Development of PAFC system with CO_2 separation

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1. ABSTRACT

Global warming is mainly caused by CO_2 emissions from fuel combustion. Carbon dioxide capture and sequestration (CCS) technology is one method that is expected to drastically reduce CO_2 emissions. Tokyo Gas Co., Ltd. has developed CO_2 separation technology for decentralized power generation systems fueled by natural gas for commercial building sector. The separated CO_2 is stored underground in the mid- or long-term (2020–). As a preliminary preparation for realization of CO_2 storage, CO_2 separation, transportation, and utilization should start in the short- and mid-term (–2020).

Tokyo Gas and Fuji Electric have developed a phosphoric acid fuel cell (PAFC) system with CO_2 separation equipment. The CO_2 separation equipment is composed of an exhaust gas pretreatment unit, pressure swing adsorption (PSA) unit, liquefier, and filling unit. The equipment is designed to be installed in a commercialized 100 kW PAFC system produced by Fuji Electric. The developed PAFC system separates 70% of CO_2 emissions compared with a conventional PAFC and uses 28% of the generated power for separation.

The CO_2 emission intensity of the developed PAFC system was estimated to be 0.21 kg-CO_2/kWh. This is as much as 40% less than that for a conventional PAFC at 0.51 kg-CO_2/kWh. The electric power supplied by this system can be considered as virtually CO_2-free when it is used as a combined heat and power (CHP) system because the amount of exhaust heat from this system is almost the same as the heat of hot water produced by a gas-fired boiler consuming as much fuel as this system.

The CO_2 separated from the exhaust gas of PAFC can be utilized as feedstock for dry ice or plastic products. This system is considered to be “CCS-ready.”

C O N T E N T S

2. BODY OF PAPER

2.1. Introduction

Global warming is mainly caused by CO_2 emissions from fuel combustion. Carbon dioxide capture and sequestration (CCS) technology is expected to be one method that can drastically reduce CO_2 emissions. In the World Energy Outlook 2010 as reported by the International Energy Agency (IEA), CCS is expected to contribute 26% of the CO_2 reduction by 2035 in the 450 ppm scenario [1].

Figure 1 shows the 2008 CO_2 emissions from each sector in Japan [2]. In this figure, CO_2 emissions caused by power utilization as the final demand are the responsibility of the consumers. The commercial building sector accounts for nearly 20% of the CO_2 emissions in Japan. In general, the main targets for CCS technology applications are currently large-scale CO_2 emission sources such as thermal power stations, but CCS technology is also being considered to dramatically reduce CO_2 emissions from the commercial building sector. Tokyo Gas Co., Ltd. has developed CO_2 separation technology for decentralized power generation systems fueled by natural gas for the commercial building sector. The separated CO_2 will be stored underground in the mid- or long-term (2020–). As a preliminary preparation for realization of CO_2 storage, CO_2 separation, transportation, and utilization should start in the short- and mid-term (–2020).

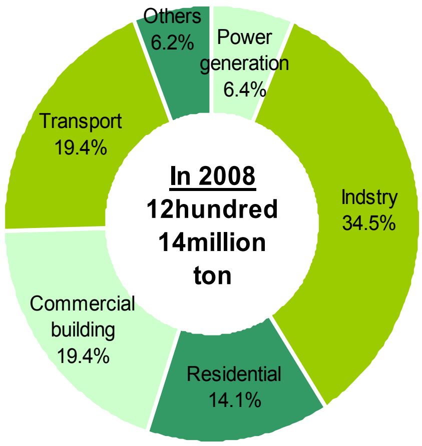

Figure 1 CO_2 emissions for each sector in Japan [2]

2.2. Decentralized power generation system with CO_2 separation

2.2.1 Characteristics of exhaust gas from power generation systems

Fuel cells and internal combustors such as gas engines and turbines are considered as power sources for decentralized power generation systems. Figure 2 indicates the difference in mechanisms between a fuel cell and an internal combustor such as an engine or turbine. The CO_2 density of exhaust gases of the reformer in the phosphoric acid fuel cell (PAFC) is four times higher than that from a gas engine or turbine. In a PAFC, fuel first reacts with steam and produces hydrogen in the fuel electrode. The hydrogen moves to the air electrode, which is separated by electrolytes from the fuel electrode, and produces electricity by reacting with oxygen in air. The off-gas from the fuel electrode mixes with air and burns to produce CO_2. In an internal combustor, fuel mixes with air before power generation to combust and produce CO_2. The amount of air that is in contact with fuel in a gas engine or turbine is four times more than that in contact with fuel in the PAFC. Because of this difference, the energies required for separating CO_2 from the exhaust gas are different for a fuel cell and internal combustor.

