# RITE Today

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**Annual Report**

Research Institute of Innovative Technology for the Earth

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Research Institute of Innovative Technology for the Earth

## Let's Pursue Innovative Ideas

Yoichi Kaya, Director General,

Research Institute of Innovative Technology for the Earth

RITE was established in 1990, and will welcome its 20th Anniversary this year. The original objective of RITE is under the name of New Earth 21 project proposed by METI to develop technologies for reducing $CO_2$ emitted into the atmosphere substantially. Projects RITE launched at that time include hydrogen production from solar energy, $CO_2$ recycling system in which $CO_2$ produced in industries is transported to remote area, converted to methanol utilizing solar energy at that area and brought back by the same ship for $CO_2$ transport, and $CO_2$ fixation via sea algae. We frankly feel now they were a little too ambitious to be realized in practice.

Then after various trials we reached the three main projects we are conducting now. The first is CCS capturing $CO_2$ from flue gas and storing it into underground and else, the second conversion of cellulose into ethanol via bio-refinery, and the third quantitative system analysis of climate change and sustainable development. The first two deal with crucial technologies now and in near future. They have produced a number of remarkable outputs which made RITE well known in the world. The system analysis is the area RITE did few efforts at the starting stage. As response to climate change has been developed worldwide, however, RITE realized importance of integrated analysis of the matter, developed quantitative models and conducted analyses actively. Due to these efforts importance of RITE analyses became well known widely.

Then how about RITE research activities in future? Present projects are still going on and we naturally promote them further. In addition, RITE wish to develop other types of innovative technologies than those we are dealing with contributing to the realization of low carbon society. One of keys toward this end is secondary energy technology. We need in future various ways of utilizing renewable energy for decarbonizing energy, which inevitably require conversion of renewables into secondary energy. At present it may be electric power as in the cases of photovoltaics and wind power, ethanol as transport fuel as in the case of present RITE biotechnology project, and hydrogen as in the case of one of earlier RITE projects. We however still wonder whether there may be other types of useful secondary energy, and also other ways of converting primary energy into secondary one in substantially higher efficiency and/or lower cost. RITE always looks for any idea of such technologies and will promote breeding these technologies actively. We wish you to encourage and help us in these efforts.

# *Research Planning Group*

## Strategy and Roadmap on Innovative Technology for Drastic Reduction of $CO_2$ Emission

### 1. Introduction

A drastic reduction of global $CO_2$ emission by 50% level by 2050 is required to stop global warming. Efforts in several fields such as energy saving or alternating chlorofluorocarbon have already been done to reduce green house gas emission. But, $CO_2$ concentration in the air is still increasing. This fact shows that present activities are not enough for quitting global warming and building sustainable society. Thus, in addition to these efforts, we also have to develop fixation and effective utilization technologies of emitted $CO_2$ as possible mitigation options in future.

Among $CO_2$ fixation and effective utilization technologies, "IPCC Special Report on Carbon Dioxide Capture and Storage" described that carbon dioxide capture and storage (CCS) was one of key technology for global warming mitigation. Furthermore, in "the Cool Earth Energy Innovative Technology Plan" submitted by Japanese Government on March, 2008, CCS was selected one of prioritized innovative technologies for 50% cut in global $CO_2$ emission by 2050.

On considering these circumstances, RITE built up a technology strategy on "$CO_2$ fixation and effective utilization" in 2004 from medium- and long-termed viewpoint and rolls it up every year. METI also issued "Technology Strategic Roadmap 2009" on the basis of our investigation and some investigations in other fields. In this paper, I would like to introduce our "Technology Strategy Roadmap on $CO_2$ fixation and effective utilization"

### 2. Overview of $CO_2$ fixation and effective utilization technologies and prioritization

Among a variety of mitigation technologies of global warming, we focused on "$CO_2$ fixation and effective utilization technologies" which are main investigation fields of RITE and on which RITE are expected to draw up a strategy roadmap by METI. In energy field, the strategy roadmap on energy saving, fuel shift from fossil to non-fossil and sift to lower carbon fuels among fossil fuels was also planed to be drawn. Thus, we draw up roadmap only on innovative conversion and utilization technologies of biomass in this field.

Overview of $CO_2$ fixation and effective utilization technologies is shown in figure 1. There are two different groups of $CO_2$ emission sources. First group is a large concentrative emission sources such as power plants, iron and steel- making works etc. Another group is small sized but large number of scattered emission sources like automobiles and houses. For the first emission group, capture and storage (CCS) are most promising. Effective utilization after capturing $CO_2$ is also possible. However, capture from the second emission group is very costly, and thus absorption & fixation of emitted and diluted $CO_2$ by living matters such as trees or grasses is considered to be promising. Not-captured $CO_2$ from large emission sites are also included in this field. Sub-technologies for these two emission groups are also shown in the same figure.

$CO_2$ capture and storage (CCS): This technology is composed of $CO_2$ capture and injection into geological formations or ocean in order to store or sequester $CO_2$. For geological storage, deep saline aquifers, coal seams, depleted oil or gas fields are available and enhanced oil or gas recoveries (EOR, EGR) are also important. In ocean sequestration technology, dissolution & dilution (mobile or stationary type), and deep sea storage are available.

Effective utilization of $CO_2$: This technology converts $CO_2$ to useful materials through chemical or biological processes. It is composed of two technology groups, decomposition to carbon and conversion to chemicals.

Absorption & fixation of $CO_2$ using living matters: This technology can fix $CO_2$ using living matters. It is composed of three groups, terrestrial storage like large scale afforestation, fixation using marine plants, and fixation using fauna like coral reef. In terrestrial storage, conversion of stacked biomass to energy or chemical materials is included.

After evaluation of effectiveness as a $CO_2$ mitigation option, $CO_2$ reduction potential, rough estimate of current cost, and cost viability in 2030 of these technologies, technologies which are effective from both reduction potential and cost viewpoint and should be moved to implementation level were selected and detailed strategic scenarios and roadmaps were written on the following focused themes:

- CCS: Capture of $CO_2$, geological storage in deep saline aquifer, coal seem, and depleted oil & gas field, EOR, EGR, and ocean sequestration
- Terrestrial storage using large scale afforestation: Suitable evaluation method for $CO_2$ fixation, increase of $CO_2$ fixation per unit area, expansion of vegetation into arid area, vegetation expansion by industrial uses of plant materials, and innovative biomass utilization.

### 3. Strategy and roadmap on CCS

CCS is composed of capture and storage (geological or ocean) processes.

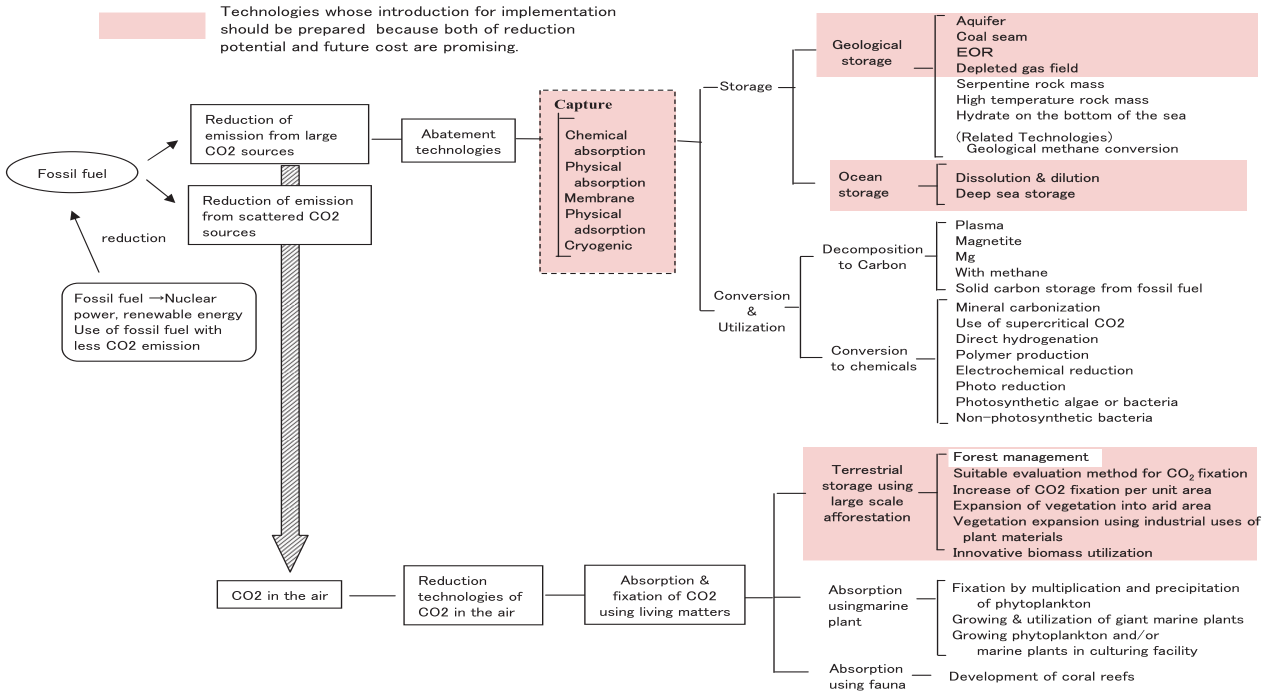



**Figure1 Technology Overview of $CO_2$ Fixation and effective $CO_2$ utilization**

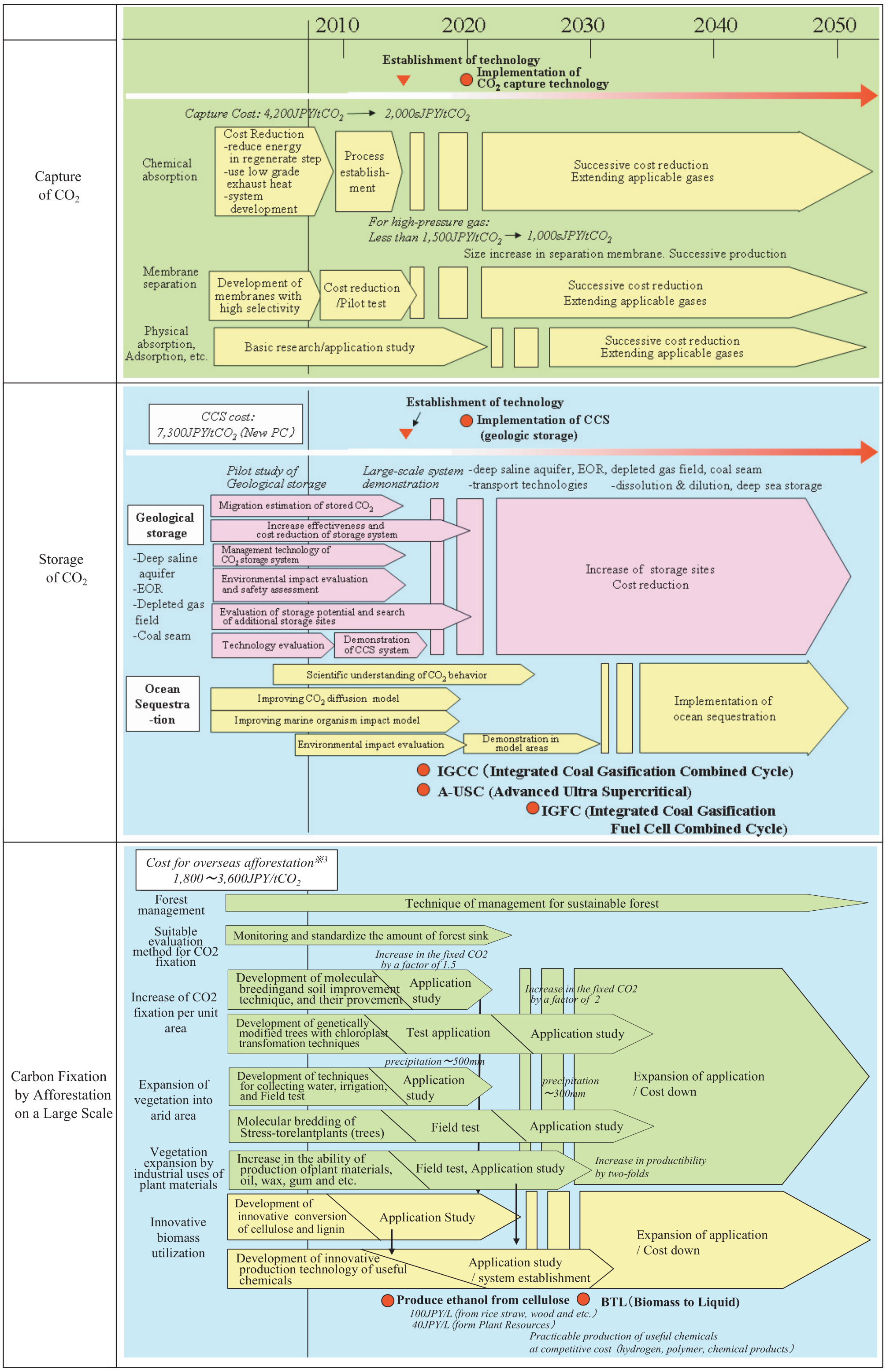
In capture process, target emission sites are power plants, iron & steel making plants, and cement works etc. As capture technologies for power plant, three processes, post-combustion for ordinary flue gas, pre-combustion for synthetic gas derived from partially fuel oxidation process like IGCC, and oxyfuel process in which fuel is oxidized by oxygen instead of air to produce flue gas with a high $CO_2$ concentration are known. Chemical absorption, physical absorption, membrane separation, adsorption, and cryogenic separation are available for separation technology of $CO_2$. Chemical absorption is promising for flue gases, and chemical absorption, physical absorption and membrane are adapted for pressured gas. Chemical absorption and physical absorption are already commercialized. But a drastic reduction in capture cost is required because cost reduction of CCS is required as a mitigation option of global warming. Current capture cost is high and estimated to be about 70% of total CCS cost. Reduction in energy consumption in capture process is another important aspect. Power plant with $CO_2$ capture requires 20-30 % additional energy compared to that without capture. To solve this problem, a lot of innovative low-energy capture processes have been investigated aggressively in the world on chemical absorption, physical absorption, membrane separation, and adsorption.

In another respect, development of capture process has to be synchronized with development of geological storage process. We have to complete the development of low energy and low cost capture processes before the start of implementation of geological storage. Purity of captured $CO_2$ is also restricted to be in the required level for geological storage.

