# RITE Today

Research Institute of Innovative Technology for the Earth

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Research Institute of Innovative Technology for the Earth

# R&D toward Decarbonized Society

Yoichi Kaya, Director General

Research Institute of Innovative Technology for the Earth (RITE)

Our institute was established in 1990 for the purpose of developing technologies mitigating global warming. At present we have about a hundred and sixty members working in 5 research areas. Our institute having published a lot of research results in academic societies, we did not try to publish any annual report in the past. Therefore we are very pleased to publish such annual report now, with the reflection of our idleness of not having done that last 15 years.

As Kyoto protocol came into effect in February 2005, most developed countries are making desperate efforts for achieving the emission targets. Noticing that these targets are only for the period between 2008 and 2012, we should try to reduce greenhouse gas emissions substantially in the longer term according to the ultimate aim listed in Article 2 of the Framework Convention for Climate Change taken. European Union already proposed to keep the earth surface temperature rise from the pre-industrial level to be less than 2 degrees in Celsius. Regardless of whether we accept this severe proposal as it is, we recognize the urgent needs of reducing greenhouse gases, particularly carbon dioxide in a drastic manner to prevent further progress of global warming. Realization of this target requires major changes in human civilization which at present relies heavily upon fossil fuels.( 80 % of primary energy supply ) Our institute aims at developing those technologies which can make such changes realizable.

Among a number of studies conducted in the institute the technology of $CO_2$ recovery and storage is a typical example of this kind. We believe that this technology is not that in decarbonized age but a technology bridging from today and future decarbonized age. Keys in realizing this technology into practice may be energy / cost reduction and to secure stable storage sites. As the former is the basic condition of putting this technology into practice, we do a lot of efforts for satisfying the former condition such as development of innovative technologies for chemical absorption and/or membrane separation which makes our institute to hold the leading position in related academic societies. At the same time we analyze and evaluate the behavior of $CO_2$ stored underground at Nagaoka experimental site, of which results contribute much to realize stable $CO_2$ storage. Another important example of our studies is to find and breed trees which grow rapidly under severe condition of water supply and sunshine, i.e. those with high $CO_2$ absorption capacity. This may be one of important study targets from now on in our institute. We also plan to explore new technology areas such as innovative ways of utilizing natural energy sources. We earnestly hope you will help us conduct these researches more actively.

# System Analysis Group

## Analysis of International Emissions Reduction Regimes beyond the Kyoto Protocol

Even though the Kyoto Protocol is an historical first step toward the reduction of GHG emissions, its effectiveness is doubtful for the following reasons: no obligations on developing countries whose emissions are anticipated to rapidly and drastically increase; the withdrawal of the US, currently the world's largest emitter; and the existence of "hot air", which is a situation where a granted emission permit quota is larger than actual emissions, for Russia, Ukraine, etc. Since Japan ratified the Protocol, she must obey it and contribute to the reduction of the world's emissions. But it is also important to explore international emission reduction regimes beyond the Kyoto Protocol because some regimes might more effectively reduce world emissions and hold lower barriers for many countries to participate in. Thus, using a world energy model, we performed consistent and quantitative analyses and evaluations to provide useful data and information for such regime examination and exploration. This paper introduces our research activities and achievements.

### 1. Research objectives and overview

The objectives of this research are to obtain minimum cost emission reduction measures and their reduction costs/marginal reduction costs that correspond to various reduction targets for such countries of interest as Japan, the US, EU, China, India, etc. Goals also include computing and evaluating emission trades, the monetary flows accompanying the emission trades, and the evaluation of various reduction regimes using integrated indexes of reduction costs/marginal costs, per capita and per GDP emission amounts, and other indicators.

To achieve these objectives, we constructed a world energy system model, DNE21+, which has high regional resolution, and used it to obtain the minimum costs and the minimum cost reduction measures for reduction targets imposed on each country based on various views. After defining such indexes as "sovereignty," "burden," "their equities," and "capability of burden sharing," we compared and evaluated the reduction regimes using these indexes.

### 2. World energy model DNE21+

The DNE21+ model explores the world's minimum cost energy systems (energy flows, capacities of energy conversion facilities, etc.) for given final energy demands and given costs of conversion technologies for a reference case having no emission reduction constraints. It also explores minimum cost systems that satisfy the final energy demands that decrease depending on energy price hikes for emission constraint cases. The model's capability includes: 1) long-term analysis to the year 2050; 2) analysis of regional differences based on the world disaggregated into 77 regions; and 3) analysis of concrete technological measures of emission reduction.

### 3. Cost effective measures for $CO_2$ concentration stabilization at 550 ppm

A case study was conducted of the minimization of the world's total cost under a constraint of 550 ppm stabilization, which is an idealistic case.

(1) Analysis Outline

The DNE21+ model analyzed the cost to Japan and the world to achieve $CO_2$ concentration stabilization at 550 ppm and derived corresponding appropriate measures.

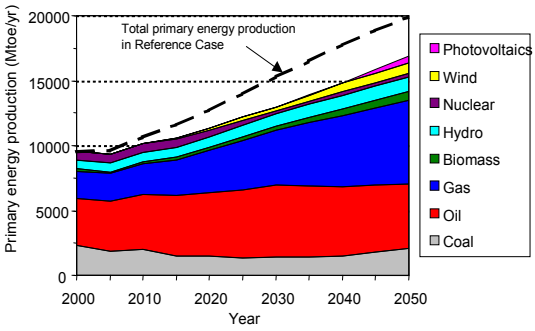
(2) Assumptions

Assumptions of future population, GDP, and final energy demands were determined based on the IPCC B2 scenario. The S550 IPCC WG1 emission scenario was adopted as an emission constraint scenario. The entire world was set to achieve targets in such a way that marginal $CO_2$ reduction cost is the same for all the regions, which is identical to the minimization of the world's total costs.

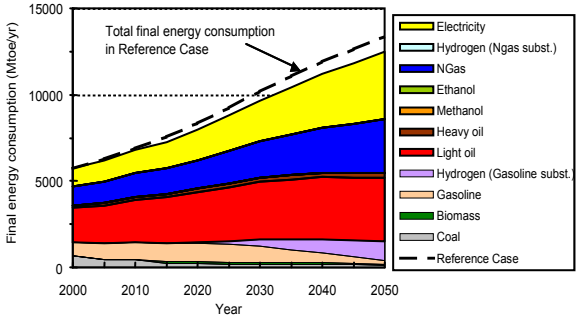
(3) Results

Figure 1 shows the optimum primary energy production and final energy consumption for the S550 achievement. Increases of wind and hydro power, photovoltaic introduction, energy savings in both primary and final energies and hydrogen usage for FCV in 2020 and thereafter were observed. The marginal cost of $CO_2$ emission reduction was computed to be 55 and 123 $/tC by 2020 and 2050, respectively. It was 135 $/tC by 2050 where FCV is unavailable, and

182 $/tC where CCS technology is unavailable. This indicates that these technologies play an important role for 550 ppm stabilization.




*(a) Primary energy production*




*(b)Final energy consumption*

*Fig. 1 Global primary energy production and final energy consumption for S550*

## 4. Comparison and evaluation of various reduction regimes

(1) Outline

For each reduction regime, reduction cost, emission amount, and their per capita and per GDP values etc. are computed for each region using the model run results; the indexes introduced in (3) were quantitatively evaluated.

(2) Simulation cases

Six cases of reduction regimes were studied. In all the cases, S550 was assumed to be a constraint on the entire world.

(a) The marginal reduction cost is the same for all the regions, as treated in Section 3.

(b) Reduction targets are based on per capita emissions.

i. Per capita emissions of all the regions converge by 2050.

ii. Per capita emissions of all the regions decrease at the same rate.

(c) Reduction targets are based on per GDP emissions.

i. Per GDP emissions of all the regions converge by 2050.

ii. Per GDP emissions of all regions decrease at the same rate.

(d) Kyoto Protocol + UK proposed target

In 2003, the UK proposed the following target for Annex I countries to achieve 550 ppm stabilization: reduction of emissions by about 60% by 2050. Considering this proposal, the following emission reduction targets by region were assumed:

<2010> Except for the US, Annex I countries obey the Kyoto Protocol; the US achieves her own target of 18% reduction in GDP intensity in 10 years. An EU bubble or joint fulfillment of 15 countries is allowed.

<2015 and thereafter> Annex I countries achieve the target proposed by the UK (61% reduction by 2050 relative to 1990). The 27 EU countries are allowed to joint fulfillment. Non-Annex I countries must constrain their emissions so that the world's total emission does not exceed S550. Emission allotment among non-Annex I countries is proportional to their historical emissions in 1990.

(3) Results

Evaluations used the following indexes: "sovereignty," which consists of $CO_2$emission amounts and its ratio to the values of the year 2000; "equity in sovereignty," which consists of per capita and per GDP "sovereignty;" "burden," which consists of $CO_2$ reduction amount, reduction costs etc.; and "capability of burden sharing," which consists of per GDP "burden" and "equity in burden," which consists of per capita " burden." It was found that the (c) i case in Section 4. (2) is advantageous for Japan and the (b) ii case is advantageous for the US, and that the (b) i case of per capita emission convergence has the highest equity when it is assumed that the smaller the variations in the above indexes among countries are, the higher equity the regime can claim.