CCS technology needs a large quantity of energy to separate CO_2 gas from exhaust gas. A higher concentration of CO_2 in the exhaust gas means less energy needed for separation. Therefore, fuel cells are considered to be a superior choice to internal combustors when we use CCS technology for the decentralized power generation.

2.2.2 Comparison with development system and existing technology

A solid oxide fuel cell (SOFC) system with CO_2 separation was previously reported by the IEA [3]. However, SOFCs are currently not yet commercially available. In contrast, PAFC systems have been commercialized for commercial buildings by Fuji Electric Co., Ltd. Tokyo Gas and Fuji Electric developed a PAFC system with CO_2 separation equipment. The developed PAFC system is considered to be commercial-ready and is expected to contribute to drastic CO_2 emission reduction in the commercial building sector.

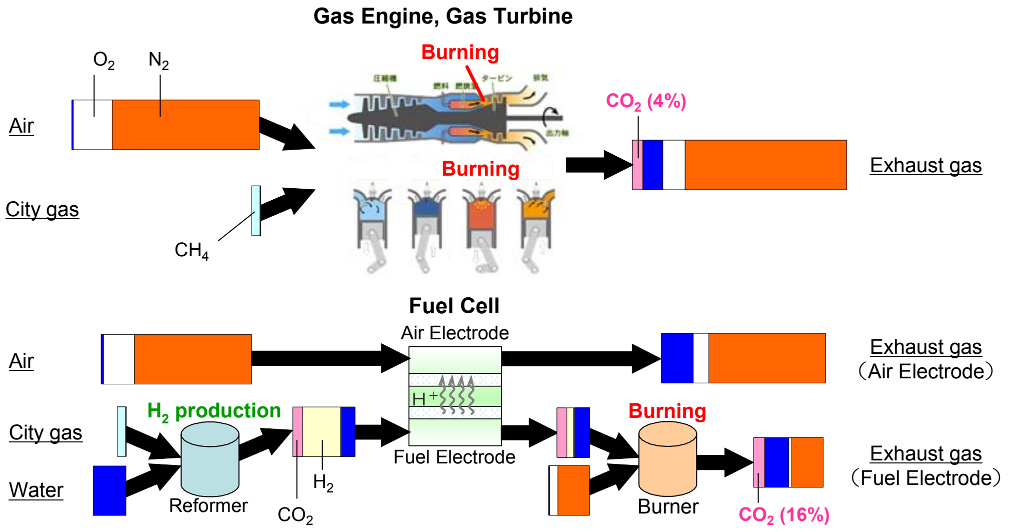

Figure 2 Difference in mechanisms for a fuel cell and internal combustor

2.3. PAFC system with CO_2 separation

2.3.1 Specifications of the PAFC system with CO_2 separation

The CO_2 separation equipment was designed for installation in a commercialized 100 kW PAFC system produced by Fuji Electric [4]. Table 1 shows the specifications of the commercialized conventional PAFC and the developed PAFC system with CO_2 separation equipment. The conventional PAFC shows 89% (based on the lower heating value : LHV) of total energy efficiency; this was attained through a combination of 40% LHV from power generation efficiency and 49% LHV from heat recovery efficiency. The amount of CO_2 emission of the conventional PAFC is estimated to 51.4 kg-CO_2/h. The developed PAFC system with CO_2 separation equipment produced a 72 kW power output and 77% LHV of total energy efficiency; this was attained through a combination of 29% LHV from power generation efficiency and 48% LHV from heat recovery efficiency. The CO_2 emissions of the developed PAFC system were estimated to be 15.4 kg-CO_2/h. The developed PAFC system reduces CO_2 emissions by 70% compared to the conventional PAFC and uses 28% of the power produced by the PAFC.

