Dry Low-NOx Combustion Technology for Novel Clean Coal Power Generation Aiming at the Realization of a Low Carbon Society

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Integrated coal gasification combined cycle (IGCC), which is considered to be a promising next-generation coal-fired power generation technology, is a clean coal-firing technology in which coal is converted into "hydrogen-containing gas" before being combusted. However, it has issues particular to hydrogen-rich fuel. Mitsubishi Hitachi Power Systems, Ltd. (MHPS) has participated in a New Energy and Industrial Technology Development Organization (NEDO) project since 2008. Combining rapid mixing and flame lifting technologies, MHPS developed a groundbreaking distributed lean burning technology for low-NOx combustion, which is applicable to IGCC coupled with a carbon dioxide (CO_2) capture facility. The characteristics of this combustion technology were examined using an actual-scale gas turbine at the EAGLE pilot plant, located in the Wakamatsu Research Institute of Electric Power Development Co., Ltd. (aka J-POWER). Based on the obtained results, we successfully installed the world's first dry low-NOx combustor for IGCC in the H-100 gas turbine, which is to be supplied to the IGCC demonstration test facility (currently under construction) of Osaki CoolGen Corporation (OCG). Although the H-100 gas turbine was formerly referred to as the H-80 because of the permitted output of the first unit (approx. 80 MW), it was thus renamed in accordance with the rated output of the gas turbine.

1. Introduction

As a core component of combined heat and power (CHP) systems or gas turbine combined cycle (GTCC) systems (in which exhaust heat from the gas turbine is used to produce steam and the steam is then fed to drive the steam turbine to generate electricity), gas turbines (GT) are expected to further contribute to the establishment of thermal power generation systems with higher efficiency and lower environmental impact.

In recent years, global climate change is an issue of increasing gravity and the means to reduce the emission of CO_2, a major greenhouse gas, have been explored. Taking part in these efforts, MHPS is contributing to the preservation of the global environment and a stable energy supply by extending the range of fuel types that are effectively applicable to GT. For the realization of a low carbon society from the perspective of widening the range of such applicable fuel types, it is important to enable the use of hydrogen-rich fuel involving lower CO_2 emissions. Of particular note as an innovative technology is IGCC. IGCC is a combined power generation system that uses exhaust heat from the gasified coal-fed gas turbine for power generation. This report introduces a low-NOx combustion technology for IGCC, which is considered to be a promising next-generation clean coal-fired power generation technology.

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2. Next-generation clean coal-fired power generation system (IGCC)

Coal will remain a key fossil fuel in the coming years, because of its widely distributed deposits around the world, abundant reserves and stable and inexpensive prices. However, as coal releases a greater amount of CO_2 per energy unit, a considerable reduction in CO_2 emissions from coal-fired power generation is an urgent need.

In IGCC, gasified coal is fed into GTCC and therefore, power generation efficiency is higher than conventional pulverized coal-fired power generation technology. The emission of particulate matter is lower owing to the pre-combustion removal of coal impurities. The absence of flue gas desulfurization processes also results in less effluent. Furthermore, as the CO_2 in the produced coal gas (syngas) can be captured under high pressure before combustion, the technological affinity with CO_2 capture and storage (CCS) systems to be installed is good.

There are two types of oxidants used in IGCC for the partial oxidation of coal: air (as in air-blown IGCC) and oxygen isolated from air (oxygen-blown IGCC). The combustion technology addressed in this report is related to oxygen-blown IGCC.

2.1 Configuration of oxygen-blown IGCC and gasified coal syngas characteristics

Figure 1 gives a simplified configuration of oxygen-blown IGCC, including the CO_2 capture unit to be installed in the future. It consists of the air separation unit (ASU), gasifier, gas cleanup unit, CO_2 capture unit and GTCC.

