Progress toward Commercializing New Technologies for Coal Use
—Oxygen-blown IGCC+CCS

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OVERVIEW: Hitachi is participating in the EAGLE Project being jointly run by New Energy and Industrial Technology Development Organization and Electric Power Development Co., Ltd. (J-Power), has supplied a set of equipment ordered by J-Power, and is supporting trial operations by that company. The EAGLE Project achieved all of its development goals for the period up to March 2007 and has now upgraded its gasifier to expand the types of coals able to be used and is conducting trial operation as part of EAGLE Step 2. Some existing plant has been diverted for use in world-leading experimental trials of the recovery of CO_2 from the syngas produced by coal gasification. Based on the experimental results from EAGLE, EAGLE Step 2, and other work, comprehensive trials are now being conducted using a 170-MW-class IGCC demonstration plant with the aim of commercializing IGCC + CCS.

INTRODUCTION

IT IS anticipated that coal will remain an important primary energy source into the future for a variety of reasons, including that it is cheap, is available in quantities that are reliable and accessible to mining with reserves not overly concentrated in particular regions, and in consistent deposits, and it is predicted that coal use will continue to expand in the future to fuel economic growth. Developed nations such as the countries of the EU (European Union), North America, Australia, and Japan have set out groundbreaking medium- to long-term CO_2 (carbon dioxide) reduction targets in response to the threat of global warming, and these reductions will be essential if use of coal is to expand because coal emits a larger volume of CO_2 for each unit of electrical power produced than other primary energy sources.

In addition to strengthening its core business in the field of coal-fired thermal power generation, Hitachi, Ltd.'s Power Systems Company also has a policy of helping build a low-carbon society on a global scale and is accelerating its development of environmental technology including improvements to generation efficiency and CO_2 capture.

This article describes how Hitachi is working to commercialize technologies for coal use that combine oxygen-blown IGCC (integrated coal gasification combined cycle) and CCS (CO_2 capture and storage).

PROSPECTS FOR OXYGEN-BLOWN IGCC GENERATION PLANT

Improvement in Efficiency at Sending End of Oxygen-blown IGCC

IGCC is a system for improving the efficiency at sending end (efficiency taking account of plant overheads) of power generation by using efficiency-

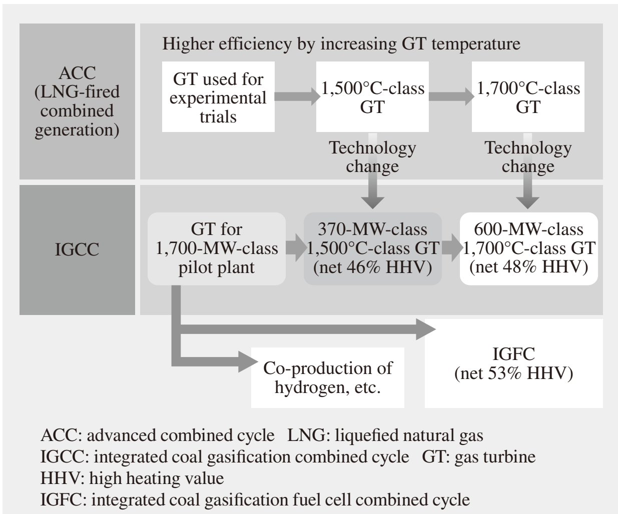


Fig. 1—Prospects for Oxygen-blown IGCC.
IGCC improves efficiency at sending end by adopting efficiency-improvement techniques that increase the operating temperature of the gas turbine. It can also minimize the reduction in efficiency at sending end caused by CO_2 capture by capturing the CO_2 from the pressurized fuel gas where it is present in high concentration.

improvement techniques that work by increasing the operating temperature of gas turbines fueled with natural gas. Oxygen-blown IGCC uses oxygen as a gasification agent, and because of the high concentration of fuel components in the gasifier syngas [including CO (carbon monoxide) and H_2 (hydrogen)], it can achieve a reduction in CO_2 of approximately 30% compared with Japan's newest coal-fired thermal power plants by using a power generation system with extremely high efficiency that incorporates a fuel cell. The technology can also improve the overall energy efficiency of electricity generation and the production of chemical feedstock (see Fig. 1).

