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Vice President, University of Hyogo

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Research Institute of Innovative Technology for the Earth

Importance of Development of CCS Technology and Renewable Materials

Yutaka Suzuki, Vice President

University of Hyogo

The Fourth Assessment Report of IPCC, “Climate Change 2007” states that it is very high confidence that climate change originated from human activities, using climate models (atmosphere-ocean coupled general circulation models). The major cause is CO_2 which is discharged into the atmosphere by burning of fossil fuels. CO_2 is a green house gas which accumulates in the atmosphere causing climate warming (generally called “global warming”). From the beginning of the Industrial Revolution, starting with the development of a highly fuel efficient steam engine by James Watt, we began to use large quantities of fossil fuels, and steam locomotives that symbolized the advancements of the Industrial Revolution began operating early in the 19th century. As we are now in the early stages of the 21st century, civilized society dependent on fossil fuels has created a serious problem called global warming in only a 200 year time-frame and sustainability of our society is in doubt.

The earth is constantly changing and evolving. But the timescale of change is on the order of several hundred thousand years or several million years. In the Triassic period, 200 million years ago, plants flourished and dinosaurs roamed the continents of the earth. Since that time, fossil fuels have formed. It is the ways of modern civilization that have led to the excavation of fossil fuels from underground or in seabeds and consumed large quantities of fossil fuels in a blink of an eye, as compared to the earth’s timescale and waste products of CO_2 have been discarded into the atmosphere. The result is climate warming, which is formed by the subtle energy balance between the atmosphere and ocean. Warming changes the amount of precipitation and regional patterns of precipitation and greatly affects vegetation and agricultural systems. Warming is melting glaciers and moving water from land to sea raising sea levels.

The basic principles for preventing global warming are to constrain consumption of fossil fuels, the major cause, and leave dependence on them ultimately. As energy sources to replace fossil fuels, nuclear energy and natural circulation-type renewable energies are alternatives. It is with a sense of urgency that we need to develop them in order to sustain an increasing world population and development of the global economy. The world now depends on fossil fuels for 90% of its enormous energy consumption needs, however, it is impossible to convert our energy in a short period of time (on the order of 100 years). Therefore, it has been deemed necessary to develop CCS (carbon capture and storage) technology, which separates and collects CO_2 discharged from the consumption of fossil fuels without discharge into the atmosphere and stores it in appropriate locations. As fossil fuels are also used as raw materials in large quantities, it is necessary to develop alternative natural circulation-type renewable materials.

RITE has achieved significant results in the development of CCS technology and renewable materials, which is a leading research institute not only in Japan but around the world. We expect and look forward to greater efforts in the future.

Systems Analysis Group

Studies that aim to contribute to international discussions and negotiations on climate change policy

1. Overview of research activities

Systems Analysis Group conducts policy-related studies of global warming mitigation. The current major subjects are 1) quantitative determination of the atmospheric concentration stabilization level of GHGs that is stipulated qualitatively in Article 2 of UNFCCC in order not to interfere with the climate system, and Post Kyoto Protocol that will stipulate the international regime of emission reductions after 2012. The latter is rather urgent and its official discussion has now started. The former is an essential issue of great importance that influences the latter. In addition to these issues under UNFCC, APP (Asia Pacific Partnership on Clean Development and Climate) one of whose aims is emission reductions through diffusion of energy efficiency technologies has been launched. This is a regional agreement based on a so-called action-oriented approach. The figure shows these issues and the objectives of the two research projects of RITE, "PHOENIX" and "Beyond 2010" with respect to the related international trends.

2. "Beyond 2010"

In last year's RITE Today booklet, we introduced an analysis of emission reduction measures and reduction costs required to achieve top-down emission reductions which are imposed on each country (top-down targets) according to various by employing a world energy model having a high regional resolution, which is intended to contribute to international discussions on Post Kyoto Protocol. Expanding this energy model, we have conducted a study to evaluate emission reduction effects and costs of imposing energy efficiency targets or specific emission targets on each industry sector (bottom-up target). The proposal of bottom-up targets is being made because economic growth and CO_2 emissions have a strong correlation with each other and such international regimes as imposing a cap on emissions by country like KP are considered difficult to fall into agreement, especially developing countries that aim at large economic growth and are unwilling to participate in such regimes as imposing emission caps on each country and may interfere with their economic growth. In order to achieve both economic growth and emission reductions, introduction of high-energy efficiency technologies is inevitable and therefore energy efficiency targets are expected to be more easily accepted by many countries. It is well known that Japan's energy efficiency is high and we have made an evaluation of the effects of introduction of energy efficiency targets using Japanese efficiency levels as a reference by use of the expanded world energy model. APP, which was launched in January 2006 aims at technology cooperation involving developing countries of large emissions such as China and India which are not obligated to reducing emissions under KP. We also evaluated the effects of energy efficiency target introductions for the six participating countries of APP and determined that approximately the same amount of emission reductions are possible at a much smaller cost through introductions of these targets at current Japanese levels with regard to the power, steel and cement sectors for the six countries to that of the KP case. This result is valuable in showing the effectiveness of the APP regime in terms of emission reductions.

3. "PHOENIX"

PHOENIX stands for Pathways toward Harmony of Environment, Natural Resources and Industry Complex and attempts to determine a desirable target for long-term emission reductions considering both warming impacts and emission reduction costs. In the past, the approach by use of integrated assessment models has been known for the above objectives. The integrated assessment model typically evaluates the warming impacts in monetary terms, expresses them as functions of temperature rise, and explores such temperature rise as minimizes the sum of mitigation costs and damage costs, while also exploring the corresponding concentration stabilization levels of GHGs.

However, the warming impacts range over various areas and the cost minimization approach is not free from personal value judgments in monetary evaluation of such impacts as on biodiversity, human health etc. In addition to the above problem, the approach veils the regional distribution of impacts when summing up impacts throughout the world and also inevitably makes some value judgments on equity between future generations in obtaining the total sum of time series impacts. Thus, the PHOENIX project certainly intends to make quantitative evaluations of warming impacts by region and by time point but not necessarily in monetary terms during the evaluation process, but it is at the final stage that value judgments are made on impacts together with mitigation costs to seek the desirable level of concentration stabilization. The detailed procedure on this approach is as follows; the future reference scenario of emissions is generated based on the IPCC SRES scenario, emission paths of 650, 550 and 450 ppm stabilization are set up based on the IPCC WG1 stabilization paths; then the climate change is calculated for each of the paths and various kinds of impacts are evaluated for the calculated climate changes; the mitigation costs are calculated in order to achieve the stabilization down from the reference path. Quantitative evaluations were possible only for sea level rise, agriculture products, human health, terrestrial biodiversity, water resources and ocean acidification as continuous events and ocean thermohaline circulation as abrupt and catastrophic events. In addition to these impacts, those on forestry, fishery, livestock, other industries, extreme weather, west Antarctic ice-sheets and Greenland ice are being studied around the world and their impacts are expected to become large as a result of climate change but the quantitative evaluations for the above emission paths were hardly possible. As for the thermohaline circulation, the impact of the circulation collapse is not very clear but it is not unreasonable to assume extremely large impacts on ocean ecology and related areas. Catastrophic events like this should be evaluated in terms of occurrence probability rather than the damage size from the viewpoint of precautionary measures and we calculated the probability of the circulation collapse for each of the stabilization emission paths and the reference path, by use of the evaluation result of the collapse by Stocker et al and the probability density function of climate sensitivity. Here it should be noted that it is between 2150 and 2200 when the collapse takes place. Other kinds of impacts than the theromohaline circulation were evaluated by region and at the time points of 2050, 2100, and 2150.

The final step is to obtain expert judgments on the desirable level of stabilization by providing all these evaluation results of impacts and mitigation costs. However, the results spread over wide areas and amount to a large volume, and we asked for preliminary judgments of experts on the relative importance of alleviations for five kinds of impacts which result from stabilizing at different levels. From the judgment results, we inferred the desirable level that each of the experts suggest, and finally provided to each of the experts all the important results of our study together with the desirable level which each of the experts is considered to suggest from the preliminary judgment, and obtained the final judgment of the experts on the desirable level of stabilization. For the final judgment, we prepared tables, graphs and geographic figures to help them understand easily the full evaluation results on impacts and mitigation. We also inquired as to how much importance the expert placed on each of the impacts, mitigation costs, regional differences and temporal differences in their judgment of a desirable stabilization level. We are now analyzing the expert judgment results and will publicize the results, which can be expected to offer significant contributions to climate policy making.

As described in the above, the Systems Analysis Group endeavors to incorporate new methodologies and tools into the accumulated expertise of the past and is carrying out research to help solve current important issues regarding climate policy.

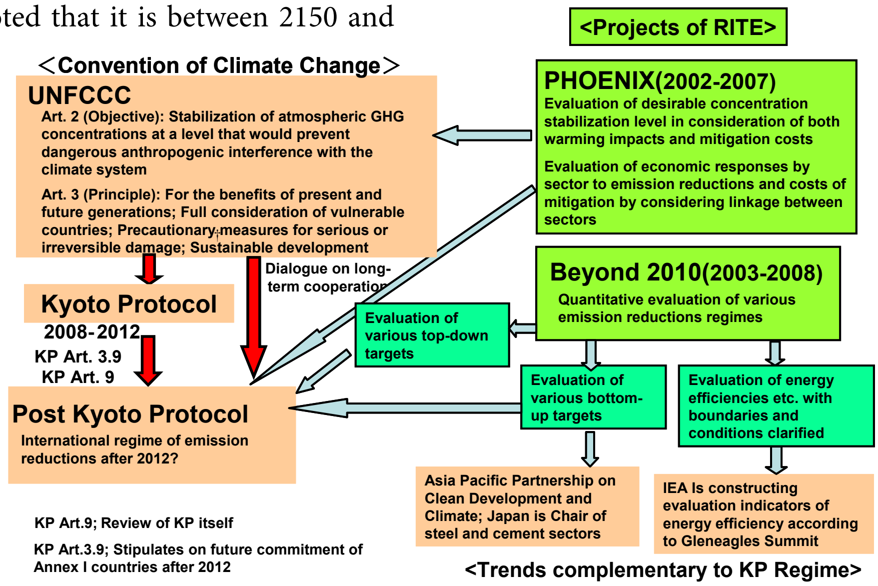


Fig. International Trends concerning Climate Policy and Aim of RITE Research

Chemical Research Group

Looking ahead to future CO_2 separation technologies and their challenges and innovations

Cessation of thermohaline circulation in the ocean as a result of global warming, which will have a destructive influence on the earth's environment, is an issue that needs to be addressed. We need to determine to what extent the CO_2 concentration in the atmosphere should be controlled scientifically in order to prevent this phenomenon. The probability of cessation of thermohaline circulation in the ocean is several percent at a CO_2 concentration of 550 ppm, and this probability increases by several tens of percent at a CO_2 concentration of 650 ppm.

In the Stern Review released last year, in spite of the fact that the above catastrophic phenomenon was not taken into consideration, it was predicted that all countries in the world will suffer from a 5% GDP loss due to global warming if the global warming problem is not addressed. The review stated that a contribution of 1 % of GDP to combat global warming is reasonable, from an economical point of view.

A CO_2 concentration of 550 ppm is twice the concentration that was present during the Industrial Revolution. If we set a target CO_2 concentration of 550 ppm for 2100, it has been predicted that not only energy saving, fuel switching, renewable energy sources (solar cells, wind power and biomass) and nuclear energy, but also CO_2 capture and underground storage will be necessary to achieve this goal. As the cost of CO_2 capture from CO_2 sources is estimated to be 70 % of the total cost of CO_2 capture and underground storage, it is important for the commercialization of this technology that the CO_2 capture cost for CO_2 capture and storage (CCS) is reduced.

Conversion technologies of fossil energy are going to progress, and we consider the power generation system of a boiler steam turbine evolving into a combined cycle with a gas turbine for power generation and a combined cycle with a fuel cell. Various CO_2 capture technologies such as chemical absorption, physical absorption, membrane separation, and the oxy-fuel method have been developed.

