Market Introduction Status of Fuel Cell System "MEGAMIE®" and Future Efforts

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Toward the realization of a carbon-free society by 2050, we are developing a system that uses a solid oxide fuel cell (SOFC), which can generate electricity with high efficiency. SOFC-MGT (Micro Gas Turbine) hybrid systems have been introduced to the market after the demonstration of a 250 kW class system and are scheduled to be delivered to Gas- und Wärme-Institut Essen e.V. (GWI) in Germany in fiscal 2021 for the first time for overseas installation, following deliveries to the Marunouchi building of Mitsubishi Estate Co., Ltd., the Technical Research Institute of Hazama Ando Corporation (hydrogen utilization) and the Ibaraki Plant of Asahi Breweries, LTD (biogas utilization). We are also proceeding with the development of MW class systems that apply MGT by reflecting the elemental technology in the integrated coal gasification fuel cell combined cycle (IGFC) for the Osaki CoolGen Project. We are also promoting the development of an improved system that uses a turbocharger (TC) as an air supply source instead of the MGT. The TC system uses a cascade system, which combines SOFCs in two stages and is expected to improve partial load efficiency. The demonstration tests are scheduled to be conducted in 2021.

1. Introduction

To curb global warming and realize a sustainable global environment, countries have set ambitious goals to rapidly shift to an energy system for decarbonization and are accelerating the movement to promote decarbonization as a strategic industrial policy. Japan has also declared its aim to realize a carbon-neutral, carbon-free society by 2050. In order to realize a carbon-free society, it is necessary to establish an appropriate energy mix by introducing highly-efficient distributed power sources and renewable energy into the advanced power grid constructed by large-scale centralized power sources, while ensuring safety, supply stability, economy and environmental friendliness. In order to establish the energy mix, it is effective to combine CCS (Carbon dioxide Capture and Storage) as a CO2 capture and storage technology and CCUS (Carbon dioxide Capture, Utilization and Storage) that uses the captured and stored CO2, in addition to converting the surplus electricity of renewable energy to hydrogen by P2G (Power to Gas) or operate it in combination with electricity storage, instead of suppressing it. Since the demand for power supply security has been increasing due to the frequent occurrence of disasters such as typhoons and torrential rains in recent years—in addition to earthquakes—it is also important to secure BCP (Business continuity plan) and power resilience.

Mitsubishi Power, Ltd. (Mitsubishi Power) is developing the "MEGAMIE" commercial industrial fuel cell system that uses SOFC (Solid Oxide Fuel Cell). SOFC can also electrolyze steam to generate hydrogen by reverse operation and is positioned as an effective application for the realization of a carbon-free society. We are currently promoting the introduction of 250 kW class SOFC-MGT hybrid systems to the market and the development of a TC system that is expected to improve operability through features such as higher partial load efficiency. We were

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also commissioned by the New Energy and Industrial Technology Development Organization (NEDO) to develop gas turbine fuel cell combined cycle power generation (GTFC) and are proceeding with the development to apply the elemental technology in the integrated coal gasification fuel cell combined cycle (IGFC) for the Osaki CoolGen Project. This paper introduces the development status of MEGAMIE.

2. Composition of MEGAMIE

Figure 1 illustrates the structure of a cell stack, which is the power generation element of tubular type SOFC. On the outer surface of the substrate tube, which is a structural member made of ceramics, cells (laminated anode, electrolyte and cathod) reacting to generate power are formed and an electron-conductive ceramic interconnector connects these cells in series. Several hundred cell stacks are bound to form a cartridge and several cartridges are contained in a pressure vessel. This is called an SOFC module (**Figure 2**). This system consists of the SOFC, MGT, recycle blower, etc. Power is generated in the two stages of the SOFC and MGT. Furthermore, when a waste heat recovery device is installed on the exhaust gas line, it can be utilized as a co-generation system that supplies steam or hot water at the same time (**Figure 3(A)**).

