Development of Co-Firing Method of Pulverized Coal and Ammonia to Reduce Greenhouse Gas Emissions

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IHI is accelerating studies such as "building carbon-free energy networks using ammonia as fuel" in the mission of reducing greenhouse gas emissions. We have been researched and developed several items to construct the networks. This paper introduces the development of the co-firing method of pulverized coal and ammonia in a coal-fired plant. We have faced numerous challenges when using ammonia as a fuel. Among them, IHI uses its own large-capacity combustion test facility to evaluate the combustion performance, and through the feasibility study, identifies issues and examines countermeasures to realize ammonia co-firing. This paper presents technologies that have been developed for the global ammonia network that IHI is aiming for.

1. Introduction

As efforts against global warming are accelerating around the world, expanding the use of hydrogen energy is important in achieving targets for reduction of greenhouse gas emissions based on the Paris Agreement. Various research and development of hydrogen energy, especially fuel cell vehicles, is being actively conducted with the aim of developing a commercial supply chain by 2030 that will procure approximately 300 000 tons of hydrogen annually and achieve a hydrogen cost of approximately 30 yen/Nm^3[(1)]. Along with this, carriers for transporting and storing hydrogen are also attracting attention, and IHI is conducting various forms of development focused on ammonia. Ammonia, which is used widely as a raw material for fertilizers and other chemicals, ① has a high hydrogen content per unit volume, ② allows utilization of existing production, transportation, and storage infrastructure, and ③ can be burned without reconversion to hydrogen; due to these and other features, rapid societal implementation is considered to be possible. With the aim of building the ammonia supply chain shown in **Fig. 1**, IHI is developing technologies for the use of ammonia in gas turbines, pulverized coal-fired boilers, and solid oxide fuel cells[(2)].

This paper reports on the development of technology to co-fire ammonia and pulverized coal aimed at reducing CO_2 emissions from coal-fired power plants.

Not only CO_2 emissions but also ash accumulation in the furnace, ash disposal, and sulfidation corrosion can be reduced by changing part of the fuel used in a coal-fired power plant from coal to ammonia. However, doing so raises some concerns regarding boiler performance, such as changes in boiler heat absorption and NO_x emissions from the combustion of ammonia. Furthermore, although in conventional coal-fired power plants ammonia is used as an NO_x reducing agent, in this study it is used as a fuel, and so a larger amount of ammonia gas is required. Therefore, since conventional facilities for handling ammonia as a reducing agent are insufficient, additional large-scale ammonia supply facilities will be necessary. In the future, prolonged continuous operation and operational evaluation with a commercial plant will be essential so as to verify concerns regarding performance and modification/expansion.

In this study, an ammonia co-fired burner was developed and evaluated using a combustion test in order to verify an ammonia co-firing method that can limit NO_x generation to the same level as that for coal firing. An additional purpose of this study is to conduct a feasibility study of the boiler directed at future verification with a commercial plant, and to identify an outline of the modifications needed when the demonstration plant is used.

2. Description of implementation

2.1 Combustion test

Ammonia has a higher nitrogen content than coal, so if it is injected into a large power generation boiler as fuel, there is a concern that the concentration of NO_x in the flue gas will be higher than that for conventional coal firing.

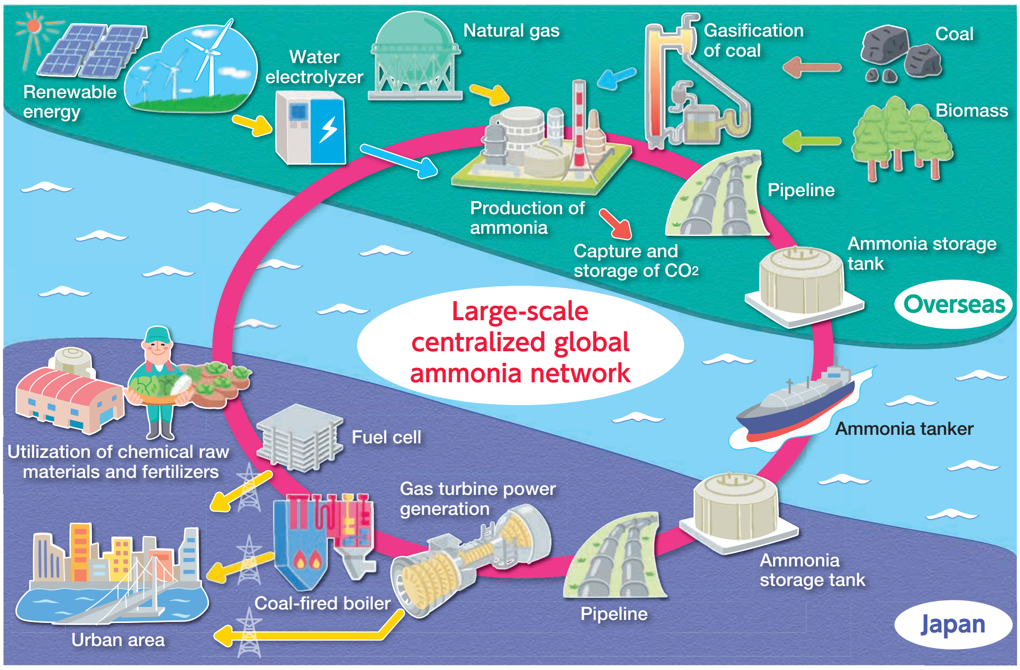


Fig. 1 Carbon-free energy supply chain targeted by IHI

Section 2.1 describes a test using a 10 MWth-class combustion test furnace at the D&D (Development & Demonstration) Park in the IHI Aioi Works, conducted mainly for the purpose of developing pulverized coal/ammonia co-firing technology that can achieve stable combustion and an NO_x concentration of 200 ppm or less (converted to oxygen concentration of 6%) with an ammonia co-firing rate of 20% (based on lower heating value).

