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Innovative Zero-emission Coal Gasification Power Generation Project

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Abstract

In our study, we conducted an in-depth feasibility study to comprehensively evaluate a total system from coal gasification power generation to CO_2 capture. This feasibility study was conducted to examine multiple candidate sites for matching CO_2 sources and storage sites. The project is being carried out to clarify the role of zero-emission coal gasification power plant-based clean coal technology in achieving Cool Earth 50 targets, with consideration to the impact on energy supply and demand in the future. In addition, the project aims to support the efficient implementation of measures toward the introduction and dissemination of zero-emission coal gasification power plants in Japan through a strategic discussion that incorporates the latest research findings.

Keywords: Cool Earth 50; CCS; IGCC; Zero-emission coal-fired power generation; Feasibility study in Japan

1. Introduction

There has been a strong call to reduce CO_2 emissions as a measure against global warming. In order to achieve the reduction target of halving global greenhouse gas emissions by 2050 compared to 2007 levels as proposed by Japan's Cool Earth 50 initiative, measures such as efficiency improvement, energy conservation, introducing renewable energy and building more nuclear power plants are not enough. Therefore, it is necessary to develop innovative technology for the separation, capture and storage of CO_2, a process which is known as carbon dioxide capture and storage (CCS). In the wake of the Fukushima Daiichi nuclear power plant disaster, it has become very difficult to build additional nuclear power plants. Consequently, there is an increasing need for the development of CCS technologies. In recognition of this, the U.S. and Europe are planning to carry out several demonstration and commercial projects relating to the recovery, transport and storage of CO_2 from IGCC and NG production that primarily focus on CO_2-EOR.

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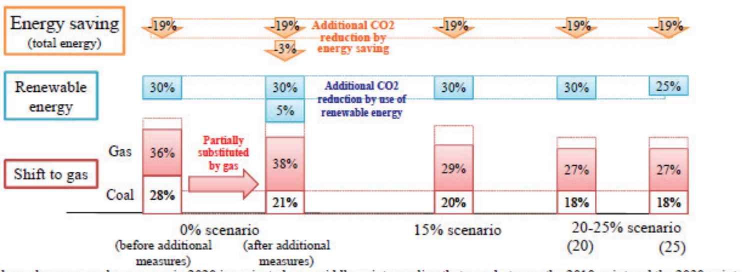
As a result, demonstration activities related to zero-emission coal-fired power generation have been accelerating around the world. There has also been growing demand to carry out CO_2 reduction technology demonstrations in the thermal power generation field in Japan. Therefore, the feasibility of zero-emission coal gasification power generation technology, including CCS technology, needs to be examined as quickly as possible.

NEDO is now carrying out the Innovative Zero-emission Coal Gasification Power Generation Project, which includes CCS technology, and it has conducted a feasibility study in order to provide a detailed assessment of the potential for implementing CCS technology in Japan. In this paper we describe the feasibility study concerning a total system from power generation to CO_2 storage.

Table 1 Power source and emission scenarios for 2030 [1]

Assessment items		2010	0% scenario				15% scenario	20-25% scenario
			Before additional measures		After additional measures			
Share of renewable energy		Approx. 10%	30% (+20%)		35% (+25%)		30% (+20%)	30-25% (+20-15%)
Share of non-fossil energy resources		Approx. 37%	30% (-5%)		35% (current level)		45% (+10%)	50% (+15%)
Coal/gas ratio in thermal power generation (including cogeneration)		1:1.2	1:1.3		1:1.8		1:1.5	1:1.5
Greenhouse gas emission (1990-level basis)	2030	-	-16%		-23%		-23%	-25%
	2020*	-	+0% (nuclear energy: 0%)	-5% (nuclear energy: 14%)	-0% (nuclear energy: 0%)	-7% (nuclear energy: 14%)	-9% (nuclear energy: 21%)	-10-11% (nuclear energy: 23-26%)



* The level of dependence on nuclear energy in 2020 is projected as a middle point on a line that runs between the 2010 point and the 2030 point.

