Development of an Environmentally Conscious Thermal Power System

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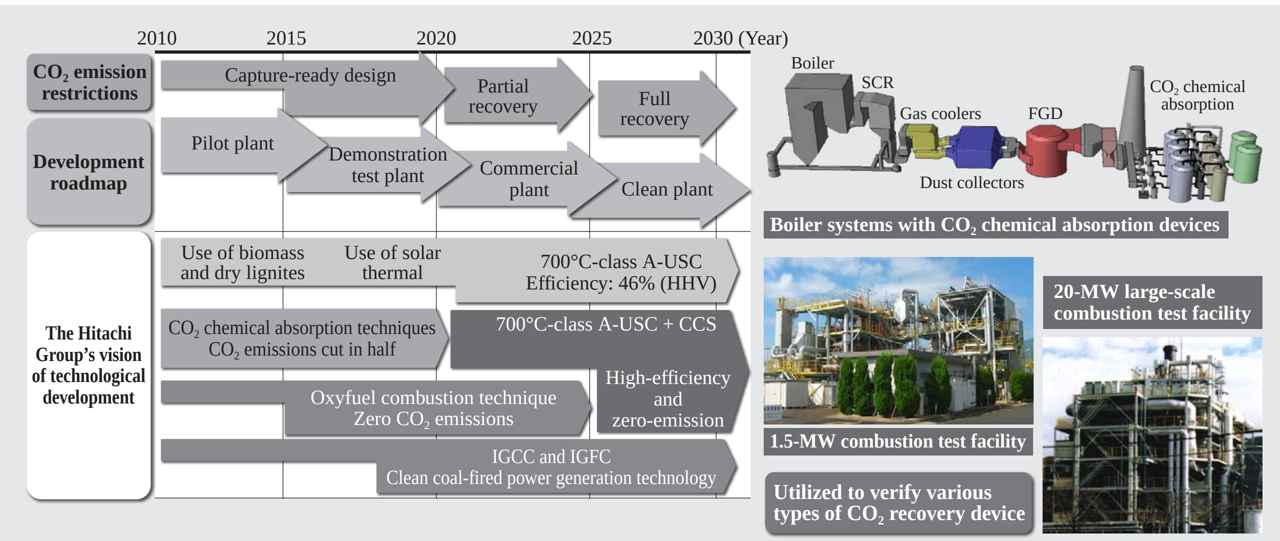
OVERVIEW: New technologies to reduce CO_2 emissions and environmentally conscious thermal power generation system technologies that effectively use coal are needed to counter global warming. In the Hitachi Group, the Power Systems Company of Hitachi, Ltd. is playing a central role in the development of technologies to reduce environmental loads. These include CO_2 recovery technology, biomass combustion that reduces CO_2 emissions, and technologies such as lignite pre-drying technology that reduce CO_2, NOx, and other substances that are emitted when coal is burned. Hitachi will continue developing technologies that can contribute to the reduction of CO_2 emissions while giving consideration to economics, in order to achieve the best possible combination of fossil fuels and renewable energy.

INTRODUCTION

AS global economic development causes the demand for energy to rise, the issue of countering global warming is growing increasingly urgent. Since coal deposits are not overly concentrated in particular regions, and since the coal is cheap, coal-fired power generation has played a major role as a source of energy for nations. Also, the Great East Japan Earthquake of 2011 has generated momentum, causing society to reevaluate and place a greater priority on this issue. Coal generates large quantities of carbon dioxide (CO_2) emissions, however, and this is why Hitachi is pursuing a wide range of efforts in the area of coal-fired power generation, towards the realization of a low-carbon society.

This article describes a demonstration testing project using CO_2 recovery technology to recover the CO_2 in the exhaust gas of coal-fired power plants, technology that increases the biomass co-firing ratio in coal to reduce CO_2, and lignite pre-drying technology, which is an effective way to use low-quality coal as part of the switch to energy conservation in coal-fired power generation.