Table 1 Specifications of the conventional PAFC and the developed PAFC system

	The conventional PAFC	The developed PAFC system
Power transmission end output [kW]	100	72
Power generation efficiency [%] (transmission end)	40	29
Heat recovery efficiency [%]	49	48
Total energy efficiency [%]	89	77
Amount of CO_2 emission [kg-CO_2/h]	51.4	15.4

2.3.2 Outline of the PAFC system with CO_2 separation

CO_2 gas is separated from the exhaust gas of the reformer in the PAFC using CO_2 separation equipment. Figure 3 shows the system flow of the CO_2 separation equipment. The equipment consists of a pretreatment unit, pressure swing adsorption (PSA) unit, liquefier, and filling unit. PSA is a physisorption method that selectively adsorbs CO_2 from a mixture of gases at high pressure and desorbs it at low pressure. First, the exhaust gas from the reformer is dried in the pretreatment unit; the dried exhaust gas then flows into the PSA unit, and CO_2-rich gas is separated from the dried exhaust gas by the PSA unit. The separated CO_2 gas is then liquefied by the liquefier at -20 °C under a pressure of 2 MPa. Using this system, around 70% of CO_2 emissions from the PAFC can be separated and easily carried away from the site as liquefied CO_2 in bottle containers.

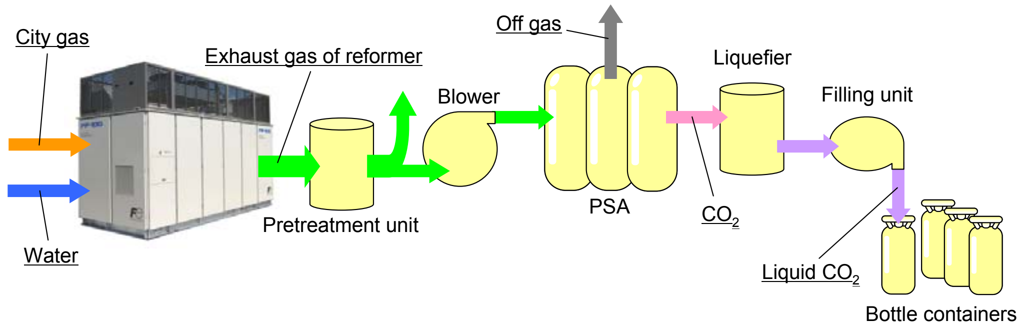

Figure 3 System flow of the CO_2 separation equipment

2.3.3 Footprint of the PAFC system with CO_2 separation

Figure 4 shows the top view of the developed PAFC system. This illustration takes into account the space for maintenance of each device. The developed PAFC system requires a footprint of 250 m^2, which is four times larger than that of a conventional PAFC. Further development is required to decrease the footprint of the developed PAFC system.