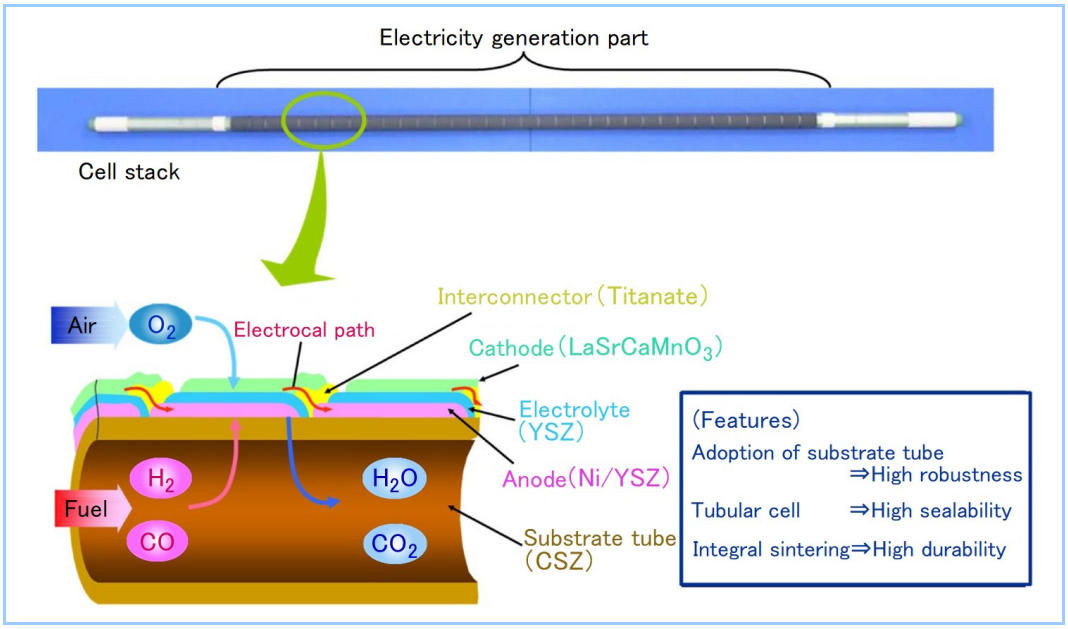

Figure 1 Structure of cell stack

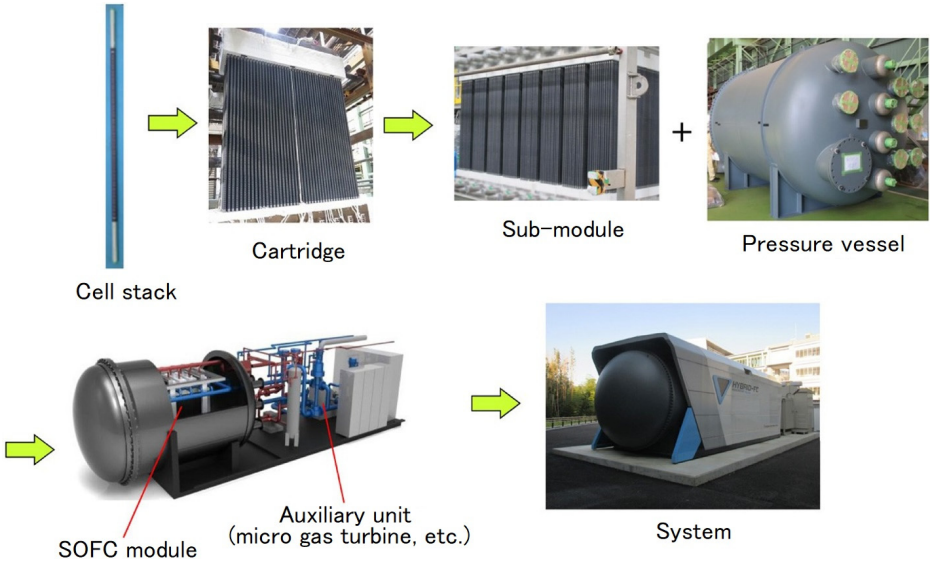

Figure 2 Composition of hybrid system

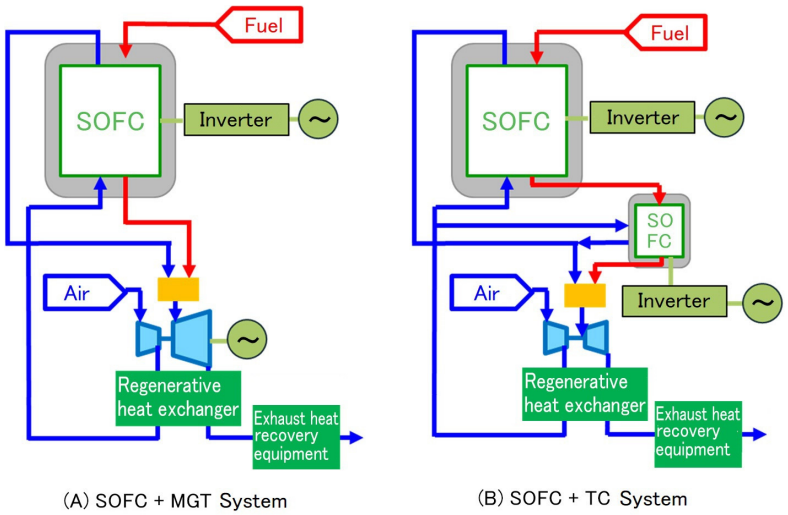

Figure 3 Comparison of MGT system and TC system

3. Status of MEGAMIE market introduction and initiatives

We introduced a 250 kW system to the "Next-Generation Fuel Cell Research Center (NEXT-FC)" established in Kyushu University aiming to fully disseminate SOFC by promoting industry-academia cooperation to use it for the "Verification of a Smart Fuel Cell Society" in the Green Asia International Strategic Comprehensive Special Zone. After that, in fiscal 2015, under the NEDO-subsidized project "Technical demonstration of commercial system using solid oxide fuel cells," demonstration tests under an actual load environment were conducted at four sites: Motomachi Plant of Toyota Motor Corporation, Komaki Plant of NGK Spark Plug Co., Ltd., Senju Techno Station of Tokyo Gas Co., Ltd. and Technology Center of Taisei Corporation (**Figure 4**). This subsidized project is a task setting type, the respective main subjects/verification items have been set at each site as follows and the demonstration tests were carried out: the start/stop operation test (once a month) for Toyota Motor Corporation, the continuous endurance test for NGK Spark Plug Co., Ltd., the start/stop operation test (once a week for 31 weeks) for Tokyo Gas Co., Ltd. and the self-sustaining function verification test for Taisei Corporation.