CO_2: carbon dioxide A-USC: advanced ultra-supercritical HHV: higher heating value CCS: carbon capture and storage
IGCC: integrated coal gasification combined cycle IGFC: integrated coal gasification fuel cell combined cycle SCR: selective catalytic reduction system
FGD: flue gas desulfurization system

Fig. 1—Hitachi Group Roadmap for Environmentally Conscious Technology.
Hitachi provides technologies that promote the best combination of fossil fuels and renewable energy.

GLOBAL OPERATIONS IN ENVIRONMENTALLY CONSCIOUS TECHNOLOGY

Hitachi has declared that it will “help reduce annual CO_2 emissions by 100 million tons by 2025 through Hitachi products and services” in its Environmental Vision 2025, and is promoting the development of technology towards the realization of a global low-carbon society. In particular, power generation departments are responsible for approximately 70% of this amount, and are proactively working to develop technologies that can contribute to reductions in CO_2 while considering economics at the same time, in order to achieve the best possible combination of fossil fuels and renewable energy.

Specifically, efficiency-improvement techniques include 700°C-class advanced ultra-supercritical thermal power generation (A-USC) and integrated coal gasification combined cycle (IGCC) technologies, the use of solar thermal, photovoltaic, wind power, and biomass renewable energy sources, exhaust gas treatment technology including SCR, FGD, and chemical absorption and oxyfuel combustion techniques as CO_2 recovery technology. Fig. 1 shows this development roadmap and vision, systems in which the equipment is used, and the exteriors of research facilities.

In developing these technologies, Hitachi has built a global network across Japan, the USA, and Europe, and is collaborating with local universities and national research institutes.

The development of materials that can withstand high temperatures and pressures is a key technology behind the 700°C-class A-USC, and Hitachi, Ltd. and Hitachi’s European base Hitachi Power Europe GmbH are collaborating with power utilities and German universities on a wide range of joint development projects, from basic testing to in-plant testing.

As for chemical absorption techniques and exhaust gas treatments, Hitachi, Ltd. and Hitachi’s American base Hitachi Power Systems America, Ltd. have commissioned a U.S. Department of Energy (DOE) research institute with a joint project to verify chemical solvents. Also, Hitachi, Ltd. and Hitachi Power Systems Canada Ltd. have started collaborating on a joint demonstration test project regarding CO_2 recovery technology with Canada’s Saskatchewan Power Corporation (SaskPower).

In the area of renewable energy, Hitachi is developing technology for mixed biomass combustion and the effective use of torrefaction biomass, as well as high-speed load change technology for traditional thermal power. Hitachi, Ltd. will also collaborate with Hitachi Power Europe GmbH to develop combustion technology for the high-moisture lignites (dry, direct combustion, etc.) that are expected to be used in increasingly larger quantities in Southeast Asia and elsewhere (see Fig. 2).

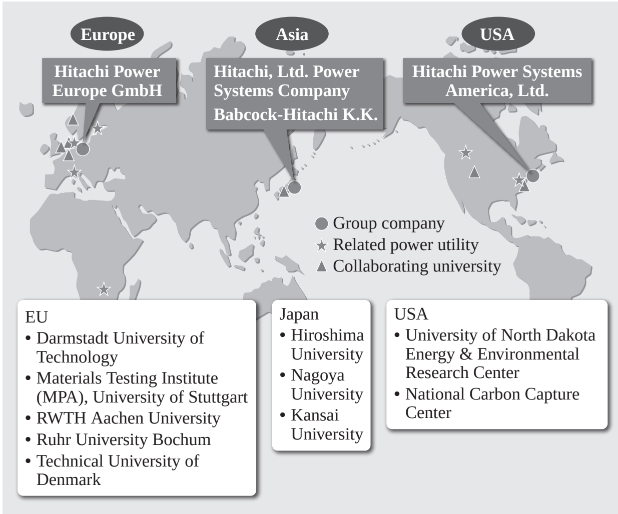


Fig. 2—Hitachi Group Global Research Framework.
Hitachi is promoting research and development in collaboration with group companies, universities, and national research institutes in each country.