RITE has been developing $CO_2$ storage or sequestration technologies. Ten thousand tons of $CO_2$ was injected into a saline aquifer in Nagaoka gas field, Niigata Prefecture. This injection experiment demonstrated safe storage of $CO_2$ in deep saline aquifer which is expected to be a most promising $CO_2$ reservoir in Japan. Injected $CO_2$ was monitored using several kind of monitoring techniques and numeric simulation to seek long-termed migration of $CO_2$ was examined. Besides, a lot of validity studies, including cost or potential evaluations, that confirmed CCS as a useful mitigation option in Japan, were carried out. Safety assessment and some other investigations on regulation and public acceptance were also done. On the basis of these investigations, issues to resolve before implementation of CCS were discussed in “CCS Study Group” formed by METI in fiscal year 2007 and large scale demonstrations were concluded to be necessary along with R&D on cost effective but safer CCS technologies and development of required regulations.

On the basis of above considerations, R&D strategy and roadmap on CCS were built up (figure 2).

**Figure 2 Strategic Technology Roadmap "CO2 fixation and effective $CO_2$ utilization"**




＊ $CO_2$ capture: New PC(830MW), Amount of CCS:1Mt-$CO_2$/yr, compression:7MPa, Steam extract from steam cycle of power plant

＊ Geological storage :Cost of $CO_2$ capture+pipeline transport 20km+injection (compression:15MPa, 0.1Mt-$CO_2$/yr/well)

＊ Afforestation: Afforestation cycle 7years(Cut down and sprout reafforestation), Biomass quantity of production 20m$^3$/hr/yr, Cost for afforestation management:17~31%, Cost of land lease:$50/hr·yr

Ocean sequestration is important technology having large reduction potential but it will take long time to build up international consensus to use it because biological impacts of $CO_2$ injection have not been clear. Thus, it is important to start the development of geological storage at first, which is going to be recognized a key technology for quitting global warming in the world. For example, a vigorous promotion of geologic storage was adopted in G8 summit and IEA, CSLF and other institutes clarified problems for implementation and made roadmaps for introducing CCS. These roadmaps in the world show that establishment of necessary technologies and regulatory framework are finished by around 2015. Thus, in our roadmap we also set the year of establishment of CCS technology in Japan in around 2015. By then, various validations or safety studies are necessary along with developments of CCS technologies including a large scale demonstration. On CCS regulations, the exsiting laws in Japan firstly should be considered and then, if necessary, new CCS regulatory frameworks should be established in accordance with international regulatory works like in London Convention. Especially, assignment of long-termed responsibility of stored $CO_2$ will have to be examined sufficiently. Besides, we also have to promote public understanding on CCS as early as possible. Meanwhile, we set the year of implementation of ocean sequestration in 2030. We have to accumulate more scientific knowledge and numerical simulation data on biological impacts by then.

Regarding capture, low energy and low cost technologies have to be completed by 2015 in harmony with the start of storage implementation. A drastic cost decrease is expected. The more capture cost decrease, the far reservoirs from emission site becomes economically available and then the storage potential becomes larger. Capture cost is plausible to be about two thousand yen in 2015 and 1000's yen/t-$CO_2$ is required as a final goal on considering emission trading price and competitiveness with foreign vendors. We have to develop innovative technologies to attain such cost targets and extend practical applications.

In accordance with this roadmap, Japan CCS Corp. which was the first company specialized in CCS, was established in 2008 and candidate sites for a large scale demonstration have been examined and conceptual design studies are being done now. Furthermore, safety and environmental issues that should be observed in implementing a large-scale CCS demonstration project in Japan were discussed in the CCS study group and the report titled "For safe operation of a CCS demonstration project" was issued in 2009. A large demonstration of CCS in Japan is being ready to start.

## 4. Strategy and roadmap on terrestrial storage using large scale afforestation

Terrestrial sequestration using large scale afforestation enables sequestration of emitted and diluted $CO_2$ in the air and should be developed together with biomass utilization. This is only technology capable of competing with CCS from a viewpoint of large decrease in $CO_2$ concentration in the air. For example in the US, the cost target for R&D of environmental forestation was set in 2008. Furthermore, development of ethanol or chemicals production from biomass becomes vigorous in the world. The US is most active and has some projects to build commercial plants.

Prior to implementation of terrestrial sequestration using large scale afforestation, technologies on selecting proper sites and type of plants, system evaluations such as water balance for forestation, environmental impact evaluations, and estimation of absorbing amount of $CO_2$ are required to be developed. In order to increase reduction potential of $CO_2$, increase of absorbing amount of $CO_2$ per unit area and expansion of vegetation into arid area are required. For preparing environment for promoting afforestation etc, consolidating regulatory framework, making standard of $CO_2$ monitoring, evaluating various advantages of forest and approving genetic recombination are pointed to be important. Biotic diversification is also a factor required to be considered. International cooperation such as co-development of innovative technologies, management cooperation to promote afforestation, and capacity building in advancing countries also should be undertaken.

In biomass utilization, efficient conversion technologies to energy or useful material and the technologies enabling to use wide variety of biomass species are important. Various kinds of chemicals are produced on the basis of petroleum platform now. Substitution of them for green chemicals from biomass is effective for cutting $CO_2$ emission and decrease of oil consumption, and thus we need innovative technologies which can convert biomass to useful chemicals effectively at lower cost. This stream from environmental afforestration to industrial use of biomass becomes world-wide paradigm shift.

Thus, we need to carry out R&D on increase of $CO_2$ fixation per unit area, vegetation expansion into arid area, and vegetation expansion using industrial uses of plant materials by 2010-2015. The year of technology combination between afforestation and biomass utilization is set in around 2020. Building up of wide variety of biomass utilization systems and large scale demonstrations are necessary by around 2030.

The roadmap in this field is also shown in figure 2. Targets and milestones are follows:

Increase of $CO_2$ fixation per unit area: First, application study of the technologies without genetic modification like molecular breeding and soil improvement should be started for earlier use. In technologies with genetic modification, we have to carry out R&D to attain the target of increasing $CO_2$ fixation by a factor of 2 and to ensure safety of genetic modified plants. On these technologies, test applications should be started from around 2015 before starting commercial applications in around 2030.

Expansion of vegetation into arid area: First, application study of technologies without genetic modification like collecting water, irrigation, and molecular breeding are to be started for earlier use. In technologies with genetic modification, we have to continue R&D on new species which can make industrial forestation under small precipitation conditions. The target is 500 mm in around 2020 and 300 mm in around 2030. We also have to ensure safety of genetic modified plants and carry out field test in around 2015 and finish commercial application by 2030.

Vegetation expansion in harmony with bio-energy utilization is composed of improving plants to produce more plant materials and innovative conversion and utilization technologies of biomass as follows:

Improving plants: Double production of energy materials like fatty oil and wax from plants is a target. Field demonstration and application study are to be started in around 2015

Innovative biomass conversion: Production of alcohol or other useful chemicals from sugar becomes in practical level now, but competition between energy utilization of corn or other grains and food production is pointed to be a problem. In order to avoid this, we have to choose cellulosic materials as a starting biomass. However, it becomes another problem that conventional saccharification of cellurosic materials is very costly. Thus, innovative saccharification techniques of cellurosic materials at low cost are strongly required. In the process of using cellurosic materials, lignin comes up as by-product. Especially, as woody materials contain much lignin, we have to consider the effective use of lignin. In the roadmap, it was described that basic R&D was to be completed by around 2010 and then application studies should be started.

Innovative biomass utilization: We need to develop highly effective and economical production technologies of fuels like alcohols, hydrogen and useful chemicals like polymers which are currently produced from petroleum. In around 2015, these utilization technologies are to be combined with innovative conversion technologies and application studies on coherent production systems from biomass to chemicals should be started.

The point of the coalition between large-scale afforestation and biomass utilization is set in around 2020. As small sized effective gas conversion system, liquid fuel production there, alcohol fermentation, innovative utilization systems described earlier are expected to be accomplished by then, we will be able to use the biomass grown by large scale afforestation. Total biomass utilization system including gathering and transportation should also be built up by then.

## 5. Conclusion

RITE publicizes this roadmap via the Internet, invites opinion from the public, and rolls up roadmap every year. Innovative technologies are required to stop global warming. We have to gather more knowledge and wisdom from universities, institutes, and companies etc. On the basis of these, purpose-fitting and effective developments and promotion of applications should be carried out. We wish that our roadmap contributes to such effective developments.

# *Systems Analysis Group*

## Development of Scenarios for Sustainable and Effective Measures against Climate Change

### 1. Introduction

The thirteenth Conference of the Parties (COP 13) took place in December 2007, in Bali, Indonesia and the negotiations resulted in the agreement of a two-year negotiating process, the Bali Roadmap, setting a deadline for the negotiations in Copenhagen to conclude the post 2012 framework on Climate Change. In the COP14 meeting held in Poznan, Poland, it is agreed that the contributions of Annex I parties to the scale of emission reductions should be informed by consideration of, inter alia, the analysis of the mitigation potential, commitment period, base year. In December 2009, the COP 15 was held in Copenhagen, Denmark. The Copenhagen Conference marked the culmination of a two-year negotiating process to enhance international climate change cooperation under the Bali Roadmap, and many world leaders attended the conference. There was concern that negotiations ended up being broken down, but political agreement entitled the "Copenhagen Accord" was taken note in the last minute. This event reminded us of the difficulty to enhanced action and international cooperation on climate change.

As Copenhagen approached most of major countries prepared to propose individual midterm reduction targets, inter alia quantified economy-wide emission targets for 2020. On Wednesday 10th June 2009, the Japanese former Prime Minister Taro Aso announced that Japan will cut greenhouse gas emissions by 15 percent from 2005 levels as its midterm target for 2020. After a change of government, Japan's new leader Yukio Hatoyama of the Democratic Party of Japan (DPJ), announced the revised Japan's mid-term target at the U.N. Climate Change Conference to be held on September 22 in New York. For its mid-term goal, Japan will aim to reduce its emissions by 25% by 2020, if compared to the 1990 level, on condition that a fair and effective international framework is established, in which all major economies participate.

The Systems Analysis Group has been conducting studies on the climate change, which include very complex and a wide range of issues, by using systematic approaches in order to gain a big picture with paying attention details. We've also made efforts to inform the public about our analysis correctly and contributed to the decision making process on setting midterm target in Japan as mentioned above by providing our scientific and rational research results.

In this paper, we would like to introduce our major analysis and their implications as a report of our research activities.

### 2. International comparisons of energy efficiency

Long term and global wide perspectives are essential to reduce carbon dioxide emissions steadily. There is usually a time lag between climate change and carbon dioxide emissions through human activities, addressing climate change with the long time scale is indispensable. Even if focusing on $CO_2$ reducing masseuses, plants and facilities for power sectors and energy-intensive industries usually have long lifetime, it is quite difficult to make a deep cut in the short or medium term, which leads to involve huge cost to achieve deeper cut. The changing global climate poses profound challenges to us. We need to take into consideration the timing of technological development and its implementation in order to reduce emissions effectively.

A global perspective is also crucial. There are huge gaps in energy efficiency across countries as shown in Figure 1. Countries with low energy efficiency are relatively easy to improve energy efficiency and have larger $CO_2$ emission reduction potentials. Taking effective measures with global perspective is necessary to fully realize emission reductions. Note that Figure 1 shows economy wide energy efficiency in aggregate form, so specific characteristics of national economy, such as industrial structure, are not considered. Manufacturing industries consume larger quantities of energy than non-manufacturing industries. Therefore, energy efficiency of a country like Japan with higher ratio of manufacturing in its economy may be biased.

Technology based efficiency is more significant to implement effective measures against global warming. To this end, precise assessment of energy efficiency on the basis of sector or even technology is necessary. We need detailed date for this analysis but international statistics is not necessarily well developed. Alternatively, better understanding of each sector helps our fair assessment of energy efficiency. Figure 2 shows energy efficiency in iron and steel sector across the countries. This results show Japanese steel sector is the most efficient in energy use. Most of countries, including China and India, have improved efficiency between 2000 and 2005 while some countries like Russia have became less efficient. This figure implies that there is still a lot of potential to reduce $CO_2$ emission globally through international technology cooperation.

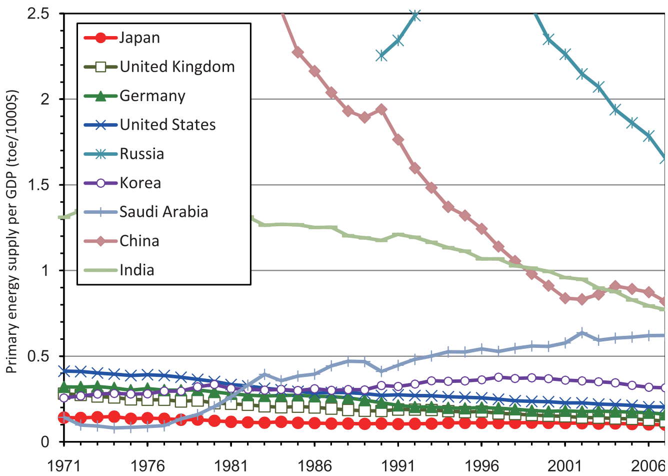



**Figure 1 Energy efficiency by country**

(Source) IEA Statistics

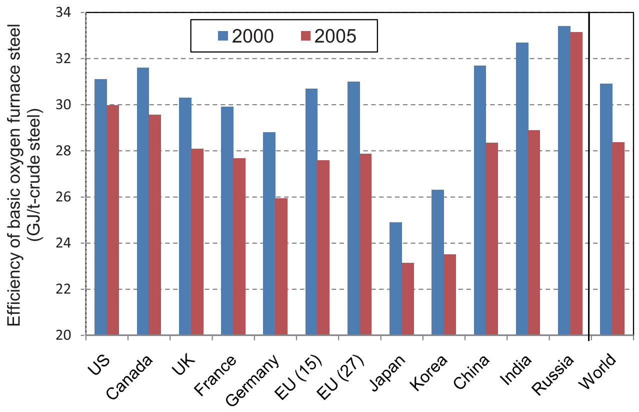



**Figure 2 Energy Efficiency in the Iron and Steel sector (BF-BOF process), 2000 and 2005**

(Source) RITE

## 3. Assessment / Analysis of Japan's midterm target and emission reduction targets around the world

The Systems Analysis Group has developed the high resolution DNE21+ model, in which various technologies to reduce $CO_2$ emissions in each sector are included. This model enables us to analyze emission reduction measures backed by technological practicability. This model is also capable of estimating mitigation costs on a global basis, which allows us to compare emission reduction target of each country. Our modeling results offer the basic data necessary for climate change negotiations domestically as well as internationally.