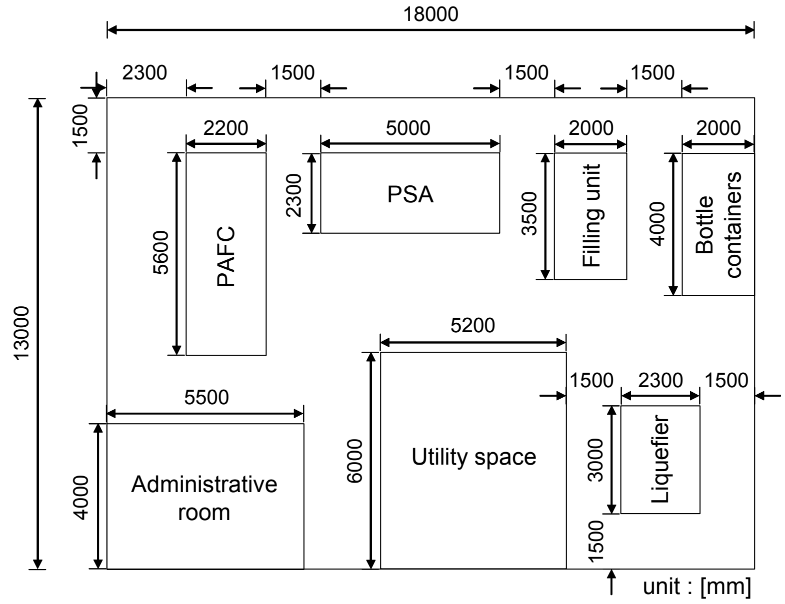

Figure 4 Top view of the developed PAFC system

2.4. Estimation of CO_2 emission reduction

Table 2 shows the estimated results for the amount of CO_2 emissions from the conventional PAFC and developed PAFC system with CO_2 separation. The developed PAFC system captures 860 kg-CO_2/day. The separation rate of the PSA in the developed PAFC system is 70%. The CO_2 emission intensity of the developed PAFC system was estimated to 0.21 kg-CO_2/kWh. This value is as much as 40% less than that of the conventional PAFC at 0.51 kg-CO_2/kWh.

Since this system is a kind of boiler, the electric power supplied by this system can be considered as virtually CO_2-free. The CO_2 emission intensity of the developed PAFC system was calculated as -0.01 kg-CO_2/kWh-chp when used as CHP. This is because the amount of exhaust heat from this system is almost as same as the heat of hot water produced by a gas-fired boiler consuming as much fuel as this system. The efficiency of the gas-fired boiler was assumed to be 85% LHV. The CO_2 emission intensity of city gas was assumed to be 2.29 kg-CO_2/Nm^3 in this study.

Table 2 Estimated amount of CO_2 emission reduction

	The conventional PAFC	The developed PAFC system
Amount of CO_2 emission [kg-CO_2/day]	1230	370
CO_2 emission intensity [kg-CO_2/kWh]	0.51	0.21
CO_2 emission intensity by installing as CHP [kg-CO_2/kWh-CHP]	0.34	-0.01

2.5. Future perspectives

The CO_2 captured from the developed PAFC system with CO_2 separation can be transported as liquefied CO_2 to aquifers when CO_2 underground storage becomes commercially viable. Therefore, this system can be considered to be “CCS-ready.” Currently, many CCS demonstration projects are being conducted in various countries including Japan, but the number of aquifers that can be used for CO_2 storage is limited for the near future. The captured CO_2 can be easily utilized as feedstock for dry ice or plastic products because the amount of CO_2 is much smaller than that from thermal power stations. The amount of CO_2 captured by the developed PAFC system will be 30–150 thousand tons per year assuming that 100–500 of these systems will be introduced in Japan in the future. The amount of currently traded CO_2 is 600–800 thousand tons per year in Japan, and the amount of captured CO_2 from this system is considered to be appropriate for CO_2 utilization; gas and coal power stations provide 150–300 million and 300–500 million tons, respectively, of CO_2 per year.

2.6. Conclusions

Tokyo Gas and Fuji Electric have developed a PAFC system with CO_2 separation equipment. The CO_2 separation equipment consists of a pretreatment unit, pressure swing adsorption (PSA) unit, liquefier, and filling unit. The equipment is designed to be installed in a commercialized 100 kW PAFC system produced by Fuji Electric. This system is expected to reduce CO_2 emissions from natural gas consumers in the commercial building sector.

The CO_2 emission intensity of this system was estimated to 0.21 kg-CO_2/kWh. This is as much as 40% less than that of the conventional PAFC at 0.51 kg-CO_2/kWh. The electric power supplied by this system is considered to be virtually CO_2 free when this system is used as a CHP because the PAFC exhaust heat matches the energy used for a gas hot-water boiler.

The CO_2 separated from the exhaust gas of the PAFC can be reutilized as feedstock for dry ice or plastic products in the short- and mid-term. In the mid- or long-term, the captured CO_2 can be transported to commercialized CO_2 storage sites, and this system is considered to be “CCS-ready.”

3. REFERENCES

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[2] Greenhouse Gas Inventory Office of Japan
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[3] CO_2 Capture from Medium Scale Combustion Installation, IEA Greenhouse Gas R&D Program, Technical Report 2007/7, July 2007
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4. ACKNOWLEDGEMENT

The development was accomplished in collaboration with Fuji Electric Co., Ltd.. Data from Tokyo Gas Chemical Co., Ltd. was used for part of the estimation.

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