CO_2 RECOVERY TECHNOLOGY

(1) Demonstration testing in Canada

Hitachi has started a joint CO_2 recovery demonstration testing project with SaskPower. The test site is the 298-MW Shand Power Station on the outskirts of the city of Estevan, Saskatchewan, which is owned by SaskPower. This plant is located in the mid-western region of Canada, which is a center of development for CCS technology. Both companies have been cooperating to consolidate CO_2 recovery technology and know-how, and are conducting comprehensive demonstration tests and evaluations of factors such as reliability and economic potential of the entire facility, with an aim towards the development of large commercial systems.

Fig. 3 shows the system flow for the demonstration testing facility. The exhaust gas is extracted from the chimney inlet and introduced to the absorber after Pre-scubber. The absorber injects solvent in the exhaust gas, absorbs CO_2, and sends it to the desorber to be recovered CO_2, after which a return to the absorber allows the system to recover CO_2 in a continuous cycle. A design was adopted that considers issues

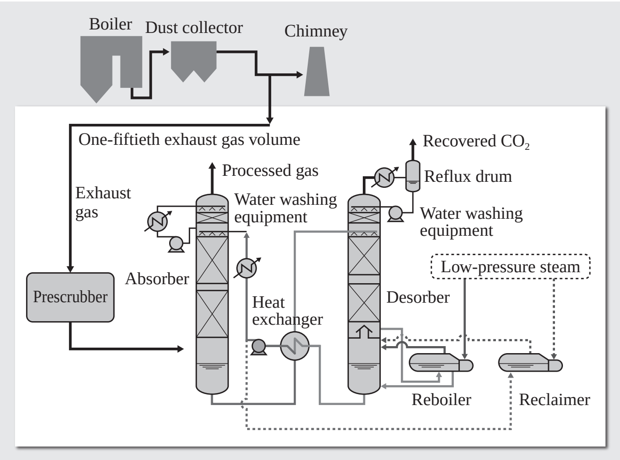


Fig. 3—System Flow of CO_2 Recovery Demonstration Testing Facilities in Canada.
Exhaust gas are extracted from the chimney inlet and introduced to the absorber, after which the CO_2 is absorbed into the solvent. After the CO_2 is discharged by the desorber, the solvent is once again returned to the absorber in a continuous process of CO_2 recovery.

such as low emission measures for the solvent from the chimney, the effective use of solvent, and energy conservation.

Fig. 4 shows the rendering of CO_2 recovery demonstration test facilities. The inside of the exterior wall of the CO_2 demonstration test system is shown against the Shand Power Station building in the background. The tall, cylindrical object visible in the steel frame structure is the absorber, which will be located adjacent to the desorber. The tests are planned to start in the middle of 2014.

Fig. 4—Artistic Rendering of CO_2 Recovery Demonstration Testing Facilities.
This rendering shows the CO_2 recovery system against the background of the Shand Power Station building in Saskatchewan.

TABLE 1. Conditions of Canadian Demonstration Testing Plan
Specifications are based on a consideration of scaling up for use in a commercial system.

Item	Design Condition
Fuel	Canadian lignite
Exhaust gas volume	23,000 m^3 N/h (wet)
Temperature	40°C
CO_2 concentration	13%
CO_2 recovery efficiency	90%
Capacity of CO_2 recovery	120 t/d

The conditions of the demonstration test plan are shown in Table 1. The scale of the system was decided based on a consideration of the scale of an actual future commercial system. It will process 120 t/d of CO_2 with a CO_2 recovery efficiency of 90%.

The CO_2 solvent used in this testing is H3-1, which was developed based on technology cultivated during the actual flue gas demonstration testing conducted at Yokosuka Thermal Power Station in joint research with Tokyo Electric Power Co., Inc. in the first half of the 1990s.