Progress in these technologies will result from development of the best combination between fuel conversion processes and CO_2 capture processes, so that CO_2 capture technologies that will consistently increase the economic benefits of technical visions, as shown in Figure 1, are developed.

Our chemical research group studies various CO_2 capture technologies, with a special focus on chemical absorption and membrane separation methods.

We can use chemical absorption to reduce the CO_2 capture cost for flue gas in an ironworks factory to 3700 JPY/t-CO_2. We are developing a chemical absorbent to reduce this CO_2 capture cost to 2000 JPY/t-CO_2. Moreover, we have discovered an excellent, world-class membrane material for the separation of CO_2 from H2-containing gas. We are engaged in the development of the structure of a new membrane composed of this material.

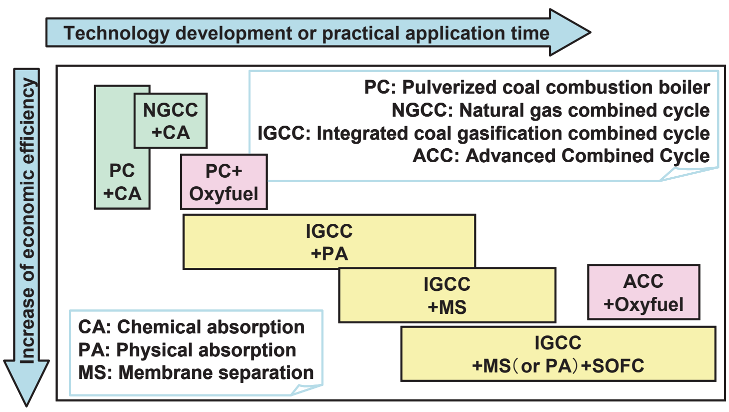


Fig.1 Vision of power plant and CO_2 capture

Development of CO_2 capture technology that uses a chemical absorption system

CO_2 capture by chemical absorption has the potential to be used in practical applications for large stationary point sources of CO_2 in the near future, and a five-year project to this end was started in 2004 in collaboration with four Japanese companies.

The objective of this project is to reduce the CO_2 capture cost to half that of the existing technology for the flue gas (blast furnace gas) stream in an integrated steel works. The main objectives, shown in Figure 2, are the development of new absorbents to enable the capture of CO_2 with less energy use, and the development of a heat utilization technology to use waste heat at steel works to supply low cost steam for regenerating CO_2.

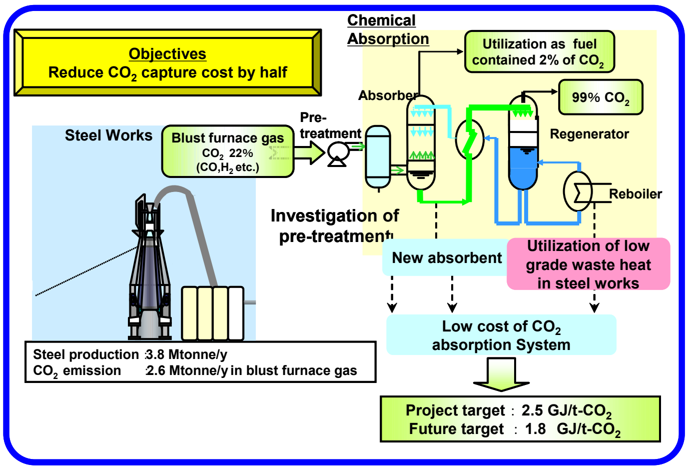


Fig.2 COCS project (Cost Saving CO2 Capture System)

RITE mainly develops new absorbents. The most desirable characteristics for new absorbents are: a lower heat of reaction with CO_2, fast CO_2 absorbance, and easy separation from CO_2. If this is achieved, CO_2 can be captured from a gas stream with a lower energy input. Among the solvents tested for CO_2 capture, amine solutions have shown the best performance.

Figure 3 shows a plan for the screening and development of new absorbents. As a first step, the reaction characteristics, such as the reaction rate of CO_2, the amounts of CO_2 absorbed and the heat of reaction with CO_2, of almost 100 samples of commercial amine solvents selected by the plan shown in Figure 3, were analyzed using laboratory apparatus. Furthermore, compound amine solutions, that can compensate for deficiencies in the amines, were prepared and their performance was investigated.

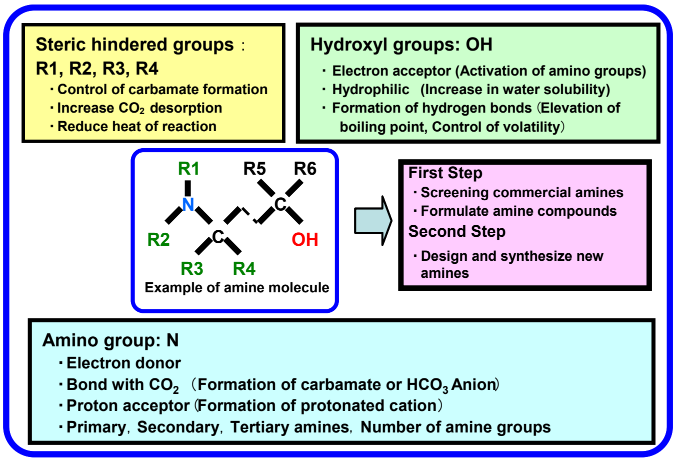


Fig.3 Development of new absorbents

From these investigations, three type of high performance absorbents (RITE-3A,-4A,-4B), that showed different characteristics, were developed. The energy for CO_2 capture of the best of these absorbents is estimated to be 2.9 [GJ/t-CO_2]. This value is very low compared to the 4.0 [GJ/t-CO_2] for a standard MEA (monoethanol amine) solution, and is close to the project goal of 2.5 [GJ/t-CO_2], as shown Figure 4.

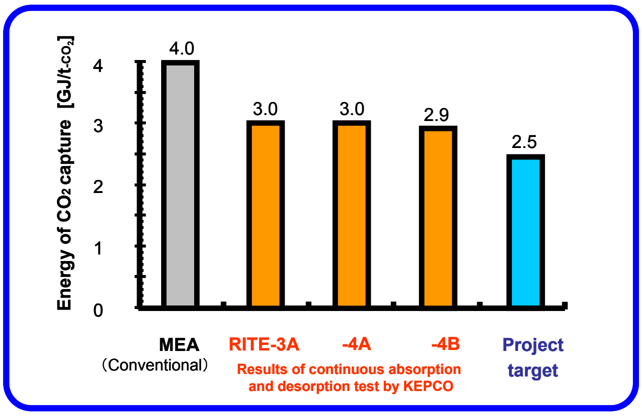


Fig.4 Energy of CO2 capture target and results

The second step of the project has also been carried out, in which new types of amine compounds, designed and prepared based on the current knowledge, are evaluated by a similar method. Furthermore, research on the optimum conditions for the chemical absorption system has been carried out, so that the best performance can be obtained from the new absorbents. Currently, the aim of the project is to reduce the CO_2 capture energy down to the target value.

Development of new techniques for regenerating the chemical absorbent solution

A regeneration technique using a material that accelerates CO_2 desorption under conditions where there is a pressure difference is being developed, in order to reduce the energy consumption of the regeneration process of the chemical absorption method, as shown in Fig. 5.

Up to now, the following observations have been made: Desorption can be accelerated by the material and the processing conditions, which can reduce energy consumption by over 1/2 in comparison with high-temperature heating regeneration of the absorbent solution in the conventional chemical absorption method.

At present, cooperation with companies is being promoted, to apply this method to the separation of CO_2 from flue gas, chemical processes, bioprocesses, etc., while development is progressing with the aim of further reducing the energy consumption.

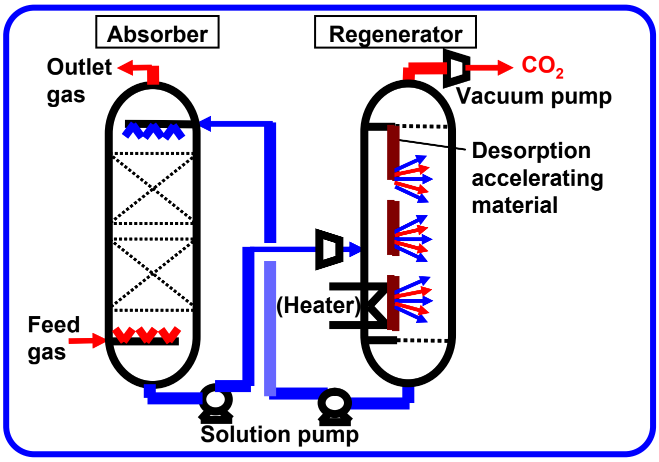


Fig.5 Concept of accelerated regeneration method

CO_2 and H_2 separation with a polymeric membrane

One promising means of lowering the cost of CO_2 separation is the development of new, high-performance CO_2 separation membranes that allow CO_2 recovery via membrane separation.

RITE is currently developing a CO_2 molecular gate membrane with the goal of producing a new, high-performance separation membrane. Figure 6 shows the basic outline of the CO_2 molecular gate function. 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 N_2 or H_2 permeating to the other side of the membrane is greatly limited and high concentrations of CO_2 can be obtained. The membrane of the RITE dendrimer shows excellent CO_2/N_2 selectivity of more than 1000, which would have the potential to replace an amine solution. Furthermore, the dendrimer has the world record for CO_2/H_2 selectivity, 730. The dendrimer membrane can attain a CO_2 separation cost of 1,500 JPY/t-CO_2 or less when the membrane system is used for CO_2 separation from a pressurized gas stream such as the product from a water-gas shift reaction.

In developing this CO_2 molecular gate membrane, RITE conducted joint research with the US Department of Energy's National Energy Technology Laboratory (NETL) as a recognized project of the Carbon Sequestration Leadership Forum (CSLF). Testing of the dendrimer composite membrane developed by RITE was carried out at the NETL (Figure 7).

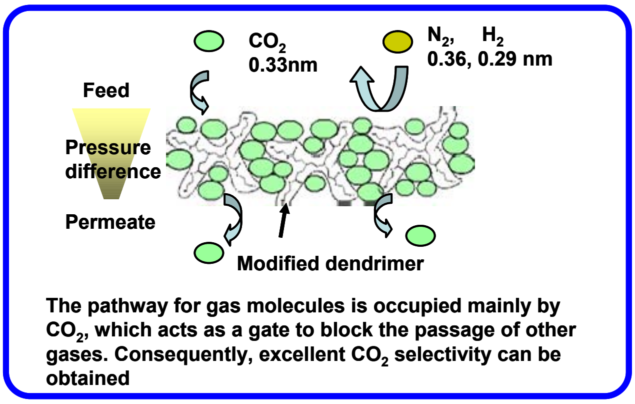


Fig.6 Molecular gate membrane

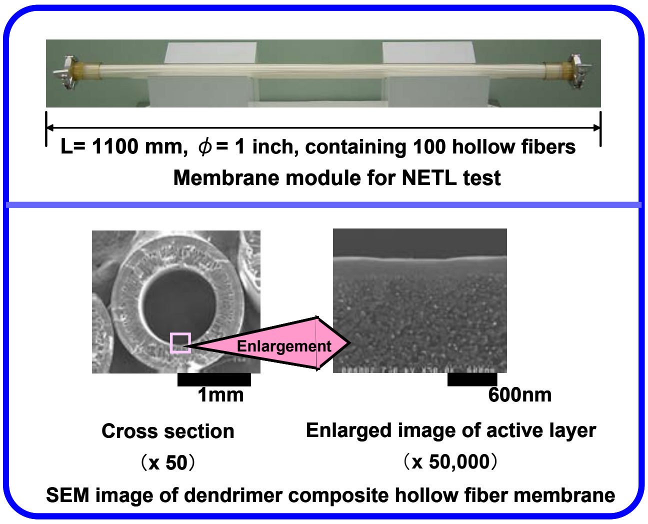


Fig.7 Dendrimer composite membrane module

Development of an inorganic membrane for the catalytic membrane at high temperature

Since zeolite and mesoporous silica possess well-defined micro/meso-pores with low thermal expansion/mobility of the framework, considerable attention has been focused on the production of membranes that are capable of separating gases with high selectivity. Based on the simulation results, we selected some candidate zeolite structures for CO_2-N_2 or CO_2-H_2 separation and have started synthesis of new zeolite membranes. Synthetic conditions for zeolite seed crystals have been studied and, recently, we successfully synthesized a new zeolite seed crystal which had never previously been used for zeolite membrane.