2.1.1 Test equipment

Table 1 and **Fig. 2** respectively show the specifications and main system diagram of the combustion test furnace used for the pulverized coal/ammonia co-firing test(3). The combustion test furnace has one burner at the front. Air supplied from the Forced Draft Fan (FDF) undergoes heat exchange with the flue gas in the Gas-Air-Heater (GAH), which recovers heat from boiler flue gas and heats combustion air using the recovered heat to promote combustion in boilers with the heated air, and is then carried to the burner as combustion air. Part of the combustion air is supplied to a port called an Over Air Port (OAP), located above the burner. Air supplied from the pulverizer air fan undergoes heat exchange with the flue gas in the GAH, and

Table 1 Specifications of test furnace

Item	Specifications
Furnace	Front firing type with water jacket cooling (Width 3 × Depth 4.5 × Height 7 m)
Burner	IHI-DF (Dual Flow) burner, single

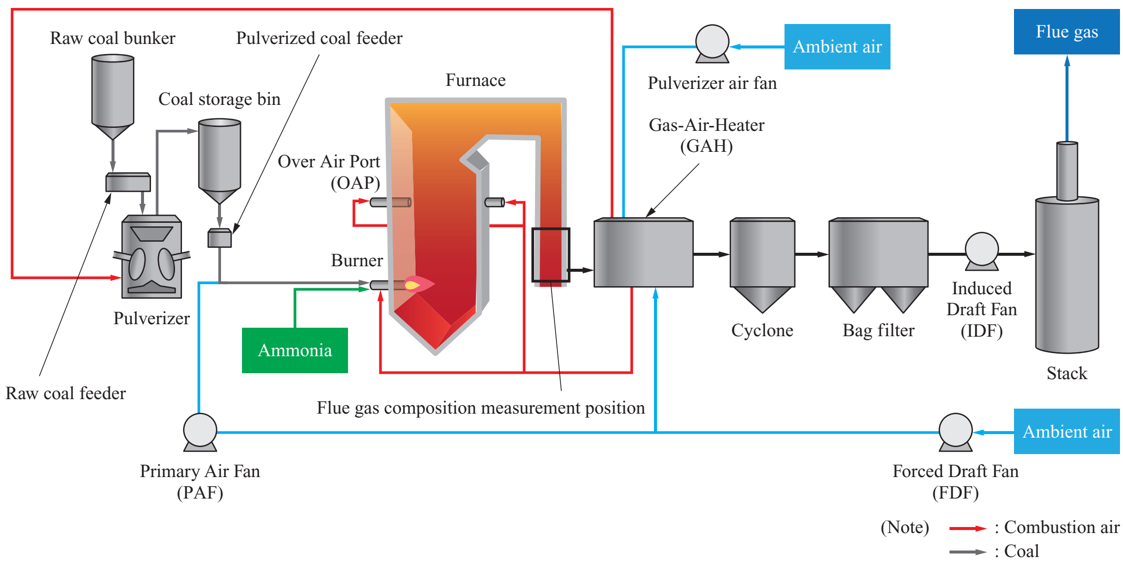


Fig. 2 Main diagram of test furnace

is then supplied to the pulverizer, where it is used to dry coal and carry pulverized coal. The pulverized coal is stored in the coal storage bin. The stored coal is unloaded at a specified rate by the pulverized coal feeder and supplied to the burner by the Primary Air Fan (PAF), together with conveyance air. The pressure in the furnace is kept negative by using the Induced Draft Fan (IDF) to draw in the air supplied to the furnace. The flue gas is sampled at the position shown in the middle of **Fig. 2** in order to analyze its composition using a gas analyzer (PG-250A, manufactured by HORIBA, Ltd.). In addition, a laser meter (LaserGas™ version II, manufactured by NEO Monitors AS) is installed at the stack inlet in order to continuously monitor the concentration of ammonia in the flue gas using infrared single-line absorption spectroscopy. This is to check that a large amount of ammonia is not released into the atmosphere when ammonia injected as fuel remains unburned.

Figure 3 shows a schematic diagram of the burner[3]. The burner has an axially symmetric structure, with pulverized coal channels, air resistors, and wind boxes arranged symmetrically from the center in that order. Together with conveyance air, pulverized coal is supplied to the furnace through the pulverized coal channels. Combustion air is supplied from the wind boxes to the furnace. The air resistors arranged at the combustion air channels have multiple movable vanes located symmetrically with respect to the axis, and the swirl force of combustion air can be adjusted by adjusting vane angle. Combustion air is swirled to form a circulation flow of gas in the furnace. This circulation flow rapidly mixes the hot combustion gas and fuel, promoting discharge of volatile matter and N content in the fuel, and thereby forming a stable flame and reducing NO_x in the reducing atmosphere.

Ammonia is carried to the burner by the ammonia supply facility. The ammonia supply facility can be equipped with four 0.5-ton cylinders and has two hot water vaporizers. Ammonia is gasified by the vaporizers and carried to the burner, with the mass flow rate being controlled. Ammonia can be supplied at a flow rate of up to 0.38 t/h. In this study, ammonia is supplied from the center of the pulverized coal burner. This is to reduce the modifications required when applying the ammonia co-firing technology to a commercial plant.

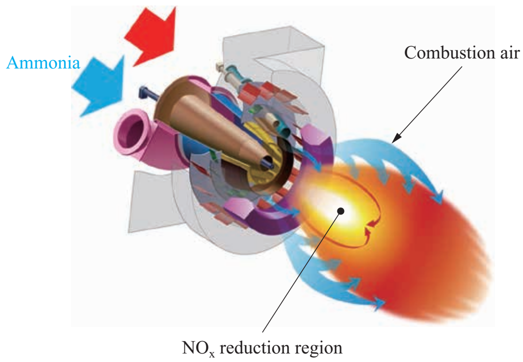


Fig. 3 Enlarged view of burner used in co-firing experiment

2.1.2 Test conditions

The following four evaluations were conducted:

(1) Checking for unburned ammonia and confirming flame stability during ammonia co-firing

(2) Effect of two-stage combustion ratio, which is the ratio of air quantity injected from OAP to all the combustion air, on flue gas composition

(3) Effect of heat input on flue gas composition

(4) Effect of fuel ratio of coal, which is the ratio of fixed carbon to volatile matter, on flue gas composition

Table 2 shows the test conditions for each item. In this test, the ammonia co-firing rate was constantly 20%, based on lower heating value. The fuel ratio of the coal used in the test (mass ratio of fixed carbon and volatile matter (–)) was 1.16 to 1.70 (bituminous coal).

2.1.3 Test results

2.1.3.1 Checking for unburned ammonia and confirming flame stability during ammonia co-firing

Figure 4 shows the change over time in the measured values of flue gas composition during coal firing and ammonia co-firing with an ammonia co-firing rate of 20%[4]. The amount of coal burned during ammonia co-firing is lower than that during coal firing by 20%, which indicates that the CO_2 concentration in the flue gas is also lower by approximately 20%. In addition, since the ammonia concentration at the stack inlet is 1 ppm, it can be concluded that almost all of the ammonia injected into the furnace is consumed within it.