The key areas in terms of performance in this process are the CO_2 absorption of the solvent, as well as the reduction in energy required for recovering CO_2. Fig. 5 shows a comparison between mono-ethanol amine (MEA), which is the standard amine solvent used for CO_2, and H3-1. When compared with MEA, the required fluid volume of H3-1 solvent is reduced by 35%, and the required energy is reduced by 26%. These figures are the result of testing commissioned to the University of North Dakota’s Energy & Environmental Research Center (EERC) in the USA. Based on this evaluation, the National Carbon Capture

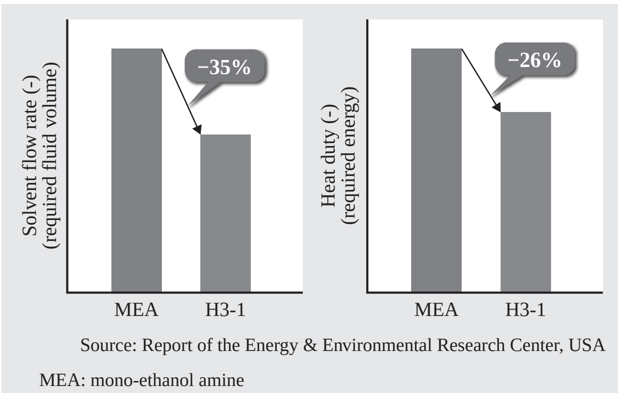


Fig. 5—Solvent Performance Comparison.
When compared to the standard solvent mono-ethanol amine (MEA), H3-1 solvent has been shown in tests to require a much lower fluid volume and much less energy.

Center (NCCC), which is a national research center in the USA, is also conducting evaluation tests.

(2) Other demonstration testing

Hitachi conducted gas-burning CO_2 recovery tests at a Norwegian research institute in the fall of 2012. Expectations are high for the establishment of CO_2 recovery technology for use with a variety of different fuels, including coal.

BIOMASS COMBUSTION TECHNOLOGY

Overview

When the biomass co-firing ratio is increased for an existing coal-fired thermal power plant, a dedicated mill (pulverizer) must be added, resulting in issues such as a need for additional on-site power and space. In order to deal with these issues, the practical application of a combustion system is being promoted that utilizes the existing mill by securing a high co-firing ratio while reducing the costs associated with constructing and modifying facilities (see Fig. 6).

In view of the goal of reducing domestic CO_2 emissions by 25%, the target co-firing ratio was set to 25 cal%. This development of the practical application of co-firing technology for existing pulverized-coal-fired boilers using only biomass is being conducted as a joint research project with the New Energy and Industrial Technology Development Organization (NEDO) (fiscal 2010 to 2013). A description of the results of this research up to this point follows.

Development Results

(1) Biomass pulverizing mills

Elemental test evaluations were conducted on multiple types of biomass including grass-based and wood-based materials, proposals were made for the appropriate structure to achieve the target co-firing ratio, and both safety (explosion-proofing) and corrosiveness were evaluated.

First, five types of biomass pellets were used in an elemental test of dedicated pulverizing. There are major differences in granularity and pulverizing force between the different types of biomass, and it has been confirmed that other than some biomass types (bark), granularity does not become finer than the feedstock granularity before pellet formation. This is necessary information for the design of a system (see Fig. 7).

Next, elemental tests were conducted of the appropriate structure to use in order to improve biomass discharging efficiency, which is a factor in achieving a high co-firing ratio through dedicated pulverizing. By reducing the vertical roller mill's particle classification function, it was determined that it is possible to efficiently discharge the pulverized biomass outside the mill. This was achieved by using a double wall for primary classification (gravity classification), and a contracted vein for secondary classification (centrifugal classification). The exterior of the mill with this structure is shown in Fig. 8.