Development of Technology for Achieving Coal-fired Generation with Zero Emissions

Because oxygen-blown IGCC can use pre-combustion capture to recover the CO_2 contained in the syngas which is at a pressure of 2.5 to 3.0 MPa and has a high CO_2 concentration of approximately 40%, the CO_2 capture equipment can be made smaller than what would be required to capture CO_2 from boiler exhaust gas (post-combustion capture) due to the lower flow rate of the pre-combustion gas, and this method also minimizes the reduction in efficiency at sending end. Hitachi is working on developing technology to achieve coal-fired generation with zero emissions using a combination of IGCC and CCS.

DEVELOPMENT OF GASIFICATION TECHNOLOGY FOR EAGLE GASIFIER

Characteristics of Oxygen-blown Gasifier (EAGLE Gasifier)

The oxygen-blown gasifier [EAGLE (Coal Energy Application for Gas, Liquid and Electricity) gasifier] uses the single-chamber two-stage swirling-flow gasification method(1) to perform gasification with high efficiency and a small amount of oxygen by encouraging particles to remain inside the gasifier(2) and by changing the oxygen distribution to suit the type of coal, while also preventing slag splatter(3) to ensure that gasification is performed with a high level of reliability (see Fig. 2).

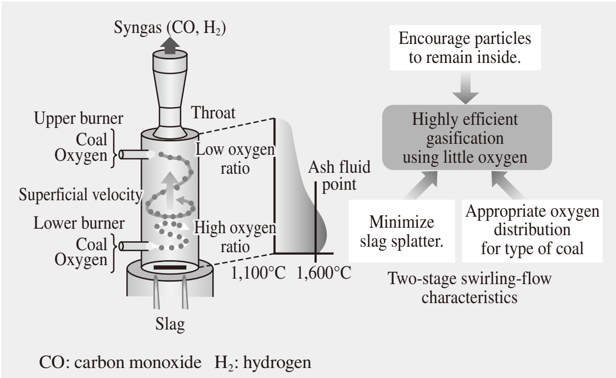


Fig. 2—Characteristics of Oxygen-blown Gasifier (EAGLE Gasifier).
The oxygen-blown gasifier [EAGLE (Coal Energy Application for Gas, Liquid and Electricity) gasifier] developed by Hitachi uses the single-chamber two-stage swirling-flow gasification method to perform gasification with high efficiency and a small amount of oxygen.

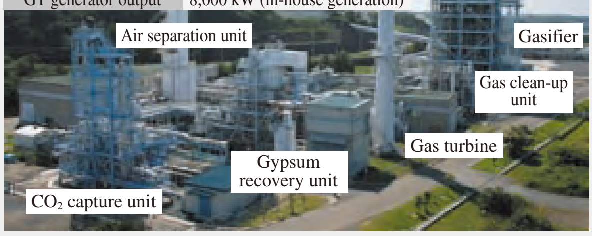
Background to Development of Oxygen-blown Gasifier (EAGLE Gasifier)

Hitachi has been working on the development of technology for coal-gasification-combined-cycle electricity generation for more than 30 years. Trials involving more than 1,000 hours of continuous operation at a pilot plant with a capacity of 50 t/d supplied to New Energy and Industrial Technology Development Organization (NEDO) and Research Association for Hydrogen-from-Coal Process Development (HYCOL) have established the basic concept of an oxygen-blown single-chamber two-stage swirling-flow gasifier, and experimental testing at this facility has also succeeded in resolving problems with ash(4).

Development of Oxygen-blown Gasifier Technology at EAGLE

Hitachi is currently participating in the EAGLE Project(5) being jointly run by NEDO and Electric Power Development Co., Ltd. (J-Power), has supplied a set of equipment ordered by J-Power, and is supporting trial operations by that company (see Fig. 3).

Coal processing capacity	150 t/d
Gasifier pressure	2.5 MPa
Syngas flow rate	14,800 m^3 *N*/h
Gas clean-up unit	MDEA wet desulfurization
Sulfur recovery	Limestone/gypsum method
GT generator output	8,000 kW (in-house generation)



MDEA: methyl di-ethanol amine

Fig. 3—EAGLE Pilot Plant.
Hitachi is participating in the EAGLE Project being jointly run by New Energy and Industrial Technology Development Organization (NEDO) and Electric Power Development Co., Ltd. (J-Power).

