# Carbon Capture and Storage Activities in JAPAN

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Notes: This report presents mainly ongoing or planned projects supported by METI.

**April, 2006**

# Cost Saving $CO_2$ Capture System (COCS Project)

## New Chemical Absorption System

### Project Outline

$CO_2$ sequestration technologies entailing of $CO_2$ capture, transport and storage underground or at depth at sea, could be an immediate potent counter measure to global warming issues. Since $CO_2$ capture of $CO_2$ sequestration constitutes more than 70% of all the $CO_2$ sequestration costs, it has to be reduced drastically by near-term adaptation of $CO_2$ sequestration. As for the capture technologies, chemical absorption processes are promising because they can be easily and practically made for large scale $CO_2$ point sources. However, to make them practical in the near future, it is essential to reduce the cost of absorbent regeneration that at present occupies more than half of the cost of $CO_2$ capture.

Based on these circumstances, a new $CO_2$ capture project by chemical absorption system has been started with collaboration of three Japanese companies since fiscal year 2004 as a five-year project.

Figure 1 shows the concept of COCS project.

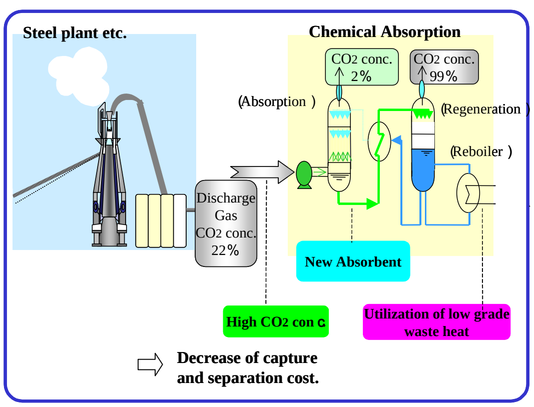


Figure 1: Concept of COCS project

First, we develop amine-complex noble absorbents, which have high absorption rate and low reaction energy, in order to regenerate them with less energy and at lower temperature than present absorbents. If we can regenerate an absorbent at lower temperature, we can utilize the low cost waste heat which is presently discharged without recovery at a steel works.

Second, we develop heat recovery technologies for waste heat sources (sensible heat of slag, sensible heat of coke oven gas, etc.) and the heat utilization system by collecting recovered waste heat at a steel works. We estimate that the energy cost for the regeneration can be reduced by almost 50% by the combination of a new absorbent and waste heat utilizing system.

### Objectives

The major objective of this project is to reduce the $CO_2$ capture cost by more than half of that using existing technology.

### Major Results

As for the chemical absorbent, with both experimental and theoretical studies on the reaction characteristics of amine compounds with $CO_2$, we found new absorbents which regeneration energy was 30% lower than that of MEA. Then, we carried out bench-scale testing of capturing $CO_2$ from blast furnace gas and evaluated absorbents from the perspective of the $CO_2$ capture process. We also investigated the amount of waste heat in the standard steel works that could be used as regeneration for absorbent.

### Future Work

We will continue to develop higher-performance absorbents and waste heat utilizing system. We will also prepare the pilot plant study. Figure 2 shows the schedule of this project.

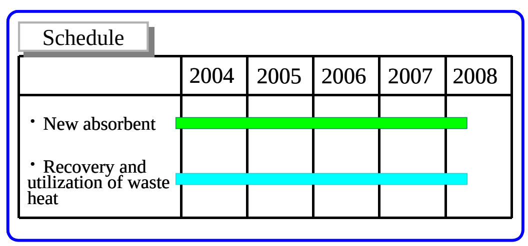


Figure 2: Schedule of COCS project


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# Innovative $CO_2$ Capture Technology for Natural Gas Plant

JGC Corporation is developing a new $CO_2$ capture technology for natural gas plant as a member of an international consortium with BASF Aktiengesellschaft, Germany. The new technology will ensure reliable and economical CCS ($CO_2$ Capture and Storage).

Natural gas is expected to continue to be used as a major energy source for several decades. Raw natural gas contains $CO_2$, normally in the range of 5% to 15%, and it is purified by acid gas removal processes in natural gas producing countries. The processes employed to remove $CO_2$ is solvent absorption in which the $CO_2$ is removed from the raw natural gas by means of an absorption solvent, and it is then separated from the absorption solvent in a solvent regenerator and finally released into the atmosphere. The amount of $CO_2$ separated from a large acid gas removal plant is estimated at several million tons per annum.

As interest in reducing the volume of greenhouse gases (GHG) has increased in recent years, CCS has come to be recognized as one of the most promising technologies. JGC has focused on CCS projects in natural gas producing countries, i.e. the $CO_2$ separated in acid gas removal units is compressed and injected into underground aquifers. This new technology can be applied there and lead to more economical CCS operations.

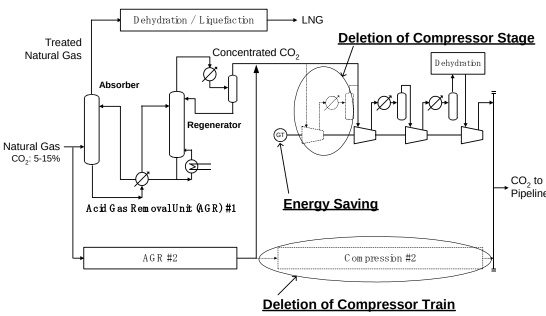
As $CO_2$ is discharged from conventional acid gas removal units at near atmospheric pressure, the cost and the energy consumption of the compressor for pressurizing it up to the underground aquifer pressure (10-20 MPa) is very large. The new technology enables an increase in the $CO_2$ discharge pressure, i.e. the suction pressure of compressor is increased. This enables reduction of energy consumption (reduction of OPEX). In addition, the $CO_2$ volumetric rate at the stage of compressor suction is subsequently reduced and therefore the train number and stages of compressors can also be reduced (reduction of CAPEX). The estimation JGC has conducted so far for a model case shows that the CCS cost (\$/ton-$CO_2$) using the new technology is as much as 20% less than that using the conventional process.