The composition of fuel gas (i.e., gasified coal syngas), which is supposed to be used in oxygen-blown IGCC, is roughly presented in **Table 1** in comparison with natural gas and hydrogen (H_2).[1] While the main constituent of natural gas is methane, gasified coal syngas is predominantly made up of CO and H_2. The proportion of H_2 in gasified coal syngas will further increase after CO_2 is captured. Both gasified coal syngas and H_2 are characterized by small calorific values per volume and high combustion speeds. **Figure 2** compares the combustion speed of gasified coal syngas used in oxygen-blown IGCC to that of natural gas.

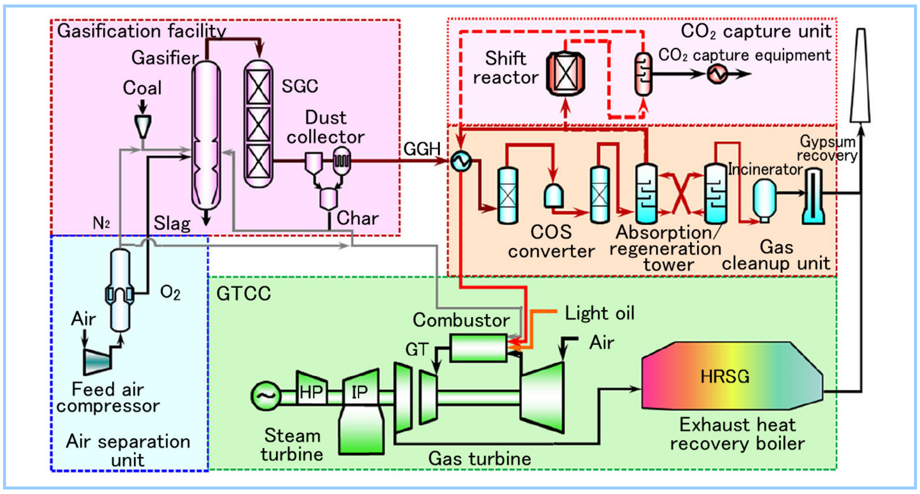

Figure 1 Structural diagram of oxygen-blown IGCC

Table 1 An example of the composition of gasified coal syngas in oxygen-blown IGCC

No.	Item		Symbol	Unit	Natural gas	Gasified coal syngas CCS: 0%	CCS: 30%	CCS: 50%	CCS: 90%	Hydrogen
1	Fuel composition	Hydrogen	$[H_2]$	Vol.%	0	26.5	45.5	58.0	83.5	100.0
2		Carbon monoxide	[CO]	Vol.%	0	60.0	43.0	30.5	5.0	0.0
3		Methane	$[CH_4]$	Vol.%	87	1.0	1.0	1.0	1.0	0.0
4		Other hydrocarbons	$[C_nH_m]$	Vol.%	13	0.0	0.0	0.0	0.0	0.0
5		Inert gas	[I.G.]	Vol.%	0	12.5	10.5	10.5	10.5	0.0
6	Relative lower heating value		LHV	Per volume	1	0.26	0.26	0.26	0.25	0.3
7				Per mass	1	0.23	0.30	0.37	0.74	2.4
8	Laminar burning velocity (as a relative value)		Su	Normalized against natural gas	1	3.3	4.5	5.3	6.5	7.8

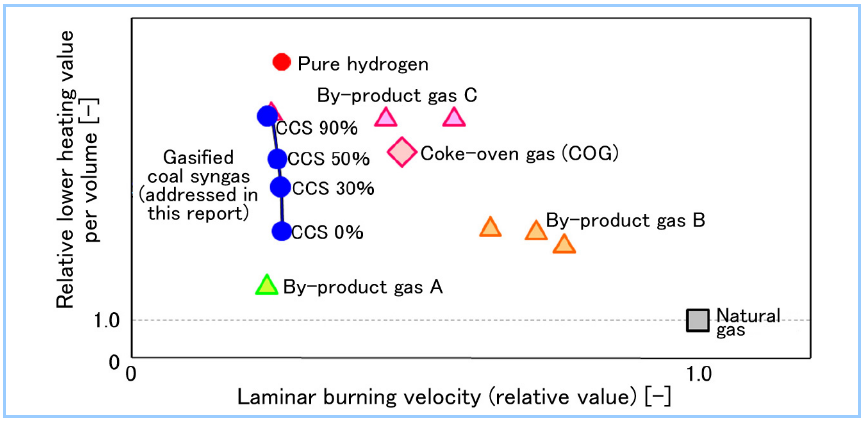

Figure 2 Calorific value and combustion speed of gasified coal syngas in oxygen-blown IGCC