In the area of safety, methods of avoiding particle explosion were considered. Switchgrass was confirmed to have a lower explosion limit oxygen (O_2) concentration of 19 vol%, and so the mill was built

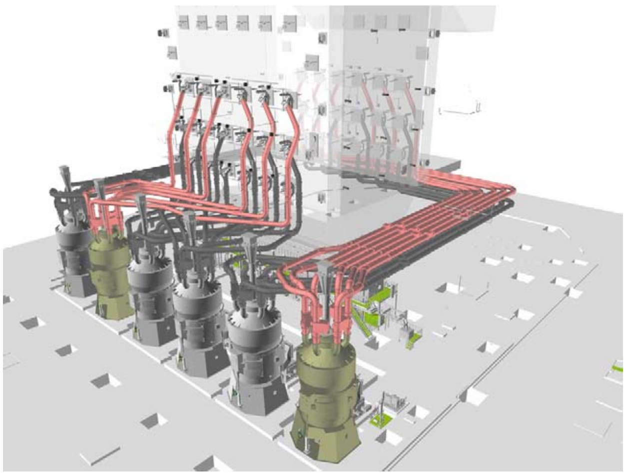


Fig. 6—Biomass Co-firing Facilities Utilizing Preexisting Combustion System.
By converting existing coal mills (pulverizers) and burners so that they can also be used with biomass, 25 cal% biomass co-firing is achieved for the entire plant. A dual-use biomass mill can also be used for the combustion of coal, and can also continue functioning as a reserve mill.

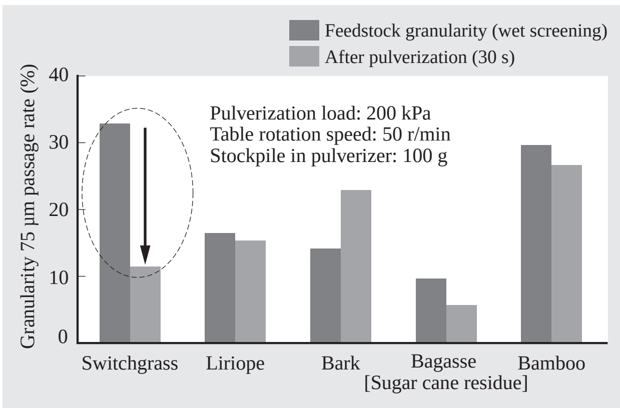


Fig. 7—Pulverized Powder Generation Characteristics of Each Type of Pellet.
Other than bark, pulverizability in excess of feedstock granularity was not confirmed. In particular, it was confirmed that switchgrass is more difficult to pulverize than other types of biomass.

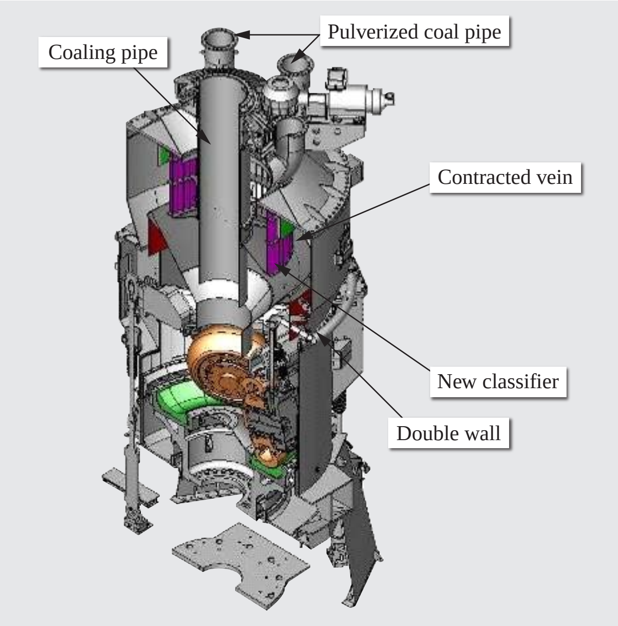


Fig. 8—Mills Using Both Biomass and Coal.
The quantity of biomass discharged during pulverization was achieved by reducing the functions of primary and secondary classification. Development enabled combustion of coal by using the same structure.