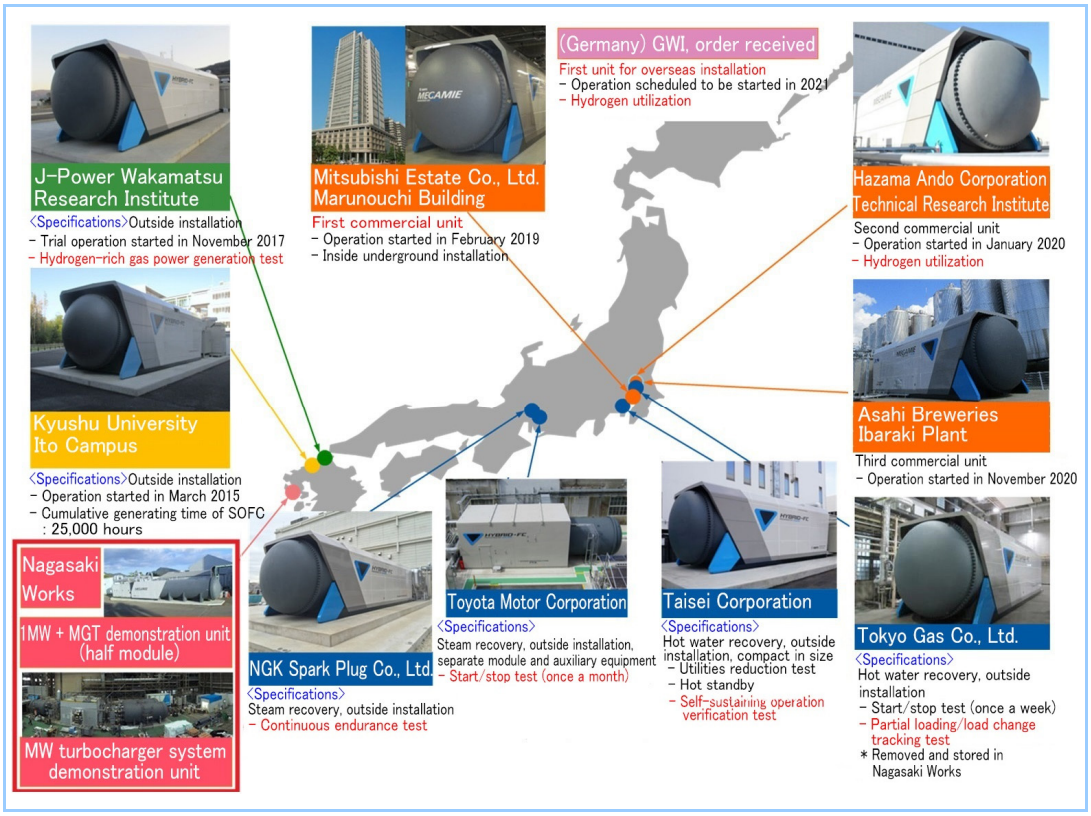

Figure 4 Operation and planning status of MEGAMIE

Based on the results of the demonstration tests, the introduction of the 250 kW class system to the market commenced in 2017. The first commercial machine was delivered to Marunouchi building of Mitsubishi Estate Co., Ltd., the second one to Technical Research Institute of Hazama Ando Corporation and the third one to Ibaraki Plant of Asahi Breweries, LTD. We will also examine the hydrogen utilization at Hazama Ando and the biogas utilization at Asahi Breweries, LTD. In addition, the system is scheduled to be delivered to Gas- und Wärme-Institut Essen e.V. (GWI) in Germany in fiscal 2021 for the first time for overseas installation.

Figure 5 shows an overview of the OCG project. This project calls for the installation of an integrated coal gasification combined cycle power generation facility (IGCC) in the first step, a CO_2 separation and capture facility in the second stage and SOFC in the third step to verify the IGFC. Toward this third