Development of solvent is one of the important issues. There are no solvents available used for conventional processes which can resist degradation at high temperature caused by saturated conditions of such high pressure regeneration. In addition, developments of process and equipment design for the new technology are also key points for developing economical CCS.

The new technology is applicable to the different fields other than natural gas plant and contributes to increasing in demands towards GHG emissions. For example it can be applied to coal gasification plant for zero emission hydrogen power plant. It is also effective for economical EOR (Enhanced Oil Recovery) by means of $CO_2$.

The consortium already found a few solvents applicable to the new technology. Under a 2-year subsidy program (2005-2006) sponsored by METI (Ministry of Economy, Trade and Industry), the thermal stability of the solvent under similar conditions to actual plants will be confirmed using a test plant. Basic data regarding solvent properties for modeling the process will also be obtained.

FIGURE 1: Advantages of High Pressure $CO_2$ Recovery Process





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# Long-Term Demonstration Tests of Flue Gas $CO_2$ Recovery from Coal Fired Boiler of Power Plant

**Background**
Prices of Oil & Gas have continued to soar with future supply of oil and natural gas becoming a major concern as coal becomes a more favorable economic option due to its low cost sustainable supply and that numerous coal fired power plants are already in operation. With Global concerns increasing regarding atmosphere preservation and conservation of resources it has become ever prudent to review CO2 emissions from fossil fired fuels that are adverse to our environment.

Since 1990 MHI has developed cost efficient CO2 recovery technologies enabling substantial energy and cost efficiency over conventional MEA process. These MHI forefront CO2 flue gas recovery technologies advanced in partnership with the Kansai Electric Power Co. Inc. with commercial plant operation in progress since 1999.

Acknowledging SOx, NOx and dust particle impurities are more abundant in coal fired flue gas systems over natural gas fired plants and it is logical that investigation to establish most favorable pre-treatment process advantages will require further research in confirmation of optimum performance.

**Purpose of the Demonstration Test**
Research and development experiments carried out at MHI pilot plant capturing some 1 metric ton CO2 per day require further investigation and require longer duration practical capacity testing demonstration.

MHI progressed this long-term demonstration, flue gas capacity producing 10 metric tons CO2 per day over a 3,000hour test period. This program is supported by J-POWER's cooperation and Japanese Government subsidy through Research Institute of Innovative Technology for the Earth (RITE).

Through this demonstration program, MHI will evaluate the long-term effect of impurities such as SOx, NOx and dust particulate with accumulation of plant operational data know-how.

**Project Outline**
Table-1, Fugure-1 &2 shows the specification, Flow scheme and schedule of the demo- plant.

| Item | Planned Specification |
|---|---|
| Location | J-Power Matsushima Power Plant (Nagasaki) |
| Flue gas source | Coal fired boiler |
| Flue gas volume | 1750 Nm3/h |
| Recovered CO2 | 10 ton-CO2/d |
| CO2 content | 14.1 v% |
| Impurities | Dust, SOx, NOx, etc. |
| Solvent | KS-1Solvent |

Table-1 Specification of the Demo-plant

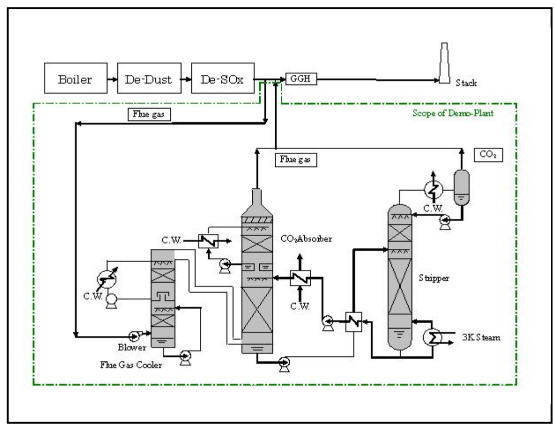


Figure 1: Flow scheme of the Demo-plant

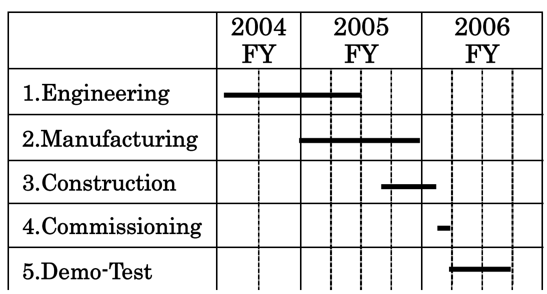


Figure 2: Schedule of the domo-test

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# Molecular Gate Membrane for $CO_2$ Capture

## Project of CSLF Recognition as $CO_2$ Separation from Pressurized Gas Stream

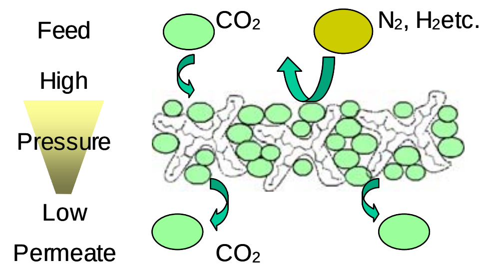


Figure 1: Concept of $CO_2$ molecular gate membrane

**Background:** $CO_2$ capture with existing technology consumes 70-80% of the cost of $CO_2$ sequestration. In this situation, development of revolutionary $CO_2$ separation membranes that can greatly reduce the energy requirements and costs of $CO_2$ separation is the urgent requirements for $CO_2$ sequestration to progress to practical usage.

RITE is currently developing a $CO_2$ molecular gate membrane with the goal of producing a new, high-performance separation membrane. The membrane will be preferably applicable to $CO_2$ capture from pressurized gas streams, such as IGCC process gas and so on.

**Primary Project Goal:** The purpose of this project is to develop a molecular gate membrane module that can greatly reduce the energy requirements and costs of $CO_2$ separation.

**Objectives:** The major objectives of this project are as follows:

1. Development of materials that have molecular gate function, which show excellent selectivity and permeability with high thermal stability.