## 5. Future study

Such reduction regimes as participation timing of emission reduction varies depending on the countries, and a "bottom-up approach" is implemented to improve $CO_2$ intensity by sector, unlike a "top-down approach" of ceilings on emission amounts, are topics for future study.

# *Chemical Research Gruop*

## Chemical Group Activity

Extensive use of fossil fuels has caused an increase in $CO_2$ emissions, resulting in a rapidly increasing atmospheric $CO_2$ concentration that in turn is causing global warming. Atmospheric $CO_2$ concentration needs to be stabilized at a low level to mitigate global warming.

There are two main measures for atmospheric $CO_2$ stabilization. One is to reduce $CO_2$ emissions, the other to sequestrate emitted $CO_2$ into land or ocean (Carbon Capture and Storage, CCS).

A scenario for $CO_2$ stabilization determines scales and schedules of the implementation of measures. The stabilization level generally considered is 550ppm by 2100 which is a level two times higher than the $CO_2$ concentration before the industrial revolution.

Stabilizing at 550ppm would be difficult if there is only implementation for improvements in efficient energy use, or fuel switching to renewable energy sources.

Therefore, additional stabilization options such as CCS technologies, which have high potential for stabilization, should be developed for practical use. Reduction of energy consumption and the cost of a CCS system is essential for its practical use.

For achieving this, basic technologies in three fields of materials, processes and systems are necessary as innovative technology elements.

Our chemical group has worked toward the establishment and gathering of such technologies, and is also involved in the process of advancing them.

We are presently focusing our research activities toward the establishment in ten years of a CCS system that uses our technology elements.

Our R&D work in this area relates not only to CCS, but also to new energy systems that enable the construction of a sustainable carbon cycle society.

## Chemical Absorption Process

A new $CO_2$ capture project by chemical absorption process has been started with collaboration of three Japanese companies since fiscal year 2004 as a five-year project.

The project aims at reducing a $CO_2$ capture cost to half and includes two main research objectives: One is to develop higher-performance chemical absorbents and the other is to utilize low-grade waste heat in integrated steel works in order to provide $CO_2$ capture process with low-cost energy.

RITE has mainly worked on developing the new absorbents. In 2004, both experimental and theoretical studies on the reaction of amine compounds with $CO_2$ were conducted and structural characteristics of hopeful absorbents were clarified. Then, the current results contributed to developing the new absorbent which was graded as one of the current highest-performance ones. In the next term, RITE aspires to develop the best absorbent ranked beyond the others.

## Practical development of membrane /absorption hybrid separation technique

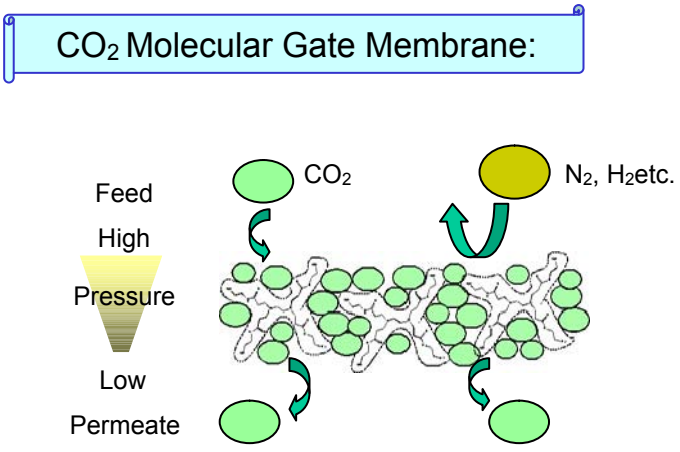
Membrane/absorption hybrid method has been studied as a new $CO_2$ separation technology. (The work was supported by NEDO and guided by Prof. Teramoto, Kyoto Inst. of Technology, in 2001-2003 fiscal year.) In this method, $CO_2$ is absorbed in the absorbent liquid in one side of the porous membrane and emitted in the other side with the liquid permeation under the reduced pressure. This method is characterized by drastically little energy consumption compared to the current separation method and highly concentrated $CO_2$ obtained. At present, cooperation with the companies is promoted for applying this method to the separation of $CO_2$ from flue gas, chemical process, bio-process, etc.

## 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 now involved in developing just such polymeric separation membranes.

Cardo polyimide having fluorene moiety was modified in the chemical structure for good $CO_2$ separation properties. The asymmetric hollow fiber membrane of the cardo polyimide shows the largest $CO_2$ permeance among existing asymmetric membranes and the top level of $CO_2$ selectivity in various polymeric membranes. A module of the membrane can recover $CO_2$ from an exhausted gas of 25 % $CO_2$ concentration at a comparable expense to amine solution by a system involving $CO_2$ liquefaction. For a higher $CO_2$ concentration flux, the membrane separation will have an advantage over amine solution in the system.

RITE is currently developing a $CO_2$ molecular gate membrane with the goal of producing a new, high-performance separation membrane. Figure 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 $H_2$ leaking to the other side of the membrane is greatly limited and high concentrations of $CO_2$ can be obtained. The membrane of RITE dendrimer shows excellent $CO_2$ selectivity of more than 1000, which would have a potential to replace amine solution.




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).

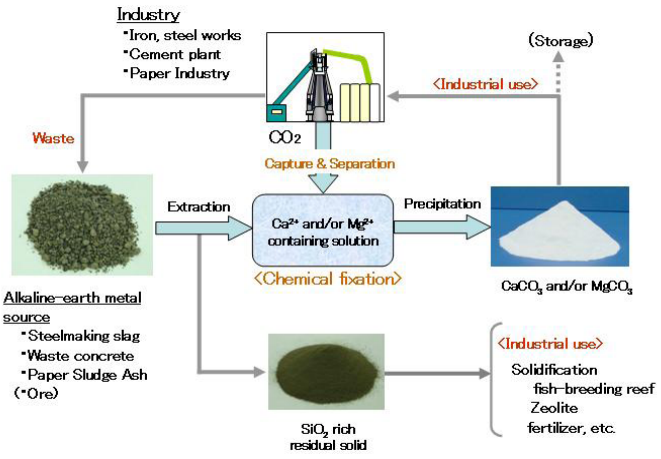
Partially carbonized membrane is a fresh subject under a founding from Global Climate and Energy Project (GCEP) in Stanford University.

## Inorganic membrane

Since zeolites and mesoporous silicas possess well defined micro/meso-pores, considerable attention has been focused on the production of membranes that are capable of separating gases with high selectivities. Polymer membrane shows good affinity for $CO_2$, however, thermal expansion/mobility of polymer at high temperature causes degradation of $CO_2$ selectivity. Since mesoporous slicas have uniform and large pores as well as high surface area, a large number of active sites or adsorption sites can be introduced uniformly on inorganic rigid pore wall by chemical grafting of surface OH group with organosilane molecules. If such a material is prepared in the thin film, a molecular movement of the functional group connected with a rigid inorganic pore wall is restricted, and it seems that the decrease in the $CO_2$ selectivity because of an increase in a free volume by thermal expansion/movement of polymeric material in the high temperature region can be controlled. We have studied surface functionalization of the pore wall of various mesoporous silicas that are specialized for $CO_2$ capture and separation. Amine-grafted mesoporous silica MCM-48 membranes (thickness: 300-500nm) were prepared and they showed high $CO_2/N_2$ separation properties and $CO_2$ permselectivities were 50-800 even at 100℃. This research proposal was awarded by GCEP(Global Climate & Energy Project) of Stanford University, and the project has started in September, 2005.

## $CO_2$ fixation as carbonates

Fixation of carbon dioxide as carbonate by the reaction with calcium and magnesium sources containing waste materials, such as iron- and steelmaking slag, waste concrete and minerals has recently been paid attention as one of the $CO_2$ sequestration method. The major advantages of this process are, long term stabilized and environmentally safe $CaCO_3$ and/or $MgCO_3$ production. Additionally, the overall carbonation process is exothermic and hence, has the potential to become economically feasible. However, the development of a new system with simple process, short reaction time, and lower energy consumption is necessary for practical use. We have proposed and investigating a new process of $CO_2$ fixation via carbonation of calcium contents in waste concrete or slag by using a solution of $NH_4Cl$. Studies for the new process have been carrying out to verify the possibility of the system.




## Development of an Innovative After Treatment System for Diesel Vehicles: A Non-Thermal Plasma System

### (A NEDO project from FY2004, joint study with Daihatsu Motor Co. Ltd.)

RITE had developed a plasma technology for natural gas (methane) conversion to acetylene and hydrogen using a high-frequency pulsed plasma in a R & D project of environmental friendly catalysis technology supported by funds from NEDO (FY1991-2000). In 2001, RITE started a three-year plasma particulate matter (PM) removal study financially supported by the Ministry of Education, Culture, Sports, Science and Technology, in which the pulsed plasma technology was used to establish a plasma PM removal system. This plasma PM removal system included a plasma reactor and a pulse power supply.