Figure 5 shows the appearance of the flame[4]. When the swirl force of the combustion air is at the same extent, the flame ignition position during ammonia co-firing is farther from the burner port than that during coal firing. This is probably because ammonia, which is flame retardant, is supplied from the center of the burner. However, by adjusting the swirl force of the combustion air, the flame ignition position during ammonia co-firing can be adjusted to that during coal firing. The test results reported in this paper were obtained with the flame ignition position during ammonia co-firing adjusted to that during coal firing.

As described above, during ammonia co-firing, the flue gas composition is stable over time, there is no unburned ammonia, and the flame shape is almost the same as that during coal firing; it was therefore concluded that ammonia co-firing is rendered feasible by using a burner that is structured to supply ammonia from the center of the pulverized coal burner.

2.1.3.2 Effect of two-stage combustion ratio on flue gas composition

The two-stage combustion ratio is an important parameter for controlling NO_x in the flue gas, and is defined as the mass ratio of the amount of air for two-stage combustion to

Table 2 Conditions of co-firing experiment

Item	Unit	Base conditions	Low-load conditions
Heat input	MW	10	6.0 – 8.6
Air ratio	—	1.2	1.1 – 1.7
Two-stage combustion ratio	—	0.3	0.2 – 0.4

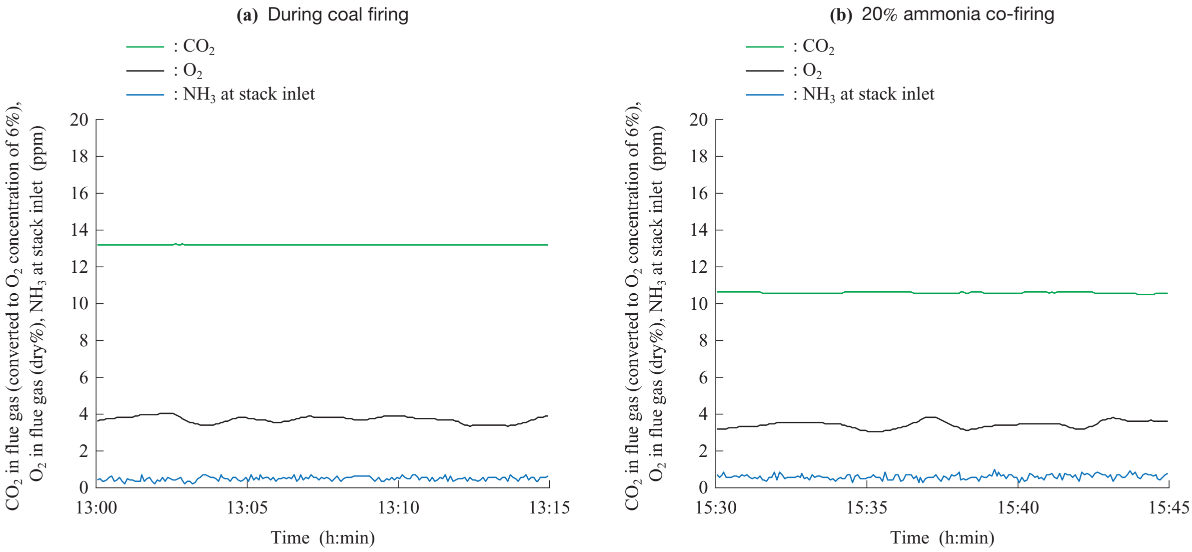


Fig. 4 Time history of flue gas composition

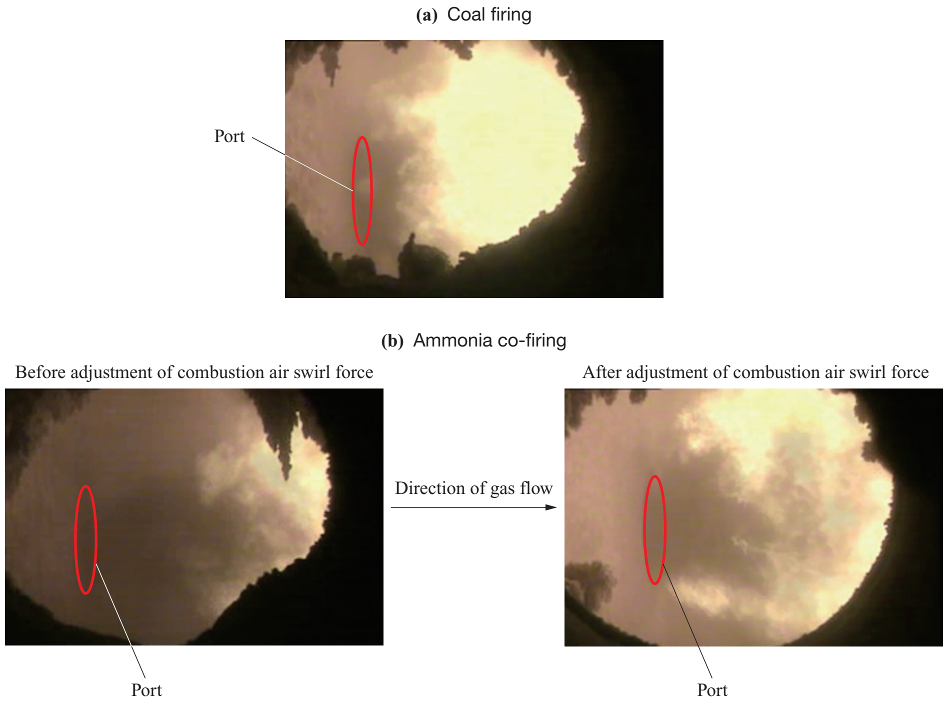


Fig. 5 Flame appearance

the total amount of air injected into the furnace. In order to evaluate how the two-stage combustion ratio affects flue gas composition, an ammonia co-firing test was conducted using the two-stage combustion ratio as a parameter, with a heat input of 10 MW and an air ratio of 1.1 to 1.2. The following reports the test results.

Figure 6 shows the relationship between the two-stage combustion ratio and NO_x in flue gas, and **Fig. 7** shows the relationship between the two-stage combustion ratio and unburned carbon in ash(4).