2. Development of the composite membrane and its module.

3. Testing of the module.

**$CO_2$ Molecular Gate Function:** Figure 1 shows the basic outline of the $CO_2$ molecular gate function. The separation membrane (separation function layer) has a pathway through which gas molecules pass. In previous macromolecular membranes, nitrogen ($N_2$) or hydrogen ($H_2$) was able to negotiate this pathway along with the $CO_2$. As a result, $N_2$ or $H_2$ ended up outside the membrane with the $CO_2$, making it difficult to obtain a high concentration of $CO_2$.

In RITE's $CO_2$ molecular gate membrane, on the other hand, the pathway for gas molecules is occupied solely by $CO_2$, which acts as a gate to block the passage of other gases. Consequently, the amount of the other gas leaking to the other side of the membrane is greatly limited and high concentrations of $CO_2$ can be obtained.

**Framework:** Cooperation in the sharing of knowledge and information across international borders is the key to the development and implementation of new, innovative technologies. In developing this $CO_2$ molecular gate membrane, RITE conducted joint research with the US Department of Energy's National Energy Technology Laboratory (NETL) and the University of Texas at Austin (UTA). NETL offers testing information and apparatus.

Development of this separation membrane is registered as an international project of the Carbon Sequestration Leadership Forum.

**Duration:**

First stage: 2003 FY to 2005 FY

Second stage: 2006 FY to 2010 FY

**Major Results:** RITE has developed novel modified poly(amidoamine) PAMAM dendrimers as $CO_2$ molecular gate functionalized material. The modified PAMAM dendrimer shows the world largest $CO_2$ selectivity of more than 1000 and excellent $CO_2$ permeability, which encourages a great reduction of the energy requirements and costs of $CO_2$ separation. RITE has also produced a 1 meter long module of PAMAM dendrimer composite membrane. The module was tested with NETL's apparatus and showed good $CO_2$ separation performance.

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# Nagaoka Project for $CO_2$ Geological Storage

## Project of $CO_2$ Geological Storage testing in Japan

**Introduction:** Time-lapse crosswell seismic tomography is being conducted to monitor the $CO_2$ at a pilot geological sequestration site in Nagaoka, Japan. The project is supported by the Japanese government (Ministry of Economy, Trade and Industry), as an R&D program of underground storage for carbon dioxide. In comparison to the offshore location of the Saline Aquifer $CO_2$ Storage project, the Nagaoka project undertaken by Research Institute of Innovative Technology for the Earth (RITE) looks at the geophysical monitoring of $CO_2$ injection in an onshore saline aquifer. A series of field surveys and measurements consisting of crosswell seismic tomography, well logging, the reservoir formation pressure and temperature measurements, and micro-seismicity monitoring has been conducted jointly with Engineering Advancement Association of Japan (ENAA), to improve understanding of the $CO_2$ movement in a sandstone reservoir.

There is no any $CO_2$ leakage from the reservoir, even a huge earthquake (M6.8) hit the Mid-Niigata area on October 23, 2004. Distance between the earthquake epicenter and the $CO_2$ injection site is about 20 kms.

**Geology and $CO_2$ injection :** The pilot $CO_2$ injection site is located at the Minami-Nagaoka gas and oil field, where Teikoku Oil Co. produces natural gas from the deep reservoir (4700 m). Figure 1 shows the location of the pilot site and the simplified geological setting well studied during oil and gas exploration.

One injection well and three observation wells were drilled at the pilot site (Figure 2). Purchased 99.9% pure $CO_2$ was injected from CO2-1 at 20-40 tonnes per day. The depth of the reservoir consisting of a 60 m-thick sandstone bed of the Haizume Formation is about 1,100 m below the ground surface. A thin permeable zone confirmed from the well pumping test results, having a thickness of 12 m within the reservoir was selected for injection of $CO_2$.

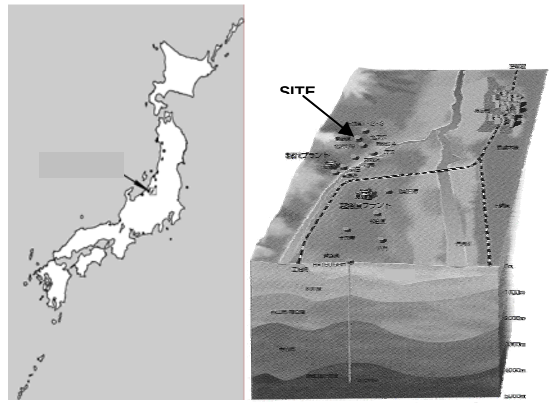


Figure 1: The Location and the simplified geological structure of the $CO_2$ injection site, Nagaoka, Niigata Prefecture.

The initial temperature and pressure of formation water were 48 °C and 10.8 MPa respectively and the transducers were installed at the reservoir formation depth in CO2-4, to monitor changes of pressure and temperature especially the formation pressure buildup during $CO_2$ injection. The $CO_2$ injection started on July 2003 and ended on January 2005. The total amount of injected $CO_2$ is 10,400 tonnes. Pressure and temperature of injected $CO_2$ were monitored continuously at CO2-1 throughout the $CO_2$ injection.

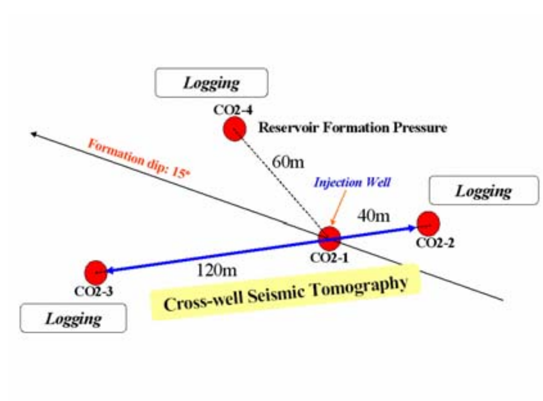


Figure 2: Configuration of the injection well and the three observation wells at the depth of the reservoir formation.

**Data acquisition and Results of field surveys:** OWS (OYO Wappa Source) was used as the seismic source in the observation well CO2-2, and a 24-level hydrophone tool was deployed down another observation well CO2-3.

