Development status and future prospects for residential and commercial use of SOFC systems

(Unofficial Translation)

Minoru Suzuki Residential Energy System Development Department Osaka Gas Co., Ltd.

1. Introduction

Fuel cells are being developed as a power generation technology for various applications including cogeneration, large-scale power generation, and automobiles. Among the various types of fuel cells, the Solid Oxide Fuel Cell (SOFC) technology which uses ceramics as the electrolyte has a long history of development, as it has been expected to provide the highest power generation efficiency. SOFC is now entering a stage of commercial use, with 100 kW systems for commercial use having been marketed in the USA since 2010, and residential-use cogeneration systems currently being commercialized in Japan. This presentation is intended to provide some insight on the current development status and future prospects of SOFC systems, which are now entering a stage of commercialization.

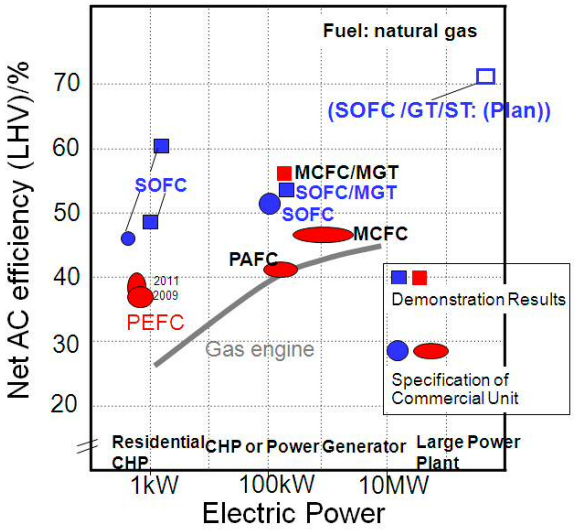

Figure 1 Power Generation Efficiency of Various Fuel Cell Systems
●: Commercial product,
■: Demonstration result, □: Planned

2. Commercialization of "Ene-Farm Type S"

As most residential houses need a hot water supply, residential-use cogeneration systems are expected to achieve a highly efficient use of energy through the effective use of excess heat from power generation. In 2003, through joint development with several other manufacturers, Osaka Gas released the "Ecowill" system which utilized a gas engine, and in 2009 the "Ene-Farm" system which used the Polymer Electrolyte Fuel Cell (PEFC). By the end of 2010, a total of 70,000 units had been sold. In fiscal 2004, Osaka Gas and Kyocera Corporation initiated a joint development of a residential-use SOFC system. In November 2005, an operational test was conducted in an actual living environment for the first time in Japan to demonstrate a 49% power generation efficiency (net AC, LHV), also to demonstrate that high efficiency power generation is feasible even in an environment with large load variations, which is common in most households. Based on the successful results of the study, it was decided that a product would be developed through the defining of specifications suitable for residential houses with less heat demand (including small stand alone houses and condominiums typically seen in urban areas). During fiscal 2006, the development effort was concentrated on making the system more compact by reducing the output power from 1 kW to 700W and redesigning the internal structure.

Durability was the biggest issue in starting commercial development. As SOFC systems are expected to operate continuously, the total operational period is expected to exceed 80,000 hours for the service life of 10 years. After successfully demonstrating the required system performance in fiscal 2005, more than 100 units were subjected to field tests (mainly within the framework of SOFC-related experimental study projects of NEDO) to evaluate the long-term stack durability, to test each component, and to analyze the results. After being assured that the target service life could be realized, the SOFC-based "Ene-Farm Type S" products were released in April 2012.

Figure 2 "Ene-Farm Type S"
Residential-use SOFC Cogeneration System

Table 1 "Ene-Farm Type S" Power Generation Unit Specifications

Manufacturer	Aisin Seiki Co., Ltd.
External Dimensions	935H x 600W x 335L (mm)
Weight	94 kg
Power Output	700W (rated output) to 50W

Power Generation Efficiency (at rated output)	46.5% LHV
Overall Efficiency (at rated output)	90% LHV
Operation Mode	Continuous load following
Regular Maintenance Cycle	3.5 years

The power generation unit of "Ene-Farm Type S," which realized a world-class power generation efficiency of 46.5% (net AC, LHV) as a commercially available residential-use fuel cell system, was developed jointly by Osaka Gas, Aisin Seiki, Kyocera, and Toyota Motor, with the cell stack produced by Kyocera and the power generation unit to integrate the cell stack produced by Aisin Seiki. In addition, the hot water supply and heating unit which utilize wasted heat are manufactured by Chofu Seisakusho, as shown in Figure 2 and Table 1. In addition to the 46.5% rated power generation efficiency offering a higher average efficiency than domestic thermal power plants (when measured at the receiving end), the thermal energy from power generation can be effectively utilized at the same time. Subsequently, based on a detached house and a family of four, average CO2 emissions can be reduced by 1.9 tons and the electricity/heating expenses can be reduced by 76,000 yen per household per annum, when compared to the same home with a gas-fired hot water supply and a home heating system.