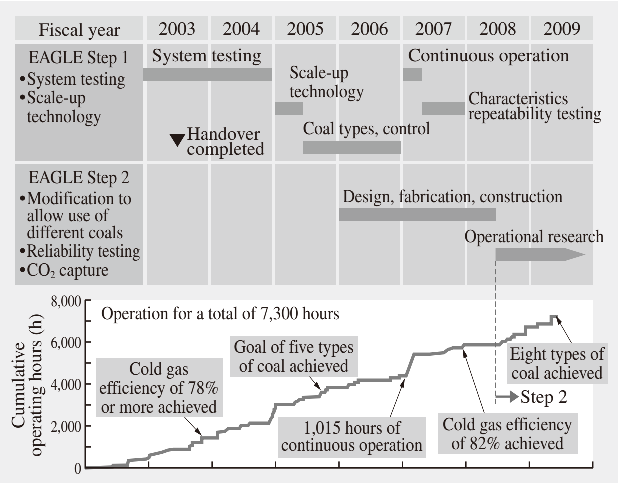


Fig. 4—Results of EAGLE Trial Operation.
EAGLE has achieved all of its development goals. EAGLE Step 2 included upgrading the gasifier to expand the types of coals able to be used and trial operation which ran until March 2010.

The EAGLE Project completed its trials in March 2007 having achieved all of its development goals(6). The gasifier is now being upgraded to expand the types of coals able to be used and EAGLE Step 2 is conducting trials that were scheduled to run until March 2010. This has mainly involved determining the characteristics and obtaining the gasification performance of three different types of coal with a high ash melting point that are mainly used in conventional pulverized-coal thermal power generation. In addition to verifying the ability to use a wider range of coals by checking that the coal gasification technology can handle the use of coal with a high ash melting point, this work has also confirmed the superiority of the EAGLE gasifier (see Fig. 4).

Principle of CO_2 Capture from Syngas

CO_2 capture from syngas (pre-combustion CO_2 capture) works by adding water vapor to the syngas (CO-rich gas) to convert the CO to CO_2 and H_2. The absorption fluid that absorbs the CO_2 is regenerated to separate and capture the CO_2 and the hydrogen-rich gas that remains after CO_2 capture is used to fuel the gas turbine. The captured CO_2 is compressed and liquefied and then transported for storage (see Fig. 5).

The technology for capturing CO_2 from syngas, also known as pre-combustion CO_2 capture technology, is widely used to capture CO_2 from natural gas and studies into its application at thermal power plants are underway in various countries.

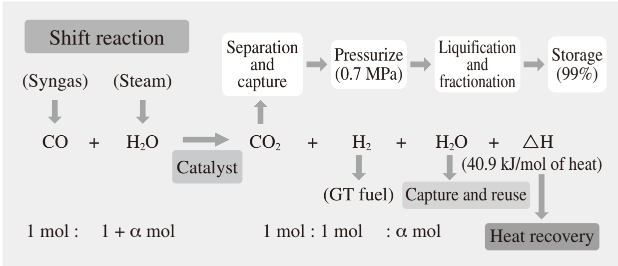


Fig. 5—Concept behind Separation and Capture of CO_2 in Syngas.
Water vapor is added to syngas (CO-rich gas) to convert the CO to CO_2 and H_2. The CO_2 is then absorbed, the absorption fluid regenerated, and the CO_2 separated out and captured.

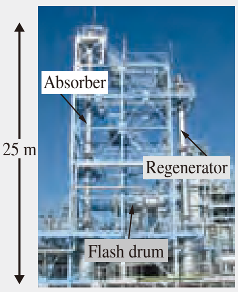
When applying this technology to a thermal power plant, it is important that the reduction in efficiency at sending end that results from installing the CO_2 capture plant is minimized. The measures necessary to achieve this are: (1) minimize the reduction in the output of the steam turbine by reducing the flow rate of the steam supplied to the shift reaction, (2) reduce losses in the CO_2 absorption and regeneration system including the power used to circulate the absorption fluid and the heat used for regeneration, and (3) minimize the reduction in the output of the steam turbine by optimizing the heat recovery system.

EAGLE CO_2 Capture Trials

In EAGLE Step 2, some of the existing equipment has been diverted for use in world-leading demonstration experiment of the recovery of CO_2 from syngas. The CO_2 separation and capture pilot plant has the capacity to process 1,000 m^3N/h of syngas and capture approximately 24 t/d of CO_2.

The CO_2 separation and capture pilot plant is made up of the shift reaction system and the absorption and regeneration system. The shift reaction system uses a combination of iron-based and copper- and zinc-based catalysts. The absorption system uses a chemical absorption method based on MDEA (methyl di-ethanol amine). For regeneration, the facility allows testing of regenerators like those commonly used to capture the CO_2 from natural gas and also flash heating regeneration which is adopted with the aim of reducing the amount of heat required for regeneration (see Fig. 6 and Fig. 7).