The Japanese government announced that by 2020 Japan will try to cut greenhouse gas emissions by 15 percent from 2005 levels as the midterm target. Overseas emission credits and the sink through forest sink were not counted in this target, which was supposed to achieve only domestic efforts. Incumbent prime minister Yukio Hatoyama of the DPJ announced the revised Japan's mid-term target to reduce its emissions by 25% by 2020, if compared to the 1990 level, on condition that a fair and effective international framework is established, in which all major economies participate. Overseas emission credits and the sink through forest sink are counted in this target. Note that we cannot make a simple comparison between these two targets because their assumptions are different. Comparatively speaking with the Kyoto's 2010 target, the former one reducing GHG emissions 15% below 2005 level (8% below 1990 level) should be compared with the figure of 0.6% below 1990 level (official target) or 3% above 1990 level (count out purchased emission credits by private sector). On the other hand, the latter target to reduce emissions by 25% below 1990 level should be compared with the Kyoto target, -6% for Japan. (Figure 3)

In any case, it is vital that we recognize how much it cost to achieve these goals and put them in a proper perspective in the context of global fairness and equitability. As a member of a team to investigate their validity for the government, RITE engaged with the project.

Figure 4 shows the marginal abatement cost (MAC) curves derived from the RITE model. The least cost solution involves implementation of all the measures at a price below the marginal cost shown in Figure 4. Given that Japan is an energy efficient country and the United States has large reduction potential partly because they are currently operating a lot of low efficient coal power plant, the shape of MAC curves are totally different, which imply Japan has less mitigation potential compared to the United States and the EU with the same cost.

If Japan try to achieve a target of 25% emission reduction below 1990 level in 2020 with only domestic efforts, the marginal abatement cost is estimated to be 476$/$tCO_2$, almost 10 times as much as the costs for the EU or the United States to achieve their respective targets. This huge cost gap will incur financial outflow from Japan not only to developing countries but also to the EU and the United Stated in order to purchase emission credits under the Kyoto mechanism. It also implies carbon leakage will occur, which does not to contribute to $CO_2$ emission reduction of the world as a whole.

All countries, at least all major developed economies, should make the same level of efforts to realize steady emission reduction in Japan and to contribute to global-wide emission reduction. Japan's salient target may be inappropriate from the global perspective. In addition to that, major emitters, even major developing country emitters, should have effective mitigation targets to some extent. Otherwise, we cannot ensure long-term sustainable efforts to combat climate change. Table 1 shows emission reduction targets, marginal abatement costs, and abatement costs per GDP of major countries pledged before the COP15 with baseline adjustment. In the "Copenhagen Accord", Annex I Parties are requested to submit individually or jointly the quantified economy-wide emissions targets for 2020 and Non-Annex I Parties are requested to submit their mitigation actions. Promotion of having ambitious targets for all Annex I countries and establishment a fair and effective international framework would be imperative to achieve the 25% emissions reduction target of Japan.

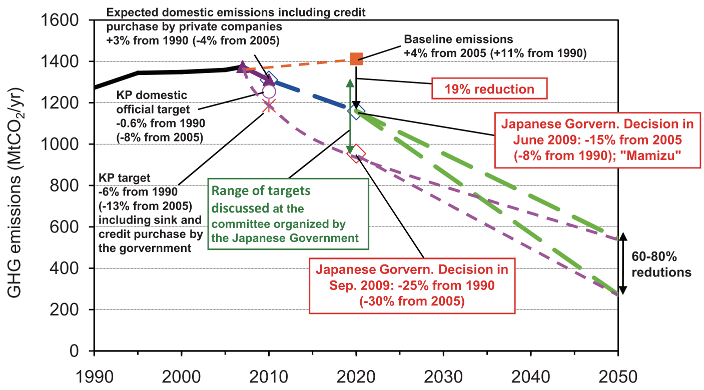



**Figure 3 Mid- and Long-term Emission in Japan**

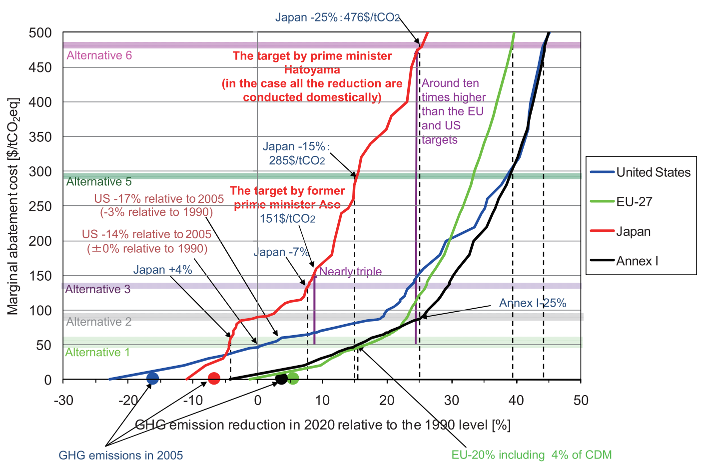



**Figure 4 Marginal Abatement Cost Curve by country, 2020**

(Source) RITE

Marginal Abatement Cost: Relationships between tons of emissions abated and the $CO_2$ price. A Metric of costs of complying with the target for reducing greenhouse gases.

## 4. For sustainable and effective measures against climate change

We only have ten years left by the year 2020. Within the time span, we need to implement existing technologies more widely and make steady development for innovative technologies. We have, however, various options to reduce GHG emissions in the long run. It would be possible to make deeper cut if we could enhance the solidarity of the international community over the issue of global warming. In conclusion, we would like to suggest three important points for sustainable and effective measures against climate change. First, a collaborative relationship among industry, government and academia and international cooperation would be essential to accelerate RD&D for innovative technologies, which drastically reduce cost and emissions. Second, we need to integrate various technologies, social infrastructure and social system, so that we can reduce costs substantially in a systematic manner. Our challenges are not limited to global warming, so we need to link climate change issues to other challenges in order to produce a better solution for maximizing social welfare. Finally, we need to change our society into an environmentally sustainable one in which measures taken against climate change could increase the utility of consumers, fostering greater environmental awareness. For this purpose, not only environmental education but also steady economic growth is crucial.

The Systems Analysis Group intends to continue precise analysis and review on measures to reduce carbon emissions, and would like to propose truly effective policy and measures for society against global warming, so that our research could help solve the problem confronting humankind ultimately.

**Table 1 Mid-term Targets by country**

| | Target | Target relative to 1990 | Target relative to 2005 | Marginal abatement cost [$/t$CO_2$] | Per-GDP Cost [%] |
|---|---|---|---|---|---|
| Japan | -25% relative to 1990 | -25% | -30% | 476 | 1.13 |
| EU | -20% – -30% relative to 1990 | -20% – -30% | -14%– -25% | 48–135 | 0.08–0.26 |
| United States | -17% relative to 2005 | -3% | -17% | 60 | 0.29 |
| Canada | -20% relative to 2006 | -3% | -22% | 111 | 0.43 |
| Australia | -5% – -25% relative to 2000 | +13% – -11% | -11% – -30% | 45–92 | 0.19–0.58 |
| Russia | -20% – -25% relative to 1990 | -20% – -25% | +17% – +25% | <$0/t$CO_2$ (Hot air) | |
| Annex I total[*1] | | -13% – -18% | -9% – -14% | 41–61 | 0.07–0.15 |
| *cf. Mitigation costs for –25% relative to 1990 in Annex I total* | *-25% relative to 1990* | *-25%* | *-22%* | *88*[*2] | *0.38*[*3] |
| Korea | -4% relative to 2005 | +80% | -4% | 21 | 0.16 |
| China[*4] | -40% – -45% for per-GDP emission relative to 2005 | +327% – +366% | +105% – +88% | <0 (Hot air) – 3 | <0 (Hot air)– 0.07 |
| India[*5] | -20% – -25% for per-GDP emission relative to 2005 | +344% – +373% | +142% – +127% | <$0/t$CO_2$ (Hot air) | |

[Notes for Table 1]

*1 Any target for aggregated Annex I countries is not proposed, but it is estimated here by aggregating the targets of countries in Annex I. The marginal abatement cost and the per-GDP cost are estimated assuming that the least cost measures are taken over the aggregated Annex I countries.

*2 The marginal abatement cost is estimated assuming the least cost measures over the aggregated Annex I countries, that is, the marginal costs are equal among all Annex I countries.

*3 The per-GDP costs are conditioned to be equal among all Annex I countries.

*4, *5 The targets of China and India are declared to be only for energy-related $CO_2$ emissions, and therefore, the estimation was considered accordingly.

# *Molecular Microbiology and Biotechnology Group*

## Global Trend of Biorefinery and Research Overview

### 1. Global trends and the Japanese situation

Since world energy demand has been increasing every year, we have to make efforts for a reduction of greenhouse gas emissions and realize a sustainable and low-carbon society to prevent global warming. In this respect, recent heightened interest in renewable resources including solar, wind, and biomass can help address the overdependence on fossil fuels that is the primary driver of adverse climate change. With regard to biomass, growing plants sequester $CO_2$ and release it only when they burn, contributing no net changes in atmospheric $CO_2$. A biorefinery concept, proposed to use biomass in place of fossil fuels in future energy production systems, can facilitate environmentally-friendly commercial production of chemicals and biofuels.

Soaring grain prices in 2008 were blamed on the diversion of food crops to bioethanol production in the U.S., attracting attention at the 2008 G8 Hokkaido Toyako Summit. A consequent global economic downturn triggered a steep decline in crude oil prices, with severe adverse effects on the economic performance of the U.S. bioethanol industry in 2009. Nonetheless, with the "Green New Deal" program of the incoming Obama administration, financial support for biorefinery development through the Stephen Chu-headed U.S. Department of Energy (DOE) was enhanced.

The 2007 U.S. Renewable Fuel Standard (RFS2) program, targets an annual production of 36 billion gallons of renewable biofuels by 2022. Considering that the 2009 U.S. bioethanol production of 10.5 billion gallons consumed as much as 30% of total U.S. corn produced that year, diversification into non-food and cellulosic biomass resources is imperative. Though no firm targets are set yet, the RFS2 roadmap calls for production of up to 100 million gallons of cellulosic ethanol by 2010. Accordingly, the DOE and U.S. Department of Agriculture (USDA) allocated $564 million of Recovery Act funds to spur 19 biorefinery projects in cellulosic ethanol plants, power from biomass feedstock, biodiesel plants, etc, in 15 states. Moreover, the U.S. Environmental Protection Agency (EPA) has mulled increasing the arbitrary ratio of ethanol blended in gasoline from E10 to E15 (15% ethanol to 85% gasoline). This has been an incentive for the several commercial-scale (over 10 million gallons per year) cellulosic ethanol plants that are scheduled to go on line in the U.S. after 2010.

In contrast to the U.S. counterpart, the European biofuels industry is dominated by biodiesel made from rapeseed oil. The European Union (EU) Biofuels Directive 2003/30/EC that came into effect in 2003 to encourage less dependence on crude oil has resulted in half of all new car sales in Europe being powered by diesel. The Directive set a reference value for a market share of biofuels at 5.75% by the end of 2010, although each country sets its own national target. Nonetheless, the EU is a net importer of biodiesel since its domestic productivity cannot meet demand (ca. 8M ton). Inevitably issues concerning environmental degradation and competition with food oils in biodiesel-exporting countries have surfaced. The coming into force of the Euro 6 standard in 2014 is projected to trigger an increase in the price of new cars, with a concomitant increase in bioethanol production in 5 to 10 years' time.

In Japan, the government set an annual target of 500,000 KL bioethanol by 2010, and demonstration plants constructed in Hokkaido have been operating since last year. The plants have a combined annual capacity of 10,000 to 30,000 KL utilizing non-standard wheat or sugar beet as feedstocks. With regard to cellulosic ethanol, a few small-scale pilot plants are now getting online in Japan. Thus Japan lags other developed countries in the biorefinery field, however, the incoming administration is committed to huge reductions in greenhouse gas emissions and wants to raise the proportion of renewable energy in the primary energy supply to as much as 10% by 2020. Further support of the government is expected for the development of technologies in the biorefinery field.

### 2. Research activities

We aim to develop an efficient biomass utilization technology based on the characteristics coryneform bacteria. The process was named "Growth-arrested bioprocess (RITE Bioprocess) " , and it has so far enabled elevated productivities in organic acids and biofuels. It is a global pioneer technology for simultaneous utilization of mixed sugars from cellulosic biomass in biorefinery settings. In collaboration with Honda Motor Company, we applied it in a production system of ethanol from cellulosic biomass, earning the Grand Prize at the 18th Nikkei Global Environment Award (see RITE Today 2009). The key to the high productivities of the process lies largely in its separation of microbial growth from production of target compound. This property enables productivities, expressed as space-time-yield (STY), that so much exceeds those of conventional bioprocesses as to be comparable to those of chemical processes. The Growth-arrested bioprocess therefore continues to receive much interest from both domestic and international industry players.

## 3. Future development

Production of green chemicals as well as biofuels derived from non-food biomass is a core technology for the reduction of GHG emission and achievement of a low-carbon society (Figure 1). The targeted green chemicals include commodity plastics such as polypropylenes, engineering plastic, special polymer like carbon fibers, etc. Japanese makers producing these special polymers command a sizable share of the world market. If these chemicals are produced from cellulosic biomass and used as materials or parts, they will help boost competitiveness of Japanese industry. Major foreign chemical companies such as DuPont and Dow Chemical also plan to produce the green chemicals as a core business, and have already started research and development.

We are developing technology for the production of biofuels and green chemicals from non-food cellulosic biomass resources by using the novel "Growth-arrested bioprocess" . In the process, mixed sugars (C5 and C6 sugars) derived from cellulosic biomass are utilized simultaneously and converted to biofuels or platform chemicals, then they are modified to the targeted green chemicals by using suitable chemical processes. To develop technologies for the production of biofuels and green chemicals, we hope to carry out collaborative research with industry in the future.