step, for the NEDO Research and Development Project "Research on coal gas application for fuel cell module," which was implemented by Electric Power Development Co., Ltd. (J-POWER), we delivered a 250 kW class system to J-POWER's Wakamatsu Research Institute in fiscal 2017 and conducted a verification test using hydrogen-rich gas, which was coal gasified fuel. Since fiscal 2016, we have been verifying a larger module (output 1 MW class and operating pressure 0.6 MPa class) at Mitsubishi Power Nagasaki Works under the NEDO commissioned project "Gas turbine fuel cell combined cycle (GTFC) technology development." We are designing and manufacturing SOFCs for the OCG third stage using these elemental technology developments as basic design data and planning to start the installation work in fiscal 2021 and verify the coal gasified fuel and high pressure (targeted at 2 MPa) after the trial operation and adjustment.

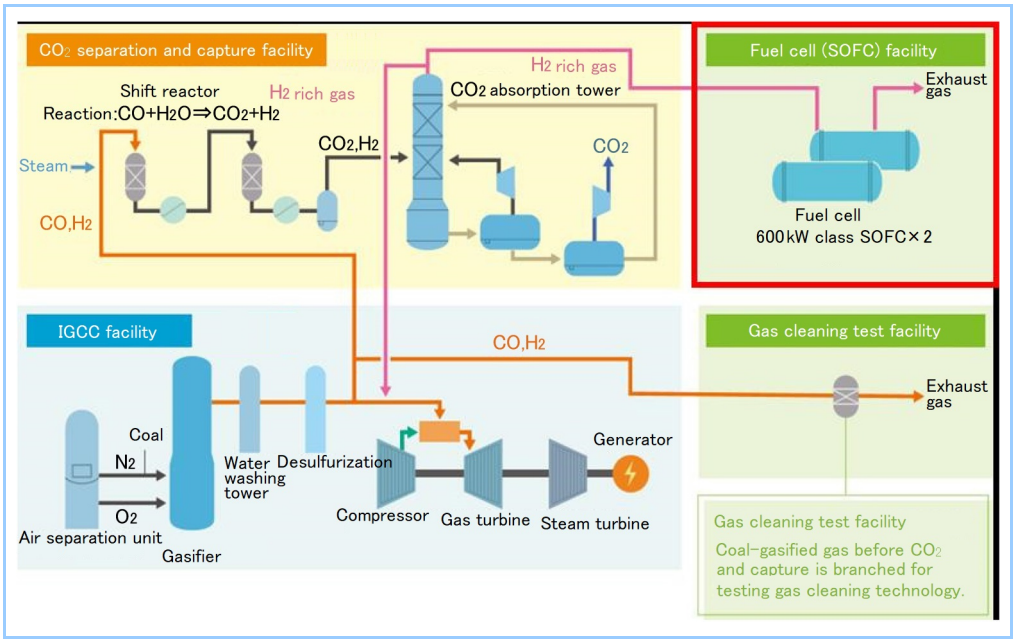

Figure 5 Overview of Osaki CoolGen Project (first step, second step and third step)