The objectives for the CO_2 pilot plant are to confirm whether CO_2 separation and capture technology can be used on syngas, to make clear progress toward the practical use of IGCC + CCS by identifying the development issues in preparation for full-scale



Capacity	1,000 m[3] *N*/h (approximately 7% of total)
Shift catalysts	Iron-based and copper- and zinc-based
Absorption method	Amine-based CO_2 separation (MDEA)
Absorber pressure	2.5 MPa
Absorber inlet CO_2 concentration	Approximately 40% by volume
Regeneration method	The regeneration method is selectable (1) Regenerator Uses steam heating to separate dissolved CO_2. (2) Flash heating Uses a pressure drop to separate dissolved CO_2.

Fig. 6—Overview of CO_2 Capture Pilot Plant.
EAGLE Step 2 ran world-leading demonstration experiments of the capture of CO_2 from syngas.

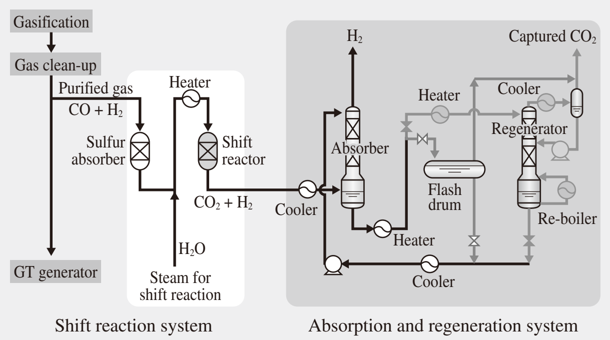
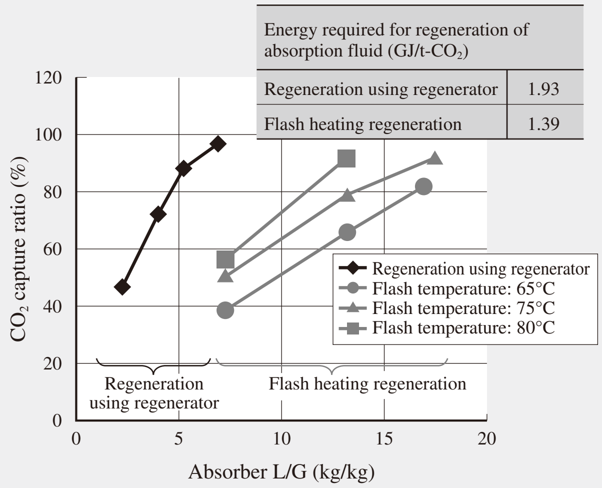


Fig. 7—Block Diagram of CO_2 Capture Pilot Plant.
The CO_2 separation and capture pilot plant consists of a shift reaction system and an absorption and regeneration system.

operation, and to collect the base data required to assess the economics of CCS by determining the basic system parameters (CO_2 capture ratio, utilities usage, and so on). The pilot plant is also used to study ways of minimizing the reduction in efficiency at sending end when the technology is applied in thermal power plants.

Results and Evaluation of CO_2 Capture Trials at EAGLE

The demonstration confirmed a CO_2 capture ratio of 90% or more both for regeneration using the regenerator and regeneration using flash heating. Because adequate regeneration of the absorption fluid could be achieved, regeneration using the regenerator achieved a high CO_2 capture ratio even when the L/G ratio (absorption fluid circulation flow rate/gas flow rate at absorber inlet) for the absorber was low. It was necessary to increase the absorber L/G ratio for flash heating regeneration because of insufficient absorption fluid regeneration compared to regeneration using the regenerator, but although the CO_2 capture ratio



Absorber L/G (kg/kg): absorption fluid circulation flow rate (kg/h) / absorber inlet gas flow rate (kg/h)

Fig. 8—Results of Testing at CO_2 Capture Pilot Plant.
The results demonstrated that both regeneration using the regenerator and flash heating regeneration can achieve a CO_2 capture ratio of 90% or better.

obtained in the trial was lower than when using the regenerator, it was still above 90% (see Fig. 8).