For coal firing, NO_x decreases monotonically as the two-stage combustion ratio increases from 20% to 40%. In contrast, for ammonia co-firing, NO_x is lowest when the two-stage combustion ratio is approximately 30%. It has been reported that, also in the case of coal firing, although NO_x decreases as the two-stage combustion ratio increases, NO_x increases when the two-stage combustion ratio exceeds a certain value(5). This is because, when the two-stage combustion ratio increases, NO_x production is suppressed at the burner level where the air ratio is low, but the unburned carbon remains and is burned at the two-stage combustion position, which causes the nitrogen content in the fuel to oxidize, thereby producing NO_x. Within the range of two-stage combustion ratio used in this test, this trend can only be seen for ammonia co-firing. Volatile matter of coal and NH_3 are presumed to be what burns at the burner level, but for ammonia co-firing, the amount of these components is larger than that for coal firing. Consequently, it is presumed

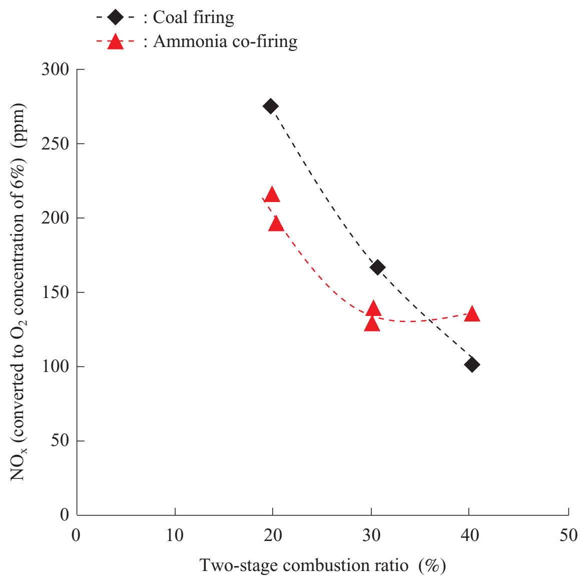
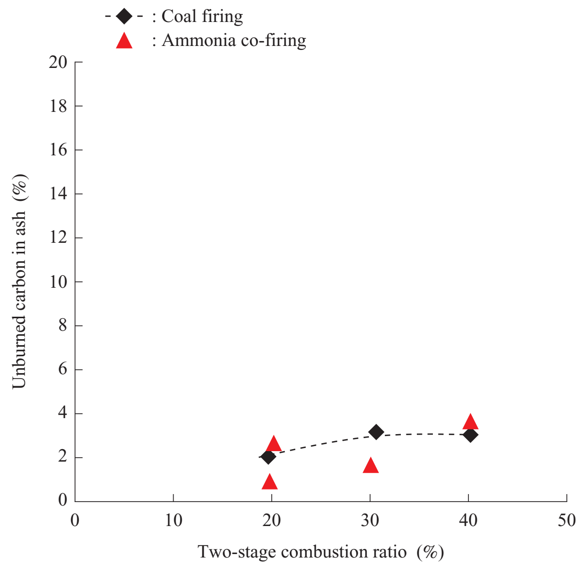


Fig. 6 Relationship between two-stage combustion ratio and NO_x



(Note) Air ratio : 1.1 to 1.2

Fig. 7 Relationship between two-stage combustion ratio and unburned carbon

that, for ammonia co-firing and with a high two-stage combustion ratio, the ratio of air to the amount of volatile matter of coal and NH_3 at the burner level is low, and a relatively large amount of unburned carbon remains, which is burned at the two-stage combustion position, thereby causing NO_x to increase.

In the range of two-stage combustion ratio used in this test, the amount of unburned carbon in ash is almost the same for ammonia co-firing and coal firing, which suggests that with an appropriate two-stage combustion ratio, it is possible to carry out ammonia co-firing such that NO_x does not exceed that which occurs with coal firing.

2.1.3.3 Effect of heat input on flue gas composition

In order to apply the ammonia co-firing technology to a commercial plant, it is desirable that ammonia co-firing be possible even at loads other than the rated load. However, there is a concern that in the low-load range, as the fuel supply decreases, the temperature in the furnace will decrease and the combustion of ammonia cannot be maintained, causing part of the ammonia to remain unburned. With regard to this, in order to confirm whether the flue gas composition is the same for ammonia co-firing and coal firing even in the low-load range, pulverized coal and ammonia were co-fired at a low load with a constant ammonia co-firing rate of 20%, and the flue gas composition was evaluated. **Figures 8** and **9** respectively show the relationship between heat input and NO_x and that between heat input and unburned carbon in ash[(6)].

From **Fig. 8**, it can be seen that for both coal firing and 20% ammonia co-firing, NO_x increases as heat input decreases, and the increase rate of NO_x for ammonia co-firing is almost the same as that for coal firing. This suggests