Recently, the emission control is becoming extremely severe for diesel vehicles, although no satisfied PM removal technologies have been found yet. The plasma PM removal technology has potential as an innovative technology for the after treatment of the exhausts from diesel vehicles. We then began a new project supported by NEDO (project of comprehensive technological development of innovative, next-generation, low-pollution vehicles, R&D of innovative after treatment systems) to continue the plasma PM removal study from 2004. This new project is a joint study with Daihatsu Motor. RITE is to develop a small plasma reactor and pulse power supply that can be loaded on a small diesel car.

# $CO_2$ 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.

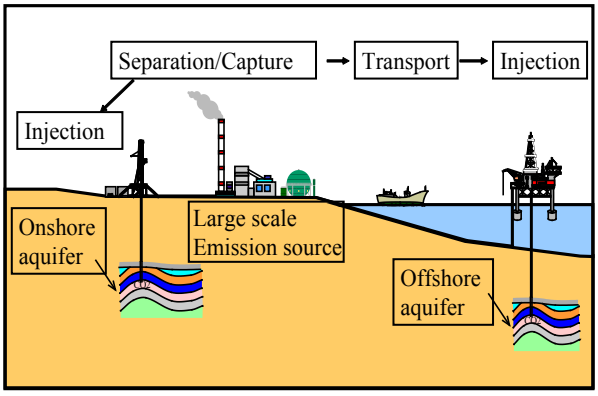



Fig1 $CO_2$ geological storage in aquifer

### 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.

Fig2 $CO_2$ 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

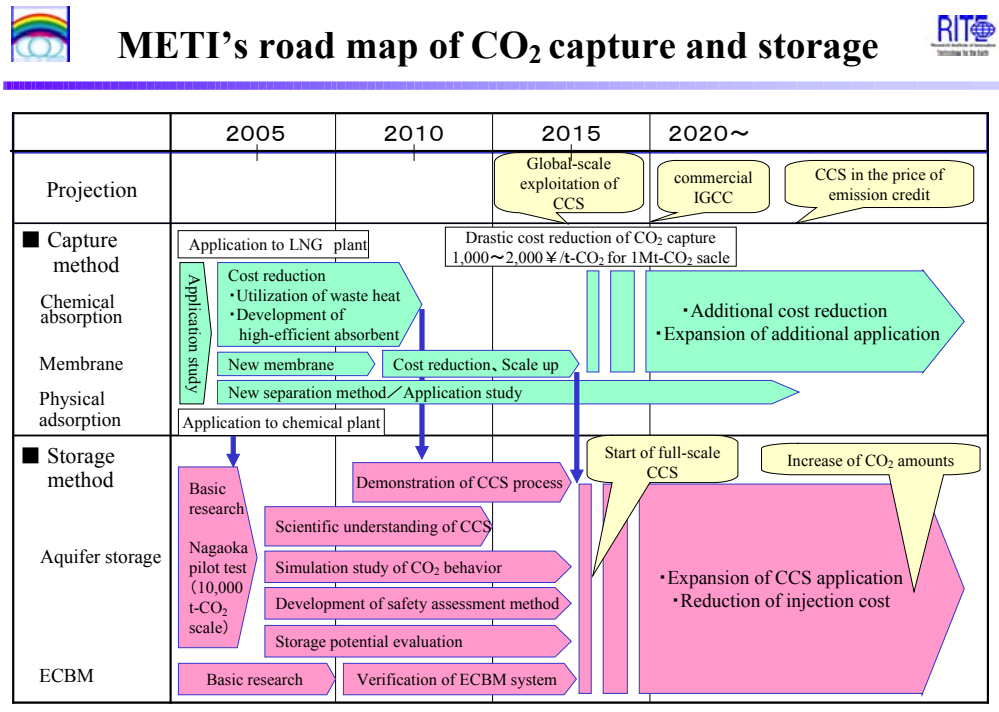
In order to improve the $CO_2$ behavior model, the following laboratory experiments will be carried out: influence of $CO_2$ dissolved into water on mechanical stability of cap rock, quantification of mineral dissolution rates under $CO_2$ presence, mechanisms of super critical $CO_2$ substitution for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




(after METI's road map of technology strategy, 2005)

Fig3 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 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" method, as shown in Fig. 1. The current states of $CO_2$ ocean sequestration concerning the storage mechanisms and technology, the ecological and environmental impacts and risks, the cost of ocean storage, and the legal aspects and public perception are reported in the chapter 6 of special report on $CO_2$ capture and storage which was accepted by IPCC last September and interested by COP11 last November, respectively.

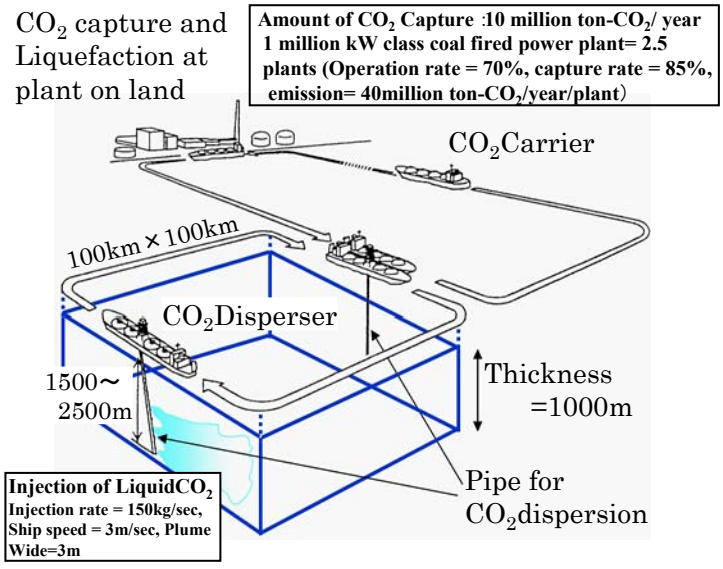



Fig.1 Image of enterprise for ocean sequestration by Moving ship

## 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 understood 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 behavior of $CO_2$ dissolved in the adjacent seas of Japan, including predictions and investigations of environmental impacts, mainly on the biota, induced by the injection of liquid $CO_2$ into the sea water, were conducted. Followings are the aims of the present project 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 the 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 FY2002, and now it is the 4th year. An 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 oversea, 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 has been carried out in a fjord of Norway from August to October in 2005. In addition, it is planed a possible international joint research project together with U.S.A, Brazil, and a South Korean. Moreover, in order to promote PO actions, investigations of the PO working group were started from FY2005. The working group has started a working plan on publicity, education and production of PO materials among other actions.

## 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*

## Forest of RITE in Western Australia

In the plant research group, we have just started the construction of Forest of RITE in Western Australia as the first step to mitigate $CO_2$ increase in the atmosphere. Environmental factors affect the growth of plant directly because plants are not allowed to move about. The most suitable ground for plant growth is usually used for food production, agriculture. In this project, plantation of trees in the semi-dry area where is not used for agriculture, to inspect quantity of the growth and $CO_2$ absorption.

Forest of RITE occupies about 30 hectares in the neighborhood of Collie, Western Australia (figure 1). Here is the semi-dry area of precipitation around 600mm in a year. In addition, it is the area where damage from salt breeze occurs partially.

When we construct a forest in arid condition such as semi-dry grounds, an application of suitable trees that are tolerance against the environmental stresses is required. Even if we apply a eucalyptus for the construction of the Forest of RITE, normal growth could not although a eucalyptus is the tree that comparatively resists drying. An application of genetically modified trees is alternative. However, the use of genetically modified trees with an environmental stress tolerance is hard to say quick-acting technology because development of those trees are in research stage and, in addition, social acceptance is required to cultivating them in the outdoors even if the genetically modified trees reached a practical use stage. The quick-acting method we used this time is the application of a non-genetically-modified but a clone of elite trees.

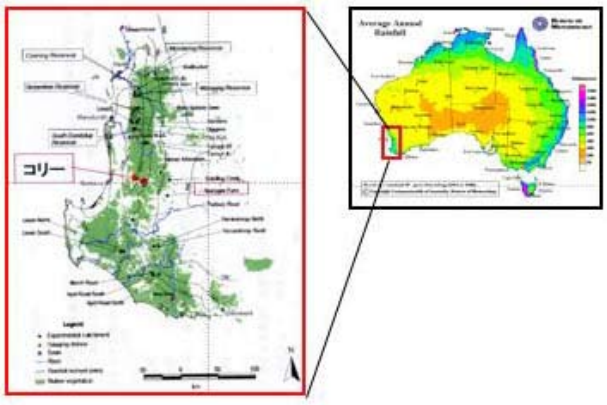



*Figure 1. Location of the Forest of RITE in Western Australia.*
Forest of RITE occupies about 30 hectares in the neighborhood of Collie, approximately 100km south of Perth.