Because the heat required to regenerate the absorption fluid is low and because a large proportion of the latent heat from the moisture in the gas output from the shift reactor can be used, the flow rate of steam taken from the steam turbine to heat the absorption fluid for flash heating regeneration can be reduced to only one-tenth that for regeneration using the regenerator. Based on this result, it was determined that flash heating regeneration can add approximately an extra 4% to the net efficiency compared to regeneration using the regenerator for a CO_2 capture ratio of 90%.

The demonstration showed that, by minimizing the reduction in steam turbine output by optimizing the heat recovery system and optimizing the operating conditions using flash heating regeneration, a CO_2 capture ratio of 90% and CO_2 purity of 99% could be achieved while also significantly reducing the drop in efficiency at the sending end that occurs when CO_2 is captured from syngas.

PLANS FOR COMMERCIALIZATION OF OXYGEN-BLOWN IGCC + CCS

J-Power and The Chugoku Electric Power Co., Inc. jointly established Osaki CoolGen Corporation on July 29, 2009 to work on "oxygen-blown IGCC technology" and "CO_2 separation and capture technology" in an efficient way. Osaki CoolGen plans to construct

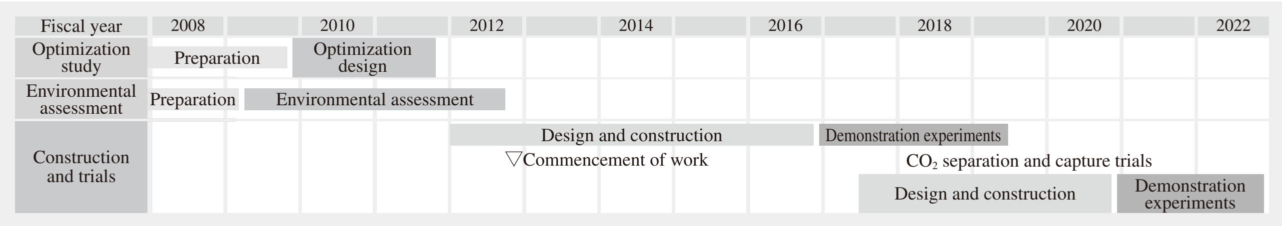


Fig. 9—Large-scale Demonstration Experiment of Oxygen-blown Gasification.
Osaki CoolGen Corporation plans to construct a large-scale 170-MW-class demonstration plant to trial oxygen-blown gasification technology and study the reliability, economics, operational characteristics, and other aspects of oxygen-blown IGCC systems, and then to conduct further trials utilizing the latest CO_2 separation and capture technology.

a large-scale 170-MW-class oxygen-blown IGCC demonstration plant to study the reliability, economics, operational characteristics, and other aspects of oxygen-blown IGCC systems and then to conduct trials utilizing the latest CO_2 separation and capture technology(7). Based on the experimental results from EAGLE and EAGLE Step 2, Hitachi intends to work toward the practical use of IGCC + CCS by using the 170-MW-class oxygen-blown IGCC demonstration plant to conduct comprehensive demonstration experiments in preparation for putting it to practical use (see Fig. 9).

CONCLUSIONS

This article has described how Hitachi is working to put technologies for coal use that combine oxygen-blown IGCC and CCS into practical use.

Hitachi has been developing oxygen-blown gasifier technology for about 30 years and, working through HYCOL and EAGLE, has made steady progress in scaling up this technology. Hitachi was among the first Japanese manufacturers to start production of gas turbines, maintaining the largest share of the market through the period in the 1990s when the shift to large combined-cycle plants in Japan was at its height, and since that time Hitachi has continued to develop gas turbines and further hone its technology. Hitachi also has more than 20 years of rich experience in burner development and is working on the development of burners suitable for oxygen-blown gasification.

Through the EAGLE Project, Hitachi has verified the reliability of the process through long-duration operation and has established technology for scaling up the gasifier, and technology for gas purification and operation as an electricity generation system. Pilot testing aimed at establishing CO_2 separation and capture technology is currently in progress.

Because the loss of efficiency resulting from CO_2 separation and capture is low for oxygen-blown gasification and a net efficiency of more than 50% can be anticipated when used in conjunction with a fuel cell, the method has potential for use in IGFC (integrated coal gasification fuel cell combined cycle) power generation. It is also ideal for ammonia production and for producing hydrogen for use as a chemical feedstock.

Oxygen-blown gasification is a technology with a wide range of potential applications and Hitachi is focusing its efforts on conducting demonstration experiments on a demonstration plant midway in size between the pilot plant (150 t/d) and a full demonstration plant with the aim of practical use of this technology.

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