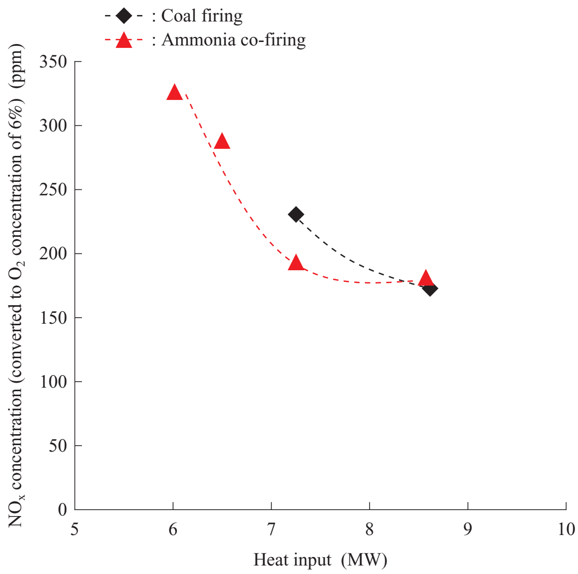


Fig. 8 Relationship between heat input and NO_x concentration

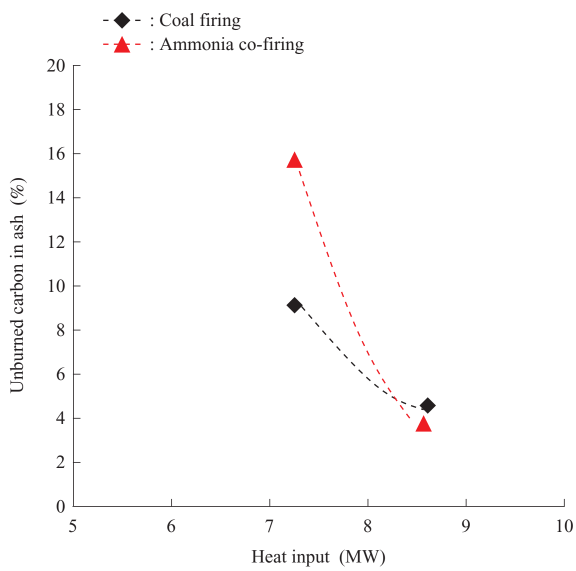


Fig. 9 Relationship between heat input and unburned carbon

that even in the low-load range, NO_x concentration during ammonia co-firing is almost the same as that during coal firing. From **Fig. 9**, however, it can be seen that with a heat input of 7.3 MW, the amount of unburned carbon in ash during ammonia co-firing is approximately twice that during coal firing. This is presumably because, under conditions where heat input is low, the ammonia flow rate and linear momentum of ammonia decrease, so that reaction of the oxygen in combustion air with ammonia is promoted while its reaction with pulverized coal is inhibited. To identify the cause of this phenomenon, it is necessary to collect more data and verify reproducibility.

2.1.3.4 Effect of fuel ratio of coal on flue gas composition

In a commercial plant, subbituminous coal may be used as fuel in addition to bituminous coal. Assuming use of subbituminous coal, the effect of the fuel ratio of the coal on flue gas composition during ammonia co-firing was evaluated in order to assess whether flue gas composition is the same for ammonia co-firing and coal firing even when ammonia is co-fired with low-fuel-ratio coal. The types of coal used have fuel ratios of 1.16 and 1.70, as shown in **Table 3**. **Figure 10** shows the results of NO_x measurement[(6)]. In this test, heat input was set to 7 MW for equipment-related reasons.

From **Fig. 10**, it can be seen that, for both coal firing and ammonia co-firing, NO_x increases slightly as the fuel ratio increases. In addition, for both fuel ratios, NO_x concentration during ammonia co-firing is lower than that during coal firing. This suggests that the fuel ratio of the coal does not greatly affect NO_x concentration in the flue gas during ammonia co-firing. This is because for 20% ammonia co-firing, 90% or more of the nitrogen contained in the injected fuel (coal and ammonia) comes from ammonia, so that the absolute amount of injected nitrogen does not change significantly within a fuel ratio range of 1.16 to 1.70; the fuel ratio of the coal is therefore considered to have little effect on the NO_x concentration in the flue gas.

This result suggests that ammonia co-firing can be used even with low-fuel-ratio coal, such as subbituminous coal.

2.2 Feasibility study with a large coal-fired power generation boiler

2.2.1 Purpose

Section 2.2 describes a feasibility study of ammonia co-firing in an existing large coal-fired power generation boiler, and gives an evaluation of the resulting boiler performance. Coal firing facilities were evaluated by considering various performance data related to performing ammonia co-firing, and this evaluation was used to examine issues arising from the application of ammonia co-firing — such as whether it is possible to use the facilities as they are, or whether additions/modifications are necessary — together with possible solutions.

2.2.2 Main conditions of boiler feasibility study

In this development, the feasibility study was conducted with an existing 1 000 MW-class large coal-fired power generation boiler. **Table 4** shows details of the conditions

Table 3 Fuel properties

Item		Unit	Coal A	Coal B	NH_3
Lower heating value		MJ/kg	29.0	29.1	18.5
Proximate analysis	Moisture content	wt%	2.2	2.0	—
	Fixed carbon	wt%	56.2	48.1	
	Volatile matter	wt%	33.0	41.6	
	Ash content	wt%	10.8	10.3	
	Fuel ratio	—	1.70	1.16	
Ultimate analysis	Carbon	wt%	71.1	69.7	—
	Hydrogen	wt%	4.6	5.3	
	Nitrogen	wt%	1.4	1.1	
	Oxygen	wt%	11.7	13.2	
	Total sulfur	wt%	0.4	0.5	

(Note) Moisture content: Air-dry basis; Other items: Dry basis

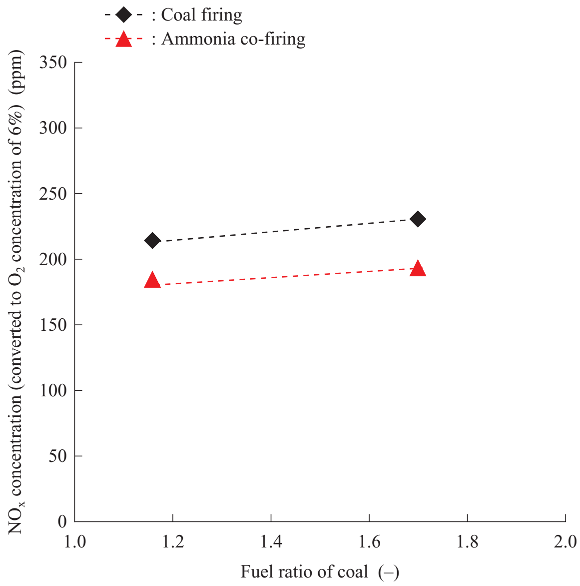


Fig. 10 Relationship between fuel ratio and NO_x concentration

Table 4 Main conditions of feasibility study for 1 000 MW-class boiler

Item	Description
Plant	1 000 MW-class power plant
Ammonia co-firing rate	20% based on higher heating value
Reference boiler performance	Assumes a new boiler.
Coal type	Assumes use of design coal with new boiler.
Load	Evaluated at MCR.
Co-firing rate at each burner	20% at each burner

under which the study was conducted[(3)]. Ammonia was mixed with coal — the main fuel — at an ammonia co-firing rate of 20% with respect to boiler heat input. In general, boiler performance deteriorates over time when operated for a prolonged time period, but this study assumes the performance of a newly installed boiler. With regard to load, the Maximum Continuous Rating (MCR) was used, at which the quantities of combustion air and flue gas are largest. With regard to the ammonia injection method, it was assumed that ammonia was supplied to all burners at an ammonia co-firing rate of 20% so as to achieve 20% ammonia co-firing in the entire plant.