4. Development status of improved MEGAMIE system

Figure 3 compares the SOFC-TC combined system currently under development and the conventional SOFC-MGT combined system. The SOFC-MGT (Figure 3(A)) system is a hybrid system where the MGT is driven by burning the fuel used and diluted during SOFC power generation and air in the MGT combustor. On the other hand, the SOFC-TC system (Figure 3(B)) is a cascade system where the fuel diluted at the SOFC module is used to generate electricity at the subsequent SOFC module stage. The upper-stage SOFC is called the topping module and the subsequent SOFC stage is known as the bottoming module. The SOFC-TC system uses fuel for power generation using a highly-efficient fuel cell, so efficiency can be expected to improve. In addition, since the amount of air under partial load can be changed, the efficiency under partial load can also be expected to improve. Furthermore, since the temperature of the turbine inlet combustor can be lowered, it is expected that its applicability to diversified fuels including hydrogen can be easily expanded.

In terms of operation, it is necessary to verify the controllability of the start-up air blower for starting the TC and the operability at partial load to optimize the controllability in start/stop and rated/partial load operation. For this reason, we installed the SOFC-TC system demonstrator shown in **Figure 6** at the Nagasaki Works. Considering transportability, this demonstrator consists of two topping modules, one bottoming module and an auxiliary equipment unit. The auxiliary equipment unit consists of a fuel recirculation blower, TC, starter blower, etc. In fiscal 2020, we installed SOFCs on one topping module and the bottoming module and conducted a verification test on the half module system. The improved MEGAMIE uses a cell stack that is being jointly developed with NGK Spark Plug Co., Ltd. (NTK). We are planning to install a cell stack with even higher performance on the remaining topping module and conduct verification as a full module system in the future. We will consider system specifications with an eye on the commercial value of the 1 MW class machine and launch it in the market.

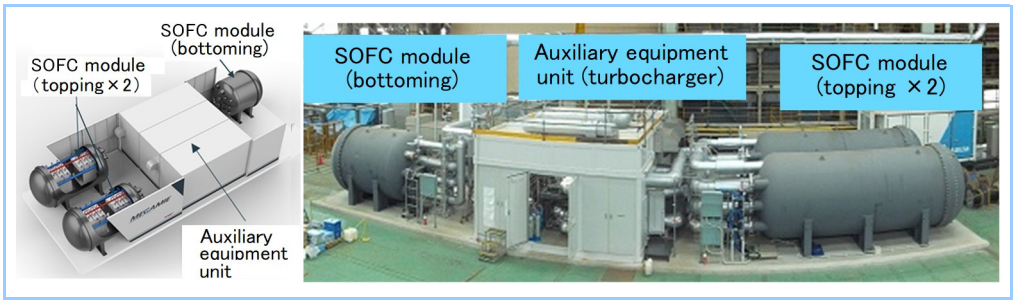

Figure 6 External view of 1 MW class half module demonstrator using MGT

5. Conclusion

SOFC is an attractive technology that can be applied to SOEC (Solid Oxide Electrolysis Cell), which produces hydrogen, CO, etc., by electrolysis when operated in reverse. Therefore, Mitsubishi Power positions SOFC applications as a trump card that is an effective technology to achieve both the reduction of CO2 emissions and the stable supply of electric power toward the realization of carbon neutrality and decarbonization by 2050, including the transitional period.

Regarding the SOFC-MGT hybrid system, a 250 kW class unit has been on the market since 2017 after demonstration projects at Kyushu University and NEDO. Since fiscal 2016, we have also been developing and verifying MW-class SOFC-MGT units with capacities larger than the 250 kW-class unit and reflecting the elemental technologies cultivated therein in SOFC for OCG, which verifies the application of coal gasified fuel.

We are also developing a TC system to improve operability. We plan to conduct a full-module system test to verify the operability features such as the start/stop characteristics, rated operation, partial load operation characteristics, protection system, etc., in fiscal 2021. We will steadily establish the technology and enhance its commercial value through this verification and put the system on the market to make a great contribution to the construction of a "safe and sustainable energy environment society."

(Acknowledgment)

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