Geophysical well logging consisting of induction, gamma ray, neutron and sonic was performed almost once every month at three observation wells of CO2-2, -3 and -4 to detect the $CO_2$ breakthrough. Such results enable us to modify the numerical model for prediction of the injected $CO_2$ within the reservoir. The crosswell seismic tomography was conducted to monitor the injected $CO_2$ between the observation wells of CO2-2 and CO2-3 at a distance of 160 m. The baseline survey was conducted prior to $CO_2$ injection in February 2003. The monitoring surveys were carried out in January and July 2004, after 3,200 and 6,200 tonnes of $CO_2$ was injected into the reservoir, respectively.

Difference tomograms were generated from the baseline- and monitor-tomograms as shown in Figure 3. These difference tomograms were obtained by subtracting each monitor velocity from the baseline velocity. Each difference tomogram shows a striking area with velocity anomaly near the injection well CO2-1. The maximum velocity reduction due to $CO_2$ injection was estimated about 3%. The low velocity zone indicates distribution of injected $CO_2$ within the reservoir. As increasing $CO_2$ injection the low velocity zone expanded preferentially along the formation up dip direction.

On October 23, 2004, a huge earthquake with a magnitude of 6.8 in JMA (Japan Meteorological Agency) Magnitude hit the Mid-Niigata area. The earthquake epicenter depth was 14 kms (JMA), and the $CO_2$ injection site is located about 20 kms away from the earthquake epicenter. The ground motions during the earthquake at 17:56, recorded by the seismicity monitoring system installed at the $CO_2$ injection site was 705 gal (maximum). There was no any seismicity observed during $CO_2$ injection before the earthquake. Both crosswell seismic and well logging surveys were repeated after the earthquake to investigate the $CO_2$ distribution within the reservoir. It is worth to note that there was no any $CO_2$ leakage from the reservoir according to the survey results.

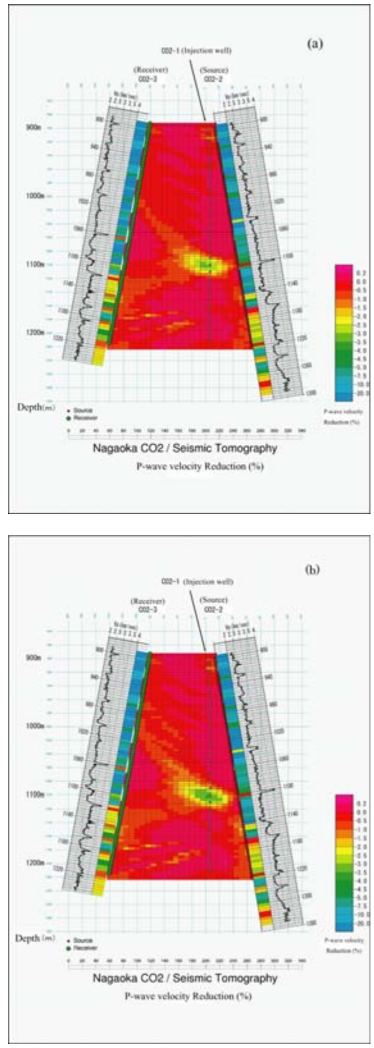


Figure 3: P-wave velocity difference tomograms between observation wells of CO2-2 and -3 at a distance of 160 m. (a) after 3,200 tonne-$CO_2$ injection, (b) after 6,200 tonne-$CO_2$ injection. The dashed line indicates the projection of injection well of CO2-1.

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# New CDM methodology for CCS in aquifers

The Mitsubishi Research Institute and JGC Corporation have developed a new CDM methodology for $CO_2$ capture and storage (CCS) projects in which $CO_2$ is stored in underground aquifers, and submitted it for approval by the CDM Executive Board. The methodology is titled "The capture of $CO_2$ from natural gas processing plants and liquefied natural gas (LNG) plants and its storage in underground aquifers or abandoned oil/gas reservoirs."

The natural gas produced from underground gas fields contains $CO_2$ in the range of 5-15 mole percent and other impurities, such as $H_2S$ and water. In natural gas processing plants and liquefied natural gas (LNG) plants, $CO_2$ and impurities are removed from the natural gas using amine solvents to meet purity limitations for products (e.g., sales gas, natural gas liquid (NGL) and LNG) and to avoid possible plugging of equipment by $CO_2$ freezing in the liquefaction process. At most plants, $CO_2$ is released to the atmosphere after incinerating the impurities to meet local environmental regulations. Therefore the $CO_2$ separated from the natural gas and the $CO_2$ resulting from the incineration are considered as the baseline emissions, meaning those emissions from the plants which will occur without CCS, and which will be avoided through the implementation of the CCS projects.

In the CCS projects, the $CO_2$ separated from the natural gas is injected into reservoirs. Prior to injection, the $CO_2$ is compressed into supercritical form with dehydration to prevent corrosion of pipelines. In this project activity, since the incineration of the impurities is not required, the $CO_2$ emission from the incinerators can be avoided. Instead of this emission, $CO_2$ is emitted due to energy consumption for the compression, transportation and injection of $CO_2$. Potential $CO_2$ escapes from the pipeline, the injection wells and the reservoir are also considered, but the possibility of those escapes can be reduced to substantially negligible levels at well-selected and managed reservoirs.

The emission reductions (*ER*) brought about by the projects are calculated as below:

*ER = Baseline Emission – Project Emission*


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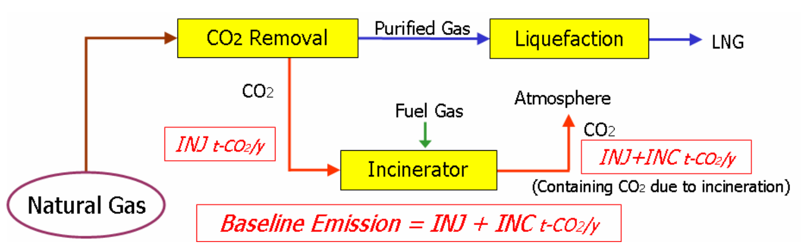
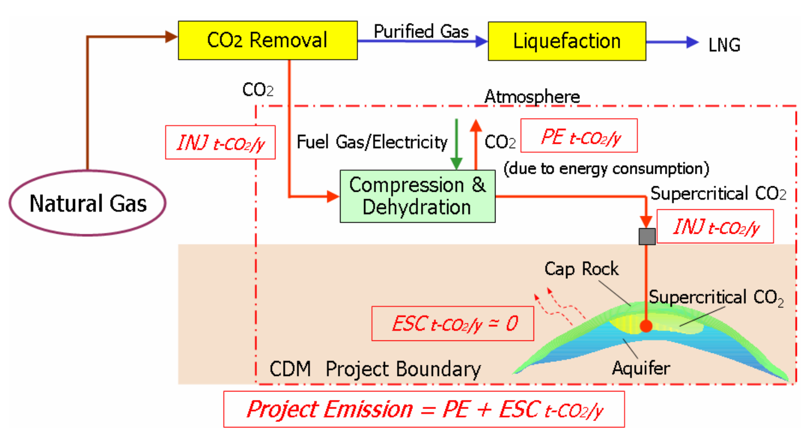
Baseline Scenario (Existing LNG Complex)




Project Scenario



# Submission of the first CDM new methodology application for CCS project activities

Mitsubishi UFJ Securities (MUS), in cooperation with other Japanese companies and a foreign registered oil exploration company, have produced and submitted the first CDM new baseline and monitoring methodology for a Carbon Capture and Storage (CCS) project. The methodology is titled "Recovery of anthropogenic $CO_2$ from industrial GHG emission sources and its storage in an oil reservoir".

The methodology is characterized by having a set of detailed applicability conditions with minimum standards for site selection (Pre-Inspection Phase Assessment), monitoring of the oil reservoir for seepage, and abandonment of wells. This is deemed necessary to alleviate public concerns about permanence of storage and safety. Lower quality projects which have little certainty in regards to permanence, are unlike to be applicable to this new methodology.

In order to confirm permanence, the methodology will monitor for significant release (through accidents, earthquakes, well failure, etc.) of stored $CO_2$ into the atmosphere. CERs equivalent to the estimated amount of $CO_2$ released (verified by a third party from seismic imaging and other applicable monitored data) will be replaced by the project participant in the event of significant release occurring. A significant release is defined as the release (from the storage structure) of an amount of stored $CO_2$ equivalent to over 0.7% of the total amount of stored $CO_2$, in a 7-year crediting period.

The methodology is made up of two parts:

1) An additionality test (Tool for the demonstration and assessment of additionality)

2) Baseline scenario and emission reduction determination

To determine the baseline scenario, the methodology examines whether $CO_2$ from the source is currently emitted into the atmosphere without being captured, and whether the current situation is likely to continue in the absence of the project. If this is the case for the project, baseline emissions are equivalent to the total amount of $CO_2$ vented/emitted by the source.

CCS projects utilizing the methodology need to determine project activity emissions due to:

1. $CO_2$ from the source which was lost during the capture, transfer or recycling processes.

2. GHG from energy used by the project equipment and machinery (both associated with fossil fuel and electricity)

3. Flaring/venting of $CH_4$ contained in waste gas derived from the $CO_2$ recycle plant

4. Seepage due to significant release of stored $CO_2$ from the storage structure

Leakage and project emissions are deducted from baseline emissions, to determine net emission reductions.

MUS submitted the new CCS methodology before the cutoff date of October 5 2005 for Round 13 of new methodology submissions. Although it passed the completeness test, the CDM EB were unsure of the eligibility of CCS projects as CDM project activates so decided to put the methodology on hold. The eligibility issue was subsequently debated at COP/MOP 1 and a decision is expected at COP/MOP 2. CCS technology will be an important tool for fighting global warming in the future. Considering the high costs of $CO_2$ capture, processing and injection, the incentive provided by income from the sale of CERs will be a critical factor in the dispersion of this technology into developing countries.

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# Japan $CO_2$ Geosequestration in Coal Seams Project (JCOP)

**Project outline**

JCOP has been in operation since JFY2002 with full subsidizy from Ministry of Economy, Trade and Industry(METI). The fundamental phase consisting of laboratory experiment and preliminary field test has been designed to investigate technical and economical feasibility of $CO_2$ sequestration in coal seams. Two wells were completed in Yubari city located in Ishikari Coalfield of Hokkaido. The distance in the coal seam between the vertical injection well and the deviated second well for observation was estimated to allow the breakthrough of $CO_2$ injected to come up from the observation well during the life of the phase by simulation model. This paper focuses on the multi well $CO_2$ injection/$CH_4$ production test which has been conducted using both injection well and observation well. This project is organized by GENERAL ENVIROMENTAL TECHNOS Co.,Ltd (KANSO) and field test is undertaken by the Japan Coal Energy Center (JCOAL).

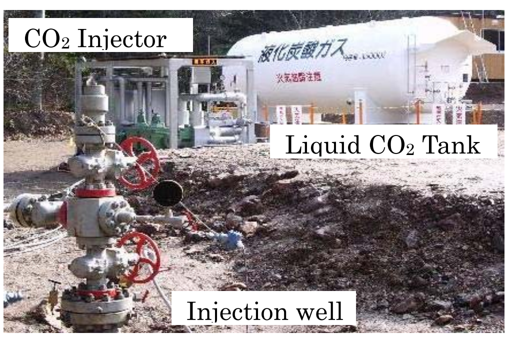


Figure 1: Photo of Preliminary Test Site

**Object**

The purposes of this Project are:

To develop the effective $CO_2$ injection technology for Japanese coal seams in safe manner,

To produce much more $CH_4$, and

To pave the way for monitoring the behavior of injected $CO_2$ in coal seams.

**Results**

We have obtained the following results from field test : Two multi-well tests were carried out in 2004 and 2005 to measure the injectivity of $CO_2$ at the injection well, and simultaneously investigate the influence of $CO_2$ injection on gas production from the observation well. At the first multi-well test (2004), a total of 35 metric tons of $CO_2$ were injected during the 16-day injection period. In the second test (2005), a total of 115 metric tons of $CO_2$ were injected during the 42-day injection period. In this test, we recognized the permeability reduction due to coal matrix swelling. Since the gas production was very sensitive to the $CO_2$ injection, the gas production rate declined immediately after the stop of $CO_2$ injection. The gas production ranged from 50m$^3$/d to 241m$^3$/d in the first multi-wells test (2004) and 75m$^3$/d to 370m$^3$/d in the second test (2005). Figure 2 shows production rates and $CO_2$ injection rates for 2005. As shown in the Figure, $CO_2$ injection rates were increased under the stable injection pressure. The gas productions were enhanced almost 5 times larger than each base production prior to the injection. History matching of the production and injection have been performed very successfully.