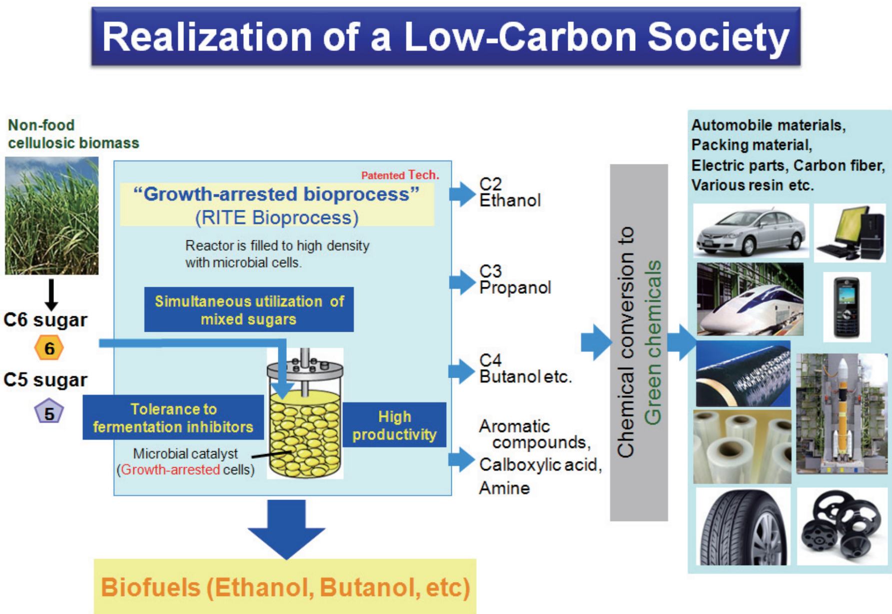



**Figure 1** Application of "Growth-arrested bioprocess" in the biorefinery field to achieve a low carbon society

# Chemical Research Group

## Our Challenges for Efficient and Industrializing $CO_2$ Capture Technologies

Discussions about a new global framework to reduce $CO_2$ emission is progressing, because China and India addressed the target of $CO_2$ reduction. The economical issue that advanced countries and developing countries how to invest $CO_2$ reduction in future is tough choices. We think that economical countermeasures will help the finding the coincidence answer in countries.

CCS ($CO_2$ capture and storage) will be one of economical promising countermeasure. It is estimated that the cost of $CO_2$ capture from $CO_2$ source s is about 60 % of the total cost of CCS, so the reduction of $CO_2$ capture cost for CCS is important for CCS deployment.

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. Then, there are various $CO_2$ capture technologies such as chemical absorption, physical absorption, membrane separation, and the oxy-fuel method. Progress in these technologies will result in the best combination between fuel conversion processes and $CO_2$ capture processes, so we should technically pursue the $CO_2$ capture technology that have the highest economic benefits in future on the basic view of Fig. 1. Our chemical research group studies on various $CO_2$ capture technologies, with a special focus on chemical absorption and membrane separation methods. We accomplished COCS Project of which target was reduction of $CO_2$ capture cost in ironworks by chemical absorption that had developed innovative chemical absorbent to reduce the $CO_2$ capture cost for flue gas in an ironworks to 3000 JPY/ton-$CO_2$. We continue to develop a chemical absorbent to reduce this $CO_2$ capture cost to 2000 JPY/ton-$CO_2$. Moreover, we started the collaboration with foreign institutes.

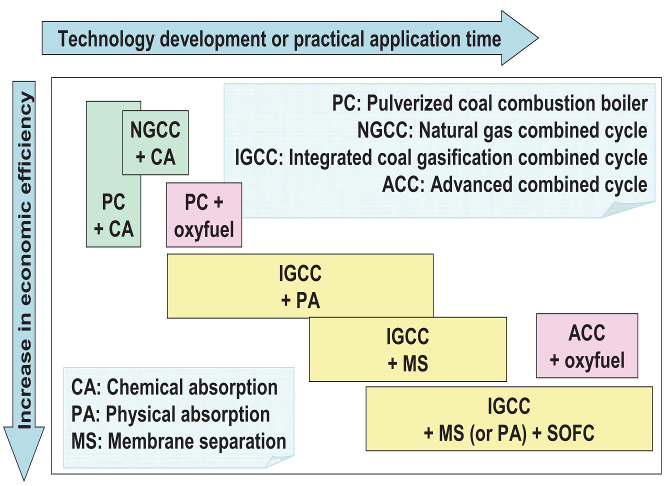



Fig.1 Vision of power plant and $CO_2$ capture

Next is about our membrane. We have discovered an excellent membrane material for the separation of $CO_2$ from $H_2$-containing gas. We are engaged in the development of the structure of a new membrane composed of this material and are developing the membrane module in order to demonstrate with practical coal gasification gas.

Reentry we find two unique materials for $CO_2$ capture under high pressures. One material is chemical absorbent and the others are adsorbent. We try to evaluate the performance of the process with those materials now.

Above all, we are developing not only innovative technologies for foundation for next generation technologies but also practical and acceptable technologies for the industries on the view of evaluating various new technologies world widely.

### Development on $CO_2$ capture technology by 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 Fig. 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 $CO_2$.

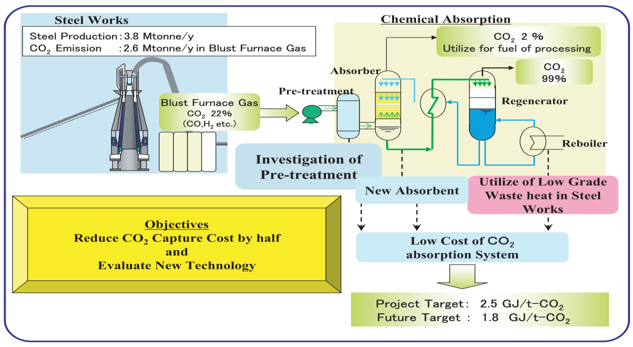



Fig.2 The Outline of cost saving $CO_2$ capture system (COCS project)

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.

As a first step for the screening and development of new absorbents, 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's samples of commercial amine solvents selected were analyzed using laboratory apparatus. Furthermore, compound amine solutions, that can compensate for deficiencies in the amines, were prepared and their performance was investigated.

From these investigations, several type of high performance absorbents (RITE-3,4 series), that showed different characteristics, were developed. In succession, new absorbents (RITE-5,6 series) has been developed through the basis of our experimental database and theoretical design of molecular structure of new amine compounds using the quantum analysis approach. As the result of bench-scale test, the energy for $CO_2$ capture of the best of these absorbents is estimated to be 2.5 [GJ/tonne-$CO_2$]. This value is very low compared to the 4.0 [GJ/tonne-$CO_2$] for a standard MEA (mono-ethanol amine) solution, so we have confirmed the accomplishment of the project target (Fig. 3).

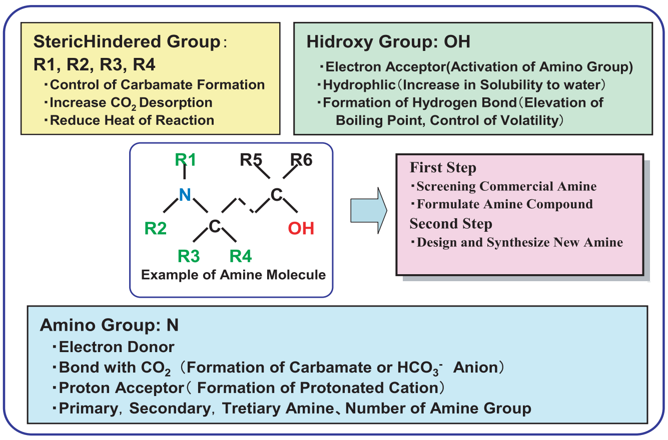



**Fig.3 Development of new absorbents**

The fruits of this project has succeeded to a new project of "COURSE 50" aiming at a drastic reduction of $CO_2$ emission in an integrated steel works. A development of new absorbents with a higher performance and application study by pilot-scale plant is scheduled hereafter.

Furthermore, based on the current knowledge on $CO_2$ absorbents, a development on new absorbents suitable for high pressure gas stream has also been carried out since 2007. In general, amine solvents can easily react with $CO_2$ under atmospheric pressure condition independent of reaction temperature. But we have confirmed that some amine solvents , nevertheless they do not react under atmospheric pressure, react with $CO_2$ depending on reaction temperature under high pressure condition (Fig. 4). We have proposed a new $CO_2$ capture system in pressurized point sources of $CO_2$ with these absorbents.

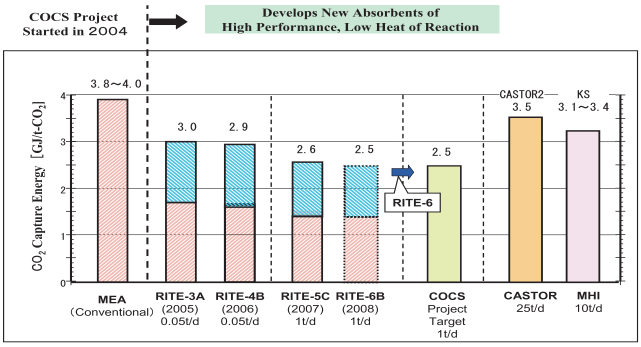



**Fig.4 Reduction of $CO_2$ capture energy by new absorbents**

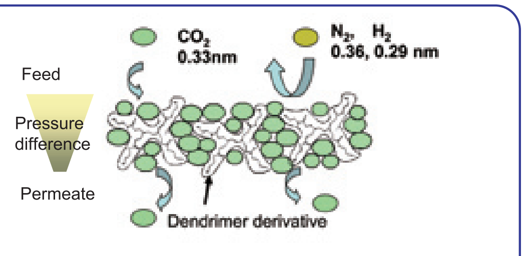
The second step of the project has also been carried out, in which new types of amine compounds, designed and prepared based on the current knowledge, are evaluated by a similar method. Furthermore, research on the optimum conditions for the chemical absorption system has been carried out, so that the 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.

## $CO_2$ and $H_2$ separation with a polymeric membrane

Japan's government has declared the reduction of $CO_2$ emission to half by 2005 as "Cool Earth 50". One promising means of dimidiating $CO_2$ emission is the development of an integrated coal gasification combined cycle with $CO_2$ capture & storage (IGCC-CCS). In the process of IGCC-CCS, $CO_2$ separation membranes will play an important role of reducing $CO_2$ capture cost. The cost estimates indicate that $CO_2$ capture cost from the pressurized gas stream with a membrane might be 1500 JPY/t-$CO_2$ or less.

We are currently developing a $CO_2$ molecular gate membrane with the goal of producing a new, high-performance separation membrane. Fig. 5 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 RITE dendrimer having excellent $CO_2/H_2$ selectivity is fixed stably in a cross-linked polymer matrix to form the separation membrane. Fig. 6

shows conceptual diagram of the PAMAM dendrimer incorporated material and its $CO_2/H_2$ separation properties along with the data reported in Science and others. Our PAMAM dendrimer incorporated material shows the world largest $CO_2/H_2$ selectivity of 30 or more.




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.

**Fig.5 Conceptual diagram for the $CO_2$ molecular gate**

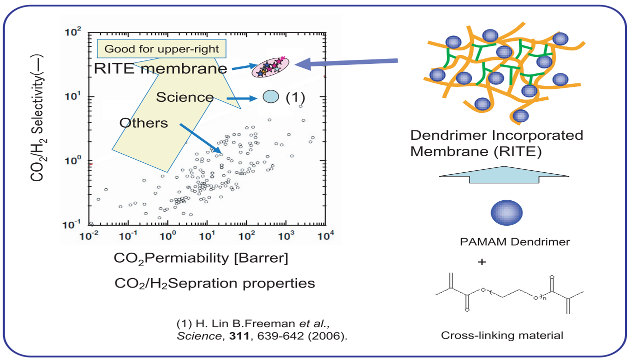



**Fig.6 Dendrimer incorporated membrane and its performance**

In developing the commercial membrane module with the PAMAM dendrimer incorporated material, RITE involves recently four major membrane companies, Daicel Chemical Industries, Ltd, Kuraray Co., Ltd., Nitto Denko Corporation, and Toray Industries. Fig. 7 shows conceptual module designs of the membrane, hollow fiber type and spiral wound type. RITE and Nippon Steel Engineering Co., Ltd. will test the trial membrane modules with newly developed simulator and demonstrate the availability of the membrane module for capturing $CO_2$ from a pressurized gas stream such as coal gasification.

In developing this $CO_2$ molecular gate membrane, the RITE conducted joint research with many foreign partners such as the US Department of Energy's National Energy Technology Laboratory (NETL) as a recognized project of the Carbon Sequestration Leadership Forum (CSLF), University of Texas at Austin and Norwegian University of Science and Technology.

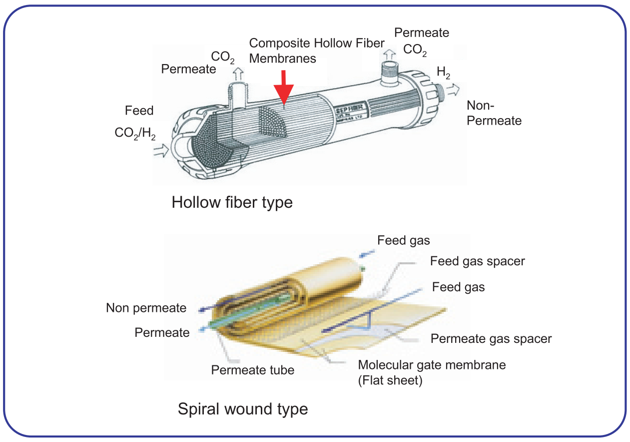



**Fig.7 Conceptual module design**

## Advanced $CO_2/H_2$ separation materials incorporating active functional agents (GCEP)

The RITE had conducted the developmental work "Sub-nano structure controlled materials: development of innovative gas separation membranes" from the Global Climate and Energy Project (GCEP) of Stanford University, USA. In a succeeding project, advanced $CO_2/H_2$ separation materials incorporating active functional agents is on going.

In the theme of advanced $CO_2/H_2$ separation materials incorporating active functional agents, supercritical and subcritical $CO_2$ works as a structure directing agent of $CO_2$ affinity materials. Fig. 8 shows the schematic image of the concept. Excellent $CO_2$ separation membrane will be obtained by strict morphology regulation in molecule scale. In the figure, supercritical $CO_2$ regulates the $CO_2$ affinity materials of membrane material in the preferable morphology for $CO_2$ permeation (State A). After removing supercritical $CO_2$, the preferable morphology would be held to form an excellent $CO_2$ separation membrane.