2. Present Status of Coal-fired Power Plants in Japan

Following the Fukushima Daiichi nuclear power plant disaster, the Japanese government proposed energy and environment policy options for national discussion in June 2012. Table 1 shows the three scenarios for reducing Japan's reliance on nuclear power generation by 2030 that were announced [1]. In the first scenario, the share of nuclear energy for power generation is zero, in the second it is 15% and in the third it is 20-25%. In FY2010, nuclear energy accounted for 26% of total electricity generation. The zero nuclear energy scenario was adopted at an Energy and Environment Council meeting on September 14, and realization of the scenario is currently being discussed by the Cabinet.

For each respective scenario, the share of coal power generation was preliminarily calculated at 28% to 21%, 20% and 18%, and the electricity shortage is expected to be covered by renewable energy and fossil fuel. Japan's total electric power generation was 1.1 trillion kWh in 2010, and it is expected to decrease to 1.0 trillion kWh in 2020, or approximately 90% of the level in 2010. However, coal power generation will still be an important power source in the future. Moreover, in order to respond to the large-scale introduction of renewable energies such as solar power and wind power, which have a large output fluctuation, transmission system stabilization measures to increase the rate of reserved electricity and more power plants will need to be constructed in the future. Therefore, further improvement of global warming measures and coal power plant generation efficiency will continue to be essential.

3. Development of CO_2 Reduction Technology for Coal-fired Power Plants

3.1. High efficiency coal-fired power plant strategy

NEDO has been carrying out research and development based on a strategy for improving power generation efficiency that was promulgated by the government in 2008 [2]. Steam cycle efficiency has been improved to increase steam temperature to more than 700°C through new materials development, and NEDO has promoted further basic research on materials. NEDO has also been conducting element research and an IGFC system demonstration using pressurized SOFC and a coal gasification furnace.

3.2. Development of oxygen-blown coal gasification integration combined cycle

NEDO's Multi-purpose Coal Gasification Technology Development (EAGLE: Coal Energy Application for Gas, Liquid & Electricity) project was undertaken to develop oxygen-blown multi-purpose coal gas production technology. A two-stage gasification furnace with a swirling flow camber has a high gasification efficiency of more than 78%. A pilot plant with a coal input of 150 t/d was constructed at the Wakamatsu Institute of J-Power (shown in Fig. 1) to develop this technology.

The technology of the EAGLE project is being applied to 170 MW IGCC generation demonstration facilities of Osaki Cool Gen Corporation (OCG) located within the Osaki Power Plant of Chugoku Electric Power as shown in Fig. 2 [3]. Supported by the Ministry of Economy, Trade and Industry (METI), the IGCC facilities are being constructed to carry out a demonstration in 2016. After the demonstration, the facilities will be used to verify CO_2 pre-combustion capture technology using the chemical absorption method as well as SOFC generation using coal gas.

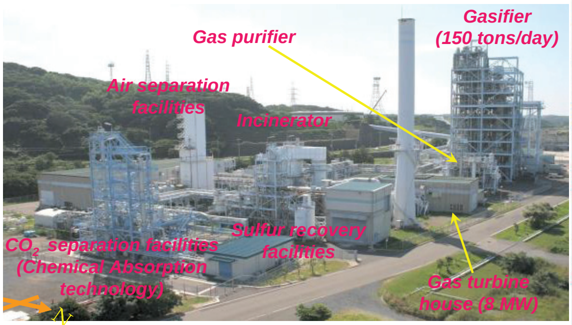


Fig. 1 Overview of EAGLE pilot plant

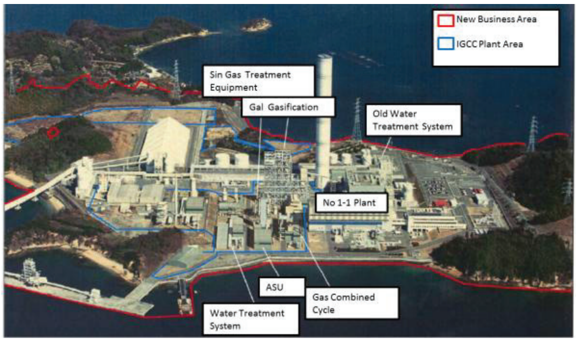


Fig. 2 Rendering of OCG facilities [3]

3.3. Development of CO_2 capture technology

(1) Development of pre-combustion IGCC CO_2 capture technology

Due to the high concentration of CO_2 and lower gas flow rate compared to post-combustion CO_2 capture, CO_2 can be efficiently recovered using an upstream IGCC gas turbine. Demonstration tests of a chemical absorption method using EAGLE technology were started in 2008, and a demonstration test of physical absorption has been carried out since 2010.