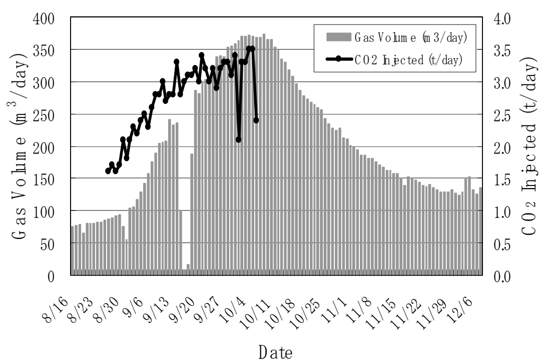


Figure 2: Gas production rate for $CO_2$ injection

**Issues in the development of technology**

As future research tasks, we plan to examine the following aspects:

- $CO_2$ injection potential and methods to increase $CH_4$ productivity
- Monitoring of $CO_2$ behaviour in coal seams
- Economic efficiency of the total system

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# Environmental Assessment of $CO_2$ Ocean Sequestration for Mitigation of Climate Change

**Background:**

In order to control global warming, it is necessary to decrease the discharge of $CO_2$ into the atmosphere. $CO_2$ ocean sequestration technology is a kind of enhancement technology for the natural process of ocean, which is the absorption of $CO_2$ in the atmosphere into the mid-depth of ocean. The $CO_2$ emission over several centuries causes the increase of atmospheric $CO_2$ concentration, and the pH of surface of the oceans decreases during taking up $CO_2$, and finally, the atmospheric $CO_2$ concentration decrease in equilibrium. If captured $CO_2$ is injected to mid-depth layer without contacting the sea water of surface layer, so, the marine organism of the surface layer is not affected by the injected $CO_2$. Injected $CO_2$ to mid-depth is dissolved into the sea water as well as the atmospheric $CO_2$ is naturally absorbed to the ocean (Fig.1).

Before the implementation of ocean sequestration, the validity of this technology should be evaluated. The biological impact study and the development of the monitoring technology are necessary for $CO_2$ ocean sequestration. And also, the feasibility study of $CO_2$ dilution technology should be implemented to confirm the viability of ocean sequestration.

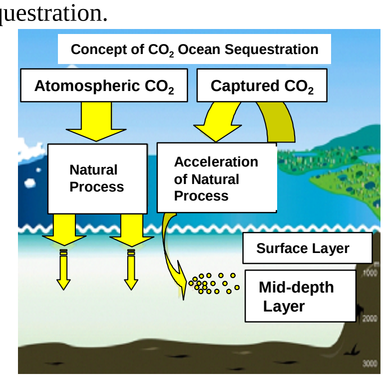



Fig.1 Concept of $CO_2$ Ocean Sequestration

**Primary Project Goal:**

Japan is developing environmental assessment technology of $CO_2$ ocean sequestration using Moving Ship system for the R&D aimed toward a practical system that can make a significant contribution to reducing atmospheric $CO_2$. The concept of Moving Ship system is shown in Fig. 2.

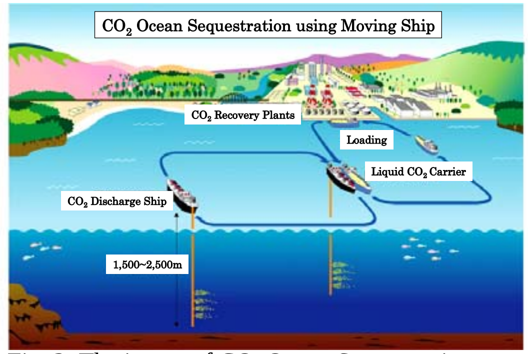



Fig. 2: The image of $CO_2$ Ocean Sequestration

The liquefied $CO_2$ injected as droplets into the mid-depths of ocean (1,500-2,500m) is diluted and dissolved in sea water. The project goal of the second phase started in 2002 is the assessment of ocean sequestration validity, the development of environmental impact assessment technology and the development of $CO_2$ dilution technology.

**Objectives:**

The major objectives of this project are as follows:

(1) The technological assessment of $CO_2$ ocean sequestration capability: The effectiveness of ocean sequestration technology must be elucidated by additional investigations using newly developed models based on the accumulated scientific knowledge.

(2) Environmental impact assessment technology: $CO_2$ impact on ocean environment, especially impact on biota in mid-depth of ocean, must be elucidated before practical implementation of $CO_2$ ocean sequestration,

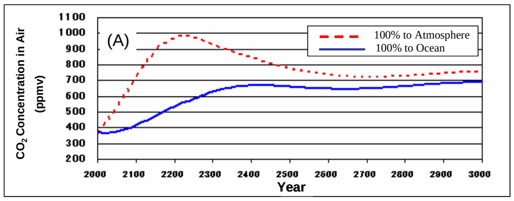
(3) $CO_2$ dilution technology: Development of $CO_2$ dilution technology is needed to reduce $CO_2$ impacts on ocean environment as much as possible and its results are applied to the study on the environmental impact assessment technology.

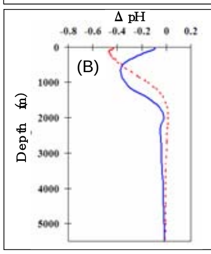
**Major Results:**

Outline of R&D results in FY-2002 to FY-2004 are followings:

(1) Technological assessment: Consequences of the $CO_2$ ocean sequestration were simulated

numerically by using global carbon cycle box model, comparing the $CO_2$ concentration in atmosphere and ocean between the reference case and ocean sequestration (Fig.3). The capability of $CO_2$ sequestration into the ocean was studied relating to the equilibrium concentration of atmospheric $CO_2$.