On the other hand, since mesoporous silica has uniform, large pores as well as a high surface area, a variety of guest molecules can be introduced into the pores by reaction with surface OH groups. As shown in Figure 8, a new type of hydrogen separation membrane was prepared by template synthesis of Pd nanoparticles in the pores of mesoporous silica membrane. It was found that dense Pd nanoparticles, of almost equivalent size to the mesopores, were successfully prepared into the pores by impregnation of Pd salt, and that the membrane showed H_2 selectivity from a mixture of H_2 and CO_2. We are now planning: (1) improvement of the performance of the membrane, (2) evaluation of its durability, (3) a larger module production and (4) application of the membrane reactor under changing reaction conditions.

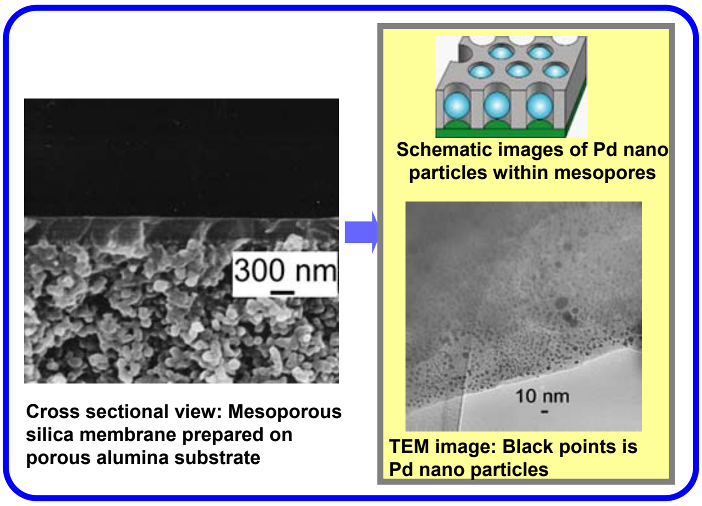


Fig.8 Hydrogen separation membrane with Pd nano particles within mesopores

Plasma PM removal system for diesel vehicles

Recently, emission controls for diesel vehicles have become extremely severe, even though no satisfactory PM removal technologies have been developed yet. Plasma PM removal technology has potential as an innovative technology for the after-treatment of exhaust gases from diesel vehicles. This project is a joint study with Daihatsu Motor Co., Ltd., which is supported by NEDO (Comprehensive Technological Development of Innovative, Next-Generation, Low-Pollution Vehicles, R&D of innovative after-treatment systems). RITE is investigating the mechanisms of plasma discharges and plasma PM oxidation. It is also developing a PM removal system as shown in Fig. 9. A PM removal system with a power supply and a small plasma reactor can be loaded onto a diesel car. This reactor will have a high PM removal ability and low pressure loss.

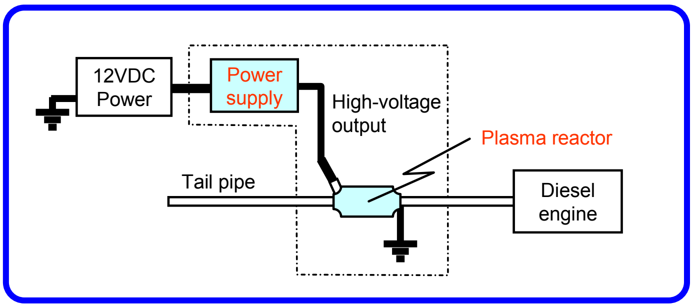


Fig.9 Plasma PM removal system

CO_2 Sequestration Research Group

R&D of CO_2 Geological Storage Project

1. Overview of CO_2 Geological Storage Technology

The CO_2 geological storage technology is to store carbon dioxide (CO_2) in geological formation safely for reducing greenhouse gas emissions. The technologies of Enhances Oil Recovery (EOR), Enhanced Coal Bed Methane recovery (ECBM), injection in oil and gas fields and saline formations are developed for the mitigation of the global worming.

RITE is developing the aquifer storage technology which is possible for long-term stable isolation with cap rock layer. CO_2 aquifer storage is thought to be one of the most effective and practical technology because the knowledge of underground natural gas storage and the experience of EOR are applicable.

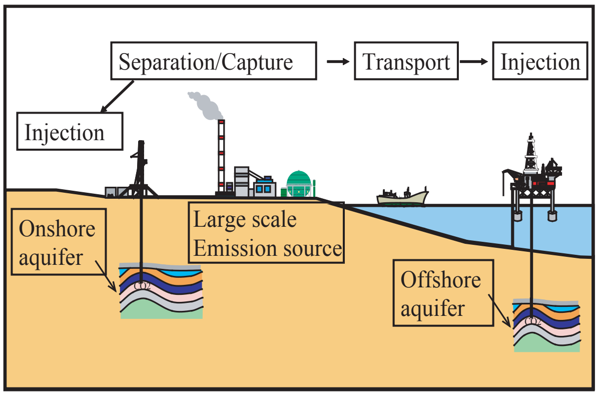


Fig.1 CO_2 geological storage in aquifer

2. Outcome of the recent project

R&D project of CO_2 geological storage technology was launched in 2000 with the support of Ministry Economy Trade Industry. From 2000 to 2004, the possibility of the aquifer storage in Japan was confirmed. Especially the injection experiment in Nagaoka city of Niigata prefecture showed that 10,400 t-CO_2 was able to be stored in a year and half between July 2004 and January 2005. The cross-well seismic tomography, well loggings, measurements of pressure and temperature of reservoir formation, and micro-seismicity monitoring were carried out for developing the simulator of CO_2 behavior. There is not any CO_2 leakage from the reservoir, even when the Nagaoka site was hit on October 23, 2004 by the huge earthquake (M6.8) of which epicenter was about 20km far from the CO_2 injection well. It has been kept to monitor the injected CO_2 for improving the model of CO_2 behavior, until now.

Fig.2 CO_2 injection facilities at Nagaoka site

3.R&D subjects of the project.

The scientific possibility of aquifer storage in Japan has been cleared by the current study. Around same time, the technology of geological storage has been progressed with recognition as mitigation technology in the world. So, the technology verification of CO_2 carbon storage (CCS) should be needed for its implementation. RITE is focusing the studies of total analysis and safty analysis to make the road map of CCS for the large scale CO_2 emission sources.

a.Total analysis

(a) Research on validity

Storage system will be classified in terms of emission source, capture methods, transporting methods, reservoir types and injection methods. Storage potentials, costs, consumed energy and mitigating effects will be analyzed for each classification. A basic scenario plan which will quantitatively explain the validity of aquifer storage in Japan will be made.

(b) Submission of road map for implementation of CCS

Technological issues of CCS implementation in Japan will be summarized, and a first draft of research and development road map which clears milestones of solutions of subjects will be made.

(c) Engineering study for supposed sites

Assumed model areas will be chosen and issues of implementation will be extracted by engineering study including safety and environmental assessment on emission sources, transportation methods, reservoir conditions and storage methods. Solutions for the issues will be proposed.

(d) Storage potential evaluation in Japan

The storage potential of aquifer in Japan will be re-estimated based on the existing data. Locations and types of emission sources will be considered. Issues of the estimation method will be summarized and a new storage model will be proposed.

(e) Survey for implementation and public outreach of CCS

Investigation on political and technical trends of CCS will be carried out including overseas and a framework for public outreach of CCS will prepared. Investigation of implementation will be carried out in terms of operating scheme, legal framework, regulations, overseas business potentials and public outreach.

(f) Investigation on safety and risk

Safety and risk analysis will be carried out and a guideline of safety assessment and environmental assessment will be presented.

b. Safety analysis

(a) Monitoring of Iwanohara site

CO_2 injected at Iwanohara site in Ngaoka will be monitored to improve the simulation model of CO_2 behavior in aquifer for confirming the safety of storage.

(b) Laboratory experiment for basic research

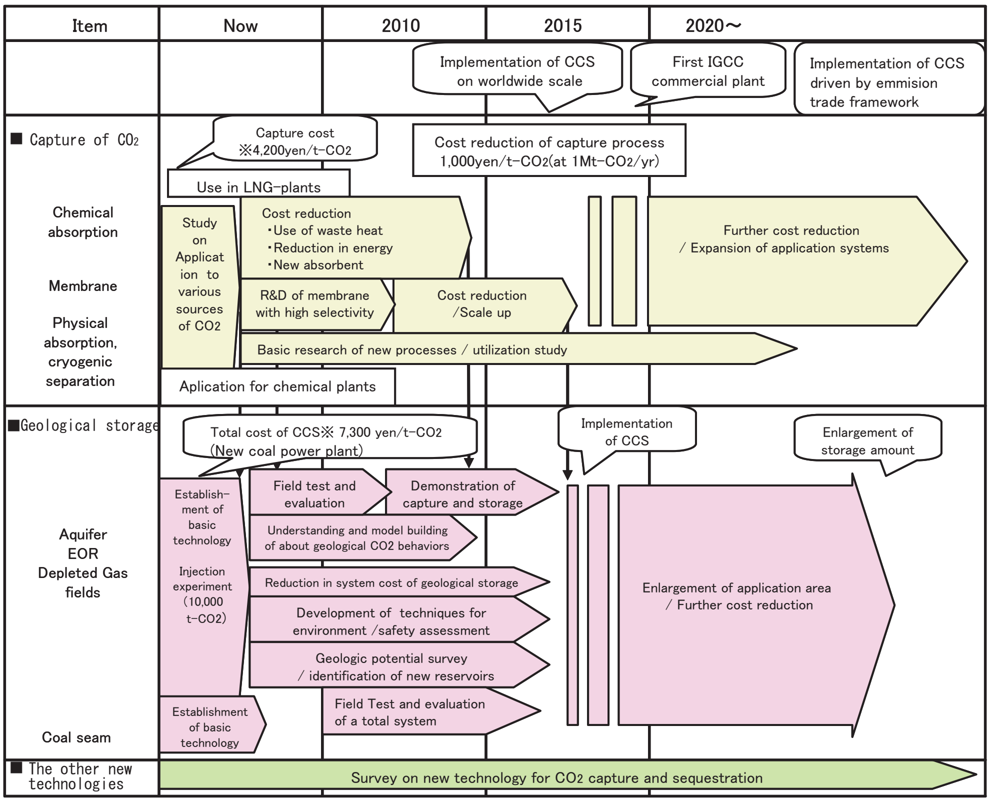
In order to improve the CO_2 behavior model, the following laboratory experiments will be carried out: influence of CO_2 dissolved into water on mechanical stability of cap rock, quantification of mineral dissolution rates under CO_2 presence, mechanisms of super critical CO_2 substitution for saline water in porous media, etc.

(c) Model integration of underground CO_2 behavior

Based on data and knowledge of the monitoring at Iwanohara and the laboratory experiments, CO_2 behavior in aquifer for a short and long period will be scientifically summarized. The improved model will be presented for safety confirmation.

4.Future of the project

It is scheduled as shown in Fig3 that total analysis and safety analysis of CO_2 geological storage project will be summarized for the future implementation of CCS in Japan in accordance with the R&D of CO_2 capture technology. A workshop entitled "International Workshop on CO_2 Geological Storage , Japan '06" was held on February 20, 21, 2006 at the Toranomon Pastoral Hotel Tokyo Japan. This workshop provided the research result of the Nagaoka Project including overseas CCS trend information and the next step of the project. See details in the page 18 of this report.