(2) Development of high efficiency oxy-fuel IGCC system [4]

To recover CO_2 by heating absorption liquid, a chemical absorption method is used to extract the low pressure steam of a steam turbine. Accordingly, power generation efficiency decreases by 10-20% in relative value at the power transmission end if the recovery rate is 90% of CO_2.

High efficiency oxy-fuel IGCC system separates CO_2 to prevent a reduction in power generation efficiency due to CO_2 recovery by condensing water vapor in exhaust gas using an oxygen combustion gas turbine as shown in Fig. 3. In order to reduce the combustion temperature of the gas turbine, the exhaust gas is recycled in the combustor. In addition, a coal gasification reaction is carried out using CO_2 by recycling exhaust gas in the gasifier.

Since the oxidation reaction in gasification is suppressed by CO_2 rather than oxygen, both cold gas efficiency and system efficiency is improved. The auxiliary power ratio of the system is high because of the large capacity of an air separation unit (ASU), but an efficiency of about 42% can be obtained with a 1500℃-class gas turbine by reducing CO_2 reclamation energy and improving gasifier efficiency.

A 3 t/d demonstration test reactor is now being developed by NEDO. After carrying out a demonstration at a several ten of ton per day pilot plant in the future, we are aiming at commercialization in 2040.

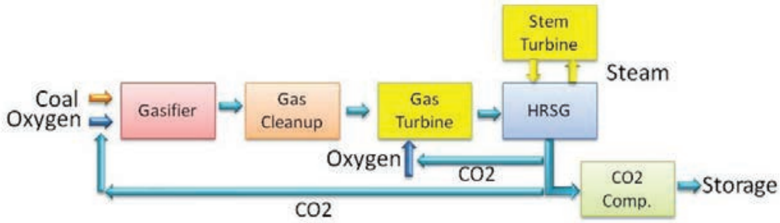


Fig. 3 Concept of high efficiency oxy-fuel IGCC system

3.4. Support for worldwide dissemination of CCT technology

Coal demand is expected to increase around the world in the future, and coal will account for a higher proportion of global primary energy consumption. Therefore, it is necessary to promote worldwide dissemination of Japanese clean coal technologies from the viewpoint of reducing the environmental impact of increased coal use. In order to promote Japan's high-efficiency power generation technology in international markets, NEDO has conducted feasibility studies in ten countries by entrusting the implementation work to entities such as private companies.

4. Feasibility Study of Zero-emission Coal Power Plant

4.1. Scope and implementation structure[5]

Japan's Ministry of Economy, Trade and Industry is working to commercialize CCS by 2015. Although various studies on the potential for CO_2 storage have been conducted to date, detailed evaluations have not yet to be carried out regarding a total system that includes power generation, capturing CO_2 from coal gasification power generation systems and separating, recovering, transporting and storing captured CO_2.

For this reason, feasibility studies were launched in 2008 to evaluate element technologies necessary for a total system in light of the following:

a) Conceptual design of a CO_2 capture IGCC system
b) Conceptual design of a transport system
c) Conceptual design of a CO_2 storage system
d) Evaluation of a total system