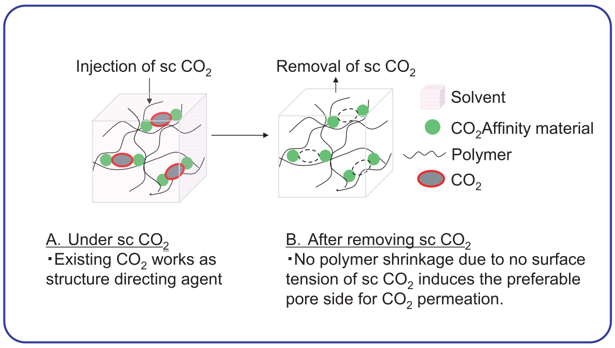



**Fig.8 Concept of supercritical(sc) $CO_2$ structure directing method**

## Development of an energy-saving $CO_2$-PSA process using hydrophobic adsorbents

In this project, newly prepared hydrophobic adsorbents have been proposed as $CO_2$ adsorbents for the separation of $CO_2$ from high pressure gas. They can overcome such obstacles to adsorption processes. Hydrophobic adsorbents have an advantage over traditional adsorbents such as activated carbon and zeolites because they can adsorb $CO_2$ in the presence of water vapour, which is usually present in flue gases from fossil fuel combustion. Furthermore, vacuum pump can be eliminated for the adsorption process from high pressure gas.

$CO_2$ adsorption capacities of 13X zeolite and newly synthesized adsorbents were shown in Fig. 9. It was confirmed that the adsorbent synthesized in our study had a hydrophobic property and adsorbed considerable amounts of $CO_2$ under high $CO_2$ pressure. It was also confirmed they adsorbed $CO_2$ even in the presence of water vapor.

From the $CO_2$ separation experiment using $CO_2$-$N_2$ and $CO_2$-$H_2$ mixed gas flow, it was confirmed that the new adsorbent was effective for the $CO_2$ separation from the gas flow in the presence of water vapor. Evaluation of the process cost is now in progress using two tower type continuous adsorption-separation experimental apparatus.

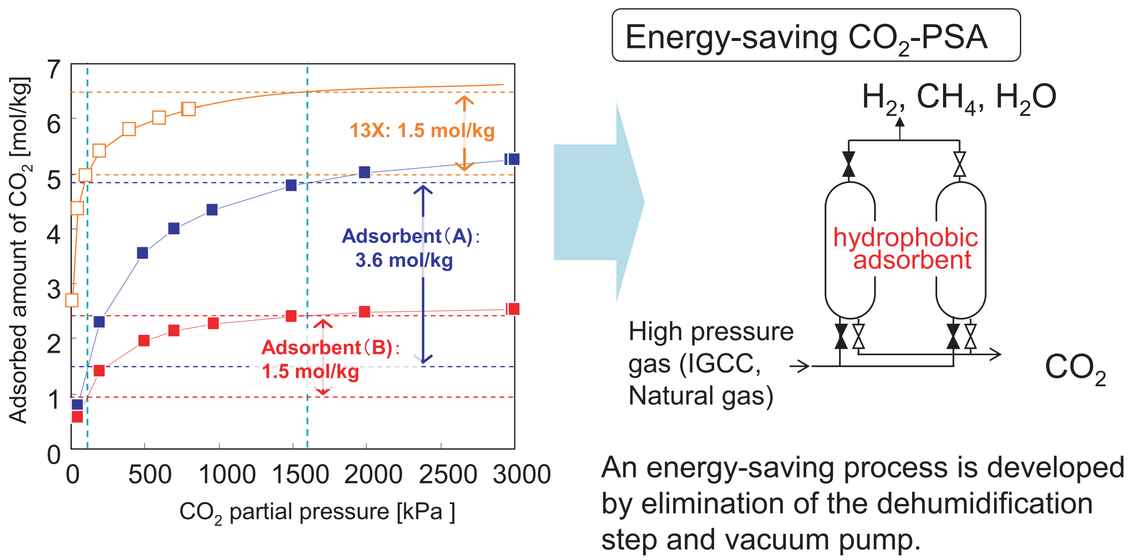



**Fig.9 Development of an energy-saving $CO_2$-PSA process using hydrophobic adsorbents**

# $CO_2$ Storage Research Group

## $CO_2$ Storage Technology Development for Practical Application

### $CO_2$ Geological Storage Project

The $CO_2$ geological storage technology is a technology for safely and securely trapping $CO_2$, a greenhouse gas, into subsurfaces instead of releasing it into the atmosphere. There are various methods for storage, including EOR, which injects $CO_2$ into depleted oil fields and recovers the enhanced oil; isolation of $CO_2$ in depleted gas fields; ECBM, which injects $CO_2$ in coal seams and recovers methane; and $CO_2$ storage in highly porous sandstone aquifers containing formation water.

RITE has been working on geological storage, which enables stable $CO_2$ storage over long periods because there is a gas- and water-impermeable sealing layer on top of the aquifer where $CO_2$ is stored. Since the technology of underground natural gas storage can be applied, this method is thought to be the most immediately effective and closest to practical use.

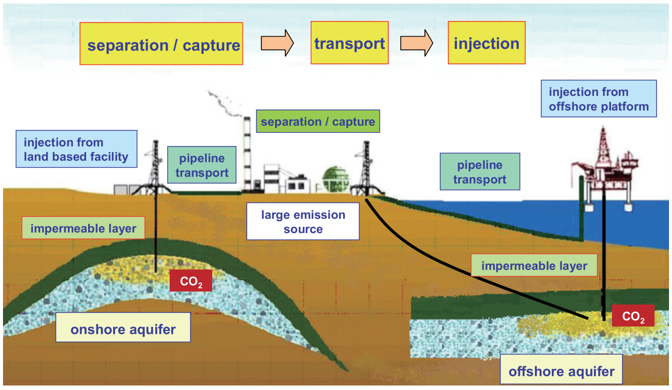



Fig.1 Concept of $CO_2$ geological storage

"R&D project of $CO_2$ Geological Storage Technology" supported by METI was launched in 2000 to scientifically verify the feasibility of $CO_2$ storage in subsurface aquifers in Japan, focusing on its effectiveness as global warming countermeasures. In particular, for the $CO_2$ injection demonstration test conducted at the test site in Nagaoka City, Niigata Prefecture, 10,400 tons of $CO_2$ were injected in the aquifer of 1,100m depth below the ground during the period from July 2003 to January 2005. The underground behavior of $CO_2$ was observed by cross-well seismic tomography and well loggings, and a behavior prediction simulator was developed, based on the observation data. In 2007, we measured the behavior of stored $CO_2$ in the reservoir using several monitoring techniques, and it was clear that the $CO_2$ had been kept safely stored in the aquifer.

The passable possibility of the implementation of geological storage in Japan was indicated by the $CO_2$ injection demonstration test in Nagaoka for eight years.



Fig.2 Nagaoka demonstration test site

RITE has supported large-scale demonstrations of $CO_2$ geological storage since 2008. Since there is a strong possibility that reservoirs under sea bottom are the place for $CO_2$ geological storage in the future in Japan, we need to develop new fundamental technologies such as monitoring methodology etc.

RITE has been working on evaluation of $CO_2$ storage performance, $CO_2$ behavior evaluation in reservoirs and monitoring technologies of long-term $CO_2$ behavior in reservoirs. In the evaluation of $CO_2$ storage performance, we have researched the development of geological structure analysis methodology and the evaluation technology of $CO_2$ storage amount to prove a stable $CO_2$ geological storage. In the $CO_2$ behavior evaluation in reservoirs, we have studied the monitoring technology of $CO_2$ behavior such as a seismic survey, its alternative monitoring technologies and the $CO_2$ behavior prediction technology including model simulation. In the monitoring technologies of long-term $CO_2$ behavior in reservoirs, we have advanced the analysis of $CO_2$ storage mechanism in reservoirs and the development of low-cost long-term monitoring technologies. Moreover, we have conducted the elastic wave measurement using rock core samples and the threshold pressure measurement for safety of the cap rock as a fundamental study supporting some technical issues of the $CO_2$ geological storage.

We intend to research and develop the technical issues found out in the large-scale demonstrations in progress and to work aiming at commercialization of $CO_2$ geological storage in the future.

## IZEC (International Zero Emission Coal) Project

Fossil fuels account for approximately 80% of global energy sources and the long-term use of coal is expected in the future. Clean coal power generation in particular attracts a lot of attention. From the perspective of global warming, the combination of high-efficiency coal power generation technology and CCS technology that separates, captures, and stores the $CO_2$ emitted from high-efficiency coal power plants receives attention and has been developed in the world.

As such combined technologies, Post-Combustion, Oxy-Fuel and Pre-Combustion are specified (See Fig.3). At present, many zero emission coal power generation projects such as FutureGen in U.S. are planned all over the world.

In Japan, some plans such as “Innovative Zero Emission Coal Gasification Generation Project” supervised by NEDO have also started.

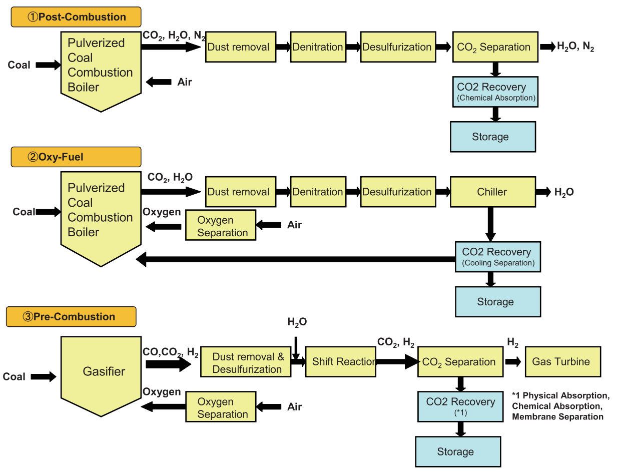



**Fig.3 Process of Zero Emission Coal Power Generation**

To demonstrate zero emission, consolidation of a broad range of technologies and strong financial resources are required. Thus, investigating the current status of zero emission coal power generation projects all over the world from viewpoints of both technology and development, and promoting and enlightening public awareness of the zero emission coal power generation are of great significance in considering our comprehensive implementation strategy for its practical use in Japan.

Reflecting the above, RITE has conducted IZEC (International Zero Emission Coal) project since FY 2007. The major subjects are (1) Collecting and sorting information regarding zero emission coal power generation projects all over the world; (2) Collecting and sorting information regarding zero emission/CCS initiatives of the nations concerned and international organizations; (3) Promoting and enlightening public awareness of zero emission coal power generation through operating “IZEC Symposium”, “IZEC Forum” and so on.

We are conducting the current status surveys of more than 48 demonstration and pilot projects mostly in EU, U.S. and Australia. Furthermore, we have investigated the initiatives, policies and strategies of EU, Britain, Norway, Holland, Germany, U.S., Canada, Australia and so on. In FY 2009, we conducted a survey on the current status and criteria of capture ready especially in Britain and Germany.

For propagation and enlightenment, we have prepared a web site for IZEC and update the databases of the International Zero Emission Coal projects, the initiatives in the world, the current status of clean coal in each nation and so on. In addition, we will hold “IZEC Forum” which informs the related industry of the collected information and “IZEC Symposium” which invites representatives of projects overseas.

Through these activities, our objective is to contribute to determine comprehensive strategy for the practical use of zero emission coal power generation in Japan.

## China CCS-EOR Project

CCS, the technology to capture and store $CO_2$ from fossil fuel, is essential as the countermeasures against global warming until 2100. In particular, CCS-EOR (Enhanced Oil Recovery) which can bring commercial advantage of increased oil production is expected to be realized at early stage.

In the United States, CCS-EOR which utilizes natural $CO_2$ has already been developed in a 60 million-ton scale a year. Moreover, its application to the coal-fired power stations which emit a large amount of $CO_2$ is expected.

In the recent years, the amount of $CO_2$ emission in China has been increasing and becomes the largest in the world. Japan also emits a large amount of $CO_2$ which corresponds to the 4th largest. Therefore, the cooperation between China and Japan in CCS-EOR study has a very significant meaning from the viewpoint of global warming prevention internationally.

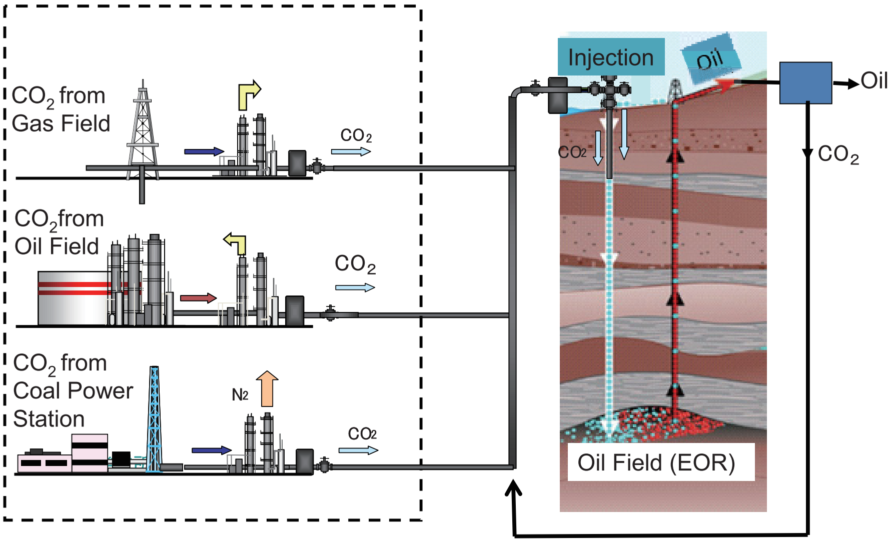
RITE has started technical exchanges including CCS-EOR, energy conservation, environmental preservation and GHG reduction with China National Petroleum Corporation (CNPC). This year, we held CCS-EOR Workshop at Beijing in September and exchanged the technical knowledge shown below:

- $CO_2$ Capture Technology (Chemical Absorption, Physical Absorption and Membrane

Separation)
- $CO_2$ Storage Basic Research
- $CO_2$ Monitoring
- $CO_2$ Simulation
- EOR
- Total System

We also sent researchers to China and exchanged technical knowledge of CT scan application in the $CO_2$ storage basic research.

From now on, we will carry forward technical exchanges and implement the practicability study of CCS-EOR based on the technical exchange results, so as to contribute realization of low-carbon society and ensure energy security.




CCS-EOR: Achievement of both Huge $CO_2$ Storage and Increasing Oil Production

Fig4. Outline of CCS-EOR

## Symposium on Innovative Environmental Technologies

Research Planning Group

Symposium on Innovative Environmental Technologies was held November 4, 2009 at Mielparque-Kyoto supported by Minister of Economy, Trade and Industry (METI), Kyoto Prefecture and Kinki Regional Countermeasure Promotion Meeting on Energy and Global Warming, attended by 245 delegates from various field including industry, academia and government.