※Capture: New PC(830MW),Amount of CCS:1Mt-CO2/yr, compression:7MPa, Steam extracts from steam cycle of power plant
※Geological storage :Cost of CO2 capture & pipeline transport 20km & injection (compression:10Mpa 0.1Mt-CO2/yr/well)

Fig.3 Road map of CCS in Japan

R&D of CO_2 Ocean Sequestration Project

1.Overview of CO_2 Ocean sequestration technology

Increasing of atmospheric CO_2 is one of the factors of global warming. This is the result of imbalance between the dissolution of atmospheric CO_2 in the ocean and the emission of anthropogenic CO_2, mainly due to the combustion of a fossil fuel. This imbalance is also due to the long time scale requires for the absorption of atmospheric CO_2 in the ocean in contrast with the rapid increase of emissions. However, there is a sufficient potentiality to dissolve anthropogenic CO_2 in the middle and deep layers of the ocean. Therefore, a bypass technology of direct injection of atmospheric CO_2, captured from high emissions, into the deep ocean was proposed. The main objection for the utilization of this technology is the resulting biological impacts when the initial concentration of injected CO_2 is high. From the viewpoint of suppressing environmental impact to the minimum extent, RITE is developing a dilution & injection technology to the middle and deep ocean layer using "Moving Ship" approach, as shown in Fig. 1.

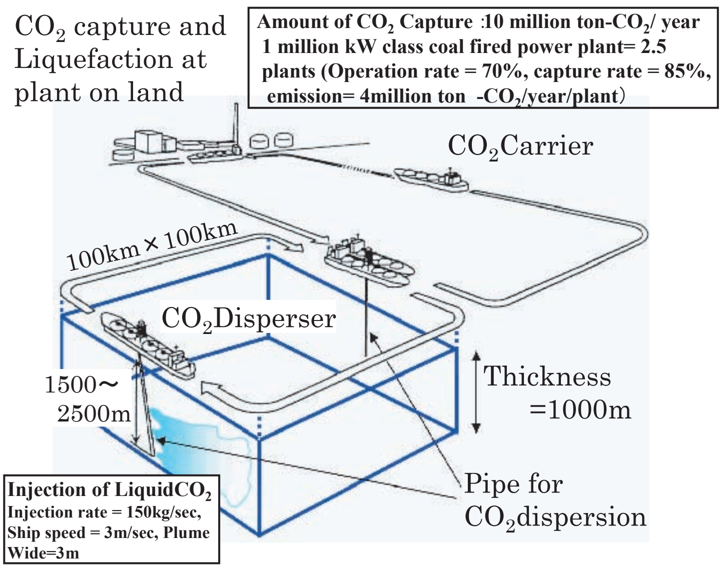


Fig.1 Image of operation for ocean sequestration by Moving ship

2. Purpose of R&D

In order to implement the anthropogenic CO_2 sequestration into the ocean as a practical used technology, it is important a prior understanding of the environmental impacts, especially onto the biosphere, to prevent possible damages caused by the application of this new technology. Therefore CO_2 sequestration technology can be clearly understand with a wide social receptiveness among the international frameworks, such as Framework Convention on Climate Change (FCCC) and Convention on the Prevention and of Marine Pollution by Dumping of Wastes and other Matter (London Convention, LC). This project is being carried out with the purpose of clarifying these subjects towards the utilization of CO_2 ocean sequestration. In addition, during the phase 1, carried out from FY1997 to FY2001, macroscopic CO_2 action grasp in the adjacent seas of Japan, including predictions and investigations of environmental effects, mainly on the biota, produced by the nozzle back discharge of CO_2, were conducted. Followings are the aims of the present projects as the phase 2 which is carried out from FY2002 to FY2006.

a. Technology assessment of CO_2 ocean sequestration
- (a) Technical evaluation of CO_2 sequestration capacity
- (b) Economic evaluation of the CO_2 sequestration
- (c) Investigation on the legal issue related to international laws

b. Development of assessment technology for CO_2 environmental impact
- (a) Investigation of marine environment
- (b) Understanding of deep-sea ecosystem
- (c) Investigation of biological impact
- (d) Development of Biological impact model

c. Development of CO_2 dilution technology
- (a) Development of CO_2 injection technology
- (b) Improvement of the simulation model of CO_2 behavior

3. Present state of the project

The phase 2 of this project started from the FY2002, and now it is the 5th year. A interim assessment of this project was carried out by the subcommittee of METI in the FY2004. As the result, the following comments and advices have been reported. "Ocean sequestration technology is an effective measure for the mitigation of global warming. However, the environmental impact assessment is an important task. Public relation, especially for oversea, international collaboration, and so on should be carried out actively." So, RITE is enhancing public outreach (PO) and the corporation with research institute of overseas, though RITE has already succeed to organize the international work shop on "Advances in Biological Research for CO_2 Ocean Sequestration" in 2003. From FY2004, the collaboration of carbon dioxide impact on marine ecosystem has been carried out with the Norwegian Institute for Water Research (NIVA) in which an experiment was carried out in a fjord of Norway in 2005 and its results will be reported in 2007. In order to promote PO actions, the special symposium of Japan Ocean Society "CO_2 ocean sequestration: what is the appropriate assessment for the environmental impact" was carried out in 2006. Moreover, in order to make clear the image of ocean sequestration, the engineering study of its implementation under the case which is the ocean sequestration of about 50 million tons of CO_2 annually into the ocean near Japan, was carried out and its biological impact is evaluated.

4. Future of the Project

Development of a CO_2 dilution technology and environmental-impact-assessment technology is progressing using laboratory experiments, field observations and numerical simulations. For an effective utilization of the ocean sequestration technology, it is necessary to prove the developed technology using field experiments in the ocean. Finally, it is necessary to trace the CO_2 behavior in several 100 km scale, and to investigate the biological impact. Therefore, field experiments covering a wide range of scale from small-scale to a real scale is desired in the next step of this project. For the final purpose, it is necessary to promote the understanding ocean sequestration in academia and obtain the agreement to the implementation of ocean sequestration in the arena of LC and other international ocean regulation, because the ocean is a human common property and the implementation of CO_2 ocean sequestration needs to build up an international consensus.

Plant Research Group

Carbon-sequestration with the use of Plants and Trees

Ambient partial pressure of CO_2 (370 ppm), which is one of the main factors causing the global warming, is expected to reach its value of 1,000 ppm on A.D. 2100. IPCC set its value to 550 ppm, about half 1,000 ppm, which shows the necessity of carbon-sequestration management at the world-wide level. Now, techniques for carbon-sequestration are developed from the two aspects: CO_2-emission suppression and CO_2-fixation enhancement. CO_2-emission suppression includes the usage of alternative energy to fossil resource energy: sun, atomic, terrestrial heat etc. In addition, the utilization of biomass energy (bioenergy) is developed. As for CO_2-fixation enhancement, geological and ocean sequestrations techniques are developed, which are non-biological approaches. Contrary to these techniques, biological sequestration technique, afforestation and the expansion of its area are developed.

We, in Plant Research Group, develop the techniques for both CO_2-fixation enhancement (carbon stock formation) and CO_2-emission suppression (alternative energy formation), that is, large scale afforestation and bioenergy usage (Figure 1). In large scale afforestation, we improve trait of plants and trees, where growth and abiotic tolerance are stimulated, using molecular biological techniques with the useful genes (afforestation project and frontier soil project). These projects contribute to the enhancement of CO_2-sequestration through the formation of carbon stock. Furthermore, we develop the improvement of plants to have the ability to produce factorial materials in chloroplasts (factorial plants project). This project contributes to CO_2-emission suppression through the production of alternative energy. As follows, we report the works of three projects.

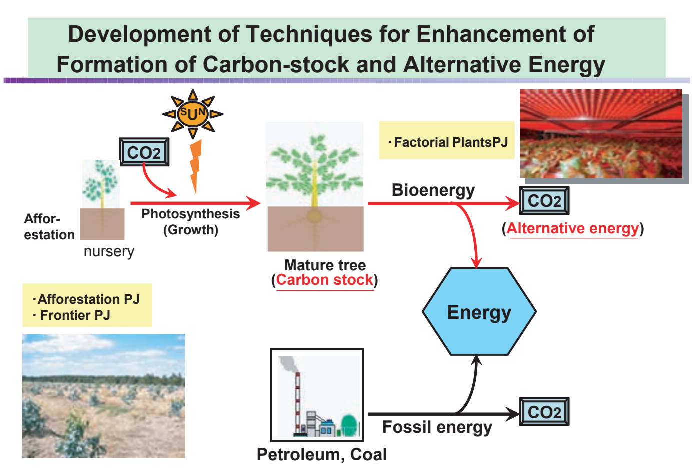


Figure 1

Afforestation Project

The purpose of this project is to develop the fundamental technologies to allow for afforestation in unsuitable area for vegetation, such as semi-arid area, to reduce atmospheric CO_2. We carry out the project in collaboration with paper companies and universities. (This project is supported by METI from FY2003 to FY2007.)

In this project, we try to develop two main techniques; (1) A technique to enhance the ability of photosynthetic CO_2 fixation or, to confer the abiotic stress tolerance on woody plants, such as Eucalyptus and Populus by genetic modification, (2) A technique to isolate the elite trees from Eucalyptus, those have superior ability of growth and stress tolerance, and produce the cloned cell lines of the elite trees.

Under combined stress with strong light and drought in semi-arid area, plants close their stomata to avoid the loss of water by transpiration. However, the close of stomata leads to decrease CO_2 influx to chloroplasts, and decline in the rate of photosynthesis. As the result, absorbed photon energy, which is usually consumed by photosynthesis, becomes excess, and the excess photon energy stimulates the production of reactive oxygen species (ROS) by reduction of dioxygen in chloroplasts. Furthermore, ROS induces oxidative damage, i.e. "sunburn", to cellular components of plants.

RITE develops the fundamental technology for suppression of ROS production and rapid elimination of produced ROS in chloroplast by genetic modification with Arabidopsis and tobacco as model plants. By overexpression of ferredoxin gene in chloroplasts of tobacco plants, RITE has succeeded to stimulate activity of cyclic electron flow around photosystem I and to enhance the ability of heat dissipation process, in which excess photon energy is consumed as heat, in transplastomic plants (Figure 2).

In future, the application of our techniques will produce drought tolerant transgenic woody plants, and they will contribute to the afforestation in semi-arid area.

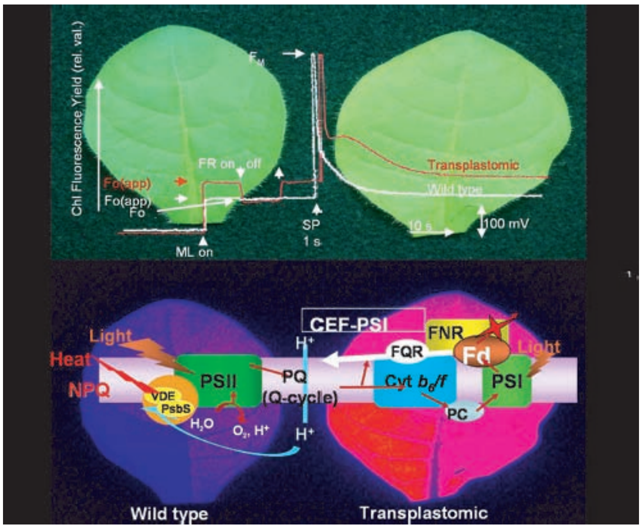


Figure 2

Frontier Soil Project

In semi-dry areas, soils are poor in nutrients and water. In cooperation with Saitama University, Kohchi University, the General Environmental Technos Co. Ltd., and Forest Products Commission in Australia, we tackle the development of a soil-improving technology using microbes and plants (Figure 3). We try to improve soils with nutrients provided from mycorrhizal fungi and nitrogen-fixing microbes including cyanobacteria and root-nodule bacteria symbiotically alive in Acacia roots. Frontier project is developing a cyanobacteria having high nitrogen-fixation capacity by a genetically engineering technique, and also searching for a mycorrhizal fungi having high absorption capacity of phosphate ions. Moringa oleifera, which survives in semi-dry areas, has water storage roots. We also evaluate the water storage capacity in the soils. Based on searching for useful microbes and useful plants and improving those physiological functions by a genetically engineering technique, our goal is applying this technology to afforestation in semi-dry areas.