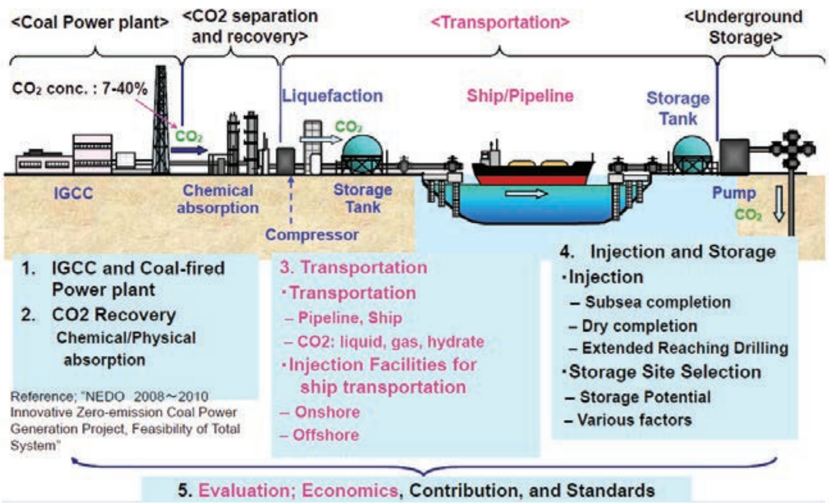


Fig. 4 System concept of zero emission coal power plant

4.2. CO_2 capture IGCC system study

We investigated chemical absorption methods and physical absorption methods which have been developed on an industrial scale in systems for separating and capturing CO_2. In the chemical absorption methods, an amine absorbent solution was economically excellent. With regard to typical physical absorption methods, the SELEXOL method was studied using a polyethylene glycol absorbent solution. In general, it can be said that chemical absorption methods are effective when the gas partial pressure is below 1.0 MPa, and physical absorption methods are effective when the gas partial pressure is 1.0 MPa or higher.

Two types of CO shift reaction catalysts can be used to separate and capture CO_2. The first is a sour shift catalyst that uses sulfur to maintain its activity, and the second is a sweet catalyst whose activity is lost due to sulfur. After examining the structure of systems using the chemical absorption and physical absorption methods as well as the two catalysts, we selected a system combining the chemical absorption method and the sweet shift catalyst as the optimal method for separating and recovering CO_2 because the system demonstrated superior performance in CO_2 absorption and energy consumption.

However, if the process pressure is increased by using a higher temperature gas turbine, it is possible that a combination of physical absorption and a sweet shift catalyst could have a higher level of performance. Fig. 5 shows the system for separating and recovering CO_2.

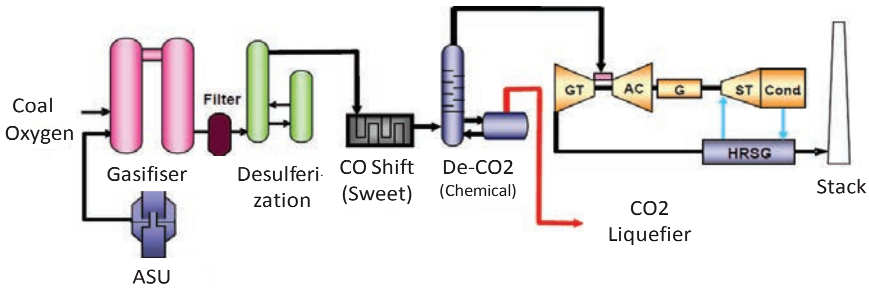


Fig. 5 System for separation and capture of CO_2

4.3. Case study of CO_2 transfer system

In Japan, demonstration experiments of underground storage technologies and capture and storage of CO_2 have already been conducted. However, because of Japan's complex geological structure, reservoirs in coastal areas close to the source of CO_2 emissions cannot store CO_2 on a large scale. Therefore, for practical use of CCS, it is necessary to use transport to multiple reservoirs present in Japanese waters for storage of CO_2. We therefore prepared a conceptual design of a storage base in accordance with the pattern of transported CO_2, boat transportation, pipelines, etc. Although previous studies indicated that in terms of transportation costs pipelines would be effective for short-distance transportation and shipping would be effective for long-distance transportation, conceptual designs were not formulated based on specific transportation cases.

The CO_2 transport system studied in this project was divided into three cases: direct access, shipping as liquefied CO_2, and CO_2 transport pipeline. Fig. 6 shows the study cases for a CO_2 transfer system.