2.2.3 Details of items examined in boiler feasibility study

Section 2.2.3 evaluates the three following items:

(1) Evaluation of boiler efficiency and material balance

Using the properties of the coal-ammonia mixture fuel, combustion calculations are carried out to examine fuel consumption and air-gas balance.

(2) Examination of modifications to boiler system

The capacity of the boiler equipment, including auxiliary equipment, is examined using the air and gas quantities produced by the combustion calculations.

(3) Examination of ammonia supply system

The ammonia injection position, equipment installed in the system, and ammonia gas purging method are examined.

2.2.3.1 Evaluation of boiler efficiency and material balance

Here, a comparison is given of boiler performance for coal firing and ammonia co-firing, and the material balance for each piece of equipment is verified; this data allows examination of whether modifications to existing facilities are necessary. **Table 5** shows the heating values of the coal (design coal) and ammonia used in this study[3].

As shown in **Table 4**, the MCR is used in this study. **Figure 11** shows the boiler efficiencies during coal firing and ammonia co-firing[3]. It can be seen that the boiler efficiency during ammonia co-firing is slightly lower than that during coal firing. This is presumably because, although ammonia co-firing reduces the loss due to unburned coal, burning ammonia increases the moisture content in the boiler flue gas, which increases the latent heat of the moisture discharged from the gas.

Figure 12 shows the coal consumptions during coal firing and ammonia co-firing[3]. Ammonia co-firing with coal at a co-firing rate of 20% results in a simple decrease in the amount of injected coal. However, because ammonia has a low heating value per unit mass, the total fuel consumption (coal + ammonia) for ammonia co-firing is higher than for coal firing, and so the running cost for ammonia co-firing tends to increase.

Figure 13 shows the combustion air quantities during coal firing and ammonia co-firing[3]. **Figure 14** shows the corresponding flue gas quantities[3]. With regard to combustion air, although the total combustion air quantity is small, the air flow ratio changes, which tends to increase the secondary combustion air ratio. With regard to the flue gas, the quantity during ammonia co-firing is slightly higher than that during coal firing. Judging from these results, detailed studies — for both the air and gas sides — are required

Table 5 Calorific value of fuel used in feasibility study for 1 000 MW-class boiler