(A)Comparison of $CO_2$ concentration in atmosphere between reference case and ocean sequestration (the calculation over 3000 year is still in execution).

(B) Vertical profile of ΔpH in the ocean at the initial state (Year: 2100)

Fig. 3 Simulated atmospheric $CO_2$ concentration and depth profile of ΔpH in the ocean

(2) Environmental impact assessment technology: The assessment technology of $CO_2$ injection impacts on environment have been developed on the assumption that applying $CO_2$ dilution technology developed by this project at suppositional area of $CO_2$ ocean sequestration near Japan. The physical-, chemical- and biological- environmental surveys have been conducted at the southeast sea area of Okinawa, where is a suppositional area of $CO_2$ ocean sequestration. Biomass, biodiversity, and food web structure of the survey area have been studied year-by-year (Fig.4). As for predicting acute impacts of high-$CO_2$ environment on marine organisms, mortality model which could estimate range and degree of impact by means of computational simulation is developed.
Furthermore, laboratory experiments on responses of marine organism to high-$CO_2$ are carried out to permit more precise prediction of an acute biological impact. As for a first step of a long-term biological impact assessment, deep-sea ecosystem model is attempted to construct based on the biological data derived by surveys at a suppositional area of $CO_2$ ocean sequestration.
Achievements of the recent studies on the environmental impact assessment technology have been published as the special section in Journal of Oceanography (Vol.60, No.4, 2004).

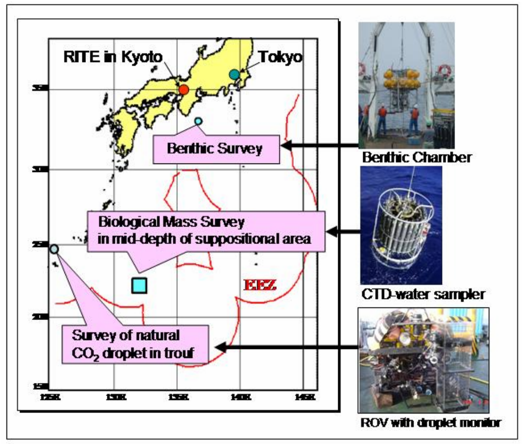



Fig. 4: R&D surveys for the Ocean Sequestration

(3) $CO_2$ dilution technology: For the prediction of $CO_2$ distribution, the meso-scale models which were enable to estimate the behavior of $CO_2$ dilution and diffusion within from 100 m to 1,000 km were developed, and the completion of large-scale models for 1,000s km is in sight by using the computer of the Earth Simulation Center (ESC) (Fig.5). The observation of $CO_2$ droplet in the Okinawa trough made sure the credibility of $CO_2$ dilution model. And the feasibility of moving-ship method for $CO_2$ ocean sequestration was investigated. As for the technology of feeding liquid $CO_2$ through pipe into sea water, the experiments of the vortex induced vibration (VIV) has been done with a large-scale water tank, and the numerical analysis of flow field were carried out to solve the VIV phenomenon which occurs in towing a long pipe by ship.

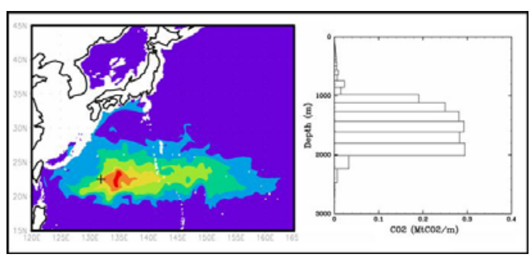


Fig. 5: Simulated $CO_2$ behavior (Earth Simulator)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# A Research Project on Accounting Rules on $CO_2$ Sequestration for National GHG Inventories

**Project Summary**

The long term risk that stored $CO_2$ could eventually return to the atmosphere through physical leakage in CCS is not ignored. This project has an aim to propose rules for calculating the actual amount of emission reduction by the CCS technologies and how to reflect it within the National Communication (Annual Inventory) under the protocols dictated by the United Nations Framework Convention on Climate Change (UNFCCC).

First, leak estimation models are developed for geological storage and ocean storage. Second, based on the models leak estimation methodology is developed. Third, accounting rules for national inventories and project-based activities are proposed. Fourth, expected influence of proposed accounting rule is simulated by an integrated assessment model. Finally, feasibility studies of CDM projects using CCS are conducted.

**Goal**

This research project aims to propose transparent and internationally acceptable accounting rules for CCS based on scientific information.

**Progress and Achievements**

1. *Proposal of accounting rules*

The summary paper of the accounting rules was presented in GHGT-7 and a detailed paper was prepared as a discussion paper, which was circulated among authors of IPCC 2006 Guideline for National Greenhouse Gas Inventories and used as a reference in the first author meeting of the IPCC 2006 Guideline.

In the proposed accounting rules, a framework of accounting rule of CCS technology is proposed based mainly on leakage estimation using newly developed models. These rules follow identified priority factors with which emphasize estimation and accounting of yearly leakage in the near term as a conservative basis for rule making. The proposed accounting rules for CCS consists of avoided emission estimation methodology, accounting rules for national inventories, and accounting rules for project-based activities. Developed accounting rules for project-based activities will be presented in GHGT-8.

2. *A leak estimation methodology for geologic storage*

A leak estimation methodology based on quality of cap rocks (seal quality) was developed and were presented in GHGT-7. To quantify quality of cap rocks, Cap-rock Quality Factors (CQF) was also newly developed. CQF is calculated reflecting features of the site, thickness of cap rock, depth of the site and possibility of three types of leakage, leakage via matrix of cap-rock, leakage via fracture of cap-rock, and leakage via wells.

3. *A global ocean system model and a leak estimation methodology for ocean storage*

A global ocean system model was developed with the purpose of understanding the physical and biochemical process within ocean system and predicting the effect of ocean storage of $CO_2$. Based on the simulated storage curves of injected amount of $CO_2$, a simple formulation for accounting the amount of $CO_2$ stored in ocean using leakage coefficients was developed. Three papers were presented in GHGT-7.