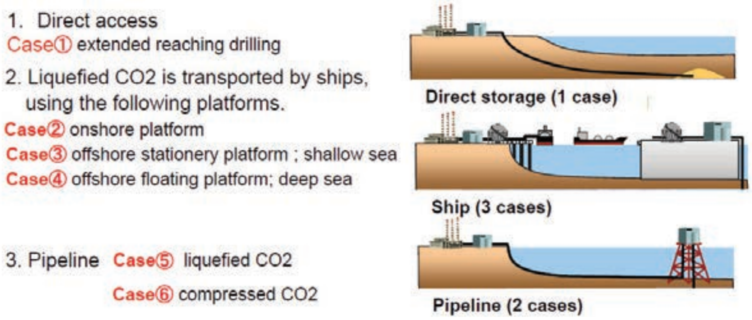


Fig. 6 Conceptual study cases for CO_2 transfer system

4.4. . Study of CO_2 reservoirs in Japanese waters

(1) Selection of storage sites and calculation of storage potential

Based on reservoir and geological information collected in the past, storage sites were selected and assumptions and calculation of their storage potential were made. In order to carry out a case study on storage, we selected several areas from possible candidates for coal gasification power generation. Furthermore, for each representative storage area we assumed the position of the storage system using such information as water depth and distance offshore. In selecting the storage layer, we were limited to ocean storage layers. As Japan is tectonically active, many old sedimentary layers dip steeply due to faults and folds, and they usually have a low permeability rate due to consolidation. For this reason, we examined relatively young strata.

According to preliminary estimates, the storage potential of possible storage sites is more than 30 million tons of CO_2, which is equivalent to the amount of CO_2 captured on a commercial basis for 20 years (1.54 million tons/year x 20).

(2) Conceptual design of storage facilities at possible storage sites

Conceptual designs of storage facilities for possible storage sites have been developed based on the above assumption (injection rate: 1.54 million tons/year, injection duration: 20 years), including the depth and number of injection wells. Taking into account the location of possible storage sites (distance offshore, water depth, etc.) and the means of transport (ships, high and low pressure pipelines), we prepared seven different conceptual designs for each storage site.

(3) Examination of draft evaluation methods and reservoir evaluation

In order to select storage layers to perform the case study, the following conditions were assumed:

a) Storage layers should have a storage capacity of about two million tons of CO_2 per year for 20 years;

b) The CO_2 plume at the end of the injection process can maintain a specific separation distance from active faults of storage layers;

c) Storage layers should be accessible and have a high as well as cost-effective injection rate.

In order to calculate cost effectiveness, the injection rate per well and the storage layer permeability rate and thickness need to be taken into consideration. Thicker storage layers with a high permeability rate are considered cost-effective. More specifically, to keep the number of wells to a minimum, storage layers need to be more than 20 meters thick and have a permeability rate of 100mD or higher. To conduct an economic evaluation of geological CO_2 sequestration, we need to construct a method of analysis using the pressure in the storage layer diffusion model that was used to evaluate the cost of storage per unit volume.

(4) Economic evaluation of storage facilities

Based on the conceptual designs of storage facilities, we calculated the cost of facilities with a land wellhead, an offshore wellhead and a seafloor wellhead. The costs were different depending on the number of wells and drilling methods (slope, extended reach drilling (ERD)) used. The cost of storage facilities can be affected by location and the physical properties of the reservoir. Also, in a storage facility cost comparison for the injection method, facilities with a land wellhead were the most cost-effective followed by facilities with an offshore wellhead and seafloor wellhead.

4.5. Economic evaluation of overall system

As part of an overall system evaluation, we conducted an economic evaluation and examined measures to reduce relevant costs based on the results of the evaluation. We also carried out an analysis of future contributions to the Cool Earth 50 initiative due to the introduction of CCS and zero emission coal-fired power plants, and evaluated the effects of introducing CCS on the supply and demand of energy in Japan by constructing relevant models. We are planning to provide basic information useful in forming policies based on this, and in accordance with international standards for the promotion of the introduction of technology, the introduction of zero-emission thermal power in Japan. Details of these activities, which will be discussed later in this section, should be regarded as interim results as the project is currently underway. In the future, when the project has been completed, we will prepare a summary and final evaluation.