Fundamental Technology for Controlling the Material Production Process of Plant Chloroplasts (Factorial Plants Project)

The development of bioprocess represents an important issue in the creation of a fossil resource-independent recycling-oriented society. To address this issue, it is necessary to develop fundamental technology for the production of industrial materials or other useful substances in plants. Gene-recombination technology succeeded in conferring resistance to herbicide or insect on transgenic plants. The purpose of this project is to improve the basic technology to produce the industrial material by functions of substance production in plants.

Photosynthetic organella, chloroplast converts CO_2 to various substances such as sugars, lipids and amino acids etc. by using light energy. We are engaged in the analysis and control of material production processes in chloroplast by using already established chloroplast transformation technology (Figure 4). The integration of transgene into chloroplast genome offers an advantage that transgene flow via pollen is absent due to maternal inheritance of the chloroplast genome.

Since plants have their own metabolic control systems, it is necessary to identify the substance production processes and to regulate key metabolic pathway. We demonstrated the enhanced productivity of isoprenoid that is of industrial importance as additives, organic materials, vitamins and ingredients in medicine by engineering chloroplast metabolic pathway. Based on the results of the analysis of the transgenic plants, we will identify a rate-controlling step in chloroplast metabolism. For the purpose of improving the chloroplast transformation technology, we will develop an artificial system that regulates the level and tissue of transgene expression.

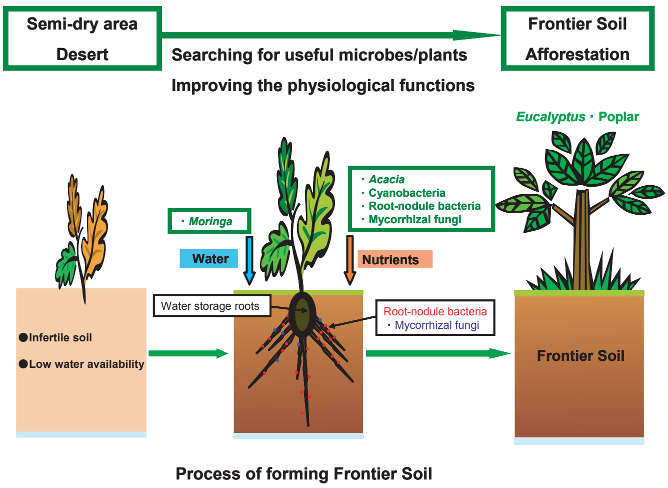


Figure 3

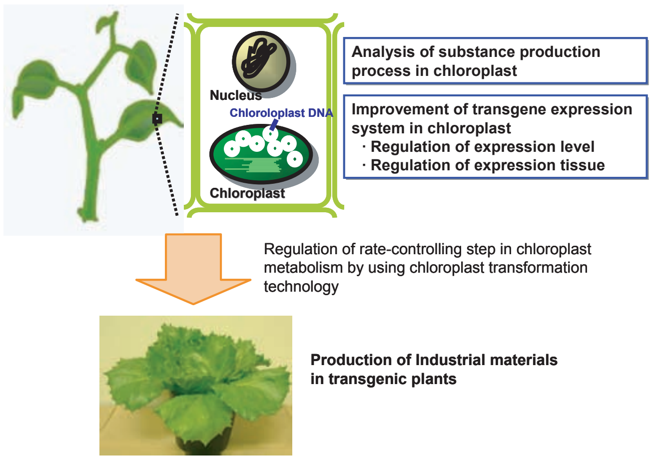


Figure 4

Microbiology Research Group

Development of biorefinery technology -Utilizing microbiological functions-

1. Introduction

Two years after Kyoto treaty had come into force, there is a need for further act against the climate change. The crude oil price recorded the highest last summer resulting in the sharp increase in the prices of petroleum-based fuels and chemicals, and this phenomenon had significant effect on our society. Despite the lowered crude oil price (<$60) this year, there is no future in the industry which consumes large amount of resources, hence there is a growing expectation on corporations as well as on society to switch to using renewable resources. The Prime Minister Abe had instructed to increase the bioethanol usage last November and there is a plan to supply 10% of nation's petrol consumption with bioethanol. As bioethanol is renewable and carbon neutral, there is no theoretical increase in CO_2 resulting from any bioethanol usage. The assignment for all the nations including developing countries is to develop an economic way to incorporate biomass cultivation, biofuels and biochemicals into the sustainable society.

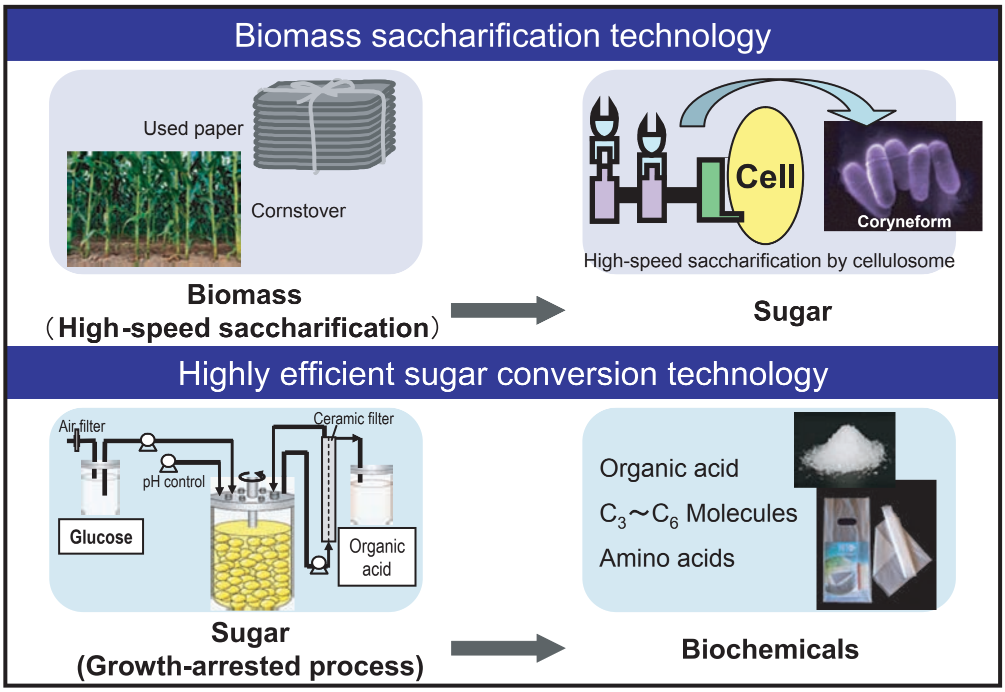
2. Biomass utilizing technology –world trend

In the USA, the government has been actively supporting the development of technology based on biomass resource usage. Unlike in the oil crisis time, there is a new concept of "biorefinery" in addition to the search for the alternative to fossil fuel and the companies are actively involved in the technological development. This is due to the expectation on the newly formed market with novel technological foundation. Moreover, there is a national strategy to become independent of the foreign supply of transportation fuel by producing bioethanol. In the state of the union speech this year, the president Bush announced his plan to supply 35×103 million gallon of renewable and alternative fuels, which is five times that proposed by existing plan, by 2017. This amount is 15% of the predicted gasoline consumption in 2017 and includes butanol and hydrogen in addition to ethanol. The EU is also aiming to introduce biofuels in their action plan and intends to supply 5.75% of transportation fuel with biofuels (mainly biodiesel fuel, BDF) by the end of 2010. In the case of biorefinery, there are constructive research and developments including use of cellulosic biomass. However, in order to achieve the practical application, it is necessary to establish bioprocess, by which the biomass is efficiently converted, hence each nation is competing in the technological development.

3. Technological development of biorefinery (in RITE)

As a consignment of NEDO, "Biorefinery research and development" project started in Japan last year. In RITE Microbiology Research Group, research has been carried out with "growth-arrested bioprocess", which is a novel and highly efficient technology, as a core technology. We are aiming to produce C3-C6 organic acids and amino acids from soft-biomass such as cornstover and used paper (http://www.nedo.go.jp/). Unlike the conventional bioprocesses of which production processes are dependent on the microbial growth, "growth-arrested bioprocess" utilizes artificially growth arrested microorganisms as catalyst to produce chemicals. By this method, the problem of low productivity (STY: Space Time Yield) associated with conventional processes has been solved and, by the continuous reaction, the productivity similar to the chemical process was made possible. With the post-genome technology, which analyzes all the gene, protein expression and function in the cell using the genome information, corynebacteria with improved production ability have been devel-

Biorefinery Technology



oped. The establishment of the "growth-arrested bioprocess" is predicted to be a key to the application of "biorefinery" in Japan.

4. Cooperation with industries

In the Microbiology Research Group, we have been conducting a collaborative R&D with industries using "growth-arrested bioprocess" as a core technology. As discussed above, bioethanol produced from biomass has been in the center of attention as a basis of energy security and transportation fuel which is effective in tackling the global warming. Owing to this fact, there is a heated research competition mainly in the U.S.A. to reduce the cost of production process. In our group, we have established the technology to produce alcoholic fuels from cellulose contained in soft-biomass not suitable for human consumption, such as cornstover and rice straw, and have moved forward to achieving the practical application. In our process, it is possible to significantly reduce the effect of fermentation inhibitors and we are carrying out R&D along with the car manufacturing company (Honda) for the practical application.

5. Future development

There is a heated competition among the nations to achieve the early practical application of biorefinery using the post-genome technology. Therefore we will devote ourselves to achieving practical application of our novel "growth-arrested bioprocess". Moreover, to accomplish the practical application of organic acid production, including succinate, we have started developing the continuous production system with the industry. We are also carrying out the primary R&D for biomass-derived hydrogen production in collaboration with electronics companies. In order to implement our bioprocess to produce wider variety of chemicals and energy, we are planning to collaborate with industries in R&D in the future.

Innovative membrane technologies in GCEP

Chemical Research Group

GCEP Global Climate & Energy Project STANFORD UNIVERSITY

RITE has received an award for developing "Sub-Nano Structure Controlled Materials: Development of Innovative Gas Separation Membranes" from the GCEP (Global Climate and Energy Project) of Stanford University, USA. In this project, synergism of research into both carbon and inorganic materials will lead to innovative materials for gas separation membranes.

Carbon membrane

In the organic materials approach, sub-nanostructure controlled carbon membranes are now under research. Conventional carbon membranes use molecular sieving of gases with different molecular diameters to get good gas selectivity.

RITE's novel carbon membrane is a thin layer of microporous carbon deposited on a porous alumina tube. Figure 1 shows the basic outline of RITE's novel carbon membrane. In the figure, micropores obtain a molecular gate function by modification of pore surfaces or insertion of dendrimers. The CO_2 molecules occupying the pores work to block the passage of other gases. Consequently, excellent CO_2 selectivity is obtained with the carbon membrane.

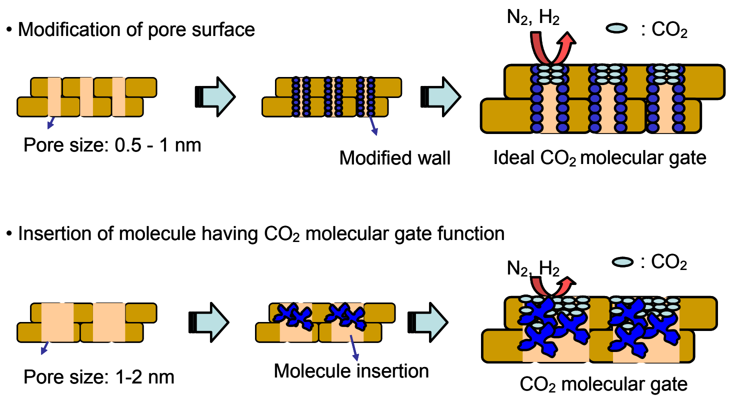


Fig.1 Modification of pore property for high CO_2 affinity in carbon membrane

Inorganic membrane (zeolite membrane)

We are now investigating an optimum zeolite structure and preparation of a grain-boundary/pinhole free zeolite membrane by molecular simulation. Based on the simulation results, we have selected some new candidate zeolite structures for CO_2-N_2 or CO_2-H_2 separation and have started synthesis of a new zeolite membrane. Synthetic conditions for zeolite seed crystals have been studied and, recently, we have successfully synthesized a new zeolite seed crystal which has never previously been used for a zeolite membrane. In addition, as shown in Figure 2, a new preparation method for zeolite membrane for growing zeolite crystals inside the pores of porous alumina substrate has been proposed.