2.2 Technological challenges of gasified coal syngas low-NOx combustion

Generally speaking, to curb nitrogen oxide (NOx) emissions, it is effective to mix fuel with a sufficient amount of air before combustion and let it be burned in a lean atmosphere. However, the high combustion speed of hydrogen-rich fuels such as gasified coal syngas can cause flashback or auto-ignition in the fuel/air premixing zone, raising the concern that the reliability of the combustor may be compromised.

Because of this, when burning hydrogen-rich fuel, a diffusion combustor in which fuel is injected directly into the combustion chamber and mixed with air therein is used. With this combustor, however, the reaction may occur under a condition in which fuel/air mixing is insufficient and consequently result in large quantities of NOx emissions. Therefore, it is necessary to prevent such emissions by cooling the flame with injected inert gases (diluents) such as nitrogen, which lowers the power generation efficiency.

To realize IGCC with higher efficiency and lower environmental impact, an advanced combustion technology in which NOx emissions can be reduced without using diluents is required. MHPS has participated in NEDO's "Innovative Zero-emission Coal Gasification Power Generation Project" since 2008 and developed a dry low-NOx combustion technology for CCS-IGCC, which can achieve reduced NOx emissions without using diluents against a wide range of H_2 levels in fuel.

3. Development of low-NOx combustion technology for IGCC

In CCS-IGCC, as shown in Table 1, the H_2 level in fuel can vary considerably from 27% to 84% depending on the CO_2 capture rate, which correspondingly causes substantial changes in the combustion speed. The CO_2 capture rate fluctuates according to the plant condition at any given time. Therefore, the combustor installed in CCS-IGCC is required to function properly in spite of varying fuel compositions or combustion speeds.

Figure 3 gives a simplified structure of the developed burner and a summary of the technologies applied to it. The most important feature is a multiple injection burner (i.e., cluster burner) which enables rapid mixing. Another technology developed for handling gasified coal syngas is flame lifting, by which the flame is steadily formed at a position away from the burner itself through the directional adjustment of jet flows of multiple coaxial sub-burners.

The cluster burner consists of a perforated plate with multiple small air holes and multiple fuel nozzles installed coaxially with these air holes. In the cluster burner, fuel dispersion and rapid fuel/air mixing due to turbulence caused in the air holes create a lean fuel/air mixture within a short mixing duration, whereby low-NOx combustion is enabled. The combination of these two technologies (i.e., rapid mixing and flame lifting) has made it possible for the flame to be formed at a position determined by the coaxial jet flow patterns downstream of the burner, under a condition in which fuel and air are sufficiently mixed. Thus, the flame can be retained at almost the same position in spite of changes in the combustion speed, while ensuring the burner reliability.

As shown in **Figure 4**, the coaxial jet sub-burners of the cluster burner are grouped into inner and outer systems. By controlling the fuel ratio of either system, we have enabled the realization of stable low-NOx combustion against variable H_2 levels and combustion speeds.

