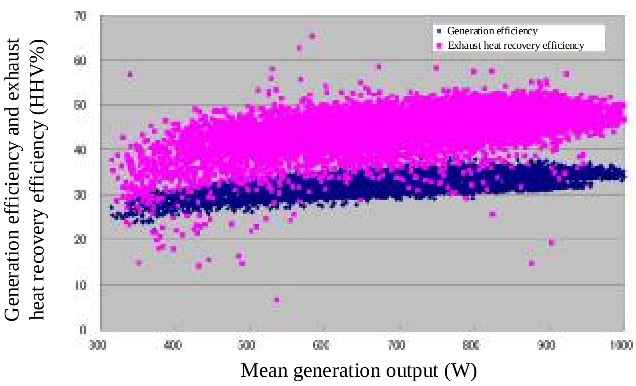

Figure 2 *Generation efficiency and exhaust heat recovery efficiency*

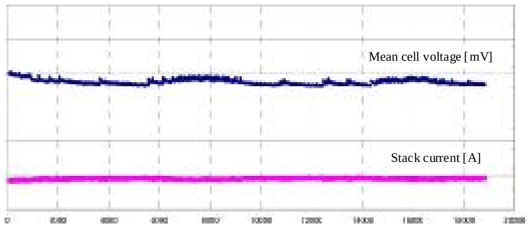

Figure 3 *Mean cell voltage and stack current*

The present model, which has been available on a limited scale since February 2005, has the following specifications. The rated electricity output is 1 kW and the heat recovery temperature is 60°C or higher. The generation efficiency is 37% based on the LHV or 33% based on the HHV. The heat recovery efficiency is 50% based on the LHV or 45% based on the HHV. The hot water tank capacity is 200 L. The fuel cell system has an optimized operation control system, which controls the output as well as the starting and stopping of the fuel cell unit according to the predicted patterns of power and water heating demand in the home. The fuel cell system is able to withstand at least 13,000 hours of generation and 1,000 generation sessions, corresponding to a service life of about three years. Figure 1 shows the appearance of the installed fuel cell system.

The operation data from the 450 units installed by December 2007 is as follows. Figure 2 plots the mean generation efficiency (HHV%) against the mean generation output, and the mean exhaust heat recovery efficiency (HHV%). The mean generation efficiency, including the start-stop energy requirements and standby power consumption, was around 30% (LHV) or higher, even during partial load operation. The heat recovery efficiency was around 40% (LHV) or higher. While the primary energy saving was found to depend highly on the site-specific water heating demand, the mean primary energy saving ratio was as high as 23.5%. The mean CO_2 reduction ratio was 37.3%, and the mean reduction in annual CO_2 emissions from a single site was 1,213 kg. These figures demonstrate a high energy-saving performance.

As to the durability, the cell voltage, stack efficiency and FPS efficiency changed little even after 13,000 generation hours. Figure 3 shows the mean cell voltage [mV] and stack current [A]. The cell voltage, stack efficiency and FPS efficiency changed little even after 1,000 generation sessions.

Averaged over all sites, 37.2% of electricity demand was served by the fuel cell. The ratio of auto-generated power against the total electricity demand at home was 40% or higher at more than half of the sites. Averaged over all sites, 75.2% of water heating demand was provided by the exhaust heat recovered from the fuel cell. The ratio of exhaust heat recovery to total water heating demand was 80% or higher at more than 40% of the sites.

3. SPECIFICATIONS OF THE NEXT-GENERATION MODEL AND IMPROVEMENTS FROM THE PRESENT MODEL

3.1 Specifications

Table 1 shows the target specifications of the next-generation model that will be released by the end of FY2008. The rated generation output is 1 kW, the generation efficiency is 37% or higher based on the LHV, and the exhaust heat recovery efficiency is 50% or higher based on the LHV. As shown below, major improvements are higher durability, higher reliability, lower cost, and greater attractiveness as a product.