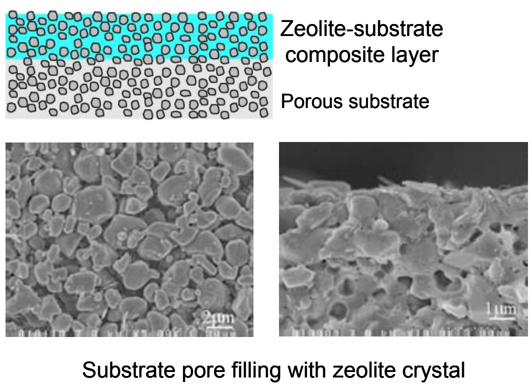
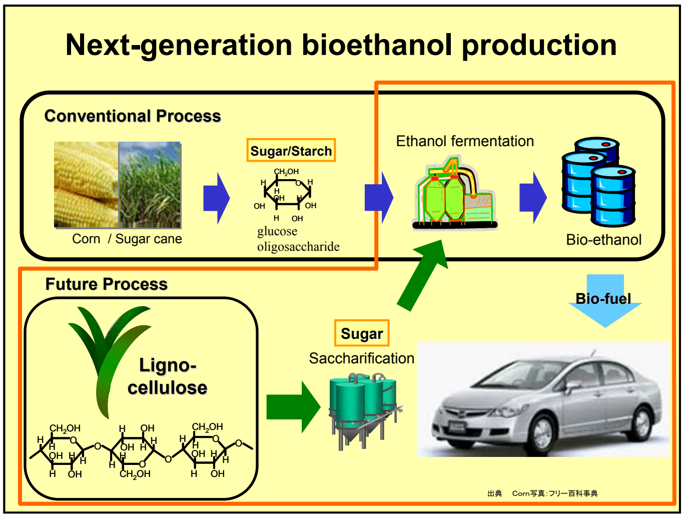


Fig.2 New preparation method for zeolite membrane

Collaborative R&D in Bioethanol production

Microbiology Research Group

As a part of our project to produce valuable substances from biomass in the Microbiology Research Group, we are carrying out R&D to produce bioethanol with industries. In the conventional bioethanol production, food part of sugarcane and corn are used. However, in our new process, ethanol is produced from non-food parts such as leaves and stems. The non-food part is called lignocellulose and those are hydrolyzed to glucose before converted into ethanol. In the pre-treatment process to hydrolyze lignocellulose to glucose, fermentation inhibitors are also produced and the activities of microorganisms, such as yeast used in the conventional application, are inhibited. On the contrary, fermentation inhibitors were found not to have significant effect on the corynebacteria used in our group as these are used in growth arrested state. In our group, we are planning to build a pilot plant with a car manufacturing company(Honda) to examine our novel process.



Commentary published in Nature Biotechnology

Microbiology Research Group

In the Microbiology Research Group, we are carrying out R&D to produce valuable substances from biomass (biorefinery). Biorefinery, which converts renewable biomass to fuel and chemicals, has been attracting attention as a fossil fuel-independent alternative to petroleum-based processes. Recently, our commentary from the global point of view on the way towards realization of biorefinery and the problems foreseen to encounter during the process to shift from fossil fuels was published in Nature Biotechnology (2006,Vol.24, No7, 761-764).

International Workshop on CO_2 Geological Storage, Japan '06

CO_2 Sequestration Research Group

A workshop entitled "International Workshop on CO_2 Geological Storage , Japan '06" was held on February 20, 21, 2006 at the Toranomon Pastoral Hotel Tokyo Japan.

This workshop was hosted by RITE as a part of CO_2 Geological Storage Research Project for the confidence building in Japan. Approximately 300 attendants for 2 days including 20 from overseas and also mainly from private sectors and research organizations listened to the presentations eagerly. Also NGO ,NPO persons joined the workshop. This workshop provided the research result of the Nagaoka Project including overseas CCS trend information and useful discussion about CCS.

2007 RITE International Symposium

-Technologies for mitigating global warming and the role of Japan-

Planning, Survey and Public Relations Group

The symposium entitled "2007 RITE International Symposium – Technologies for mitigating global warming and the role of Japan –" was held on 18 January 2007, at the Shinagawa Intercity Hall.

This symposium was organized by RITE (Research Institute of Innovative Technology for the Earth), co-organized by NEDO (New Energy and Industrial Technology Development Organization), and supported by METI (Ministry of Economy, Trade and Industry), SCEJ (The Society of Chemical Engineers,Japan), JSER (Japan Society of Energy and Resources), JIE (The Japan Institute of Energy), and JSBBA (Japan Society for Bioscience, Biotechnology, and Agrochemistry).

As the keynote speaker, Dr. Levine of Lawrence Berkeley National Laboratory outlined the energy and climate change issues. As the representatives of Japanese industrial sector, Mr. Furuno of Toyota Motor Corporation and Mr. Ono of Nippon Steel Corporation presented their challenges for the GHG reduction. In the afternoon session, Dr. Metting of Pacific Northwest National Laboratory presented an overview on the biofuel technologies in the US and Dr. Yukawa of RITE highlighted the R&D of RITE in this field. Regarding CO_2 geological storage, Mr. Kaarstad of Statoil spoke about the current activities and future potential and Dr. Ohsumi of RITE presented Japanese achievement. The symposium closed with the speech by Dr. Kaya of RITE and he provided his insight into the Japan's strategy for mitigating climate change.

Systems Analysis Group

■2006 Paper

	Title	Researchers	Journal
1	Analysis of Technological Portfolios for CO_2 Stabilizations and Effects of Technological Changes	F. Sano, K. Akimoto T. Homma, T. Tomoda	The Energy Journal
2	Development of a multi-regional and multi-sectoral energy-economic model and assessment of the global warming mitigation policy	T. Homma, S. Mori K. Akimoto, T. Tomoda	The Energy Journal (International association for energy economics)
3	Integrated Assessment of global Warming Issues and an Overview of Project PHOENIX - A Comprehensive Approach	S. Mori, K. Akimoto, T. Homma F. Sano, J. Oda A. Hayashi, K. Dowaki, T. Tomoda	IEEJ Transactions of Electrical & Electronic Engineering
4	Economic Evaluation of the Geological Storage of CO_2 Considering the Scale of Economy	K. Akimoto, M. Takagi T. Tomoda	International Journal of Greenhouse Gas Control
5	Public Perceptions on the Acceptance of Geological Storage of Carbon Dioxide and Information Influencing the Acceptance	K. Tokushige, K. Akimoto T. Tomoda	International Journal of Greenhouse Gas Control
6	Evaluation of Energy Saving and CO_2 Emission Reduction Technologies in Energy Supply and End-use Sectors Using a Global Energy Model	J. Oda, K. Akimoto F. Sano, T. Homma T. Tomoda	IEEJ Transactions of Electrical & Electronic Engineering
7	Diffusion of Energy Efficient Technologies and CO_2 Emission Reductions in Iron and Steel Sector	J. Oda, K. Akimoto F. Sano, T. Tomoda	Energy Economics

■2006 Oral Presentaion

	Title	Researchers	Forum
1	An Integrated Assessment of Global Warming-Project Phoenix	S. Mori, K. Akimoto, F. Sano A. Hayashi, T. Homma J. Oda, T. Tomoda	22th Conference on Energy System, Economy and Environment 26-27, January, 2006
2	Current Status of Legal Aspects on CO_2 Gelogical Storage	K. Tokushige, T. Ohsumi	22th Conference on Energy System, Economy and Environment 26-27, January, 2006
3	Evaluation of technological options for mitigating climate change in paper & pulp industrial sector with a world energy system model	F. Sano, K. Akimoto J. Oda, T. Homma T. Tomoda	22th Conference on Energy System, Economy and Environment 26, January, 2006
4	Evaluation of Global Impact on Agriculture under Several GHG Emission Scenarios	K. Akimoto, F. Sano S. Mori, T.Tomoda	22th Conference on Energy System, Economy and Environment 26-27, January, 2006
5	Cost Analysis of CO_2 Geological Storage in Japan	K. Akimoto, T. Ohsumi	22th Conference of Energy System, Economy and Environment 26-27, January, 2006
6	Effects of Transfer and Diffusion of Energy Efficient Technologies in Industrial Sectors on CO_2 Emission Reduction	K. Akimoto	The Workshop on Globalization, Technology Transfer, and Energy-Efficiency of Energy Intensive Industries in Asia (START, UNU, IHDP) 12-13, January, 2006
7	Evaluations of Global Warming Mitigation Policy Using a Multi-sectoral and Multi-regional Energy-economic Model	T. Homma, S. Mori K. Akimoto, T.Tomoda	22th Conference on Energy System, Economy and Environment 26-27, January, 2006
8	Evaluations of Technological Options for Mitigating Climate Change in Iron & Steel Sector with a World Energy System Model	J. Oda, K. Akimoto F. Sano, T. Homma T. Tomoda	22th Conference on Energy System, Economy and Environment 26, January, 2006
9	Long-term Traget of GWM and Integrated Assessment	T. Tomoda	3rd International Workshop on Integrated Climate Models: An interdisciplinary assessment of climate impacts and policies 12-13, January, 2006
10	Evaluation of Global Warming Impact on Human Health	A. Hayashi, K. Akimoto, F. Sano S. Mori and T. Tomoda	25th Meeting on Energy and Resources 9, June, 2006
11	Economic Evaluation for CO_2 Geological Storage Considering the Scale of Economy	K. Akimoto, M. Takagi Y. Hirota, T. Ohsumi Y. Mizuno, T. Tomoda	8th International Conference on Greenhouse Gas Control Technologies 20, June, 2006
12	Public perceptions on the acceptance of CO_2 geological storage and the valuable information for the acceptance	K. Tokushige, K. Akimoto T. Tomoda	8th International Conference on Greenhouse Gas Control Technologies 19-22, June, 2006
13	Contribution to Climate Change by Region and Brazil Proposal (3)	A. Kurosawa, T. Tomoda	Annual Meeting on Environmnet and Economy Policy Society (2006) 4-7, July, 2006
14	Evaluation of Global Warming Mitigation Technology in Consideration of ITAcceleration	T. Homma, S. Mori, K. Akimoto T. Tomoda	25th Meeting on Energy and Resources 9-10, June, 2006
15	Evaluation of Global Warming Mitigation Policies with a Dynamic World Energy-economic Model Considering Changes in Industrial Structures by IT Penetration	T. Homma, S. Mori K. Akimoto, T. Tomoda	9th Annual Conference on Global Economic Analysis (GTAP 2006 conference) 15-17, June, 2006

	Title	Researchers	Forum
16	Evaluation of global warming mitigation policies considering changes in industrial structures and IT penetration	T. Homma, S. Mori K. Akimoto, Y. Murota T. Tomoda	Intermediate Input-Output Meetings 2006 on Sustainability, Trade & Productivity (IIOA 2006 conference) 26-28, July, 2006
17	An impact analysis on greenhouse gases including an effect of non-CO_2 emissions.	K. Dowaki, K. Akimoto F. Sano, T. Tomoda S. Mori	Operation Research Society 6, September, 2006
18	International Cooperation on Technology-oriented Measures for Global Warming and Effect of CO_2 Emission Reduction	K. Akimoto	Symposium on Innovative Environment Technology (RITE) 5, October, 2006 (Osaka) 18, October, 2006 (Tokyo)
19	Transition to LCS: effects of technology diffusions in both energy supply side and demand side	K. Akimoto	The Annual Energy Modelling Conference of the UKERC 6, December, 2006
20	Integrated Assessment PHOENIX - Land-use Modeling and Global Warming Impacts on Agriculture -	K. Akimoto, S. Mori T. Tomoda	Energy Modeling Forum (EMF) 22: Climate Policy Scenarios for Stabilization and In Transition, 14, December, 2006
21	Which is more effective, the setting-up of a series of short-term targets or a long-term target of emission reductions?	K. Akimoto	Japan/US Workshop on Technology Development and Policy 17, October, 2006
22	Evaluations of Technological Options for Mitigating Climate Change in Steel and Cement Sectors with a World Energy Systems Model	J. Oda, K. Akimoto F. Sano, T. Homma T. Tomoda	25th Meeting on Energy and Resources 9, June, 2006