(1) Economic evaluation of cost-based evaluation

Based on cost data and the conceptual design of each facility for CO_2 collection, transportation and storage, an economic evaluation was performed for each case selected (Fig. 7, Fig. 8). The cost of power generation with CCS is roughly two times that without CCS. CO_2 capture costs are about two times higher to transport CO_2 compared to ERD that does not require CO_2 transport. It was found that the proportion of transport costs is greatly affected by transportation distance and other factors.

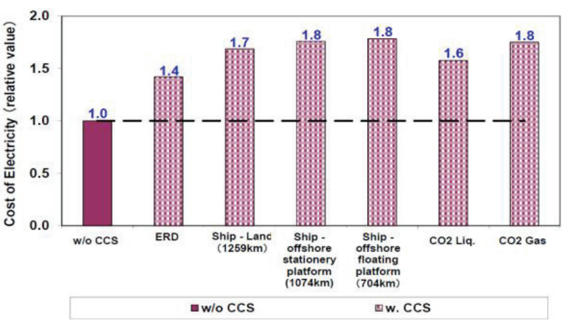


Fig. 7 Economic evaluation of generation cost

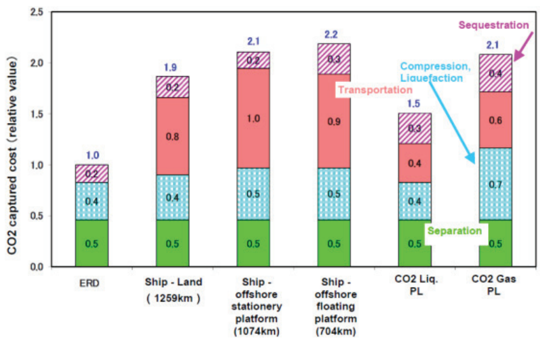


Fig. 8 Economic evaluation of CO_2 capture cost

(2) Development and evaluation of energy supply and demand impact assessment model

In addition to making contributions to the Cool Earth 50 initiative by reducing CO_2 emissions, the introduction and promotion of CCS for coal-fired power generation systems and other sources of CO_2 emissions are expected to have effects on Japan's energy supply-demand structure on a long-term basis. Relevant models were developed to analyze such effects. By using these models, information useful in formulating long-term energy and environmental policies will be provided in the future.

We have conducted several case studies using data on demand for promising new technologies. In the future, we are planning to carry out an analysis of the introduction of a CCS scenario from a wide-ranging perspective while observing the changes in energy policy after the Great East Japan Earthquake.

5. 5. Conclusion

Current optimal specifications for each system that constitutes the total system, including power generation system and CO_2 storage, have been clarified through the feasibility study. We also conducted an economic evaluation of the system to determine the impact on processing costs and the impact of CO_2 on the cost of power generation with CCS. Furthermore, various issues concerning system cost, such as for breakdown capture, transportation and storage of CO_2, were clarified. The economic evaluation also indicated that transportation constitutes a greater portion of the total cost compared to relevant cases overseas. As a result, we started to review ways to reduce transportation costs. In addition to examining the impact on total cost by applying new technologies, we are carrying out an analysis of scenarios for introducing CCS, which will be applicable to changes in energy policy following the Great East Japan Earthquake. In the future, we will make recommendations to support measures to disseminate and efficiently introduce zero-emission coal gasification power generation in Japan.

NEDO is conducting research and development that aims to provide a stable supply of energy and also addresses global environmental issues by using CCT, including coal gasification technology. Abundant energy resources and environmental protection are essential for human beings to live, but in the past the characteristics of these two requirements were diametrically opposite. However, through scientific and technological advances in Japan and other countries, it is now becoming possible to develop technologies that can address energy as well as global environmental problems.

Acknowledgements

The results described herein were obtained during a NEDO project that has been carried out since 2008.

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