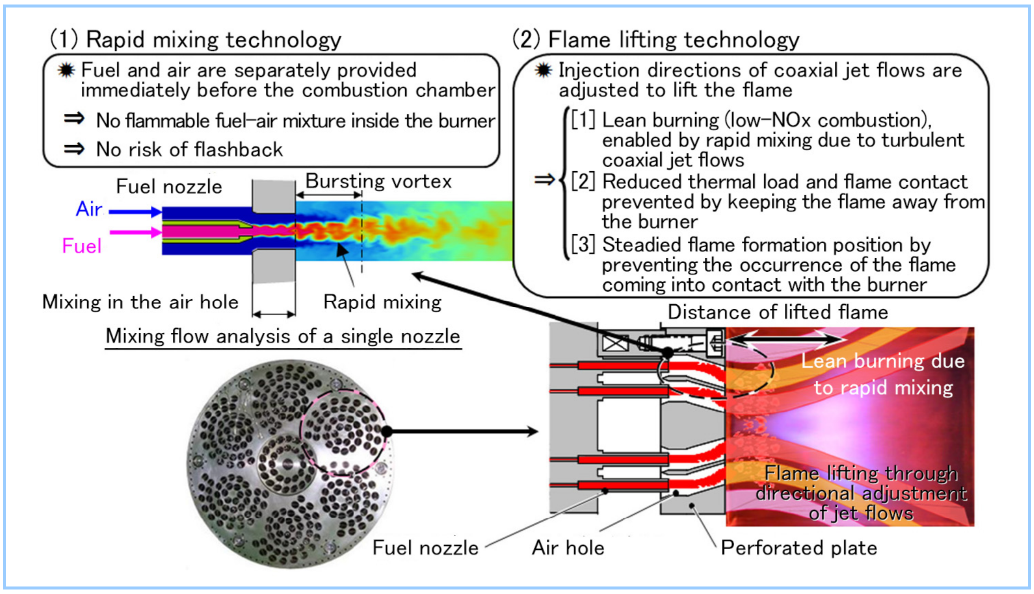

Figure 3 Structure of the developed burner (cluster burner) and applied technologies

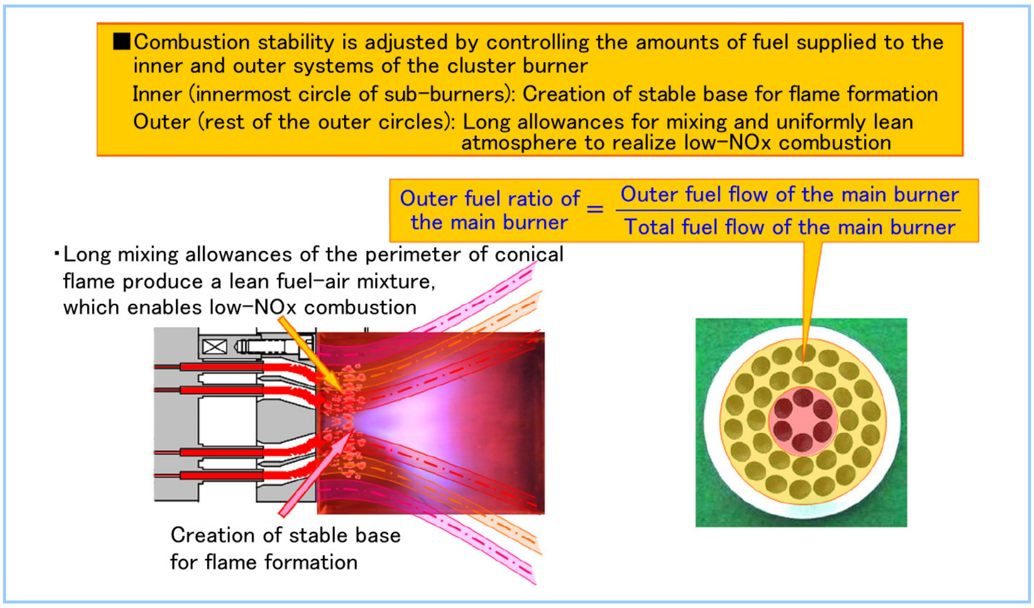

Figure 4 Cluster burner system grouping and technology to handle the fuel compositional change

4. Dry low-NOx test combustor for CCS-IGCC

Based on the developed technologies, a test combustor with several cluster burners (which can be installed in real H-100 gas turbines) was made and its combustion characteristics were examined using a surrogate fuel as a dummy gasified coal syngas. This is because the main constituent of gasified coal syngas is CO and it is impossible, mainly for safety reasons, to obtain as large a quantity of such syngas as is necessary for conducting the test with a real-scale combustor. The surrogate fuel was prepared to exhibit the combustibility corresponding to that of gasified coal syngas.