The advanced information on $CO_2$ fixation and effective $CO_2$ utilization were presented by researchers from RITE and other institutions to provide the importance of environmental technologies and the strategies of developing technologies. Active discussion was carried out among the participants to expand the collaboration with industry and academia, and to contribute to devise the Technology Strategy Map.

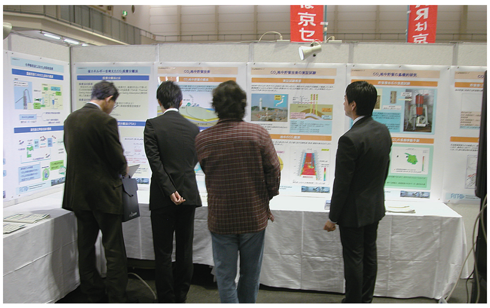
## Kyoto Eco Festival

Research Planning Group

RITE participated in “Kyoto Eco Festival 2009” held in Pulse Plaza on November 21 and 22, 2009 to present how RITE has dedicated to the mitigation of global warming and to promote understanding of its activities to the public.

“Kyoto Eco Festival” is held every year and the exhibitors are from NPO, educational institutions and private sectors based in Kyoto. Each exhibition was designed to enjoy, experience and learn environmental issue and technologies. “Kyoto Eco Festival 2009” attracted 28,000 visitors in two days.

RITE exhibited posters about its research activities and a model of $CO_2$ geological storage. A video on $CO_2$ geological storage was also shown to the visitors during the period.



## IIASA-RITE International Symposium 2009

Systems Analysis Group

The IIASA-RITE International Symposium 2009 was held at Keidanren-Kaikan in Tokyo on March 3rd, 2009. This symposium was co-hosted by the International Institute for Applied Systems Analysis (IIASA), the Japan Committee for IIASA, and the Research Institute of Innovative Technology for the Earth (RITE) with support from the Ministry of Economy, Trade and Industry, Japan (METI).

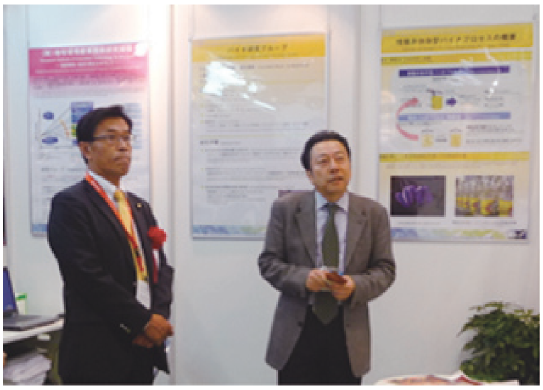
We are honored to have a variety of leading experts in the field of climate change and energy issues, including Prof. Winterfeldt, the new director of the IIASA, Prof. Nakicenovic and Dr. Amann from the IIASA, Prof. Misono, the president of the National Institute of Technology Evaluation (NITE), and Mr. Sugiyama, Senior researcher of the Central Research Institute of the Electric Power Industry (CRIEPI). They introduced latest research developments and discussed how to create a sustainable social economy and exchange views on necessary measures.

We had an attendance of 230 people, such as participants from industries, ministries, and universities, leading people to build a sustainable social economy and individuals who commit themselves to environmental issues locally. Their active discussion motivated us to dedicate further efforts to our research and development.


## Many Visitors to BioJapan2009 (World Business Forum)

Molecular Microbiology and Biotechnology Group

World Business Forum organized by BioJapan Organizing Committee and Nikkei Business Publications Inc. was held at Pacifico Yokohama from October 7 to October 9, 2009. Director, Dr. Hideaki Yukawa moderated the seminar of Biorefinery summit [Energy /Chemicals production from sustainable biomass]. We also displayed the highly efficient bio-conversion technology, 'RITE-Bioprocess', along with posters and a video presentation, which allowed to introduce our group activity. Also our collaborative companies joined the exhibition and their panels were displayed in the same booth. We would like to take this opportunity to express our thanks for coming to BioJapan2009. We are planning to give a presentation and exhibition this year too, and we hope to show our latest works at the next BioJapan.



**Mr. Chiaki Takahashi, left, parliamentary secretary of Minister of Economy, Trade and Industry, stopped by our exhibition booth.**

**RITE exhibition booth in BioJapan 2009.**

# CSIRO-RITE Science & Technology Symposium -Amines for Post Combustion Capture-

Chemical Research Group

The CSIRO-RITE Science & Technology Symposium -Amines for Post Combustion Capture- was held at the Kyoto International Conference Center on May 26 (Tue), 2009.

This symposium was co-hosted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Research Institute of Innovative Technology for the Earth (RITE), under the auspices of the Australian government.

The symposium ended in a great success with 121 participants from the Australian Embassy, Tokyo, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the New Energy and Industrial Technology Development Organization (NEDO), as well as universities and private companies from around the world.

The following speakers delivered lectures to participating experts on the subject of research & development results of amine-based $CO_2$ capture technologies and the current performance assessments of pilot plants in the world:

-Professor Gary Rochelle (The University of Texas, the United States)

-Professor Akira Miyamoto (Tohoku University, Japan)

-Professor Hallvard Svendsen (Norwegian University of Science and Technology, Norway)

-Professor Paitoon Tontiwachwuthikul (University of Regina, Canada)

-Mr. Cai Ming (Thermal Power Research Institute, China)

Researchers of CSIRO and RITE also provided lectures, helping participants increase the understanding of amines exhibiting higher $CO_2$ capture capacity. For further details on the symposium, please visit the "Events" page of RITE's website.


Kyoto International Conference Center

# International Zero Emission Coal-fired Generation IZEC Symposium 2009

$CO_2$ Storage Research Group

The IZEC symposium 2009 -International Zero Emission Coal-fired Generation- was held at Hotel Pacific Tokyo on 19th November 2009. This symposium was supported by Ministry of Economy, Trade and Industry, Agency for Natural Resources and Energy, New Energy and Industrial Technology Development Organization, and Japan Coal Energy Center.

Measures against $CO_2$ issues are required that Coal-fired generation keep playing a role of major source of electricity in the future; CCS (Carbon dioxide Capture and Storage) has a key role.

Stakeholders are invited from European Commission, the regulatory agency of EU member nations, suppliers of power generating plant, and so forth for this symposium.

The current status of CCS was introduced as well as the status of FutureGen project promoted by US DOE and the activities of GCCSI (Global CCS Institute) which received attention as the promotion of CCS by Australian government.

The effort for supporting the CCS demonstration project networks in EU was introduced. Carbon Capture Readiness (CCR, a way to address the practical issues that will enable CCS facilities to be installed at a later date) regulated by the U.K. government ahead of the EU Directive on CCS was explained that it is valuable preliminary step towards CCS in order to avoid “carbon lock-in”. Additionally, suppliers in EU provided a detailed explanation of technical development on CCS demonstration projects including CCR.


IZEC Symposium, Hotel Pacific Tokyo

## 4th Japan-China Energy Conservation Forum

$CO_2$ Storage Research Group

On November 8th 2009, 4th Japan-China Energy Conservation Forum was held at Beijing Great Hall of the People hosted by the Ministry of Economy, Trade and Industry (METI) and the Japan-China Economic Association together with the National Development and Reform Commission (NDRC) and the Ministry of Commerce of the People's Republic of China gathering round 500 related persons from Japan and China respectively.

On the Overall meeting, after speeches were made by Masayuki Naoshima, Minister of METI, Akio Mimura, Vice President of the Japan-China Economic Association, Li Keqiang, Vice Premier of People's Republic of China, Xie Zhenhua, Vice Chairman of NDRC and so on, exchange of 41 Agreement Documents regarding Japan- China energy conservation and environmental cooperation were carried out successfully. Agreement of Japan-China CCS-EOR cooperation between RITE and International Department of China National Petroleum Corporation was included in 41 Agreements.

Moreover, fruitful discussion was made on the seven section meetings of top- runner system, economic circulation, conversion of sea water into fresh water, automobiles, power generation/coal, chemicals and long term trade.


**Agreement Document Exchange of Japan-China CCS-EOR Cooperation**

## Systems Analysis Group

### ■2009 Original Paper (Peer-reviewed)

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | Evaluation of Global Warming Impacts for Different Levels of Stabilization as a Step toward Determination of the Long-term Stabilization Target | A. Hayashi, K. Akimoto, F. Sano, S. Mori, T. Tomoda | Climatic Change (In press) |
| 2 | Land-Use Traffic Model for Impact Assessment of Urban Policies on Carbon Dioxide Reduction and Sustainability | M. Kii, K. Akimoto | Journal of Japan Society of Energy and Resources (In press) |
| 3 | Study on the Sustainability of Demand-supply System of Bio-fuels in Asian Region | M. Kii, A. Maruyama, S. Kai | Infrastructure Planning Review, Vol.26, 341-346, March 2009 |
| 4 | Strategic Visioning Model for Sustainable Urban Transport under the Depopulating Society | M. Kii, T. Suzuki, M. Tanishita, K. Doi | Japan Society of Civil Engineers Vol.65, No.3, August 2009 |
| 5 | Public Support for Energy R & D | J. Oda | The 30th Anniversary of Institute of Applied Energy, "Oshima prize-winning paper", January 2009 |
| 6 | Stability of International Climate Coalitions - A Comparison of Transfer Schemes | M. Nagashima, R. Dellink, E.van. Ierland, H-P. Weikard | Ecological Economics, Vol.68, Issue 5, pp.1476-1487, 2009. |
| 7 | An Evaluation of Energy Efficiency in Iron and Steel Sector | J. Oda, K. Akimoto | Journal of Japan Institute of Energy, Vol.88, 1009-1016, January 2009 |
| 8 | Introduction of Subsidisation in Nascent Climate-friendly Learning Technologies and Evaluation of its Effectiveness | U. K. Rout, K. Akimoto, F. Sano, T. Tomoda | Energy Policy (In press) |

### ■2009 Other Paper (e.g., Review, Comment)

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | The Global Warming Aspects and Efforts toward Post-Kyoto Protocol | K. Akimoto | Newsletter 'INSTREAM', March 2009 Instrumentation & Process Control Engineers' Association |
| 2 | Technological Outlook toward Cool Earth 50 and Analysis of Mid-term Target Establishment | K. Tokushige, K. Akimoto | Environment Solution Technology, August 2009 (monthly journal by Japan Industrial Publishing CO., LTD.) |
| 3 | Mid-term Target against Global Warming and Nuclear Power | K. Akimoto | Energy for the Future, September 2009 |
| 4 | Technology Innovation toward Low Carbon Society | K. Akimoto | Economic Trend, October 2009 |
| 5 | Firm Actions with Eyes toward Scientific Facts | K. Akimoto | Gyousei, Cabinet Secretariat 'Comment on the Mid-Term Target for Global Warming Measures,' October 2009 |
| 6 | Japan's Mid-term Target in the Post-Kyoto Framework | K. Akimoto | Environment Solution Technology, November 2009 (monthly journal by Japan Industrial Publishing CO., LTD.) |
| 7 | Six Alternatives for the Mid-term Target in Japan | K. Akimoto | Journal of Japan Environmental Management Association for Industry, November 2009 |
| 8 | Simulation of Global Warming | K. Akimoto | Journal of The Institute of Electrical Engineers of Japan, December 2009 |

### ■2009 Oral Presentation (Domestic Conference)

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | A Study on Spatial Distribution Structure of Cities and its Future Estimation | M. Kii, K. Akimoto | 25th Conference on Energy, Economy, and Environment, January 29, 2009 |
| 2 | Evaluating the benefits of subsidy procurement to component cluster global learning technologies with and without a climate stabilization in DNE21+ model. | Ullash Kumar Rout, K. Akimoto, F. Sano, T. Tomoda | 25th Conference on Energy, Economy, and Environment, January 29, 2009 |
| 3 | Evaluations of CO2 Emission Reduction on Target after 2013 | K. Akimoto, F. Sano, J. Oda, T. Homma | 25th Conference on Energy, Economy, and Environment, January 30, 2009 |
| 4 | Putting Synergy or Trade-off Relationships among Climate Policies and Sustainable Development Policies | A. Hayashi, K. Akimoto, T. Homma, K. Tokushige, J. Oda, F. Sano, T. Tomoda | 25th Conference on Energy, Economy, and Environment, January 30, 2009 |
| 5 | Evaluation of Consumption-based CO2 Emissions Based on the Beneficial Pays Principle | T. Homma, K. Akimoto, T. Tomoda | 25th Conference on Energy, Economy, and Environment, January 30, 2009 |
| 6 | Evaluation of Energy Innovative Technologies for Ambitious CO2 Emission Reduction | F. Sano, K. Akimoto, J. Oda, T. Tomoda | 25th Conference on Energy, Economy, and Environment, January 30, 2009 |

| | Title | Researchers | Forum |
|---|---|---|---|
| 7 | An Analysis of Mitigation Measures and Effects of Scrap Availability in Iron & Steel Sector | J. Oda, K. Akimoto, F. Sano | 25th Conference on Energy, Economy, and Environment, January 30, 2009 |
| 8 | International Comparison on the Implementation of Global Warming Measures | K. Tokushige, K. Akimoto, J. Oda | 25th Conference on Energy, Economy, and Environment, January 30, 2009 |
| 9 | Assessment of Mitigation Measures Considering Social Barriers about Price and Behaviors | M. Nagashima, K. Akimoto, F. Sano, J. Oda | 25th Conference on Energy, Economy, and Environment, January 30, 2009 |

■2009 Oral Presentation (International Conference)

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Toward deep emission cuts by the joint efforts of developed and developing countries through sectoral approach | K. Akimoto | Joint Dialogue on Future International Actions to Address Global Climate change, February 2009 |
| 2 | The Sectoral Approach to Analyze Global Mitigation Potential | M. Nagashima | Workshop on mitigation potentials, comparability of efforts and sectoral approaches, March 23, 2009 |
| 3 | The Sectoral Approach to Analyze Global Mitigation Potential | M. Nagashima | AWG-KP Workshop on issues relating to the scale of emission reductions to be achieved by Annex I parties, March 27, 2009 |
| 4 | Estimates for GHG Mitigation Potentials and Costs by RITE | K. Akimoto | Workshop on estimating GHG mitigation potentials and costs for Annex I countries, May 28-29, 2009 |
| 5 | Evaluation of CO2 emissions based on the consumption-based measurement under CO2 reduction scenarios of different reduction levels | T. Homma, K. Akimoto, T. Tomoda | Twelfth Annual Conference on Global Economic Analysis, June 10-12, 2009 |