Item	Unit	Coal (design coal)	Ammonia
Higher heating value	MJ/kg	24.1	22.4

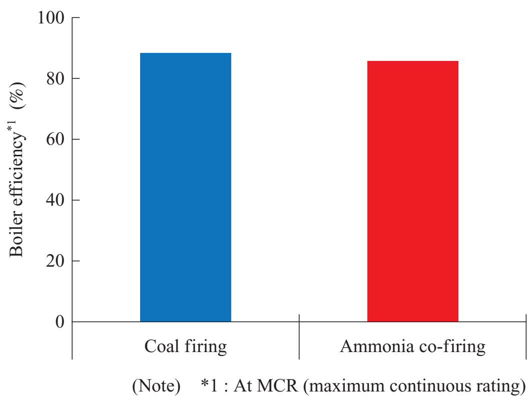


Fig. 11 1 000 MW-class boiler_boiler efficiency

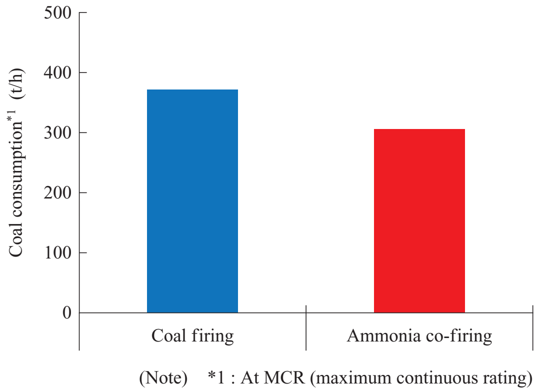


Fig. 12 1 000 MW-class boiler_fuel consumption

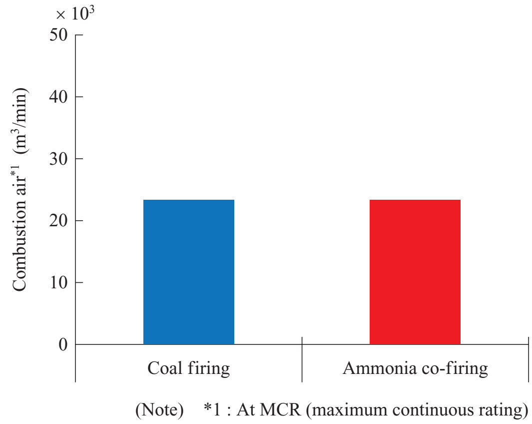


Fig. 13 1 000 MW-class boiler_combustion air

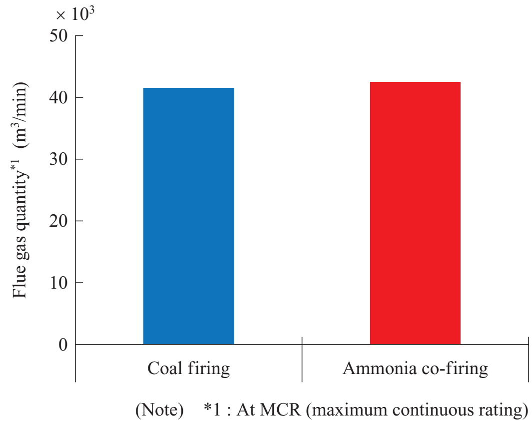


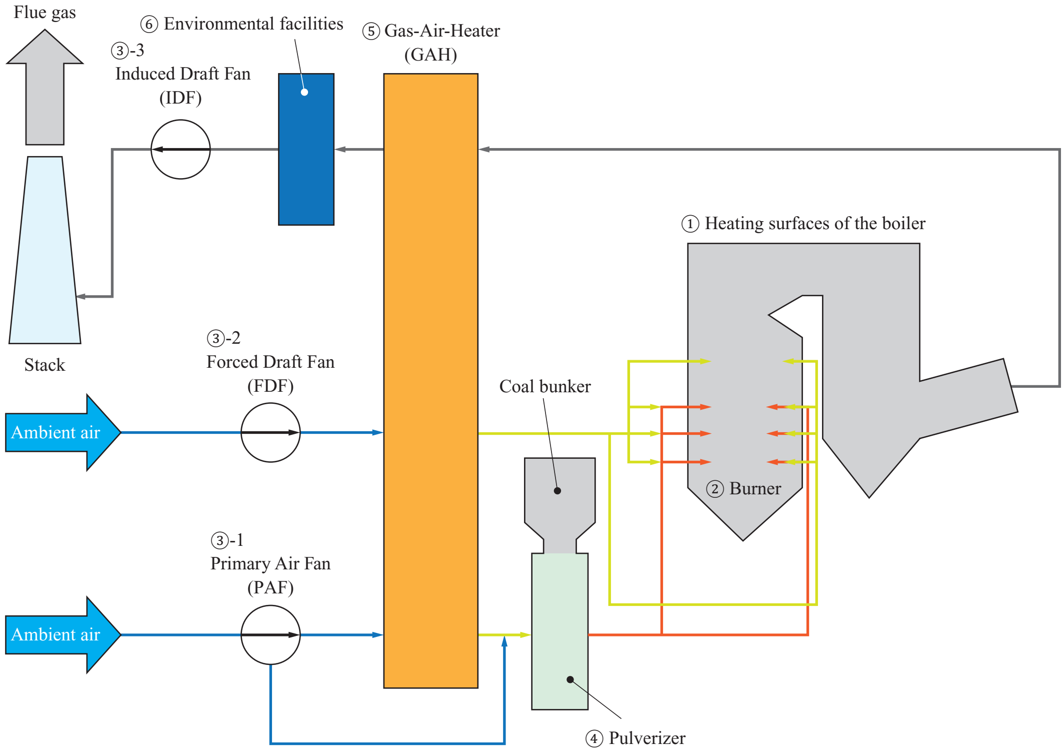
Fig. 14 1 000 MW-class boiler exhaust gas volume

regarding surplus capacity of the draft system and other factors in order to determine if draft system components designed for coal firing can be used for ammonia co-firing without modifications.

2.2.3.2 Examination of modifications to boiler system

After first confirming a common system configuration, **Section 2.2.3.2** examines modifications to the boiler system. **Figure 15** shows a common system configuration for a coal-

(a) System configuration of coal-fired boiler system



(b) Items examined in coal-fired boiler system

No.	Item	Description
①	Heating surfaces of the boiler	As a result of numerical analysis that simulates a boiler(3), it was found that the heat recovery quantity is almost the same for coal firing and ammonia co-firing, and since the steam and gas temperatures throughout the system are not different from those that were designed, ammonia co-firing requires no modifications to the boiler heating surfaces.
②	Burner	Basically, burners designed for coal firing are also used for ammonia co-firing. However, it is necessary to add ammonia supply facilities, including equipment that injects ammonia gas into the burner and systems that address concerns arising from the use of ammonia.
③-1	PAF	As stated in the preceding description, the PAF is used to carry pulverized coal to the burner. During ammonia co-firing, some of the pulverized coal used as fuel is replaced by ammonia gas, and so the amount of air used to carry coal decreases; therefore, the PAF requires no modifications.
③-2	FDF	The air required for combustion is supplied by the PAF and FDF. During ammonia co-firing, the amount of air supplied by the PAF decreases, and the FDF has to compensate for this in order to ensure the required amount of air for combustion. Hence, the flow rate on the FDF side tends to increase. In the model plant used in this study, there is some surplus capacity in the design specification of the FDF, and so no modification is necessary. However, depending on the design specification, such surplus capacity may not exist, and so careful consideration is required in order to determine whether modification is needed.
③-3	IDF	As a result of material balance evaluation, it was found that the gas quantity tends to increase slightly for ammonia co-firing. As with the FDF, in the model plant used in this study, there is some surplus capacity in the design specification of the IDF, and so no modification is necessary. However, careful consideration is required, since modification may be needed depending on the setting in which surplus capacity is ensured.
④	Pulverizer	Because the amount of injected coal decreases for ammonia co-firing, the operation load of the pulverizer decreases. Therefore, no modification of the pulverizer is necessary. In addition, because the amount of injected coal decreases, the required temperature of the air for drying the coal decreases. As a result, some of the heat recovered by the GAH during coal firing remains in the flue gas during ammonia co-firing, and so the flue gas temperature during ammonia co-firing tends to be higher.
⑤	GAH	The flue gas temperature tends to increase because not all the heat from the gas side can be recovered due to a decrease in pulverizer inlet temperature, increase in gas flow rate, change in gas properties, etc. Flue gas temperature needs to be examined in detail, but since it increases by around 10 degrees Celsius, this level of increase can be absorbed by the surplus capacity available when the facility is newly installed, and so no modification of the GAH is required.
⑥	Environmental facilities (NO_x removal equipment, dust collector, and SO_x removal equipment)	It was confirmed that during ammonia co-firing, NO_x concentration is almost the same as during coal firing, and that CO_2, SO_2, and dust decrease as the amount of injected coal decreases. Although the environmental regulation values are satisfied, it was confirmed that there is an increase in the amount of gas and moisture content of the flue gas, so it is necessary to further evaluate modification and expansion of environmental facilities.

Fig. 15 General system configuration of coal-fired boiler system

fired boiler, together with points for examination[3].

In a coal-fired boiler, combustion air is sent to the GAH by the FDF. In the GAH, the element is heated when it comes into contact with the hot gas at the boiler outlet (recovery of heat from the boiler flue gas), the heated element heats combustion air, and the heated combustion air promotes combustion in the boiler. The hot air from the GAH is sent to the burner. At the same time, part of the air sent by the FDF is supplied from the top of the boiler in order to supply combustion air in two steps, thereby reducing NO_x in the combustion flue gas. This reduces the amount of excess air supplied to the burner and intentionally forms a reducing atmosphere around it, thereby reducing NO_x (Fuel NO_x) caused by the N content in the fuel. Overall, supplying air in two steps compensates for the shortage of oxygen, thereby achieving the required air excess ratio.

The rest of the combustion air supplied from the FDF is sent to the pulverizer by the PAF. The primary air is used to carry the pulverized coal pulverized by the pulverizer to the burner and also to dry the coal. Part of the primary air is sent to the GAH and heated. This hot air is mixed with cool air at the pulverizer inlet to adjust the temperature to one suitable for drying the coal in the pulverizer, and then sent to the pulverizer.

After combustion by the burner, the generated combustion flue gas is drawn by the IDF. For this reason, the furnace is always maintained at negative pressure. Heat is recovered from the combustion flue gas by the heating surfaces of the boiler and by the GAH, and then its gas properties are adjusted by passing it through environmental facilities that remove NO_x, dust, and SO_x. Finally, the gas is released into the atmosphere.