Figure 5 illustrates the burner component of the CCS-IGCC dry low-NOx test combustor. This is a distributed lean burning (multi-cluster) combustor, in which the pilot burner is located at the center and serves as the fire source for the whole combustor. The pilot burner is surrounded by six main burners.

Figure 6 shows the NOx emission characteristics of the multi-cluster test combustor at the rated load. The parameter is the ratio of fuel supplied to the outer system, which controls the low-NOx combustion performance of the main burner. In the CCS rate range of 0% to 90%, NOx emissions of any fuel type decreases as the fuel ratio of the main burner outer system increases. Low-NOx combustion performance (<30 ppm) has been achieved without injecting diluents.[2]

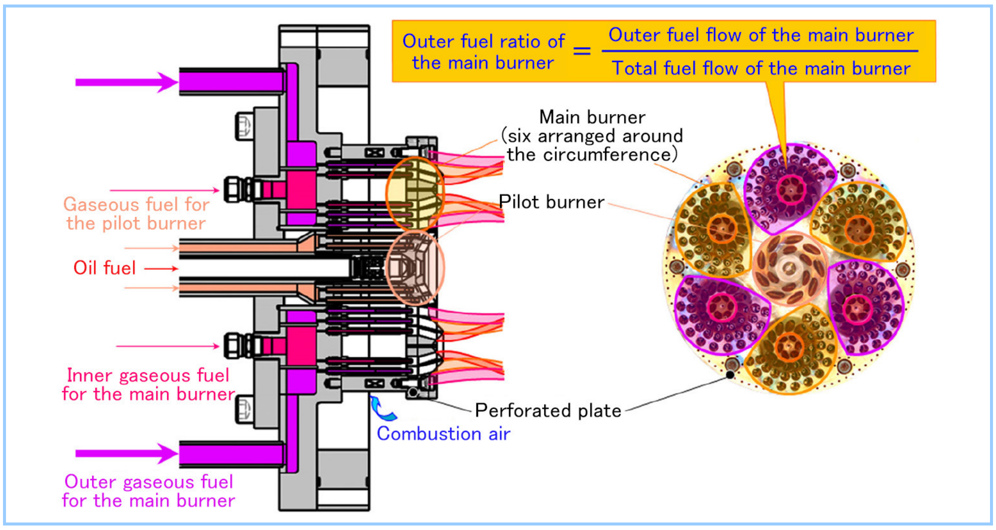

Figure 5 Burner component of the CCS-IGCC multi-cluster test combustor for H-100 gas turbines

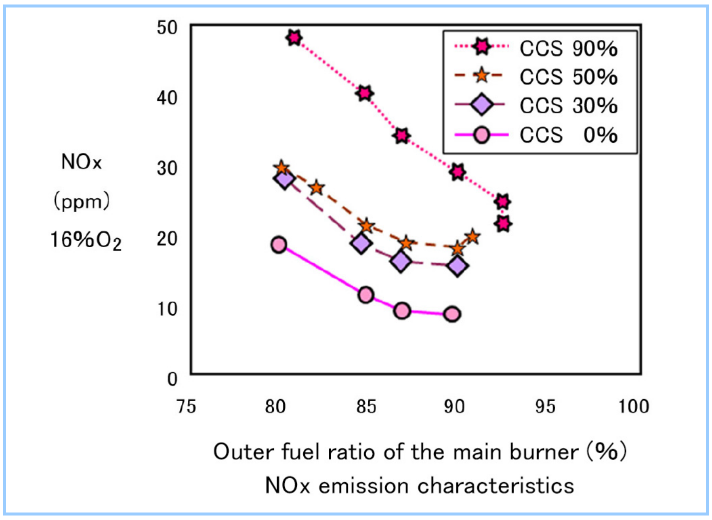

Figure 6 NOx emission characteristics of the CCS-IGCC multi-cluster test combustor for H-100 gas turbines