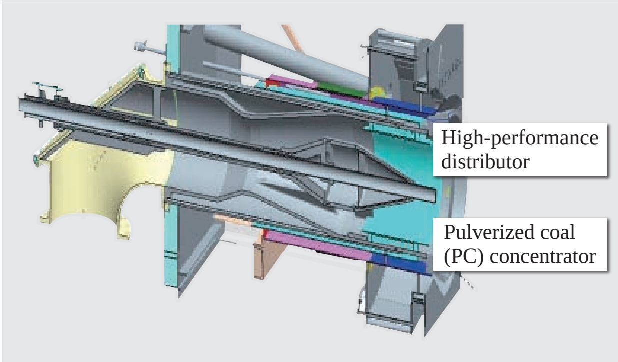


Fig. 9—Burners for Both Biomass and Coal.
Stable combustion in a low-oxygen atmosphere was secured with an improved NR-LE burner developed for use with low-grade coal.

Table 2. Dedicated Combustion Characteristics of Single Burner Equipment
Since the absolute amount of ash content is low in biomass, unburned carbon in fly ash of biomass has a relatively high value when compared to coal, and a favorable combustion efficiency. NOx, CO, and other emissions are equal to or lower than emissions during coal combustion.

Fuel	Switchgrass	Coal (Australian Bulga)
NO*x*	137 ppm (6% O_2)	136 ppm (6% O_2)
CO	0 ppm (actual O_2)	13 ppm (actual O_2)
Unburned carbon in fly ash	8.7%	6.2%
Combustion efficiency	99.6%	99.0%

to operate with an inlet O_2 concentration of 18 vol%.

Chemical equilibrium computations were performed in order to evaluate the gas composition of the exhaust gas recirculation system and analyze corrosiveness. In the case of switchgrass, sulfur trioxide (SO_3) concentration is low, at 0.1 ppm in the mill outlet of the exhaust gas recirculation system (with an O_2 concentration of 18 vol%), indicating that the risk of corrosion is low in the mill and pulverized coal piping.

(2) Dedicated biomass burners

Combustion performance was evaluated for switchgrass using a single burner pilot plant for the combustion of biomass at the pilot scale. For the burner, a flame stability type NR-LE burner that can handle the combustion of lignite or other biomass with a low O_2 carrier gas was used as the basic structure (see Fig. 9).

In the case of the aforementioned switchgrass, with carrier gas O_2 concentration at 18 vol% conditions, the ability to combust in a stable manner with the burner load's range of use between 40% and 70% was confirmed. The concentrations of nitrogen oxide (NO*x*) and carbon monoxide (CO) were the same or lower as the concentrations reached during the combustion of coal (Bulga coal in Australia). Although the unburned carbon in fly ash was higher than for coal due to the lower ash content in the biomass, combustion efficiency was higher than for coal (see Table 2).

(3) Biomass co-firing system

A large-scale combustion facility was used in tests to demonstrate that there are no combustion problems in the operation of a boiler furnace. For biomass, switchgrass used for the dedicated combustion burner, and cedar was used for the co-firing burner. For coal, Australian Bulga coal was used. A dedicated combustion burner that was verified during single burner testing was used for the dedicated combustion burner, a coal burner was used for the co-firing burner, and combustion performance was evaluated with the co-firing ratio around a target value of 25 cal% by adjusting between 20 cal% and 33 cal%. There were no problems in the ignition of the dedicated combustion burner, and a stable flame was formed. As the co-firing ratio increased, NO*x* was reduced, and almost no secondary CO was generated. In addition, there was almost no increase in unburned carbon in fly ash.

(4) Expected performance of actual boiler and consideration of potential for system establishment

As an example representative of the cases considered, the result of considering gas state quantity around key devices during biomass 25 cal% co-firing is shown in Fig. 10. Based on the assumption of wood-based material (pine) with a strict lower explosion limit, the evaluation calculated the O_2 concentration in the biomass carrier gas as 11 vol%. When compared with the combustion of coal, the increase in gas temperature amounts to several degrees, and the increase in gas quantity amounts to several percentage points. This was confirmed to be within a range where it would not cause problems in the configuration of the facility.

(5) Summary of development results

As described above, pulverizing elemental tests, single/multiple burner furnace tests, and others were used to determine characteristics, and a vision of the practical application of a biomass co-firing ratio of 25 cal% with the current state of coal thermal power was achieved. Future plans involve the completion of an entire system, including operational methods, with the addition of wood-based material test evaluation in an expanded range of verification, verification using a continuous pilot mill and exhaust gas treatment systems, and comprehensive evaluation.