Table 1 *Specifications*

Rated output	1.0 kW
Minimum output	0.3 kW
Generation efficiency	33% (HHV), 37% (LHV)
Heat recovery efficiency	45% (HHV), 50% (LHV)
Heat recovery temperature	60°C or higher
Tank capacity	200 L
Durability	40,000 generation hours 4,000 generation sessions (equivalent to a service life of about 10 years)
Reliability (failure rate)	5% annual
Cost	1.2 million yen

3.2 Durability

In the development project, we defined the durability requirement for the next-generation model as *the ability to maintain the generation capability after 40,000 generation hours and 4,000 generation sessions*. By meeting this requirement, the system has a service life of about 10 years.

Since a PEFC had never been operated anywhere for 40,000 hours or more, improvement of durability was a very difficult challenge. The mechanism of cell stack degradation was not fully understood and there was no established method for evaluating the durability of the entire system including the FPS. Therefore, we had to carry out the evaluation while periodically checking the validity of our evaluation techniques.

As to the evaluation procedure, we first evaluated individual components, then checked whether or not these evaluation results at the component level were applicable when the components were part of the whole system, and finally evaluated the system as a whole. We thus concluded that the next-generation model would meet the requirement.

3.3 Reliability

We analyzed the causes of various failures experienced during operation of the present model, and fed the results back to the development of the next-generation model. The aim was to decrease the failure rate (the average probability of a single system experiencing any failure in a year) to about 5%, which is the failure rate of typical water heaters.

Specific measures included the use of a redundant control algorithm, higher resistance to incidences, higher resistance to external disturbances, and a review of production materials. In addition, the reliability was enhanced by testing prototypes under a harsh environment, and by subjecting them to irregular operating instructions and seeing how they would respond.

3.4 Cost

We aimed to reduce the price from several million yen for the present model to about 1.2 million yen by reviewing the system configuration and reducing the cost of parts.

Specific measures included the following. We created a unitary equipment design by simplifying the system configuration: we decreased the number of cells in the cell stack and simplified the construction of the FPS. We also standardized the auxiliary component specifications through a national project involving multiple manufacturers, and decreased the number of auxiliary components by simplifying the system flow. These efforts helped to reduce the cost.

3.5 Attractiveness as a Product

The attractiveness as a product is a function of the ease of installation, ease of maintenance, and ease of operation for users.

As to the ease of installation, we facilitated transport by reducing the weight of each component and by shortening the time required for the trial run. These improvements greatly shortened the time for installation, which will also reduce the installation cost.

As to the ease of maintenance, one of the targets in the development project has been to ensure that the next-generation model allows Tokyo Gas to provide periodical maintenance and primary responses to a failure (all maintenance for the present model is done by the manufacturers). Parts are laid out so as to make maintenance easier, which speeds up maintenance and also reduces the required installation space, enabling more consumers to install the system.

The ease of operation for users depends greatly on the remote controller function. Users of the existing model provided valuable feedback about the remote controller, based on which the next-generation model has been enhanced to display the power generation and exhaust heat recovery history, giving the user more satisfaction in being able to generate power at home. For those customers who prefer to control the fuel cell operation by themselves, an *automatic operation mode* for controlling generation according to the predicted patterns of electricity and water heating demand in the home will be complemented by a *hot water quantity instruction mode* that allows the user to run the fuel cell according to the hot water requirement, a *scheduled operation mode* that allows the user to specify the hours of the day when the fuel cell should run to generate power, and a *manual operation* mode for the user to start up the fuel cell for power generation at any time. The next-generation model also allows the exhaust heat to be used for floor heating and similar purposes.

4. CONCLUSION

Between February 2005 and December 2007, Tokyo Gas provided 450 units of the “LIFUEL” fuel cell cogeneration system to residential users, and confirmed the high energy-saving capability and durability of the units.

By the end of FY2008, the company will release the next-generation model, named ENEFARM, which will feature major improvements based on the operating results of the present model. This new model will expand the use of fuel cell cogeneration systems in the home.