Although propagation of the elite trees usually performs by the method of cutting, the application of normal cutting method to a eucalyptus, the tree we use for Forest of RITE, seems to be difficult. Thus we used an alternative method for the propagation of elite eucalyptus instead of general cutting method. The alternative method has basically been developed by Nippon Paper Industries, including a tissue culture technique to amplify eucalyptus tissue in a container, an effective rooting technique under a relatively high $CO_2$ condition. As the result, we prepared a young plant of 20,000 elite clones containing high growth rate, drought tolerance and salt stress tolerance, respectively, in a relatively short period. After acclimatization, the plantation has started in July that is local rainy season (figure 2).

We will measure growth rate and photosynthetic activity of the planted trees. We will improve the practical use of elite clone planting through evaluation of Forest of RITE in terms of $CO_2$ reduction.

*Figure 2. Elite clone seedlings (the left) and scenery of the planting (the right).*

# *Microbiology Research Group*

## Biorefinery in the post-genomic era

### Introduction

In recent years, the term biorefinery has received a lot of attention. The biorefinery concept is a new concept in which renewable resources such as biomass are converted to fuel and chemicals. This is in contrast to oil refinery technology by which chemicals and fuel are produced from fossil fuels oil refineries. In the United States, where this concept was developed, massive R&D in the fields relating to biorefineries has been the result of increased environmental awareness and rapid progress in biotechnology. The biorefinery concept is expected to develop into a key industry of the 21st century, and is envisioned to bring forth an industrial revolution of the 21st century because of the significance of its fundamental technology and effect it will have on the industrial paradigm.

### A novel bioprocess technology at RITE.

The main technical hurdle in the development of biorefineries is the efficiency of conversion of the biomass resources used as raw material. A suitable bioprocess to accompany biotechnological modification of microbial cells must be developed in order to achieve optimal efficiency. At RITE, we have developed novel bioprocess techniques based on a totally different concept from the conventional fermentation method (Figure 1).

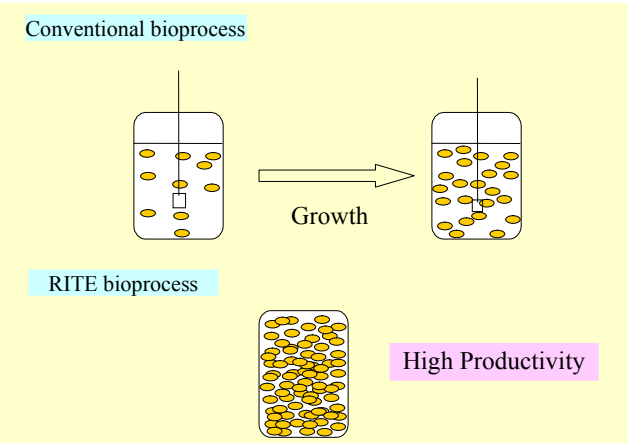



*Figure 1 Illustration of conventional bioprocess and RITE bioprocess.*

Unlike conventional bioprocesses, this novel process does not require "space" for growth (cell division). By using a compact bioreactor filled with "catalyst" (microbial cells) at high density, chemicals can be produced through continuous reaction. Microbial cells can be used in a similar manner as in chemical catalysis. Thus a highly efficient bioprocess can be established and productivity equivalent to or above conventional chemical processes can be expected.

This break-through technology enables us to overcome the shortcomings of conventional bioprocesses. By using this bioprocess as core technology, the RITE Microbiology Research Group, in collaboration with the private sector, is now advancing R&D aimed at environmental conservation. Our latest research regarding the highly efficient conversion of biomass to industrially useful chemicals is outlined below.

### Applications in chemical production

* Succinic acid

Succinic acid is used in the manufacture of food and pharmaceutical products, surfactants and detergents, green solvents and biodegradable plastics. It is an ingredient in formulations that stimulate animal and plant growth, and an intermediate for chemical synthesis. Although known to be a fermentation by-product of anaerobic bacteria, succinic acid to date is mostly produced commercially by way of chemical processes utilizing fossil oil. However, cost effective fermentative production of succinic acid from renewable carbohydrate feedstocks for the sake of environmental conservation has recently become necessary. By adapting the RITE bioprocess to succinic acid production, we successfully synthesized succinic acid from biomass-derived sugars. The process is continuous and cost-effective, with the addition benefit of net consumption of $CO_2$ Now we are in collaboration with the chemical company, Showa Highpolymer Co., Ltd., toward industrial succinic acid production.

* Production of ethanol

Ethanol production using bioprocess technology gained prominence in response to the oil crises of the 1970s. However R&D for ethanol production in Japan unfortunately faded away due to the stability in the international oil trade in the 1980s and 1990s. In contrast, however, basic and applied studies aimed at bio-ethanol production in the USA continued. As a result, many companies producing ethanol from biomass are now being established. The estimated amount of bio-based ethanol to be produced in the USA is this year is 10 M tons, double the amount produced in the past 5 years. Most of the produced bio-ethanol is consumed as gasoline additive.

According to the plans of the USA Department of Energy, cost reduction of bio-ethanol to less than 20 cent/L should be realized by 2015. The basis of this reduction is the creation and utilization of ethanol-producing microbes optimized for bioindustry through biotechnology. However, it is apparent that the technology pursued by the USA cannot avoid the main drawback of conventional bioprocesses – requirement for space in a reaction chamber for cell growth. We developed a new cost-effective bio-ethanol producing process utilizing the RITE bioprocess. It may lead to a new horizon in bio-ethanol production.

* Bio-hydrogen

Biological hydrogen production occurs at ambient temperatures and pressures, thus lowering the energy requirements of the production process. In contrast, the well-established method for hydrogen production in which oil or natural gas is chemically refined occurs at high temperatures and pressures. It often produces carbon monoxide, which is an extremely harmful byproduct to fuel cells. Bio-hydrogen production has the merit of being devoid of this problem. However bio-hydrogen producing systems have the serious limitation of commercially low volumetric hydrogen productivity. Previous studies on bio-hydrogen indicate that the low volumetric productivity is attributed to low hydrogen production rate per cell and low cell density in the reactor, the latter which is a result of low growth rate under anaerobic conditions. The RITE bioprocess overcomes these limitations because microbial cells are not growing and can be used in a similar manner as in chemical catalysis. A bioreactor filled with the "catalyst" at high density. By using the RITE bioprocess, we achieved hydrogen productivity two orders of magnitude higher than that of conventional bio-hydrogen producing systems. At such productivity, a reactor the size of a coffee cup can generate enough hydrogen to supply the energy requirements of a household television set, while a 1.8-liter PET bottle-sized reactor can satisfy the electricity requirements of a typical household.

## Conclusion

The key for biorefinery development is the underlying bioprocess technology. The RITE Microbiology Research Group has developed a new, highly effective bioprocess technology. By using this, we demonstrated the production of useful chemicals using biomass as raw material. We are currently advancing the R&D toward practical application in bio-industry.

# Development of Innovative Gas Separation Membranes through Sub-Nanoscale Materials Control

Chemical Research Group

GCEP(Global Climate & Energy Project) was set up with a research and development project of the global warming countermeasure technology which made started in U.S.A in 2003, and operating by Stanford University.

RITE was awarded for research proposal (three years) by GCEP as the first research organization except for universities and the second one except for U.S.A in September 2005.

This project intends to develop a variety of efficient, low-cost polymeric and inorganic membranes that separate $CO_2$. Material structure engineering at the scale of gas molecules will be used to increase permeability and selectivity.

Since the effective size of $CO_2$, $N_2$, $H_2$ and other gases present in fossil fuel conversion systems are very similar, membrane pore spaces must be controlled on a scale comparable to the size differences among these gas molecules. This will be achieved for a variety of membrane types using several different techniques.

Hollow fiber cardo polymer membranes will be optimized for $CO_2$ permeability and selectivity, for example, by carbonizing the outer surface of the membrane. Thermal motion of organic polymers can cause variations in the morphology and effective pore size of the membrane. Carbonization by UV, plasma, or ion beam treatment could serve to restrict the thermal motion of the polymer chain and enhance the molecular gate function of the polymer. Functionalizing the polymer may change its morphology at the sub-nanoscale, allowing for fine tuning of the pore space (Fig.1).

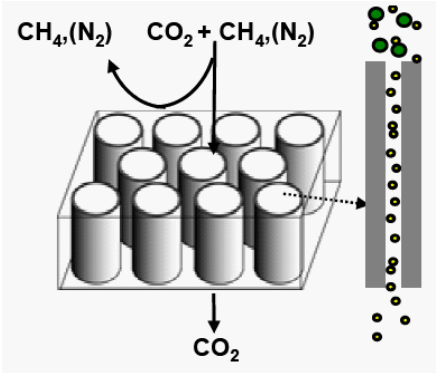



**Fig.1**: Porous inorganic membranes act as molecular sieves

While most zeolite membranes consist of randomly oriented crystals, a thin, mono-layer crystal with an ordered lattice of pores would demonstrate superior permeability and freedom from defects. As illustrated in Fig.2, this will be achieved by applying a coating of seed crystals on a substrate with perpendicularly oriented channels. After secondary crystal growth, the properties of the resulting pore structure reflect the morphology of the seed crystal.