LIGNITE PRE-DRYING TECHNOLOGY

Overview

High-moisture lignites lose a great deal of heat due to water, and are low in net thermal efficiency. Furthermore, when lignite is dried, it tends to spontaneously ignite. Although dry technology has been under continuous development for many years, since the dryer itself is large, the technology has been difficult to apply to power plants, and this has prevented the technology from being practically applied. For this reason, Hitachi is working to develop effective dry technology for use with high-moisture lignites.

Development of Lignite Pre-dryers

(1) Test facility

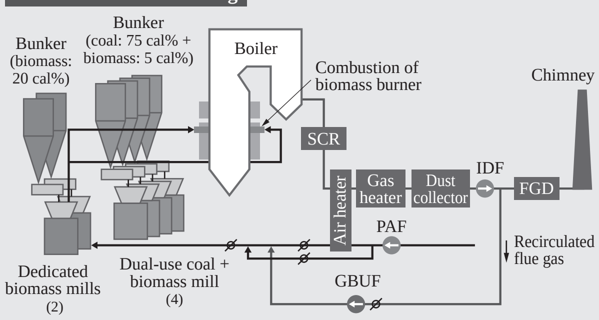
The air-fluidized process was selected based on considerations regarding how to efficiently dry the lignites, and an original mobile fluid dynamics conveyor was incorporated. Fig. 11 shows the exterior of the test facility.

(2) Test results

Dry test results are shown in Fig. 12. As the test results indicate, although it used to take approximately 50 minutes to dry the moisture in lignite to 20%, with the new technology it is possible to do the same in just around six minutes. Also, the temperature during drying, which used to be around 100°C, can now be reduced to around 50°C.

Since the drying period is shortened, this reduces the size of the coal hold-up, which in turn makes it possible to reduce the required space. Installation space requirements are compared in Fig. 13. Although in the past it was necessary to install the dryer in a separate location, with the newly developed system, it can be installed inside the boiler building.

Biomass 25 cal% co-firing



Effect on downstream equipment (coal combustion ratio)

Downstream equipment	Gas temperature	Gas quantity	Gas properties
SCR	±0°C	+6%	No increase in NO*x*, SO_2, or dust concentration.
Air heater	±0°C	+6%	
Gas heater	+8°C	+6%	
Dust collector	+8°C	+6%	
FGD	+8°C	+3%	

IDF: induced draft fan PAF: primary air fan GBUF: gas boost up fan

Fig. 10—Effects on Downstream Boiler Equipment (Ratio with Respect to Coal Combustion).
It was confirmed that when compared to the combustion of coal, the increases in gas temperature and quantity for biomass 25 cal% co-firing are within a range such that they will not cause problems in the configuration of facilities.

Fig. 11—Elemental Test System for Lignite Pre-drying Technology.
An air-fluidized process is adopted in an original mobile fluid dynamics conveyor.

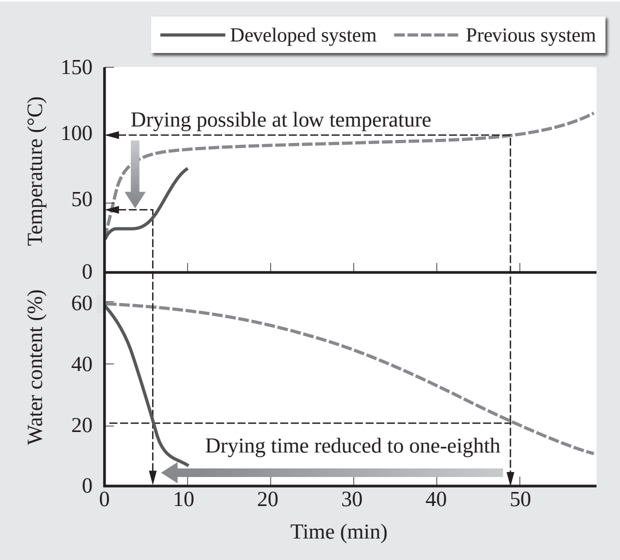


Fig. 12—Results of Elemental Test of Lignite Pre-drying Technology.
When compared to previous systems, the developed system cuts drying temperature in half and reduces drying time to one-eighth.