5. Multi-can combustion test with real gas at the EAGLE pilot plant

To examine the characteristics of the developed multi-cluster combustor with the use of real gasified coal syngas, a multi-cluster combustor was installed in the H-14 gas turbine at the oxygen-blown IGCC pilot plant known as EAGLE ("Coal Energy Application for Gas, Liquid and Electricity), located at the Wakamatsu Research Institute of J-POWER. It was conducted as part of the Research and Development of Coal Gasification Technology with Innovative CO_2 Capture project. **Figure 7** shows an exterior view of the EAGLE pilot plant and **Figure 8** shows a schematic diagram of the H-14 gas turbine. **Figure 9** illustrates the multi-cluster combustor used in the multi-can combustion test with real gas.

Throughput of coal	150 t/d
Gasifier pressure	2.5 MPa
Air separation unit	Pressurized cryogenic separation
Oxygen capacity/purity	4600m^3_N/h 95Vol%
Produced gas flow	14800m^3_N/h
Gas cleanup unit	MDEA wet desulfurization
Sulfur recovery	Limestone/ gypsum method
GT generator output	8000kW

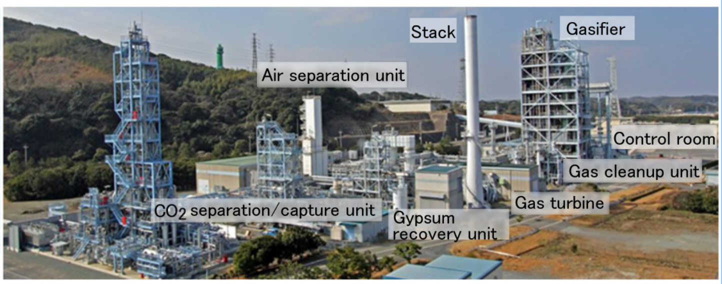

Figure 7 Pilot plant outline for the research and development of coal gasification technology with innovative CO_2 capture (Coal Energy Application for Gas, Liquid and Electricity: EAGLE-STEP 3)

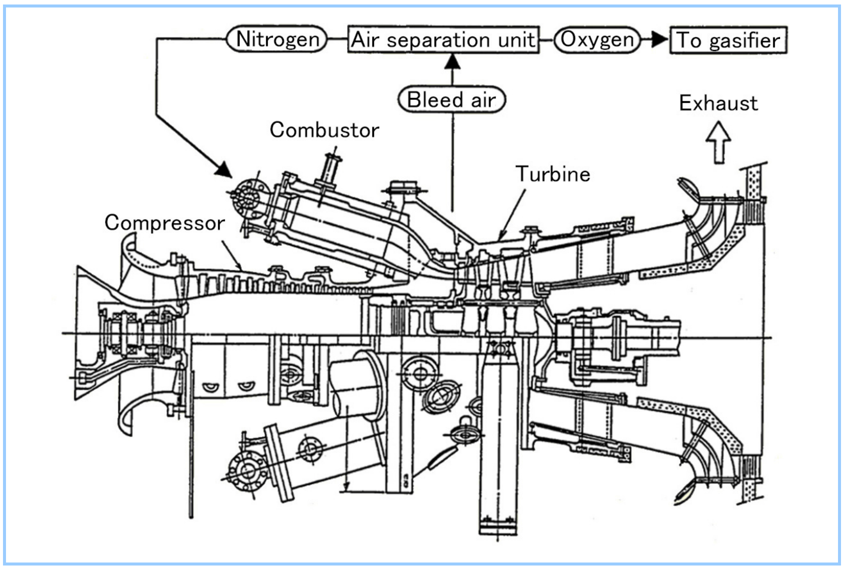

Figure 8 H-14 gas turbine used in the EAGLE multi-can combustion test with real gas