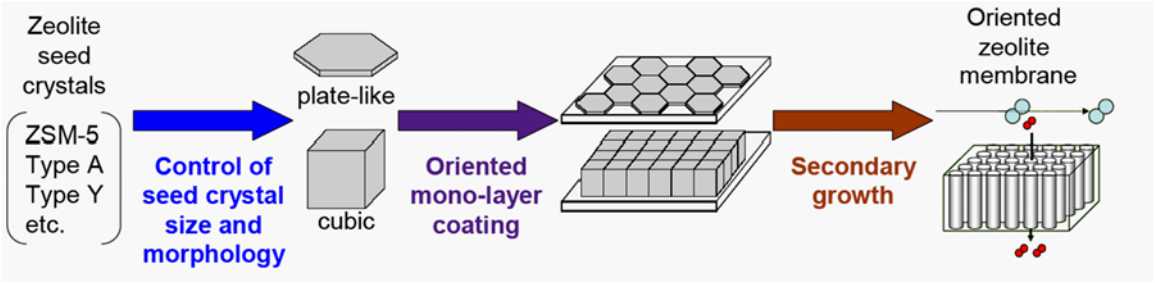



**Fig.2**: Functionalization process for a mono-layer crystalline zeolite pore structure

The development (It is compared with the present by the $CO_2$ separation cost, and a big breakthrough is realized with 1/3.) of the progressive high-performance $CO_2$ separation membrane which controls sub-nano structure is expected as a result of this project.

(GCEP WEB site: http://gcep.stanford.edu/)

## $CO_2$ Capture Enabling Technologies for Coal-fired Power Generation

Chemical Research Group

A workshop entitled "$CO_2$ Capture Enabling Technologies for Coal-fired Power Generation" was held on September 16, 2005 at the Australian pavilion in the Aichi EXPO Japan.

This workshop was hosted by Australian Department of Industry Tourism and Resources (DITR) in cooperation with RITE, Japan. Approximately fifteen researchers from Australian side and forty participants including RITE, JCOAL, NEDO and the private sectors in Japan gathered on the day.

Firstly Mr. John Hartwell, resources director of DITR, Dr. Kaya, head of RITE and the Mr. Cliff Mallett, head representative of CSIRO made opening announcements and then three sessions on "Gasification and Gas Stream Technologies", "Oxy-Fuel Combustion" and "Post Combustion and Appropriate Gas Stream Technologies" were followed in this workshop. In their opening addresses, Mr. Hartwell highlighted the importance to cooperate with Japan for resolution of the global warming issues and Prof. Kaya mentioned the necessity of consideration about a post-Kyoto protocol and cost evaluation as well.

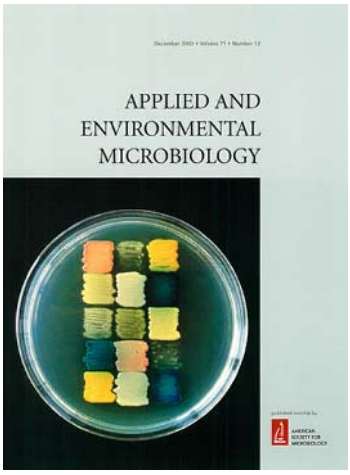
Prof. Yamada of RITE summarized that the carbon sequestration technology should be recognized as an important bridge toward the possible renewal energy period and wide range of researches from basic study to actual testing levels had been carried out. It was also mentioned that bilateral partnership in the fields of oxygen combustion and developing membrane technologies should be more promoted.

After this workshop was over, it was highly evaluated from the Australian government as an invaluable opportunity for the leading researchers of both countries in that they had lively face-to-face exchange of views about $CO_2$ Capture Enabling Technologies.

## One of our research achievement -A cover for the journal published by American Society for Microbiology

Microbiology Research Group

In the Microbiology Group, we focus our work on devising microbiological conversion methods to produce useful substances. The keys of our research are the engineering of production strains and the development of bio-process techniques that have industrial potential. Specifically, our research group aims at harnessing coryneform bacteria, as these bacteria have a long history of biotechnological use and possess an almost unmatched set of intrinsic attributes to produce a variety of different fine chemicals, including amino acids. The ability to efficiently manipulate coryneform bacteria at the genetic level opens the possibility to apply a wide array of technologies that have been devised in other areas in the field of the life sciences.




We report our results in leading international scientific journals. For example, to illustrate the latest advancements in modifying the genomes of coryneform bacteria, we have recently published a review article revisiting the various recombinant DNA tools that are available for corynebacterial research and defining the next major objectives to accomplish in this area. The picture, which is related to this review article, is the cover of the December issue of the journal Applied and Environmental Microbiology, published by the American Society of Microbiology.

## System Analysis Group

■2005 Paper

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | Narrative Scenario Development Based on Cross-Impact Analysis for the Evaluation of Global-Warming Mitigation Options | A. Hayashi, K. Tokimatsu<br>H. Yamamoto, S. Mori | Applied Energy |
| 2 | Public Acceptance and Risk-benefit Perception of $CO_2$ Geological Storage for Global Warming Mitigation in Japan | K. Tokushige, K. Akimoto<br>T. Tomoda | Mitigation and Adaptation Strategies for Global Change |
| 3 | Costs and Technology Role for Different Levels of $CO_2$ Concentration Stabilization | K. Akimoto, T. Tomoda | Avoiding Dangerours Climate Change |

■2005 Oral Presentaion

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Costs and Technology Role for Different Levels of $CO_2$ Concentration Stabilization | K. Akimoto, T. Tomoda | International Scientific Symposium: Avoiding Dangerous Climate Change<br>1-3, February 2005 |
| 2 | A multi-regional and multi-sectoral energy-economic model for the assessment of the carbon emission reduction policy | T. Homma, S. Mori<br>K. Akimoto, H. Yamamoto<br>T. Kosugi, T. Tomoda | 28th Annual IAEE International Conference<br>4-6, June 2005 |
| 3 | Development of a multi-regional and multi-sectoral energy-economic model for climate policy assessments | T. Homma, S. Mori<br>K. Akimoto, H. Yamamoto<br>T. Kosugi, T. Tomoda | 8th Annual Conference on Global Economic Analysis<br>9-11, June 2005 |
| 4 | Analysis of subsidy effectiveness for renewables considering technology learning | F. Sano, K. Akimoto<br>T. Homma, T. Tomoda | The 28th Annual IAEE International Conference<br>5, June 2005 |
| 5 | Development of a Dynamic Energy-economic Assessment Model with Multi-regions and Multi-sectors for the Evaluation of the Carbon Emission Reduction Policy | T. Homma, S. Mori<br>K. Akimoto, T. Tomoda | International Energy Workshop (IEW) 2005<br>7, July 2005 |
| 6 | Evaluation of various international schemes for climate change mitigation after Kyoto protocol | F. Sano, K. Akimoto<br>T. Homma, T. Tomoda | International Energy Workshop (IEW) 2005<br>6, July 2005 |

## Chemical Research Group

■2005 Original Paper

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | Adsorption of Carbon Dioxide on Aminosilane Modified Mesoporous Silica | N. Hiyoshi, K. Yogo, T. Yashima | Journal of the Japan Petroleum Institute. 48 (1), 29-36 (2005) |
| 2 | Adsorption Characteristics of Carbon Dioxide on Organically Functionalized SBA-15 | N. Hiyoshi, K. Yogo, T. Yashima | Microporous and Mesoporous Materials, 84 357-365.(2005) |
| 3 | $CO_2$ separation by membrane/absorption hybrid method | K. Okabe, M. Nakamura, H. Mano M. Teramoto, K. Yamada | Studies in Surface Science and Catalysis (in press) |
| 4 | $CO_2$ capture and enrichment by novel hollow fiber facilitated transport membrane module with low energy consumption | M. Teramoto, S. Kitada, S. Shimizu N. Ohnishi, H. Matsuyama N. Matsumiya, M. Nakamura K. Okabe, H. Mano | Greenhouse Gas Control Technologies, 2567-2571 (2005) |
| 5 | Oxygen separation properties of bis(phenyl)fluorene-based cardo polymer membranes | S. Kazama, T. Teramoto, K. Haraya | High Performance Polymers. 17 (1) 3-17 (2005) |
| 6 | Cardo Polyimide Membranes for $CO_2$ Capture | S. Kazama, S. Morimoto, S. Tanaka H. Mano, T. Yashima, K. Yamada K. Haraya | Greenhouse Gas Control Technologies Volume I Peer Reviewed Papers), 75-82 (2005) |
| 7 | Diesel Particulate Matter Removal Using DBD Pulsed Plasmas | S. Yao, K. Madokoro, C. Fushimi K. Yamada | Fourth International Conference on the Physics of Dusty Plasmas, ed. L. Boufendi, M. Mikikian, and P.K. Shukla, American Institute of Physics, 209-212(2005) |
| 8 | Stand biomass estimation method by canopy coverage for application to remote sensing in an arid area of Western Australia | H. Suganuma, Y. Abe, M. Taniguchi H. Tanouchi, H. Utsugi, T. Kojima K. Yamada | Forest Ecology and Management (in press) |