■2009 Non-Journal Publication

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | The Global Warming Aspects and Efforts toward Post-Kyoto Protocol | K. Akimoto | The 47th Kansai Economic Federation Seminar, February 5 2009 |
| 2 | Mid-term Target; Model Analysis Suggestions | K. Akimoto | The 152th Nippon Keidanren Gusethouse Forum, 'Mid-term Target, Post-Kyoto Protocol and Role of business toward the Effective Measures against Global Warming ', February 25, 2009 |
| 3 | Six Alternatives and Stances to be taken toward Post-Kyoto Protocol | K. Akimoto | Environment and Safety Board Seminar, Kansai Economic Federation, April 24, 2009 |
| 4 | International Trend of Post-Kyoto Protocol and Japan's Mid-term Target | K. Akimoto | Environment Board, Toyama Employer's Association, May 20, 2009 |
| 5 | Development and Challenges of Emission Reduction Technologies toward Low-Carbon Society | K. Akimoto | Reliability Forum, The Society of Materials Science, Japan, May 23 2009 |
| 6 | Methodology on the Establishment of Low-carbon Strategic Scenario | K. Akimoto | Ritsumeikan University Seminar, June 18, 2009 |
| 7 | Mid- and Long-term Strategies to Combat Global Warming | K. Akimoto | Conference on Energy in Chugoku Region and Promotion Policies against Global Warming, July 14, 2009 |
| 8 | Mid- and Long-term Energy Supply and Demand Systems in Japan | K. Akimoto | The Institute of Electronics, Information and Communication Engineers TOKAI Symposium, September 10 2009 |
| 9 | Study on the Mid-term Target of Japan; International fairness and Compliance with Long-term Target | K. Akimoto | Summer Wrokshop, Journal of Japan Society of Energy and Resources, September 24, 2009 |
| 10 | Study on the Mid-term Target of Japan | K. Akimoto | Intellectual Café, Research Center for Advanced Science and Technology, the University of Tokyo, September 25, 2009 |
| 11 | Sectoral GHG emission reduction in the World, Japan and Korea | F. Sano, K. Akimoto | Green Business Seminar for Korea-Japan Low-Carbon Green Growth, October 21, 2008 |
| 12 | International Trend of Post-Kyoto Protocol and Japan's Mid-term Target | K. Akimoto | Takaoka Aluminium Meeting, October 23, 2009 |
| 13 | The Current Situation and Countermeasures of Global Environmental Issues, Concentrating on Global Warming | K. Akimoto | The 50th Environmental Session, the Gnenral Insurance Association of Japan November 6, 2009 |
| 14 | The Countermeasures against Global Warming and Prospects for the Railroad Industry | K. Akimoto | The 46th Cybernetics Symposium, Japan Railway Engineer's Association, November 12, 2009 |
| 15 | Verification of 25% GHG Reduction-How Much CO2 Emission Could Be Reduced? | K. Akimoto, *et al.* | Energy Forum, December 28, 2009 |
| 16 | The 46th "Day of Nuclear Power" Commemoration Symposium Green New Deal Age and Nuclear Power—Environmental, Economic Harmony and Role of Nuclear Power | K. Akimoto, *et al.* | Nuclear power culture, Japan Atomic Energy Relation Organization, December 2009, |

## Molecular Microbiology and Biotechnology Group

### ■2009 Original Paper

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | Characterization of a new 2.4-kb plasmid of *Corynebacterium casei* and development of stable corynebacterial cloning vector. | Y. Tsuchida, S. Kimura, N. Suzuki, M. Inui and H. Yukawa. | Appl. Microbiol. Biotechnol. 81:1107-1115. 2009. |
| 2 | Involvement of the LuxR-type transcriptional regulator RamA in regulation of expression of the *gapA* gene, encoding glyceraldehyde-3-phosphate dehydrogenase of *Corynebacterium glutamicum*. | K. Toyoda, H. Teramoto, M. Inui and H. Yukawa. | J. Bacteriol. 191:968-977. 2009. |
| 3 | Identification of new secreted proteins and secretion of heterologous amylase by *C. glutamicum*. | N. Suzuki, K. Watanabe, N. Okibe, Y. Tsuchida, M. Inui and H. Yukawa. | Appl. Microbiol. Biotechnol. 82:491-500. 2009. |
| 4 | Scanning the *Corynebacterium glutamicum* R genome for high-efficiency secretion signal sequences. | K. Watanabe, Y. Tsuchida, N. Okibe, H. Teramoto, N. Suzuki, M. Inui and H. Yukawa. | Microbiology 155:741-750. 2009. |
| 5 | Regulation of *Corynebacterium glutamicum* heat shock response by the extracytoplasmic-function sigma factor SigH and transcriptional regulators HspR and HrcA. | S. Ehira, H. Teramoto, M. Inui and H. Yukawa. | J. Bacteriol. 191:2964-2972. 2009. |
| 6 | Molecular mechanism of SugR-mediated sugar-dependent expression of the *ldhA* gene encoding L-lactate dehydrongease in *Corynebacterium glutamicum*. | K. Toyoda, H. Teramoto, M. Inui and H. Yukawa. | Appl. Microbiol. Biotechnol. 83:315-327. 2009. |
| 7 | Identification and functional analysis of the gene cluster for L-arabinose utilization in *Corynebacterium glutamicum*. | H. Kawaguchi, M. Sasaki, A.A. Vertès, M. Inui and H. Yukawa. | Appl. Environ. Microbiol. 75:3419-3429. 2009. |
| 8 | Regulation of expression of genes involved in quinate and shikimate utilization in *Corynebacterium glutamicum*. | H. Teramoto, M. Inui and H. Yukawa. | Appl. Environ. Microbiol. 75:3461-3468. 2009. |
| 9 | The *ldhA* gene, encoding fermentative L-lactate dehydrogenase of *Corynebacterium glutamicum*, is under the control of positive feedback regulation mediated by LldR. | K. Toyoda, H. Teramoto, M. Inui and H. Yukawa. | J. Bacteriol. 191:4251-4258. 2009. |
| 10 | Regulation of quinone oxidoreductase by the redox-sensing transcriptional regulator QorR in *Corynebacterium glutamicum*. | S. Ehira, H. Ogino, H. Teramoto, M. Inui and H. Yukawa. | J. Biol. Chem. 284:16736-16742. 2009. |
| 11 | Identification of a second β-glucoside phosphoenolpyruvate: carbohydrate phosphotransferase system in *Corynebacterium glutamicum* R. | Y. Tanaka, H. Teramoto, M. Inui and H. Yukawa. | Microbiology 155:3652-3660. 2009. |
| 12 | Engineering of pentose transport in *Corynebacterium glutamicum* to improve simultaneous utilization of mixed sugars. | M. Sasaki, T. Jojima, H. Kawaguchi, M. Inui and H. Yukawa. | Appl. Microbiol. Biotechnol. 85:105-115. 2009. |
| 13 | Isolation, evaluation and use of two strong, carbon source-inducible promoters from *Corynebacterium glutamicum*. | N. Okibe, N. Suzuki, M. Inui and H. Yukawa. | Lett. Appl. Microbiol. 50:173-180. 2010. |
| 14 | Sugar transporters in efficient utilization of mixed sugar substrates: current knowledge and outlook. | T. Jojima, C.A. Omumasaba, M. Inui and H. Yukawa. | Appl. Microbiol. Biotechnol. 85:471-480. 2010. (Mini-Review) |
| 15 | Xylitol production by recombinant *Corynebacterium glutamicum* under oxygen deprivation. | M. Sasaki, T. Jojima, M. Inui and H. Yukawa. | Appl. Microbiol. Biotechnol. (in press) |

### ■2009 International Oral Presentation

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Production of Biofuels/Biochemicals from Non-Food Based Biomass | H. Teramoto and H. Yukawa. | Americana International Trade Show 2009, 17 March 2009. |
| 2 | *C. glutamicum* Secretory System | N. Suzuki and H. Yukawa. | BIT Life Sciences' 2nd Annual World Congress of Industrial Biotechnology 2009 (ibio-2009), 7 April 2009. |
| 3 | Biofuel and Biochemical Productions from Mixed Sugars Derived form Lignocellulosic Biomass by the RITE Bioprocess | H. Teramoto and H. Yukawa. | 2009 AIChE Spring National Meeting, 29 April 2009. |
| 4 | Identification of Genes Involved in Cell Separation in *Corynebacterium glutamicum* | H. Ogino, Y. Tsuge, H. Teramoto, M. Inui, and H. Yukawa. | 109th ASM General Meeting, 17-21 May 2009. |
| 5 | Transcriptional Regulation of the *gapA* Gene Encoding Glyceraldehyde-3-phosphate dehydrogenase in *Corynebacterium glutamicum* | K. Toyoda, H. Teramoto, M. Inui, and H. Yukawa. | 109th ASM General Meeting, 17-21 May 2009. |
| 6 | Genome-Wide Systematic Screening of Signal Peptides from *Corynebacterium glutamicum* | K. Watanabe, Y. Tsuchida, N. Okibe, H. Teramoto, N. Suzuki, M. Inui, and H. Yukawa. | 109th ASM General Meeting, 17-21 May 2009. |
| 7 | Biofuel and Biochemical Productions from Mixed Sugars Derived from Lignocellulosic Biomass by the RITE Bioprocess | T. Jojima and H. Yukawa. | 2009 International Symposium & Annual Meeting of the Korean Society for Microbiology and Biotechnology, 25 June 2009. |
| 8 | Biofuel/Commodity Chemical Production by Simultaneous Utilization of Mixed Sugars | K. Hiraga and H. Yukawa. | The 6th World Congress on Industrial Biotechnology and Bioprocessing, 21 July 2009. |

| | Title | Researchers | Forum |
|---|---|---|---|
| 9 | Cellulosic bioethanol production by the RITE bioprocess | H. Teramoto and H. Yukawa. | SIM Annual Meeting, 29 July 2009. |
| 10 | Search for transporters involved in C4-dicarboxylates utilization in *Corynebacterium glutamicum* | H. Teramoto, T. Shirai, M. Inui, and H. Yukawa. | SIM Annual Meeting. 26-30 July 2009. |
| 11 | Transcriptional regulation of the *ldhA* gene encoding L-lactate dehydrogenase in *Corynebacterium glutamicum* | K. Toyoda, H. Teramoto, M. Inui, and H. Yukawa. | SIM Annual Meeting. 26-30 July 2009. |

■2009 International Publication etc.

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Advanced fermentation technologies. | M. Inui, A.A. Vertès and H. Yukawa. | Biomass to Biofuel: Strategies for Global Industries, Wiley, 2010. |
| 2 | L-aspartic acid. | S. Okino, M. Inui and H. Yukawa. | The Encyclopedia of Industrial Biotechnology: Bioprocess, Bioseparation, and Cell Technology, John Wiley & Sons, Inc. (in press) |
| 3 | L-isoleucine. | T. Jojima, M. Inui and H. Yukawa. | The Encyclopedia of Industrial Biotechnology: Bioprocess, Bioseparation, and Cell Technology, John Wiley & Sons, Inc. (in press) |

## Chemical Rsearch Group

### ■2009 Original Paper

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | Oxidization Mcehanisim of Diesel Particulate Matter in Plasma Discharges | S.Kodama, S.Yao, S.Yamamoto, C.Mine, Y.Fujioka | Chemistry Letters, 38(1) 50-51(2009) |
| 2 | Experimental investigation of carbon oxidization | S.Yao, C.Mine, S.Kodama, S.Yamamoto, Y.Fujioka | Chemistry Letters, 38(2) 168-169(2009) |
| 3 | Evaluation method of novel absorbents for CO2 capture | K. Goto, H. Okabe, S. Shimizu, M. Onoda and Y. Fujioka | Energy Procedia, 1, 1083-1089 (2009) |
| 4 | Separation and recovery of carbon dioxide by a membrane flash process utilizing waste thermal energy | K.Okabe, S.Kodama, H.Mano, Y.Fujioka | Energy Procedia 1, 1281-1288(2009) |
| 5 | Development of novel tertiary amine absorbents for CO2 capture | F.A.Chowdhury, H.Okabe, S.Shimizu, Y.Fujioka<br>M.Onoda, (Nippon Steel Corporation) | Energy Procedia 1, 1241-1248(2009) |
| 6 | Techno-economic evaluation of the coal-based gasification combined cycle with CO2 capture and storage technology | R. Nagumo, S. Kazama and Y. Fujioka | Energy Procedia, 1, 4089-4093 (2009) |
| 7 | Experimental Study of SOF Oxidation Catalysts under Plasma Discharge Condition | S.Yamamoto, S.Yao, S.Kodama, C.Mine, Yuichi Fujioka | Chemistry Letters 38(6) 598-599(2009) |
| 8 | Development of cesium-incorporated carbon membranes for CO2 separation under humid conditions | T.Kai, S.Kazama, Y.Fujioka | Journal of Membrane Science342 14-21(2009) |
| 9 | Pulsed plasma PM removal from diesel exhaust emissions. Influences of reaction conditions | Shin Yamamoto, Shuiliang Yao, Satoshi Kodama, Chieko Mine, Yuichi Fujioka<br>Chihiro Fushimi(The University of Tokyo),<br>Kazuhiko Madokoro(Daihatsu Motor Co.,Ltd.),<br>Kazuya Naito(Daihatsu Motor Co.,Ltd.),<br>Yoon-Ho Kim(Daihatsu Motor Co.,Ltd.) | Electrochemistry 1013-1017(2009) |
| 10 | On the Scale-Up of Uneven DBD Reactor on Removal of Diesel Particulate Matter | Yao, Shuiliang; Fushimi, Chihiro; Kodama, Satoshi; Yamamoto, Shin; Mine,Chieko; Fujioka, Yuichi; Madokoro, Kazuhiko; Naito, Kazuya; and Kim,Yoon-Ho | International Journal of Chemical Reactor Engineering 7 A76 (2009) |