3. Development Trends and Outlook for Residential-use SOFC

The target objective for the development of the residential-use SOFC cogeneration system for the domestic market was to realize a better power generation efficiency (based on equivalent operational conditions) than that of PEFC systems which were leading in development, while placing top priority on the reliability and durability in order to increase system integrity. Following their participation in the NEDO-led SOFC-related experimental study programs conducted up to fiscal 2010, TOTO and NGK Spark Plug issued a number of development / progress reports based on the studies. To date, TOTO has developed tubular cell stacks for low-temperature SOFC operations using Lanthanum Gallate electrolyte thin films, and is currently aiming for a joint commercialization of the residential SOFC system with Noritz Corporation. According to recent reports, the stacks show good durability though testing time is limited to several thousand hours. NGK Spark Plug is currently developing SOFC planar stacks suitable for high output power density, with Honda Motor announcing last year that they are developing an SOFC system to use the NGK Spark Plug stack. Furthermore, Murata Manufacturing as well as NGK Insulators is in the process of developing cell stacks to be suitable to residential-use SOFC.

Conversely, overseas venture companies appear to be taking different approaches towards the development of residential-use SOFC. Ceramic Fuel Cell (CFCL) in Australia has achieved a very high efficiency rate of 60% (net AC, LHV) when the output power is 1.5 kW, and the high efficiency performance characteristics have been verified in Australia, Europe, USA, and Japan (including an evaluation by Osaka Gas) through actual installation. Ceres Power in UK is currently developing a compact and light-weight wall-mountable product through the integration of a 700W SOFC power generation unit and a 25kW hot water boiler into one unit, aiming to acquire an alternative market for existing household boilers. The main feature of this product is that the cell formed by the electrodes and electrolyte is supported on a thin stainless steel substrate, making each layer made up of a cell and separator very thin. Although the current density per unit area is not particularly high, it appears that high output power density per unit weight (or unit volume) has been achieved. Although it appears that the SOFC products of these two companies have some reliability and durability problems to be resolved, the development specifications are very attractive as they seem to maximize the potential of SOFC.

Even if it may not be able to reach the 60% efficiency rate as demonstrated by CFCL, it is expected that residential-use SOFC products which are able to achieve high power generation efficiency well over 50% (LHV) will become commercially available in a few years. If it is possible to significantly improve the power generation efficiency and reduce the heat to power ratio, the capacity of the exhaust heat recovery tank can be reduced without sacrificing energy efficiency. Accordingly, it is expected that a more compact product capable of integrating the exhaust heat recovery tank will be able to be designed in a less costly manner. As one of the most important drivers for the popularization of SOFC is the realization of low cost cell stacks, the necessity to reduce the amount of material per unit output power and to improve the manufacturability is well understood. For this, it would become technically important to establish effective ways of handling relatively fragile cell stacks and to ensure durability at high output power density.

4. Development Trends and Outlook for Commercial-use SOFC

Fuel cells with capacity in the range of tens to hundreds of kW are considered in the mainstream of fuel cell systems. Bloom Energy of USA released a 100 kW SOFC system in 2010, with the total accumulated installed-base capacity of at least 30MW. Although power generation efficiency exceeds 50%, it is not a cogeneration system, i.e., only electric power is used, and the systems have mostly been introduced to data centers. Although very little technical details have been published from the company, what is considered technologically unique is that a number of hand-size unit cells are used to realize both 100kW and 200kW versions of the product. As they use a conventional

cell structure where a stand alone electrolytic plate is attached with fuel and air electrodes, it is considered advantageous in terms of quality control because the warp-free nature of this method can easily lead to improved dimensional accuracy, compared to the use of the co-firing method to attach electrolytes onto a support structure. In Europe, although they have fully established their research and development frameworks from materials to cell stacks, it is understood that no manufacturer plan to release their products into the market within the next few years. Convion in Finland is one of the system integrators in Europe and has succeeded the work of Wartsila OYJ Abp, the company that conducted technical demonstrations on a 50kW class system. In Japan, Mitsubishi Heavy Industries is developing pressurized SOFC systems, aiming to realize a triple combined system to deliver several hundred megawatts with a power generation efficiency of 70% from a complex system to integrate large scale, high efficiency gas turbine and steam turbine systems. In addition, Miura Co., Ltd. and Sumitomo Precision Products are currently developing a 4.2kW SOFC system for commercial use.

Due to the fact that it can achieve a power generation efficiency of well over 50%, there are very high expectations for SOFC as the next generation cogeneration system. Also expected is the development of new markets in which thermal demand is not assumed. Although a company in USA has begun the release of business use SOFC systems into the market, it is currently recognized that moves towards the commercialization of business-use SOFC systems are not so active compared to that of residential-use systems, and they are still unable to meet the expectations of the commercial market. Various types of basic structure cell stacks are currently being developed for the residential-use SOFC systems, while working to overcome a number of problems and challenges in cell stack manufacture, durability, control, and other areas. In addition to the mainstream development of medium to high capacity SOFC systems, using a number of residential-use SOFC cell stacks to build an increased capacity, the high efficiency SOFC system featuring several kW output power for business use is considered a reasonable and practical approach towards the commercialization of business-use SOFC systems. It is considered desirable to first implement small scale business-use SOFC systems for commercialization and market development in order to promote the development and popularization of medium to large scale SOFC systems.

5. Acknowledgments

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6. References

1) March 12, 2012 press release, "Completion of the development for residential-use fuel cell (SOFC) and commencement of sales for the Ene-Farm Type S systems", by Osaka Gas Co., Ltd., Kyocera Corporation, Aisin Seiki Co. Ltd., Chofu Seisakusho, and Toyota Motor Corporation.