■2005 Oral Presentation

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Adsorption/desorption properties of carbon dioxide on aminosilane-modified mesoporous silica | K. Yogo, A. Thujimoto, Y. Sakamoto K. Yamada | Pacifichem 2005 December 19, 2005 |
| 2 | Inorganic and Organic membrane development | K. Yogo | Australia-JapanWorkshop – $CO_2$ Capture Enabling Technologies for Coal-fired Power Generation –, Australian Pavilion Aichi Expo Site, Nagoya September 16, 2005 |
| 3 | $CO_2$ separation by membrane/chemical absorption hybrid method | H. Mano | Australia-Japan Workshop, Australian Pavilion, Aichi Expo Site, Japan September 16, 2005 |
| 4 | $CO_2$ separation by membrane/absorption hybrid method | K. Okabe, M. Nakamura, H. Mano M. Teramoto, K. Yamada | ICOM 2005, Seoul,Korea August 21-26, 2005 |
| 5 | $CO_2$ separation by membrane/absorption hybrid method | K. Okabe, M. Nakamura, H. Mano M. Teramoto, K. Yamada | APCRE'05, Gyeongju, Korea June 12-15, 2005 |
| 6 | Development of a new chemical absorption system for $CO_2$ capture | K. Goto | The International $CO_2$ Capture Network (University of Texas, Austin Texas,USA) October 3, 2005 |
| 7 | Novel absorbents for removal of $CO_2$ from gas stream | K. Goto | Australia-Japan Workshop, Australian Pavilion, Aichi Expo Site, Japan September 16, 2005 |
| 8 | Polymeric $CO_2$ Separation Membrene for Mitigating Global Warming | S. Kazama, K. Yamada | Pacifichem 2005, 19, December, 2005 |
| 9 | Formation and Charaterization of Dendrimer Composite Membrane for $CO_2$ Separation | S. Duan, T. Kouketsu, S. Kazama K. Yamada, K. Nagai, B. D. Freeman | ICOM 2005, 21-26, August, 2005, Seoul, Korea |
| 10 | $CO_2$ Separation Membrane Of Modified PAMAM Dendrimer | F. A. Chowdhury, Y. Shimada, H. Oku S. Kazama, K. Yamada | ICOM 2005, 21-26, August, 2005, Seoul, Korea |
| 11 | Fundamental study on diesel particulate matter removal using a dielectric barrier discharge reactor | C. Fushimi, K. Madokoro, S. Yao K. Yamada | 6th Workshop on Fine Particle Plasmas, National Institute for Fusion Science, Toki, Japan December 16, 2005 |
| 12 | Kinetic Study of ZnO Carbonation | S. Yao, Y. Kashima, C. Mine K. Yamada | China/USA/Japan Joint Chemical Engineering Conference, Beijing October 12, 2005 |
| 13 | Diesel Particulate Matter Removal Using DBD Pulsed Plasmas | S. Yao, K. Madokoro, C. Fushimi K. Yamada | International Conference on the Physics DustyPlasmas, ICPDP 2005, Orleans, France June 17, 2005 |
| 14 | How to Promote an Afforestation Project as a $CO_2$ Sequestration Measure | K. Yamada | 8th International Conference on Desert Technology, Nasu, Japan November 27-December 2, 2005 |
| 15 | Death of Trees at Wheat Belt in Western Australia; Identification of its Causes by Chemical Analysis of Soil | H. Hamano, N. Saito, T. Kojima S. Kato, M. Saito, A. Kinnear K. Yamada | 8th International Conference on Desert Technology, Nasu, Japan November 27-December 2, 2005 |

| | Title | Researchers | Forum |
|---|---|---|---|
| 16 | Effect of Temperature and Light on Germination of 12 Afforested Trees in South Western Australia | S.Kawasaki, S.Kaneoya, H. Tanouchi, H. Hamano, T. Kojima K. Yamada | 8th International Conference on Desert Technology, Nasu, Japan November 27–December 2, 2005 |
| 17 | Soil mite (Acari) Assemblages in Early Stage Reafforested, Highly Degraded Semiarid Landscapes in Western Australia | A. Kinnear, P. Curry, T. Kojima K. Yamada | 8th International Conference on Desert Technology, Nasu, Japan November 27–December 2, 2005 |
| 18 | Litter and Soil Carbon Dynamics in Arid Forest Ecosystems and its Implication to Corbon Sequestration by Arid Land Afforestation | T. Kawanishi, S. Kumada, Y. Hayashi, K. Ogomori, Y. Kobayashi, N. Takahashi, M. Saito, H. Hamano, T. Kojima K. Yamada | 8th International Conference on Desert Technology, Nasu, Japan November 27–December 2, 2005 |
| 19 | A Modeling Methodology of Large Scale Water Balance and Salt Accumulation for Afforestation in Arid Land | T. Hirukawa, N. Asaka, H. Hamano K. Yamada, T. Kojima | 8th International Conference on Desert Technology, Nasu, Japan November 27–December 2, 2005 |
| 20 | Stand Growth Estimation of an Afforestation and Natural Forests in Arid Land of Western Australia | K. Shiono, H. Suganuma, Y. Abe H. Tanouchi, H. Utsugi, M. Saito N. Takahashi, T. Kojima, K. Yamada | 8th International Conference on Desert Technology, Nasu, Japan November 27–December 2, 2005 |
| 21 | Development of Tree Growth Simulator based on a Process Model of Photosynthesis for Eucalyptus camaldulensis in arid land | Y. Egashira, M. Shibata, K. Ueyama H. Utsugi, T. Kojima N. Takahashi, S. Kawarasaki K. Yamada | 8th International Conference on Desert Technology, Nasu, Japan November 27–December 2, 2005 |
| 22 | Vegetation Limiting Factors as Salt Accumulation and Soil Thickness in Leonora Western Australia | M. Saito, H. Tanouchi, T. Saito D. Naito, Y. Abe, K. Yamada | 8th International Conference on Desert Technology, Nasu, Japan November 27–December 2, 2005 |
| 23 | Water Use Efficiency of the Trees in Arid Lands –The Plasticity for Fluctuation of Water Conditions— | H. Tanouchi, H. Utsugi, N. Takahashi H. Hamano, S. Kawarasaki, T. Kojima K. Yamada | 8th International Conference on Desert Technology, Nasu, Japan November 27–December 2, 2005 |
| 24 | Effects of Calcined Bauxite as a Water-holding Material and a Way of Mixing it with Soil on Tree Growth | N. Takahashi, H. Hamamo, Y. Abe T. Kojima, K. Yamada | 8th International Conference on Desert Technology, Nasu, Japan November 27–December 2, 2005 |

■2005 Non-Journal Publication

| | Title | Researchers | Magazine, Newspaper, etc. |
|---|---|---|---|
| 1 | Mineral carbonation and industrial uses of carbon dioxide | M. Mazzotti, J. C. Abandades R. Allam, K. S. Lackner F. Meunier, E.. Rubin J. C. Sanchez, K. Yogo R. Zevenhoven | "IPCC Special Report on Carbon Dioxide Capture and Storage: Chapter 7, IPCC, Cambridge University Press (2005). |

## $CO_2$ Sequestration Research Group

■2005 Original Paper [$CO_2$ Geological Storage Project]

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | FIELD TEST OF $CO_2$ INJECTION IN NAGAOKA, JAPAN | Katsuhiko Kikuta, Seiji Hongo, Daiji Tanase and Takashi Ohsumi | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P1367-1372,5-9 September 2004,Vancouver,Canada (printed in 2005) |
| 2 | DOES CARBON DIOXIDE REMAIN DISSOLVED IN AQUIFER? | Ikuo Okamoto, Ziqiu Xue and Takashi Ohsumi | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P2195-2198,5-9 September 2004,Vancouver,Canada (printed in 2005) |
| 3 | COAL MATRIX SWELLING CAUSED BY ADSORPTION OF CARBON DIOXIDE AND ITS IMPACT ON PERMEABILITY | Ziqiu Xue and Takashi Ohsumi | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P2253-2256,5-9 September 2004,Vancouver,Canada (printed in 2005) |
| 4 | EFFECTS OF BEDDING PLANE ON $CO_2$ MIGRATION AND DEFORMATION STRAIN IN WATER-SATURATED POROUS SANDSTONE | Ziqiu Xue and Takashi Ohsumi | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P2203-2206,5-9 September 2004,Vancouver,Canada (printed in 2005) |
| 5 | NUMERICAL SIMULATIONS OF THE INJECTION AND MIGRATION BEHAVIOR OF CARBON DIOXIDE | Yukio Imaseki, Takashi Ohsumi, Toshimasa Tomoda, Motoo Uno, and Hiroshi Ohkuma | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P2181-2184,5-9 September 2004,Vancouver,Canada (printed in 2005) |
| 6 | $CO_2$ SEQUESTRATION INTO GEOTHERMAL FIELDS | Akira Ueda, Tatsuya Yajima, Hideshi Kaieda and Takashi Ohsumi | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P2007-2010,5-9 September 2004,Vancouver,Canada (printed in 2005) |
| 7 | EXPERIMENTAL STUDY REGARDING PUBLIC PERCEPTION OF $CO_2$ UNDERGROUND SEQUESTRATION TECHNOLOGIES | Motoo Uno, Yasuko Mori and Yoko Endo | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P2481-2484,5-9 September 2004,Vancouver,Canada (printed in 2005) |
| 8 | EXPLORATION OF PUBLIC ACCEPTANCE REGARDING $CO_2$ UNDERGROUND SEQUESTRATION TECHNOLOGIES | Motoo Uno, Yasuko Mori, Kohko Tokushige & Akira Furukawa | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P1705-1710,5-9 September 2004,Vancouver,Canada (printed in 2005) |