■2006 Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Economic Developments of China and India and their Impacts on Global Energy and CO_2 Emission	S. Mori, T. Homma and Y. Murota	Weekly Economist
2	CO_2 Storage for Global Warming Mitigation (Chapter 1)	K. Akimoto	Illustrative Introduction to CO_2 Storage

Chemical Research Group

■2006 Original Paper

	Title	Researchers	Journal
1	CO_2 separation by membrane/absorption hybrid method	K. Okabe, M. Nakamura , H. Mano M. Teramoto, K. Yamada	Studies in Surface Science and Catalysis, 159 409-412 (2006)
2	Uneven dielectric barrier discharge reactors for diesel particulate matter removal	S. Yao, C. Fushimi, K. Madokoro K. Yamada	Plasma Chemistry and Plasma Processing, (26) 481-493 (2006)
3	A Novel High-Voltage Power Generator for Diesel Exhaust Gas Treatment	M. Okumoto, S. Yao, K. Madokoro E. Suzuki, T. Yashima	Recent Advances in Multidisciplinary Applied Physics, 291-295(2006) Elsevier
4	Diagnostics of a Pulsed Plasma Discharge	S. Yao, M. Okumoto , T. Yashima E. Suzuki	Recent Advances in Multidisciplinary Applied Physics, 313-317(2006) Elsevier
5	Development of PAMAM Dendrimer Composite Membrane for CO_2 Separation	S. Duan, T. Kouketsu, S. Kazama K. Yamada	J. Membrane Sci, 283 2-6 (2006)

■2006 Oral Presentation

	Title	Researchers	Forum
1	Development of PAMAM Dendrimer Composite Membrane for CO_2 Separation	T. Kai, S. Duan, T. Kouketsu S. Matsui, S. Kazama, K. Yamada	North American Membrane Society (NAMS) 17th Annual Meeting, Chicago 17 May 2006
2	Novel Absorbents for CO_2 Capture from gas stream	K. Goto	9th International CO_2 Capture Network, Copenhagen 16 June 2006
3	Separation and recovery of CO_2 by membrane/absorption hybrid method	H. Mano, K. Okabe, M. Nakamura M. Teramoto, K. Yamada	GHGT-8, Trondheim 20 June 2006
4	Novel Absorbents for CO_2 Capture from gas stream	S. Shimizu, M. Onoda, K. Goto K. Yamada, T. Mimura	GHGT-8, Trondheim 20 June 2006
5	Molecular gate functionalized dendrimer membrane for CO_2 capture	S. Kazama, T. kai, T. Kouketsu S. Duan, F.A. Chowdhury K. Yamada	GHGT-8, Trondheim 21 June 2006
6	Design and Evaluation of a New CO_2 Fixation Process Using Alkaline-earth Metal Wastes	S. Kodama, K. Yogo, K. Yamada T.Nishimoto	GHGT-8, Trondheim 21 June 2006
7	Preparation and CO_2 separation properties of amine modified mesoporous silica membrane	Y. Sakamoto, K. Yogo, K. Yamada K. Nagata	Symposium on Zeolites and Microporous Crystals, Yonago 1 August 2006
8	Development of PAMAM Dendrimer Composite Membrane for CO_2 Separation	S. Duan, T. Kouketsu, T. Kai S. Matsui, S. Kazama, Y. Fujioka K. Yamada	3rd Conference of Aseanian Membrane Society, Beijing 25 August 2006
9	Regeneration of CO_2 absorbent solution by accelerated desorption method	K. Okabe, H. Mano, K. Yamada	17th International Congress of Chemical and Process Engineering, Prague 29 August 2006
10	Evaluation of an uneven dielectric barrier discharge reactor for particulate matter removal from a diesel engine	C. Fushimi, K. Madokoro, S. Yao K. Yamada	11th Asian Pacific Confederation of Chemical Engineering(APCChE), Kuala Lumpur August 2006
11	Development of Innovative Gas Separation Membranes through Sub-Nanoscale Materials Control	Y. Fujioka	GCEP Research Symposium, Pittsburgh 20 September 2006
12	Development of Innovative Gas Separation Membranes through Sub-Nanoscale Materials Control	S. Kazama, T. Kai, N. Yamamoto K. Uoe, K. Yogo, Y. Fujioka K. Yamada	GCEP Research Symposium, Pittsburgh 20 September 2006 (Poster)
13	Experimental Investigation of a Molecular Gate Membrane for Separation of Carbon Dioxide from Flue Gas	S. Kazama, T. Kai, T. Kouketsu S. Matsui, K. Yamada J.S. Hoffman, H.W. Pennline	Pittsburgh Coal Conference 27 September 2006
14	Characterization of a non-thermal plasma system at atmospheric pressure	S. Yao, C. Fushimi, K. Madokoro Y. Fujioka	48th Annual Meeting of the Division of Plasma Physics, Philadelphia 1 November 2006

CO_2 Sequestration Research Group

■2006 Original Paper［CO_2 Geological Storage Project］

	Title	Researchers	Journal
1	Seismic monitering and modelling of supercritical CO_2 injection into a water–saturated sandstone:interpretation of P–wave velocity data	Ji–Quan Shi, Ziqiu Xue Sevjet Durucan	International Journal of Greenhouse Gas Control, September 2006, submitted
2	Economic Evaluation for the Geological Storage of CO_2 Considering the Scale of Economy	Keigo Akimoto, Masato Takagi Toshimasa Tomoda	International Journal of Greenhouse Gas Control, July 2006(submitted), in press
3	Public Perceptions on the Acceptance of Geological Storage of Carbon Dioxide and Information Influencing the Acceptance	Kohko Tokushige, Keigo Akimoto Toshimasa Tomoda	International Journal of Greenhouse Gas Control, submitted
4	Modeling and analysis of the pressure response in the CO_2 injection experiment conducted at Iwanohara at Nagaoka, Japan	White,s., Xue,Z. and Satp,T.	International Journal of Greenhouse Gas Control, submitted
5	Pressure transient analysis of a long–term supercritical CO_2 injection experiment at Nagaoka, Japan	Horne, R. and Xue, Z.	Energy Convension and Management, submitted

■2006 Oral Presentation［CO_2 Geological Storage Project］

	Title	Researchers	Forum
1	Modeling and Analysis of the Pressure Response in the CO_2 Injection Experiment Conducted at Iwanohara, Niigata Prefecture, Japan	Stephen White, Ziqiu Xue Tatsuya Sato	GHGT–8(Trondheim, Norway), June 2006
2	Seismic Monitering and Numerical Simulation of Supercritical CO_2 Migration in Water–Saturated Sandstone	Ji–Quan Shi, Ziqiu Xue Sevjet Durucan	GHGT–8(Trondheim, Norway), June 2006
3	Experimental study on resistivity and SP monitering during CO_2 injection into water–satureted prous sandstone	Kenji Kubota, Koichi Suzuki and Ziqiu Xue	GHGT–8(Trondheim, Norway), June 2006
4	Time Lapse Well Logging to Monitor the Injecxted CO_2 in an onshore aquifer, Nagaoka , Japan	Ziqiu Xue, Jiro Watanabe Nozomu Inoue, Daiji Tanase	GHGT–8(Trondheim, Norway), June 2006
5	Monitering of Pilot CO_2 Injection in Nagaoka Using Time Lapse Well Logs	Jiro Watanabe	JFES(Japan Formation Evaluation Society)55th Chapter Meeting、May 2006
6	Economic Evaluation for CO_2 Geological Storage Considering the Scale of Economy	Keigo Akimoto, Masato Takagi Yoshitsugu Hirota, Takashi Ohsumi Yasunobu Mizuno Toshimasa Tomoda	GHGT–8(Trondheim, Norway), June 2006
7	Public perceptions on the acceptance of CO_2 geological storage and the valuable information for the acceptance	Kohiko Tokushige, Keigo Akimoto Toshimasa Tomoda	GHGT–8(Trondheim, Norway), June 2006
8	Mineral trapping of CO_2 at Nakagoka test site	Saeko Mito, Ziqiu Xue Takashi Osumi	GHGT–8(Trondheim, Norway), June 2006
9	Pilot CO_2 injection into an onshore aquifer in Nagaoka, Japan and its simulation study	Daiji Tanase, Hiroshi Okuma Nozomi Inoue, Yuko Kawata Takashi Ohsumi	GHGT–8(Trondheim, Norway), June 2006
10	Time–Lapse Crosswell Seismic Tomography for Monitering the pilot CO_2 injection into an onshore aquifer, Nagaoka Japan	Hideki Saito, Hiroyuki Azuma Dai Nobuoka, Daiji Tanase Ziqiu Xue	GHGT–8(Trondheim, Norway), June 2006
11	An experimental study of Residual Gas Saturation of Carbon Dioxide in water–saturated porous sandstone by using multi–channel seismic wave imaging method	Keigo Kitamura, Ziqiu Xue	2006 AAPG International Conference & Exbition, December 2006
12	Quantifying CO_2 Saturation from Time–lapse Well Logging in An Onshore Saline Aquifer, Nagaoka, Japan	Ziqiu Xue, Jiro Watanabe Daiji Tanase	2006 AAPG International Conference & Exbition, December 2006
13	An Onverview of the Nagaoka Project	Daiji Tanase	1st CO2 ReMoVe・SP4 Workshop, September 2006
14	Time–lapse well logging to monitor injected CO_2 in an aquifer at Nagaoka (Part I)	Daiji Tanase, Jiro Watanabe Zique Xue, Hiroyuki Azuma	2nd Monitoring Network Meeing of IEA, October 2006

■2006 Oral Presentation［CO_2 Ocean Sequestration Project］

	Title	Researchers	Forum
1	Effect of High CO_2 on Benthic Communities in the Norwegian Fjord	Hiroshi Ishida, Tatsuo Fukuhara Yuji Watanabe, Yoshihisa Shirayama and Lars Golmen	European netwaork CO_2 GEONET workshop 1 April
2	System Plan Considering Spare Capacity Allowed for Weather Conditions for CO_2 Marine Transport and Release in Deep Waters	Masahiko Ozaki, Junichi Minamiura Makoto Ohta, Yuichi Sasaki Masami Matsuura	OMAE(25th International Conf.on Offshore Mechanics and Arctic Eng'g) 4–9June 2006,Hamburg,Germany