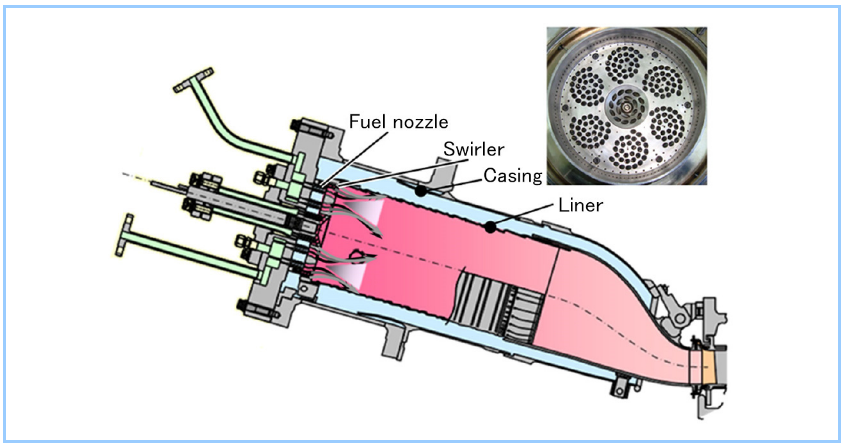

Figure 9 Multi-cluster combustor used in the EAGLE multi-can combustion test with real gas

Figure 10 shows the NOx emission characteristics at the maximum load of the multi-can combustion test with real gas (equivalent to the rated load), in comparison with those of the single-can combustion test with surrogate fuel. Both are in agreement with each other in the vicinity of the designed condition (80%), which confirms the validity of development using a surrogate fuel, as well as the excellent low-NOx combustion performance with an NOx level of less than 10 ppm (corrected at 16% O_2).

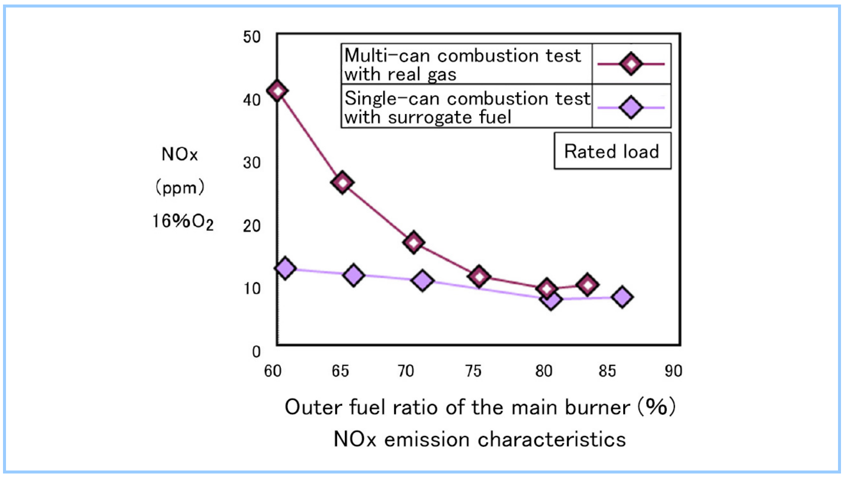

Figure 10 NOx emission characteristics of the EAGLE multi-can combustion test with real gas

6. Dry low-NOx combustor for the IGCC demonstration test facility

Based on the test results, the world's first multi-cluster combustor for IGCC dry low-NOx combustion was installed in the H-100 gas turbine, which is to be supplied to the OCG's IGCC demonstration facility (currently under construction in Osakikamijima, Hiroshima, Japan). **Figure 11** gives a schematic diagram of the developed multi-cluster combustor, while **Figure 12** is a photograph of the H-100 gas turbine. We will focus on the commencement of demonstration testing and commercial operation starting from February 2017.