■2005 Original Paper [$CO_2$ Ocean Sequestration Project]

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | OCEAN UPTAKE POTENTIAL FOR CARBON DIOXIDE SEQUESTRATION | Masao Sorai and Takashi Ohsumi | Geochemical Journal, Vol.39,No.1,29-43, 2005 |
| 2 | EVALUATION OF BENEFITS OF $CO_2$ OCEAN SEQUESTRATION | Koji Tokimatsu, Masao Sorai, Yoichi Kaya, Michimasa Magi and Takashi Ohsumi | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P773-781,5-9 September 2004, Vancouver,Canada (printed in 2005) |
| 3 | BIOLOGICAL IMPACT ASSESSMENT OF DIRECT $CO_2$ INJECTION INTO THE OCEAN | Jun Kita and Takashi Ohsumi | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P783-789,5-9 September 2004, Vancouver,Canada (printed in 2005) |
| 4 | $CO_2$ RELEASE IN DEEP OCEAN BY MOVING SHIP | Junichi Minamiura, Hideyuki Suzuki, Baixin Chen, Masahiro Nishio and Masahiko Ozaki | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P809-817,5-9 September 2004, Vancouver,Canada (printed in 2005) |
| 5 | A LAGRANGIAN METHOD COMBINED WITH HIGH RESOLUTION OCEAN GENERAL CIRCULATION MODEL TO EVALUATE $CO_2$ OCEAN SEQUESTRATION | Yoshio Masuda, Yasuhiro Yamanaka, Taketo Hashioka, Michimasa Magi, Shigeo Murai and Takashi Ohsumi | Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,P819-827,5-9 September 2004, Vancouver,Canada (printed in 2005) |

■2005 Oral Presentation [$CO_2$ Geological Storage Project]

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Geophysical Monitoring of $CO_2$ Sequestration at an Onshore Saline Aquifer in Nagaoka, Japan | Daiji Tanase, Ziqiu Xue, Hiroyuki Azuma | 2nd Monitoring Network Meeting of IEA, October 2005 |
| 2 | Pilot Test of $CO_2$ Injection in Nagaoka, Japan | Daiji Tanase, Hiroshi Okuma, Hideki Saito | $CO_2$Store Group Steering Committee Meeting, October 2005 |
| 3 | Time-lapse Cross-well Seismic Tomography for the Monitoring of $CO_2$ | Hideki Saito, Dai Nobuoka, Daiji Tanase | $CO_2$Store Group Steering Committee Meeting, October 2005 |
| 4 | Simulation Study of Pilot$CO_2$ Injection in Iwanohara, Nagaoka City, Japan | Hiroshi Okuma | $CO_2$Store Group Steering Committee Meeting, October 2005 |
| 5 | Development of Simulator for Geological $CO_2$ Sequestration | Hiroshi Okuma | $CO_2$Store Group Steering Committee Meeting, October 2005 |

| | Title | Researchers | Forum |
|---|---|---|---|
| 6 | An Overview of the Nagaoka Project in Japan | Masanori Abe, Ziqiu Xue, Keigo Akimoto, Daiji Tanase, Yasunobu Mizuno | Society of Petroleum Engineers-Applied Technology Workshop, November 2005 |
| 7 | Time-lapse crosswell seismic tomography and well logging to monitor the injected $CO_2$ in an onshore aquifer, Nagaoka , Japan | Ziqiu Xue, Daiji Tanase, Dai Nobuoka | SEG International Exposition, November 2005 |
| 8 | $CO_2$ monitoring at the pilot-scale $CO_2$ injection site in Nagaoka, Japan | Daiji Tanase, Ziqiu Xue, Hideki Saito | 2005 AGU Fall Meeting, December 2005 |
| 9 | The effects of $CO_2$ injection on the geomechanical behavior of Australian brown coal:Uniaxial testing | Ziqiu Xue | Alaska Rocks 2005, June 2005 |

■2005 Oral Presentation [$CO_2$ Ocean Sequestration Project]

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Numerical Simulation of Mortality of Zooplankton Caused by Direct Injection of Carbon Dioxide in the Ocean | Toru Sato、Yuji Watanabe、Koji Toyota | 4th annual conference on carbon capture & sequestration,2-5 May 2005, Alexandria,Virginia |
| 2 | Trophic structure determination of the deep-sea copepods in the South Western Pacific by the stable isotope analysis | Haruko Kurihara, Saeko Mito, Jun Kita | The 9th International Conference on Copepoda, July 2005 |
| 3 | Japan program for $CO_2$ sequestration | Takashi Ohsumi | Seminar on Sub-sea $CO_2$ storage technical challenges, risk and environmental aspects, September 2005,Oslo |
| 4 | Advances in Japanese Project on $CO_2$ ocean storage | Jun Kita | Seminar on Sub-sea $CO_2$ storage technical challenges, risk and environmental aspects, September 2005,Oslo |

■2005 Non-Journal Publication [$CO_2$ Ocean Sequestration Project]

| | Title | Researchers | Magazine, Newspaper, etc. |
|---|---|---|---|
| 1 | Extended probit mortality model for zooplankton against transient change of $PCO_2$ | Toru Sato, Yuji Watanabe, Koji Toyota Joji Ishizaka | Marine Pollution Bulletin, April 2005 submitted |

## Plant Research Group

■2005 Paper

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | Cyclic electron flow around PSI is essential for photosynthesis | Y. Munekage, M. Hashimoto<br>C. Miyake, K. Tomizawa, T. Endo<br>M. Tasaka, T.Shikanai, | Nature 429: 579–582 |
| 2 | Response of Cyclic Electron Flow around PSI (CEF–PSI) to $CO_2$ in Tobacco Leaves–Electron flux ratio in PSI to PSII Determined the Magnitude of Non–Photochemical Quenching (NPQ) of Chl Fluorescence | C. Miyake, M. Miyata<br>Y. Shinzaki, K. Tomizawa | Plant Cell Physiol (in press) |
| 3 | Enhancement of cyclic electron flow around PSI at high light and its contribution to the induction of non–photochemical quenching (NPQ) of Chl fluorescence in intact leaves of tobacco plants | C. Miyake, Y. Shinzaki, M. Miyata<br>K. Tomizawa | Plant Cell Physiol. 45: 1426–1433 |
| 4 | Isolation of Intact Vacuoles and Proteomic Analysis of Tonoplast from Suspension–Cultured Cells of *Arabidopsis thaliana* | T. Shimaoka, M. Ohnishi, T. Sazuka<br>N. Mitsuhashi, I. Hara, K. Shimazaki<br>M. Maeshima, A. Yokota,<br>K. Tomizawa, T. Mimura | Plant Cell Physiol., Jun 2004; 45: 672–683 |
| 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<br>H. Yamamoto, H. Hayashi<br>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<br>Y. Shinzaki, M. Nishioka, S. Kitajima<br>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<br>H. Deguchi | Bryologist submitted |