4. *Simulation of influence of proposed accounting rule*

The proposed accounting rule is evaluated by the sensitivity analysis, which is conducted by an integrated assessment model to simulate accounting rule and leakage rate effects to the energy system, CO2 emissions and atmospheric concentration under CO2 concentration constraint.

5. *Feasibility studies of CDM projects using CCS*

Case studies are conducted to examine feasibility of CDM projects using CCS in two sites (Indonesia and Vietnam) applying proposed accounting rules.

**Future Tasks**

Future tasks are development of leak estimation methodology using monitoring technology and simulation models and design of institutional arrangements for promoting project-based activities of CCS.

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# Research and Development for Producing Afforestation Trees in Semi-Arid Land

To offset global warming due to increase in $CO_2$ at atmosphere, we direct our attention to the ability of plants to fix the $CO_2$ in photosynthesis and expect plants to sequestrate the $CO_2$. That is, we try to green semi-arid land occupying most of un-used land on the Earth for $CO_2$-sequestration. In this strategy, utilization of trees to fix $CO_2$ in greening, afforestation, is an ideal photosynthetic organism, because trees can keep the fixed carbon in themselves for a long time. And for these trees are required the following two characters: (1), a large photosynthetic capacity per unit land area; (2), a large tolerance to environmental stress for the enlargement of afforestation area. Therefore, in this project, we set five subjects to make trees which have the above characters: (A), an acquisition of genes for improving both $CO_2$ fixation and nutrients uptake; (B), an acquisition of genes for increasing tolerance to environmental stress; (C), a development of transformation technique of trees, eucalyptus or poplar, for the introduction of the genes acquired in (A) and (B); (D), a development of suppression technique of pollen diffusion from transformed trees not to disturb natural ecosystems; (E), a development of selection technique of elite species of eucalyptus which can grow faster even under semi-arid land.

For three years, we got the following fruitful results. In the subject (A), *Arabidopsis thaliana* mutant having a high capacity of $CO_2$ fixation was isolated. The identification of mutated gene would be useful for improvement of photosynthesis in eucalyptus or poplar by their transformation. A gene enhancing phosphate uptake by eucalyptus from acid soil was isolated, which results would make possible eucalyptus grow under acid lands, ex. Brazil. In the subject (B), a molecular mechanism to protect leaves from photoinhibition under limited photosynthesis conditions was elucidated, and strengthened by plastid transformation technique. Furthermore, a gene enhancing salt tolerance was isolated from mangrove and its introduction to eucalyptus made them grow under salty land. In the subject (C), a technique for stable transformation at a constant site in genome was developed. Using this technique, an arbitrary required amount of gene product would be obtained in eucalyptus leaves. In the subject (D), a technique of grafting eucalyptus root, which was transformed with a gene relating enhanced phosphate-uptake, to shoot, which was native eucalyptus tree, was developed. That is, a diffusion of transformed gene in root would be suppressed, because pollen does not have the gene. In the subject (E), we construct several experimental fields in semi-dried area of Western Australia, where three elite species of eucalyptus were grown. First species showed a higher growth rate, second one salt tolerance and third one drought tolerance. By comparative analysis of these species in their growth and $CO_2$ fixation capacity, we will develop selection marker to pick up super elite in the filed.

Resolving these subjects and their unifying would supply ideal trees for afforestation, which have the above two characters (1) and (2). And these improved trees would contribute to $CO_2$-sequestration in future.

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# Workshop on CDM Methodological Issues in Regard to CCS

**Introduction:** The COP/MOP, in its decision at its first session, established the process with a view to making its final decision on the methodologies for CCS projects at its second session to be held in November 2006. In order to support the COP/MOP's decision, the CDM Executive Board will consider proposals for new methodologies for CCS projects and make recommendations to the COP/MOP at its second session. Also a workshop for considering CCS projects as CDM is scheduled to be organized at the twenty-fourth session of the UNFCCC, Subsidiary Body for Scientific and Technological Advice (SBSTA) in May 2006.

METI's workshop is intended to develop and deepen mutual understanding among both sides of CCS and CDM with experts invited from both fields, and to discuss how to implement CCS projects as CDM through examining two CDM methodologies proposed by Mitsubishi UFJ Securities (MUS) and Mitsubishi Research Institute, Inc. (MRI), focusing on three key methodological issues identified by the COP/MOP such as project boundary, leakage and permanence. The results of this workshop are expected to provide useful input for the forthcoming workshop and for the discussions at the CDM Executive Board and the COP/MOP at its second session.

**Dates:** April 20th (Thu) and 21st (Fri), 2006

**Venue:** Le Palais des Congrès de Paris, France

**Language:** English

**Tentative Agenda:**

<The 1st day>

Opening remarks — Dr. Hiroshi Yamagata, Director for Environmental Affairs, METI

Introduction of IPCC Special Report CCS
Case Study of the Weyburn Project
Case Study of the Sleipner Project
Introduction of Inventory Guidelines
Introduction of CDM scheme

＜The 2nd day＞

Introduction on the CDM CCS Methodologies

- Introduction on the MUS CDM CCS methodology "Recovery of anthropogenic CO2 from large industrial GHG emission sources and its storage in an oil reservoir"
  (Mr. Junji Hatano, MUS)
- Introduction on the CDM CCS-Aquifers methodology "The capture of CO2 from natural gas processing plants and liquefied natural gas (LNG) plants and its storage in underground aquifers or abandoned oil/gas reservoirs"
  (MRI and JGC)

Issue relating to Project boundary

- Panel discussion on improving the CDM CCS methodologies
  (Key topics)
  ・Issues related to Project boundary determination
  ・Implications of the London Convention and other treaties

Issue relating to Leakage and Permanence

- Panel discussion on improving the CDM CCS methodologies
  (Key topics)
  ・Applicability conditions in regard to Site selection and management
  ・Effective monitoring techniques
  ・Frequency of measurements and sample size
  ・Whether and how to define a limit for an acceptable amount of leakage
  ・How to identify a significant release of stored CO2
  ・Monitoring and the reservoir model
  ・How to consider a discount rate relating to leakage
  ・What action should be taken in the event of leakage
  ・The cost of seismic surveys and other monitoring techniques

Wrap up of the discussions — Dr. Makoto Akai, AIST

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