### ■2009 International Oral Presentation

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Theoretical Investigation on the Mechanism of CO2 Absorption by Aqueous Alkanolamine Solutions | Shinkichi Shimizu、M.Ismael、Ai Suzuki、R.Sahnoun、Michihisa Koyama、Hideyuki Tsuboi、Nozomu Hatakeyama、Akira Toyama、Hiromitsu Takaba、C.D.Carpio、Momoji Kubo、Akira Miyamoto(TOHOKU UNIVERSITY) | International Symposium of Experiment-Inetgrated Computational<br>17 January 2009 |
| 2 | Functionalized Blending Membranc of PAMAM Dendrimer in the Rigid Polym | R.Shimizu,I.taniguchi,, S.Kazama, Y.Fujioka | 1st International Conference on Multifunctional, Hybrid and Nanomaterials<br>ours,France<br>15 March 2009 |
| 3 | Poly(amidoamine)dendrimer in Poly(ethylene glycol) Network for a CO2 Separation Membrane:Mechanism of Preferential CO2 Separation | I.Tanioguchi, S.Duan, S.Kazama, Y.Fujioka | 237thACS National Meeting&Exposition<br>Soltlake City<br>28 March 2009 |
| 4 | PAMAM Dendrimer Membrane for CO2/H2 Separation from Pressurized Gas Stream | S.Kazama | Advanced Membrane Technology IV: Membranes for Clean and Sustainable Processes<br>Tronbheim |
| 5 | Development of CO2 selective separation membranes of poly(amidoamine) dendrimer incorporated into cross-linked poly(vinyl alcohol) | S.Duan, I.Taniguchi, S.Kazama, Y.Fujioka | The 5th Conferennce of Aseanian Membrane Society<br>Kobe, Japan<br>13 JULY 2009 |
| 6 | Dendrimer immobilized hydrogel membrane for the separation of carbon dioxide | R.Shimizu, I.Taniguchi, S.Kazama, Y.Fujioka | The 5th Conferennce of Aseanian Membrane Society<br>Kobe, Japan<br>14 JULY 2009 |
| 7 | Hydrogen separation membrane encapsulating Pd nanoparticles in a mesoporous silica layer | K.Nagata, M.Miyamoto, K.Yogo, Y.Fujioka | The 5th Conferennce of Aseanian Membrane Society<br>Kobe, Japan<br>14 JULY 2009 |
| 8 | Electonic and Atomistic Structure of Alkanolamine for CO2 Capture | Shinkichi Shimizu、M.Ismael、Ai Suzuki、R.Sahnoun、Michihisa Koyama、Hideyuki Tsuboi、Nozomu Hatakeyama、Akira Toyama、Hiromitsu Takaba、C.D.Carpio、Momoji Kubo、Akira Miyamoto(TOHOKU UNIVERSITY) | 5th Conference of the Aseanian Membrane Society<br>Kobe University<br>17 JULY 2009 |
| 9 | CO2-Selective Membrane of Poly(amidoamine) Dendrimer incorporated into cross-linked poly(vinyl alcohol) for CO2 Capture | S.Duan, I.Taniguchi, S.Kazama, Y.Fujioka | The 5th Joint CHINA/JAPAN Chemical Engineering Symposium<br>Shaanxi Guesthouse<br>21 JULY 2009 |

| | Title | Researchers | Forum |
|---|---|---|---|
| 10 | Development of cesium-incorporated carbon membranes for CO2 separation under humid conditions | T.Kai, S.Kazama, Y.Fujioka | EUROMEMBRANE 2009<br>Le Corum, Palais des Congrès<br>Montpellier、France<br>7 September 2009 |
| 11 | A simple modification of the Sanchez-Lacombe equation of state for improved representation of pressure-volume-temperature data | H. Machida<br>Y. Satoa and R.L. Smith Jr.b<br>a Department of Chemical Engineering, Research Center of Supercritical Fluid Technology, Tohoku University, Japan<br>b Graduate School of Environmental Studies, Tohoku University, Japan | 5th International Symposium of MTMS'09<br>Lecture Hall Graduate School of Natural Science & Technology<br>Kanazawa University<br>1 JULY 2009 |
| 12 | CO2 separation from gas mixtures by physical absorption using ionic liquids | Shinkichi Shimizu、Yuichi Fujioka、Mitsuhiro Kanakubo other 4（AIST TOHOKU）、Masami Onoda (Nippon Steel Corporation), Kinya Tomisaki（Ryukoku University） | 5th International Symposium of Molecular Thermodynamics and Molecular Simulation<br>Kanazawa University<br>4 August 2009 |
| 13 | Development of Zero Emission CCS(CO2 Capture and Storage) by Ionic Liquid Physical Absorption Technique | Shinkichi Shimizu、Yuichi Fujioka、Mitsuhiro Kanakubo other 5（AIST TOHOKU）、Masami Onoda (Nippon Steel Corporation), Kinya Tomisaki（Ryukoku University） | Supergreen 2009 —International Conference on Supercritical Fluid—<br>Tohoku University<br>12 August 2009 |
| 14 | Advanced CO2/H2 Separation Materials Incorporating Active Functional Agents | Ryosuke Shimizu, Shuhong Duan, Ikuo Taniguchi, Teruhiko Kai, Shingo Kazama, Yuichi Fujioka | GCEP Research Symposium 2009<br>Stanford University<br>6 October 2009 |
| 15 | Development of Molecular Gate Membrane for CO2 Capture | Shingo Kazama | CSLF London Meeting<br>London<br>7 October 2009 |

## $CO_2$ Storage Rsearch Group

### ■2009 Original Paper

| | Title | Researchers | Journal |
|---|---|---|---|
| 1 | Evaluation of caprock integrity in geological $CO_2$ storage: Laboratory measurements on threshold pressure of argillaceous rock injected supercritical $CO_2$ | Soshi Nishimoto, Ziqiu Xue, Tamotsu Kiyama, | Exploration Geophysics, Vol.62 No.4, 2009 |
| 2 | Application of crosswell seismic tomography using difference analysis with data normalization to monitor $CO_2$ flooding in an aquifer | Kyosuke Onishi, Tetsuyuki Ueyama, Toshifumi Matsuoka, Dai Nobuoka, Hideki Saito, Azuma Hiroyuki, Ziqiu Xue | International Journal of Greenhouse Gas Control,3, 311-321, 2009 |
| 3 | Ultrasonic velocity and attenuation during $CO_2$ injection into water-saturated porous sandstone: Measurements using difference seismic tomography | Xinglin Lei, Ziqiu Xue | Physics of the Earth and Planetary Interiors,176, 224-234, 2009 |
| 4 | Monitoring and simulation studies for accessing macro- and mesoscale migration of $CO_2$ sequestered in an onshore aquifer: Experiences from the Nagaoka pilot site, Japan | Kozo Sato, Saeko Mito,Tadashi Horie , Hiroshi Ohkuma, Hideki Saito, Jiro Watanabe, Tsukasa Yoshimura | International Journal of Greenhouse Gas Control, in submit |
| 5 | Saline aquifer $CO_2$ sequestration in Japan methodology of storage capacity assessment | Toyokazu Ogawa,Shigetaka Nakanishi,Takumi Shidahara,Tadahiko Okumura,Eiji Hayashi | International Journal of Greenhouse Gas Control, in submit |
| 6 | Numerical simulation on multi-scale diffusion on $CO_2$ injected in the deep ocean in a practical scenario | Se-Min Jeong , Toru Sato, Baixin Chen, Shigeru Tabeta | International Journal of Greenhouse Gas Control, in press |
| 7 | Development of a multi-scale ocean model by using particle laplacian method for anisotropic mass transfer | Se-Min Jeong , Toru Sato, Baixin Chen, Shigeru Tabeta | International Journal for Numerical methods in Fluids, accepted |
| 8 | Diffusion simulation of $CO_2$ discharged in mesoscale deep ocean by using moving-nesting grid technique | Se-Min Jeong , Toru Sato, Baixin Chen | International Journal of Offshore and Polar Engineering, . Vol.19, No.4, pp.1-6, 2009 |

### ■2009 Articles

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | A Sensitivity Study of $CO_2$ Behavior for the Practical Use of CO2 Geological Storage | Ikuo Okamoto, Saeko Mito, Kameichiro Nakagawa | Transactions of the Japan Society of Mechanical Engineers. B, in press |
| 2 | Geological Storage of Carbon Dioxide (in Japanese) | Eiji Hayashi, Hironobu Komaki, Shininchi Terada, Hiroshi Matsumoto | The Thermal and nuclear power Vol.60 No10 pp.1029-1034, 2009/10 |
| 3 | Numerical estimation of vertical diffusivity in the deep ocean by using moored ADCP | Shinichiro Hirabayashi, Toru Sato, Yuji Watanabe, Fumiyasu Nishibori, Noboru Ioka | The Japan Society of Naval Architects and Ocean Engineers, in press |
| 4 | Triple I of $CO_2$ Ocean Sequestration against Ocean Surface Acidification | Toru Sato, Toshitaka Omiya | Journal of the Japan Society of Naval Architects and Ocean Engineers, 8, p9-16 |
| 5 | Linear forcing for numerical generation of anisotropic turbulence field | Shinichiro Hirabayashi, Toru Sato | Journal of the Japan Society of Naval Architects and Ocean Engineers, 8, p 53-59 |

### ■2009 Oral Presentation

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Storage Capacity Assessment in Japan:<br>Comparative Evaluation of $CO_2$ aquifer storage capacities across regions (in Japanese) | Toyokazu Ogawa, Takumi Shidahara, Shigetaka Nakanishi, Eiji Hayashi, Tadahiko Okumura | 64th JSCE Annual Meeting, 2009 |
| 2 | Effectiveness of de-ghost process using dual sensor data acquired for CCS site characterization (in Japanese) | Shigeyuki Suda, Kenichi Akama, Taku Kawanaka, Nobuo Kawai, Hideaki Yonekura, Tsukasa Yoshimura, Shiro Ohkawa | 120th Society of Exploration Geophysicists of Japan (2009Spring) Conference |
| 3 | A Sensitivity Study of $CO_2$ Behavior for the Practical Use of Geological Storage (in Japanese) | Ikuo Okamoto, Saeko Mito, Kameichiro Nakagawa | 14th National Symposium on Power and Energy Systems (SPES2009) |
| 4 | Effect of carbon dioxide ($CO_2$) at high concentration on the population of nitrifiers and denitrifiers in pelagic seawater column - a in situ experiment with a pelagic chamber-<br>(in Japanese) | Ikuo Yoshinaga, Tomoki Maeda, Takahisa Nakamura, Yosuke Onishi, Hiroshi Ishida, Kazuhisa Takeuchi, Saeko Mito, Yoshihiko Sako, Yuji Watanabe | 12th Annual Meeting of Japanese Society for Marine Biotechnology |
| 5 | Post-injection monitoring to ensure safety of $CO_2$ storage - A case study at Nagaoka pilot site - | Saeko Mito, Ziqiu Xue | 5th IEA GHG Monitoring Network Meeting, Tokyo, Japan, 2009. |
| 6 | Experimental study on seismic monitoring of residual supercritical $CO_2$ in water-saturated porous sandstones | Keigo Kitamura, Ziqiu Xue | The 9th SEGJ International Symposium |
| 7 | Influence of formation water composition on mineral trapping of $CO_2$ | Saeko Mito, Kameichiro Nakagawa | Goldschmidt2009 |
| 8 | An experimental study on threshold pressure measurement of caprock when injecting supercritical $CO_2$ (in Japanese) | Tamotsu Kiyama, Soshi Nishimoto, Ziqiu Xue, Keigo Kitamura, Daisuke Miyazawa, Yoji Ishijima | Fall meeting of the Mining and Materials Processing Institute of Japan, 2009 |

| | Title | Researchers | Forum |
|---|---|---|---|
| 9 | Safety assessment of CCS (in Japanese) | Hironobu Komaki, Eiji Hayashi, Kameichiro Nakagawa | Fall meeting of the Mining and Materials Processing Institute of Japan, 2009 |
| 10 | Activity for Safety Assessment of CCS at RITE | Eiji Hayashi, Kameichiro Nakagawa, Hironobu Komaki, Hiroshi Matsumoto, Ikuo Okamoto, Saeko Mito, Keigo Kitamura | Japan Geoscience Union meeting 2009 |
| 11 | Progress and Next R&D Topics of $CO_2$ Ocean Sequestration Technology | Michimasa Magi, Shigeo Murai | 14th National Symposium on Power and Energy Systems (SPES2009) |
| 12 | Current Status of CCS Technlogy in Japan | Shigeo Murai | 5th Japan -Korea Symposium on Electric Power Technology |

■2009 Others

| | Title | Researchers | Forum |
|---|---|---|---|
| 1 | Evaluation Study of CCS for the Mitigation Measure of Atmospheric $CO_2$ and Ocean Acidification by the Global Carbon Cycle Model | Michimasa Magi | Goldschmidt2009 |
| 2 | A sensitivity study of long-term $CO_2$ behaviour in Nagaoka reservoir rock | Ikuo Okamoto, Saeko Mito, Kameichiro Nakagawa | Workshop - Modeling and risk assessment of geological storage of $CO_2$ |
| 3 | $CO_2$ Sequestration Monitoring in a Low Salinity Formation Water Environment | Xing Wang Yang, Doug Murray, Tadashi Horie, Tukasa Yoshimura, Saeko Mito | AAPG Hedberg Conference |
| 4 | $CO_2$ Sequestration Monitoring in a Low Salinity Formation Water Environment | Xing Wang Yang, Doug Murray, Tadashi Horie, Tukasa Yoshimura, Saeko Mito | SEG 2009 Summer Research Workshop |
| 5 | A feasibility study of $CO_2$ geological storage in Japan (saline aquifer, geothermal area, serpentinite area) | K. Nakagawa, A. Ueda, H. Wakahama, S. Mito, I. Okamoto | International conference on $CO_2$ sequestration processes |
| 6 | Monitoring activities at RITE: a pilot $CO_2$ injection project at an onshore aquifer, Nagaoka, Japan. | Saeko Mito, Kameichiro Nakagawa | International conference on $CO_2$ sequestration processes |
| 7 | Monitoring and verification of stored $CO_2$ at the Nagaoka pilot injection site | Saeko Mito | ESF-FWF Conference in Partnarship with LFUI $CO_2$ Geological Storage:Latest Progress |
| 8 | Detecting and monitoring $CO_2$ with p-wave velocity and resistivity from both laboratory and field scales | Z. Xue, J Kim., S. Mito, K. Kitamura, T. Matsuoka | SPE2009 |
| 9 | Diffusion of low ph/high $CO_2$ environment at natural $CO_2$ venting sites | Kiminori Shitashima, Michimasa Magi | The eleventh Pacific Science Inter-Congress |
| 10 | Long term prediction of atmospheric $CO_2$ concentration and ocean acidification | Michimasa Magi | The eleventh Pacific Science Inter-Congress |

## Notes

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