## Microbiology Research Group

■2005 Original Paper

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | Multiple large segment deletion method for *Corynebacterium glutamicum*. | N. Suzuki, H. Nonaka, Y. Tsuge, S. Okayama, M. Inui and H. Yukawa | Appl. Microbiol. Biotechnol. 69: 151–61. 2005 |
| 2 | New multiple deletion method for *Corynebacterium glutamicum* genome using a mutant *lox* sequence. | N. Suzuki, H. Nonaka, Y. Tsuge, M. Inui and H. Yukawa | Appl. Environ. Microbiol. 71: 8472–80. 2005 |
| 3 | Manipulating Corynebacteria from Individual Genes to Chromosomes | A.A. Vertès, M. Inui and H. Yukawa, | Appl. Environ. Microbiol. 71: 7633–42. 2005 |
| 4 | Enhanced hydrogen production from formic acid by formate hydrogen lyase–overexpressing *Escherichia coli* strain. | A. Yoshida, T. Nishimura, H. Kawaguchi, M. Inui and H. Yukawa | Appl. Environ. Microbiol. 71: 6762–8. 2005 |
| 5 | Production of organic acids by *Corynebacterium glutamicum* under oxygen deprivation. | S.Okino, M. Inui and H. Yukawa | Appl. Microbiol. Biotechnol. 68: 475–80. 2005 |
| 6 | Anaerobic degradation of aromatic compounds by *Magnetospirillum* strains: isolation and degradation genes. | Y. Shinoda, J. Akagi, Y. Uchihashi, A. Hiraishi, H. Yukawa, H. Yurimoto, Y. Sakai and N. Kato | Biosci. Biotechnol. Biochem. 69: 1483–91. 2005 |
| 7 | Degradation of corn fiber by *Clostridium cellulovorans* cellulases and hemicellulases and contribution of scaffolding protein, CbpA. | R. Koukiekolo, H–Y. Cho, A. Kosugi, M. Inui, H. Yukawa and R.H. Doi. | Appl. Environ. Microbiol. 71: 3504–11. 2005 |
| 8 | Molecular cloning and transcriptional and expression analysis of *engO*, encoding a new noncellulosomal family 9 enzyme from *Clostridium cellulovorans*. | S.O. Han, H. Yukawa, M. Inui and R.H. Doi. | J. Bacteriol. 187: 4884–9. 2005 |
| 9 | Large scale engineering of the *Corynebacterium glutamicum* genome. | N. Suzuki, S. Okayama, H. Nonaka, Y. Tsuge, M. Inui and H. Yukawa. | Appl. Environ. Microbiol. 71: 3369–72. 2005 |
| 10 | Effect of carbon source on the cellulosomal subpopulations of *Clostridium cellulovorans*. | S.O. Han, H. Yukawa, M. Inui and R.H. Doi. | Microbiology. 151: 1491–7. 2005 |
| 11 | Cre/*loxP* mediated deletion system for large genome rearrangements in *Corynebacterium glutamicum*. | N. Suzuki, Y. Tsuge, M. Inui and H. Yukawa. | Appl. Microbiol. Biotechnol. 67: 225–33. 2005 |
| 12 | A new insertion sequence, IS*14999*, from *Corynebacterium glutamicum*. | Y. Tsuge, K. Ninomiya, N. Suzuki, M. Inui and H. Yukawa. | Microbiology. 151: 501–8. 2005 |
| 13 | Isolation and characterization of a native composite transposon, Tn*14751*, carrying 17.4 kilobases of *Corynebacterium glutamicum* chromosomal DNA. | M. Inui, Y. Tsuge, N. Suzuki, A.A. Vertès and H. Yukawa. | Appl. Environ. Microbiol. 71: 407–16. 2005 |
| 14 | Metabolic engineering of *Corynebacterium glutamicum* for fuel ethanol production under oxygen–deprivation conditions. | M. Inui, H. Kawaguchi, S. Murakami, A.A. Vertès and H. Yukawa. | J. Mol. Microbiol. Biotechnol. 8: 243–254. 2004 |
| 15 | *Corynebacterium glutamicum* glyceraldehyde–3–phosphate dehydrogenase isoforms with opposite, ATP–dependent regulation. | C.A. Omumasaba, N. Okai, M. Inui and H. Yukawa. | J. Mol. Microbiol. Biotechnol. 8: 91–103. 2004 |

■2005 Oral Presentation

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Growth–Arrested Microbial Cells as Whole–Cell Biocatalysts: a New Paradigm for Efficient Production in Biorefinery Complexes | Alain A. Vertès, Masayuki Inui, and Hideaki Yukawa | 14th European Biomass Conference and Exhibition、October 2005 |
| 2 | Biohydrogen Production for Commercialization | Alain A. Vertès, Masayuki Inui, and Hideaki Yukawa | 14th European Biomass Conference and Exhibition、October 2005 |
| 3 | The Energy Revolution: Technology for Ethanol Production | Alain A. Vertès and Hideaki Yukawa | Eastern Biofuels Conference & Expo II、September 2005 |
| 4 | Application of the RITE Bioprocess in Hydrogen Production | Hideaki Yukawa and Masayuki Inui | SIM Annual Meeting、August 2005 |
| 5 | Bio–refinery Technologies | Hideaki Yukawa | BioClusters Asia、July 2005 |
| 6 | Analysis of a new insertion sequence IS*14999* from *Corynebacterium glutamicum* | Yota Tsuge, Nobuaki Suzuki, Masayuki Inui, and Hideaki Yukawa | American Society for Microbiology 105th General Meeting、June 2005 |
| 7 | Novel large segment deletion method for *Corynebacterium glutamicum* in which multiple deletions are possible | Nobuaki Suzuki, Yota Tsuge, Satoshi Okayama, Masayuki Inui, and Hideaki Yukawa | American Society for Microbiology 105th General Meeting、June 2005 |
| 8 | Development of a new bioprocess for organic acid production using *Corynebacterium glutamicum* | Shohei Okino , Hideo Kawaguchi, Masayuki Inui, Hideaki Yukawa | The 27th Symposium on Biotechnology for Fuels and Chemicals、May 2005 |

| | Title | Researchers | Forum |
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| 9 | Genome engineering and analysis for *Corynebacterium glutamicum* | Nobuaki Suzuki, Hiroshi Nonaka, Naoko Okai, Yota Tsuge, Masayuki Inui, Hideaki Yukawa | The 2nd Annual World Congress on Industrial Biotechnology and Bioprocessing、April 2005 |
| 10 | A novel bioprocess for the production of fuel ethanol and chemicals from lignocellulosic sugars | Masayuki Inui, Shohei Okino, Hideo Kawaguchi, Hideaki Yukawa | The 2nd Annual World Congress on Industrial Biotechnology and Bioprocessing、April 2005 |
| 11 | Biohydrogen Research and Development in Japan | Hideaki Yukawa, Masayuki Inui | The 2nd Annual World Congress on Industrial Biotechnology and Bioprocessing、April 2005 |
| 12 | High-efficiency hydrogen production from formate | Hideo Kawaguchi, Akihito Yoshida, Taku Nishimura, Masayuki Inui, Hideaki Yukawa | International Workshop on Biorefinery、February 2005 |
| 31 | A novel bioprocess for the production of fuel ethanol and chemicals from lignocellulosic sugars | Shohei Okino, Hideo Kawaguchi, Masayuki Inui, Hideaki Yukawa | International Workshop on Biorefinery、February 2005 |
| 32 | The complete genome sequence of *Corynebacterium glutamicum* R and the comparative genome analysis with other corynebacteria | Hiroshi Nonaka, Peter Kós, Naoko Okai, Masayuki Inui, Hideaki Yukawa | International Workshop on Biorefinery、February 2005 |
| 33 | The complete genome sequence of the anaerobic dehalorespiring *Desulfitobacterium* sp. Y51 | Hiroshi Nonaka, Yoshifumi Shinoda, Gabor Keresztes, Yuko Ikenaga, Miyuki Abe, Kae Naito, Kenichi Inatomi, Kensuke Furukawa, Masayuki Inui, Hideaki Yukawa | International Workshop on Biorefinery、February 2005 |
| 34 | The whole genome shotgun (WGS) sequencing of *Clostridium kluyveri* for efficient utilization of protein-derived biomass | Hiroshi Nonaka, Yoshifumi Shinoda, Yuko Ikenaga, Miyuki Abe, Masayuki Inui, Hideaki Yukawa | International Workshop on Biorefinery、February 2005 |
| 35 | Novel large segment deletion method for *Corynebacterium glutamicum* in which multiple deletions are possible | Nobuaki Suzuki, Hiroshi Nonaka, Yota Tsuge, Satoshi Okayama, Masayuki Inui, Hideaki Yukawa | International Workshop on Biorefinery、February 2005 |
| 36 | High throughput transposon-mediated mutagenesis and construction of disruptant library of *Corynebacterium glutamicum* | Nobuaki Suzuki, Naoko Okai, Hiroshi Nonaka, Yota Tsuge, Masayuki Inui, Hideaki Yukawa | International Workshop on Biorefinery、February 2005 |
| 37 | New Transposable Elements in *Corynebacterium glutamicum* | Yota Tsuge, Nobuaki Suzuki, Masayuki Inui, Hideaki Yukawa | International Workshop on Biorefinery、February 2005 |
| 38 | Transcriptome and proteome analysis of oxygen deprived metabolism in *Corynebacterium glutamicum* | Masako Suda, Yoshifumi Shinoda, Shikiko Murakami, Shohei Okino, Hiroshi Nonaka, Masayuki Inui, Hideaki Yukawa | International Workshop on Biorefinery、February 2005 |

■2005 Non-Journal Publication

| | Title | Researchers | Magazine, Newspaper, etc. |
|---|---|---|---|
| 1 | Vitamin Synthesis: Carotenoids, Biotin, and Pantothenate | G. Sandmann and H. Yukawa | Handbook of *Corynebacterium glutamicum* |

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