	Title	Researchers	Forum
3	Development of environmental assessment technique for CO_2 ocean sequestration	Kiminori Shitashima, Takashi Ohsumi	OMAE（25th International Conf.on Offshore Mechanics and Arctic Eng'g) 4–9June 2006,Hamburg,Germany
4	A Study of Effectiveness of CO_2 Ocean Sequestration for Acidification of the Ocean	Michimasa Magi, Shigeo Murai Masao Sorai, Takashi Ohsumi	GHGT8（8th International Conf.on Greenhouse Gas Control technologies) 19–22 June,Trondheim,Norway
5	Ecosystem model for assessment of CO_2 effecst on deep-sea planktonic communities	Kishi Yasuyuki, Yuji Watanabe Hiroshi Ishida, Kisaburo Nakata	GHGT8（8th International Conf.on Greenhouse Gas Control technologies) 19–22 June,Trondheim,Norway
6	Assess the effect of high concentration of CO_2 on deep-sea benthic microorganisms using a benthic chamber system	Hiroshi Ishida, Tatsuo Fukuhara Yuji Watanabe, Yoshihisa Shirayama Lars Golmen	GHGT8（8th International Conf.on Greenhouse Gas Control technologies) 19–22 June,Trondheim,Norway
7	Fate of liquid CO_2 discharged from the hydrothermal area in the Okinawa Trough	Kiminori Shitashima, Yoshiaki Maeda Yuichi Koike, Takashi Ohsumi	GHGT8（8th International Conf.on Greenhouse Gas Control technologies) 19–22 June,Trondheim,Norway
8	System Plan and Possible Merits of Locating Plural Sites for CO_2 Ocean Storage	Masahiko Ozaki, Junichi Minamiura Kazuhisa Takeuchi, Yuichi Sasaki	GHGT8（8th International Conf.on Greenhouse Gas Control technologies) 19–22 June,Trondheim,Norway
9	A numerical study with an eddy-resolving model to evaluate chronic impacts in CO_2 ocean sequestration	Yoshio Masuda, Yasuhiro Yamanaka Yoshikazu Sasai, Michimasa Magi Takashi Ohsumi	GHGT8（8th International Conf.on Greenhouse Gas Control technologies) 19–22 June,Trondheim,Norway
10	Impact assessment of high-CO_2 environment on marine organisms	Jun Kita, Yuji Watanabe	GHGT8（8th International Conf.on Greenhouse Gas Control technologies) 19–22 June,Trondheim,Norway
11	Preliminary study of CO_2 ocean sequestration technology for ocean acidification control	Michimasa Magi, Shigeo Murai	WPGM(Western Pacific Geophysics Meeting 2006)　24–27 July, Beijing,China
12	Strategy of environmental assessment for CO_2 ocean sequstration	K.Shitashima, Y.Maeda and T.Ohsumi	WPGM(Western Pacific Geophysics Meeting 2006)　24–27 July, Beijing,China
13	Naturala analogue of CO_2 dispersion at deep-sea hydrothermal system	K.Shitashima, Y.Maeda and T.Ohsumi	2006 AGU Fall Meeting　2006

Plant Research Group

■2006 Paper

	Title	Researchers	Journal
1	Stomatal development in new leaves is related to the stomatal conductance of mature leaves in poplar (*Populus trichocarpa x P. deltoides*).	S.-I. Miyazawa, N.J. Livingston D.H. Turpin	Journal of Experimental Botany 57(2): 373-380
2	Ferredoxin limits cyclic electron flow around PSI (CEF-PSI) in higher plants-Stimulation of CEF-PSI enhances non-photochemical quenching of Chl fluorescence in transplastomic tobacco-	H. Yamamoto, H. Kato, Y. Shinzaki S. Horiguchi, T. Shikanai, T. Hase T. Endo, M. Nishioka, A. Makino K-I. Tomizawa, C. Miyake	Plant Cell Physiol. 47(5): 1355-1371
3	Efficient and Stable Transformation of Lactuca sativa L. cv. Cisco (lettuce) Plastids.	H. Kanamoto, A. Yamashita, H. Asao S. Okumura, H. Takase, M. Hattori A. Yokota, K. Tomizawa.	Transgenic Research 15(2): 205-217
4	A strategy for desert afforestation using plastid transformation technique for CO_2 sequestration	S. Okumura, M. Sawada, M. Shimamura Y. W. Park, T. Hayashi, A. Yamashita M. Hattori, H. Kanamoto, H. Takase C. Miyake, K. Tomizawa	Journal of Arid Land Studies 15: 505-508
5	Singlet oxygen inhibits the repair of photosystem Ⅱ by suppressing the translation elongation of the D1 protein in Synechocystis sp. PCC 6803	Y. Nishiyama, SI Allakhverdiev H. Yamamoto, H. Hayashi N. Murata	Biochemistry. 2004 Sep 7; 43(35): 11321-30
6	Photoinactivation of Ascorbate Peroxidase in Intact Chloroplasts from Tabacco Leaves -*Galdieria partita*-APX maintains the activity of the Water-Water Cycle in Transplastomic Tabacco Plants.-	C. Miyake, M. Okamura, M. Miyata Y. Shinzaki, M. Nishioka, S. Kitajima A. Yokota, K. Tomizawa	Plant Cell. subumitted
7	Massive accumulation of green fluorescent protein in tobacco chloroplasts by transplastomic transformation.	K. Tomizawa, A. Yokota	Nature biotech. subumitted
8	Sporophyte anatomy of Cavicularia densa Steph. (Blasiaceae)	M. Shimamura, T. Furuki H. Deguchi	Bryologist submitted

■2006 Oral Presentation

	Title	Researchers	Forum
1	Reduction of plastoquinone in low-light conditions functioned as a signal for high-light adaptation in transplastomic plants. -Physiological function of plastoquinone as the redox sensor-	Kato H, Shinzaki Y, Horiguchi S Yamamoto H, Nishioka M, Takase A Hase T, Makino A, Miyake C Tomizawa K	2006 ASPB meeting

Microbiology Research Group

■2006 Original Paper

	Title	Researchers	Journal
1	Complete genome sequence of the dehalorespiring bacterium *Desulfitobacterium hafniense* Y51 and comparison with *Dehalococcoides ethenogenes* 195.	H. Nonaka, G. Keresztes, Y. Shinoda, Y. Ikenaga, M. Abe, K. Naito, K. Inatomi, K. Furukawa, M. Inui and H. Yukawa.	J. Bacteriol. 188: 2262-2274. 2006.
2	Properties of cellulosomal family 9 cellulases from *Clostridium cellulovorans*.	T. Arai, A. Kosugi, H. Chan, R. Koukiekolo, H. Yukawa, M. Inui and R.H. Doi.	Appl. Microbiol. Biotechnol. 71: 654-660. 2006.
3	Phototrophic growth of a Rubisco-deficient mesophilic purple nonsulfur bacterium harboring a Type III Rubisco from a hyperthermophilic archaeon.	S. Yoshida, M. Inui, H. Yukawa, T. Kanao, K. Tomizawa, H. Atomi and T. Imanaka.	J. Biotechnol. 124: 532-544. 2006.
4	High throughput transposon mutagenesis of *Corynebacterium glutamicum* and construction of a single-gene disruptant mutant library.	N. Suzuki, N. Okai, H. Nonaka, Y. Tsuge, M. Inui and H. Yukawa.	Appl. Environ. Microbiol. 72: 3750-3755. 2006.
5	Engineering of a Xylose Metabolic Pathway in *Corynebacterium glutamicum*.	H. Kawaguchi, A.A. Vertès, S. Okino, M. Inui and H. Yukawa.	Appl. Environ. Microbiol. 72: 3418-3428. 2006.
6	Enhanced hydrogen production from glucose using *ldh*- and *frd*-inactivated *Escherichia coli* strains.	A. Yoshida, T. Nishimura, H. Kawaguchi, M. Inui and H. Yukawa.	Appl. Microbiol. Biotechnol. 73. 67-72. 2006.
7	Implementing biofuels on a global scale.	A.A. Vertès, M. Inui and H. Yukawa.	Nat. Biotechnol. 24: 761-764. 2006.
8	Efficient induction of formate hydrogen lyase of aerobically grown *Escherichia coli* in a three-step biohydrogen production process.	A. Yoshida, T. Nishimura, H. Kawaguchi, M. Inui and H. Yukawa.	Appl. Microbiol. Biotechnol. 17. Nov. 2006. [Epub ahead of print]
9	Technological Options for Biological Fuel Ethanol.	A.A. Vertès, M. Inui and H. Yukawa.	J. Mol. Microbiol. Biotechnol. (in press)
10	Random segment deletion based on IS*31831* and Cre/*loxP* excision system in *Corynebacterium glutamicum*.	Y. Tsuge, N. Suzuki, M. Inui and H. Yukawa.	Appl. Microbiol. Biotechnol. (in press)
11	Synthesis of *Clostridium cellulovorans* minicellulosomes by intercellular complementation.	T. Arai, S. Matsuoka, H-Y. Cho, H. Yukawa, M. Inui, S-L. Wong and R.H. Doi.	Proc. Natl. Acad. Sci. USA. (in press)

■2006 Oral Presentation

	Title	Researchers	Forum
1	Growth-Arrested Corynebacteria as Whole-Cell Biocatalysts for Commodity Chemicals Production in a Biorefinery	H. Yukawa, A.A. Vertès and M. Inui.	Pacific Rim Summit on Industrial Biotechnology and Bioenergy, 12-13 January 2006.
2	The growth-independence bioprocess for ethanol production using *Corynebacterium glutamicum*	M. Inui, A.A. Vertès, S. Okino, T. Watanabe and H. Yukawa.	The 28th Symposium on Biotechnology for Fuels and Chemicals, 30 April - 3 May 2006.
3	Succinic Acid Production by genetically modified *Corynebacterium glutamicum* under Oxygen-Deprivation	S. Okino, A.A. Vertès, M. Inui and H. Yukawa.	The 28th Symposium on Biotechnology for Fuels and Chemicals, 30 April - 3 May 2006.
4	Molecular Characterization of Microbial Communities in a Niigata Oil Well	K. Inatomi, S. Ishii, M. Inui and H. Yukawa.	American Society for Microbiology 106th General Meeting, 21-25 May 2006.
5	Random Genome Deletion Studies of *Corynebacterium glutamicum*	Y. Tsuge, N. Suzuki, M. Inui and H. Yukawa.	American Society for Microbiology 106th General Meeting, 21-25 May 2006.
6	Genome engineering and analysis of *Corynebacterium glutamicum*	M. Inui, N. Suzuki, Y. Tsuge, N. Okai, M. Suda, A.A. Vertès and H. Yukawa.	10th International Symposium on the Genetics of Industrial Microorganisms, 24-28 June 2006.
7	Oxygen-Deprived Bioprocesses for Biorefining Mixed Sugars using Growth-Arrested Corynebacteria	M. Inui, A.A. Vertès and H. Yukawa.	The 3rd Annual World Congress on Industrial Biotechnology and Bioprocessing, 11-14 July 2006.
8	Regulation of Expression of Cellulosomes in *Clostridium cellulovorans* During Growth on Different Composition Biomass	S.O. Han, M. Inui, R.H. Doi and H. Yukawa.	The 3rd Annual World Congress on Industrial Biotechnology and Bioprocessing, 11-14 July 2006.
9	A Simple, Robust, and Economical Process for Biorefineries: Efficient Production of Ethanol and Organic Acids by Growth-Arrested Corynebacteria	M. Inui, S. Okino, M. Suda, H. Teramoto, T. Jyojima, A.A. Vertès H. Yukawa.	Society for Industrial Microbiology Annual Meeting and Exhibition 2006, 30 July - 3 August 2006.
10	Towards biorefineries and cellulosic ethanol or organic acids: Efficient production from mixed sugars by growth-arrested bioprocesses using Corynebacteria	M. Inui, S. Okino, M. Suda, H. Teramoto, T. Jyojima, A.A. Vertès H. Yukawa.	232nd ACS National Meeting, 10-14 September 2006.
11	Genome sequencing of dechlorinating bacterium *Desulfitobacterium hafniense* Y51 and development of its DNA microarray	K.. Inatomi, S. Yamamoto, X. Peng, H. Nonaka, M. Inui, K. Furukawa and H. Yukawa.	14th Annaul International Meeting on Microbial Genomics, 24-28 September 2006.

	Title	Researchers	Forum
12	Biorefining Mixed Sugars using High Densities of Growth-Arrested Corynebacteria	H. Yukawa, M. Inui and A.A. Vertès	AIChE 2006 Annual Meeting, 12-17 November 2006.
13	Conversion of Mixed Sugars into Ethanol by Recombinant *Corynebacterium glutamicum*	M. Inui, H. Kawaguchi, S. Okino, M. Suda, M. Sasaki, A.A. Vertès and H. Yukawa	AIChE 2006 Annual Meeting, 12-17 November 2006.
14	Efficient conversion of glucose and xylose mixtures by growth-arrested *Corynebacterium glutamicum* cells under oxygen-deprivation conditions	H. Teramoto, H. Kawaguchi, S. Okino, A.A. Vertès, M. Inui and H. Yukawa.	International Symposium on Biocatalysis and Biotechnology, 6-8 December 2006.

Research Institute of Innovative Technology for the Earth

9-2, Kizugawadai, Kizugawa-Shi, Kyoto
619-0292 JAPAN
TEL. +81-774-75-2300　FAX. +81-774-75-2314
URL http://www.rite.or.jp