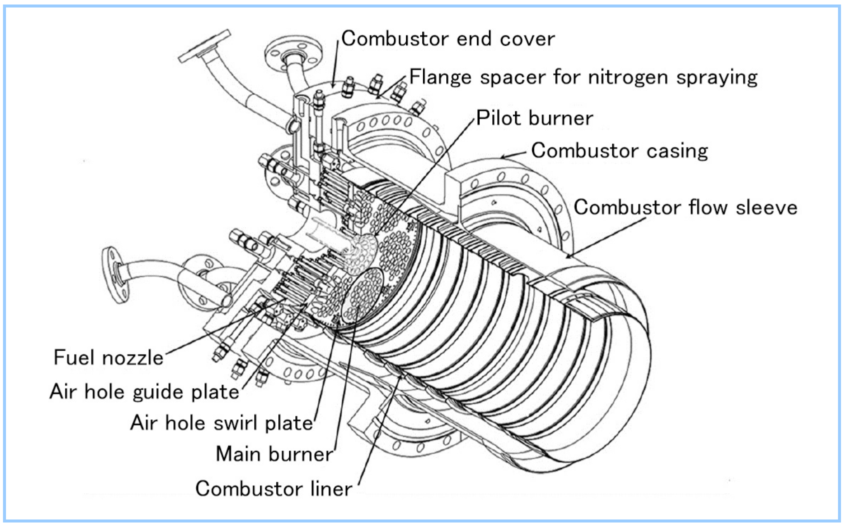

Figure 11 Schematic diagram of multi-cluster combustor for the IGCC demonstration facility

Figure 12 H-100 gas turbine, to be supplied to the IGCC demonstration facility (OCG Project)

7. Conclusion

IGCC is characterized by its higher power generation efficiency and lower environmental impact. As the next-generation of coal-fired power generation technology, IGCC is expected to serve as a core technology with high potential for the realization of a low carbon society. Having participated in NEDO's "Innovative Zero-emission Coal Gasification Power Generation Project" since 2008 and based on these results, MHPS successfully installed the world's first IGCC low-NOx combustor in the H-100 gas turbine, which is to be supplied to the IGCC demonstration facility of OCG. As indicated in **Figure 13**, we will expand the range of hydrogen-rich fuels applicable to this technology, thus contributing to the preservation of the global environment through the effective utilization of energy resources owing to increased types of usable fuels in gas turbines.

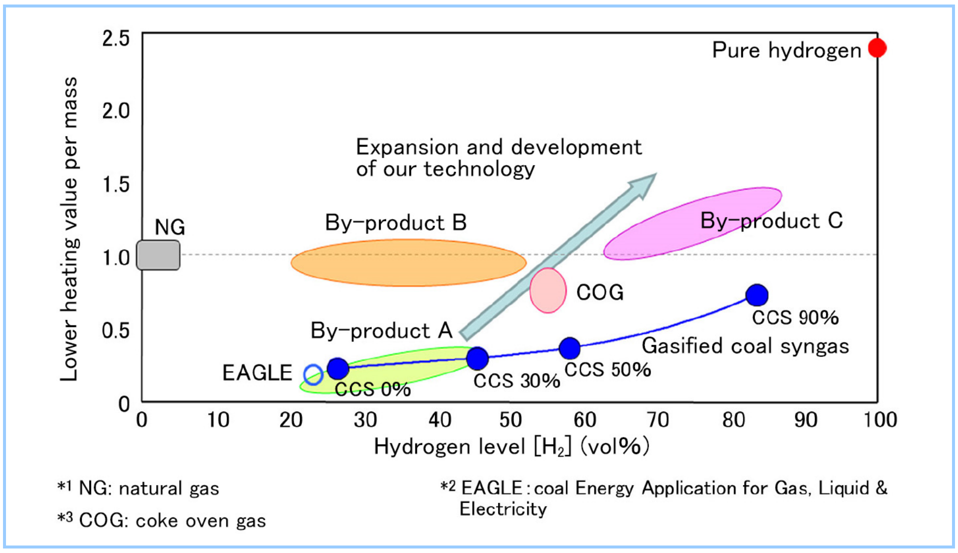

Figure 13 H_2 levels and lower heating values of hydrogen-rich fuels

References

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