Here, the six following parts were examined with regard to modification of the boiler system (see **Fig. 15** for details of these parts):

1. Heating surfaces of the boiler
2. Burner
3. Draft system components (PAF, FDF, and IDF)
4. Pulverizer
5. GAH
6. Environmental facilities (NO_x removal equipment, dust collector, and SO_x removal equipment)

2.2.3.3 Examination of ammonia supply system

In order to achieve ammonia co-firing, it is necessary to add an ammonia gas system between the ammonia gasification facility and the burner. **Figure 16** is a schematic diagram of the ammonia gas system examined in this study[3]. During ammonia co-firing, liquid ammonia is gasified and the ammonia gas is co-fired with coal, and so, in order to ensure reliability, the ammonia gas system has basically the same system configuration as a fuel system designed for a boiler which uses a gas fuel as its main fuel. In addition, the ammonia gas and coal are co-fired coaxially, and all burners are provided with ammonia gas piping so that each burner can co-fire at a co-firing rate of 20%. One of the most important issues when considering ammonia co-firing is not allowing ammonia gas, which is deleterious and poisonous, to leak out of the system, i.e., not allowing it to be released into the atmosphere. Because this requirement constitutes a major premise, a basic design policy is that ammonia gas be purged to pretreatment facilities by using N_2, etc., rather than released into the atmosphere as is usually done with other

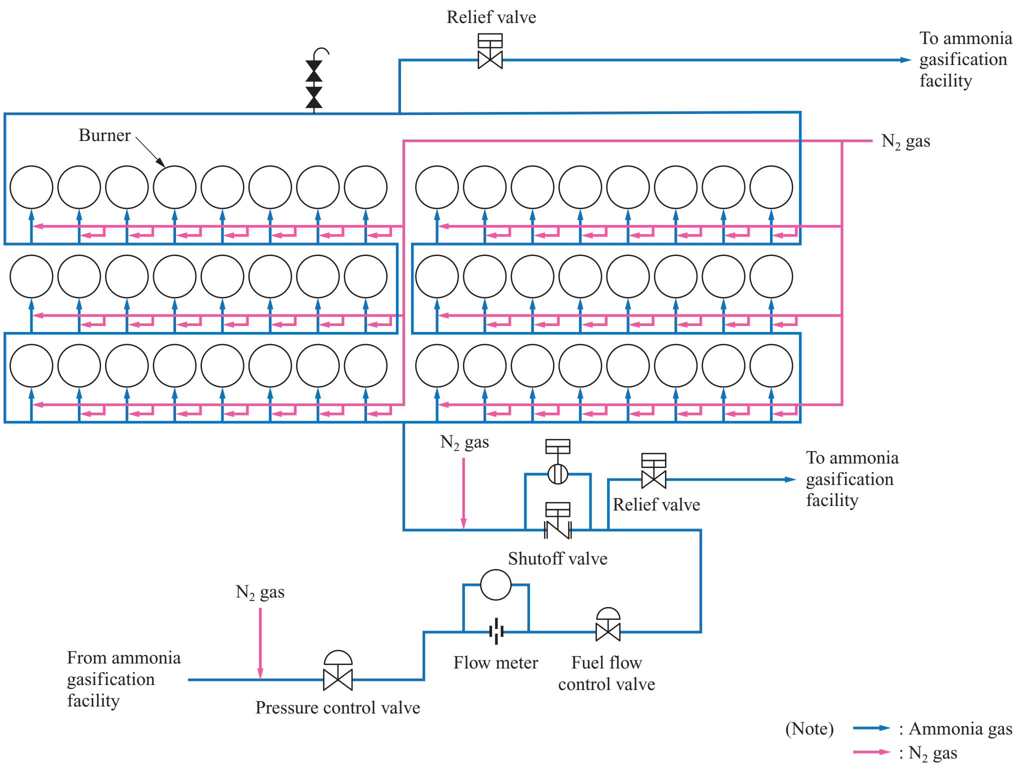


Fig. 16 Schematic diagram of 1 000 MW-class boiler_ ammonia gas system

gas fuels.

In the current study, only a basic system configuration was examined, but in the future it will be necessary to verify boiler operation items and specifications for ammonia co-firing, and perform further examination of the details of the system taking these factors into account. In addition, consideration of safety is indispensable when using ammonia gas, and so we also intend to examine safety measures.

3. Conclusion

As a method of reducing CO_2 emissions from coal-fired power plants, we developed a pulverized coal/ammonia co-firing technology in order to use ammonia — a hydrogen carrier — as fuel for coal-fired power generation.

In the combustion test, it was demonstrated that, even for ammonia co-firing, NO_x can be limited to the same level as for coal firing and a stable flame maintained by supplying ammonia from the center of a coal-fired burner. In addition, the effect of the two-stage combustion ratio, heat input, and coal fuel ratio on flue gas composition was evaluated, and it was confirmed that, under appropriate conditions, NO_x concentration does not exceed that for coal firing. From the results of this test, it was found that there is almost no necessity to install additional large NO_x-related facilities when performing co-firing of pulverized coal and ammonia. Going forward, in order to enhance feasibility for societal implementation, we will evaluate the possibility of ammonia co-firing with a lower heat input and develop a burner that can co-fire pulverized coal and ammonia at co-firing rates above 20%.

In the feasibility study for large coal-fired power generation boilers, it was found that the only modifications required for ammonia co-firing were in the ammonia supply system, with all other facilities being usable in their existing specifications. However, this result was obtained through evaluation under only one set of specific conditions, and continuing consideration is required due to dependency of the result on coal type, ammonia co-firing rate, etc. In addition, we will continue investigation of subjects related to boiler operation, such as timing of fuel injection, operation at low loads, and methods for stopping ammonia co-firing, for purging ammonia, and for detoxifying ammonia.

We will continue research and development regarding the performance and facility-related problems to be solved arising from the ammonia co-firing performed in this study, but in the future, it will be necessary to perform operational evaluation using a commercial plant so that this technology can be applied to existing plants. In addition to developing new burners and conducting feasibility studies in order to solve relevant problems, we will perform early determination of candidate demonstration sites for the evaluation of operation on a larger scale, and conduct a demonstration project. As the world moves toward greater consideration of the environment, IHI will accelerate its research and development of ammonia co-firing technology so that it can contribute to reducing greenhouse gas emissions.

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