Table 3. Performance Comparison between Lignite Pre-dryer Development System and Previous Systems
The developed system using power plant lignite pre-drying technology successfully reduces drying time, temperature, and size when compared with previous systems.

Item	Developed system	Previous system
Water content in coal	60%→20%	60%→20%
Drying time	Within 10 min	Around 50 min
Dryer size	Compact (installed inside boiler building)	Installed in separate location
Dryer materials	Carbon steel	Stainless steel
Temperature	60°C or less	Approximately 100°C
Safety (particle explosion)	No particle explosion	-
Safety (combustible gas)	No combustible gas	-
Net thermal efficiency	Two-point improvement	-

Furthermore, since past dryers operated at a high drying temperature, the low pH of the evaporated water would cause corrosion of the dryer's materials, making it necessary to use stainless steel. The newly developed dryer operates at a lower drying temperature, and so the evaporated water has a pH equivalent to that of ordinary water, and therefore carbon steel can be used.

With regards to safety, the results of explosion tests conducted on pulverized powder extracted during testing confirm that explosions do not occur at the static electricity level. CO combustible gas was also monitored during testing, but CO was not generated. An expected improvement of the target amount of approximately two points was confirmed in the net thermal efficiency.

As described above, the results meet the original development targets, and there are plans to carry out final verification tests while giving consideration to actual operation.

(3) Summary of development results

It was confirmed that when compared to previous systems, this development system greatly reduces drying time, temperature, and size (see Table 3).

CONCLUSIONS

This article provided an overview of a demonstration testing project using CCS technology to recover the CO_2 in the exhaust gas of coal-fired power plants, technology that increases the biomass co-firing ratio in

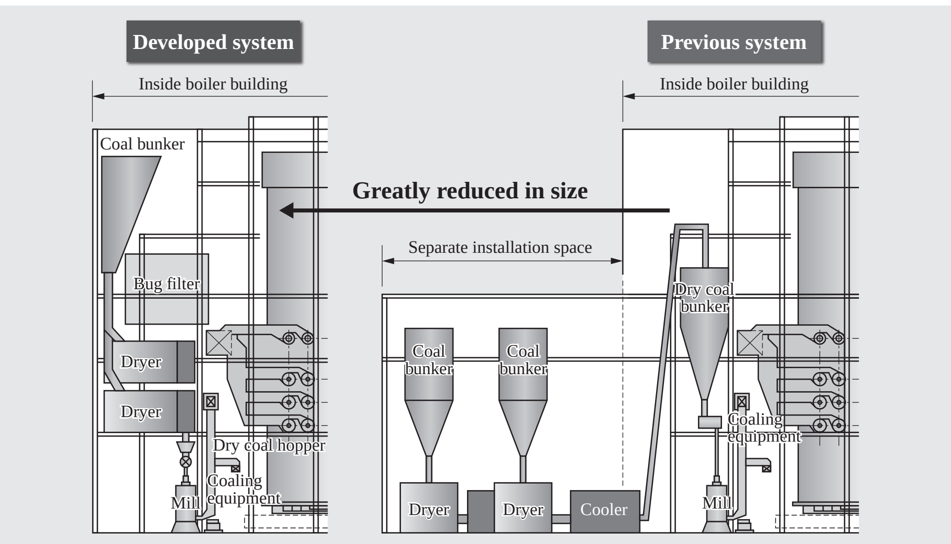


Fig. 13—Comparison of Installation Space Requirements.
The newly developed dryer does not require a separate installation space, and can be installed inside the boiler building.

coal to reduce CO_2, and lignite pre-drying technology, which is an effective way to use low-quality coal as part of the switch to energy conservation in coal-fired power generation.

Hitachi will continue developing technologies that can contribute to the prevention of global warming.

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