RITE Today

Research Institute of Innovative Technology for the Earth

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Annual Report

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Research Institute of Innovative Technology for the Earth

Enjoy Your Research Life

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Major challenges in the 21st century are making a clear image after the first decade. While global constraints of natural resources and environmental capacities such as the global warming have been apparent in a concrete manner, new emerging nations such as China are achieving remarkable economic growth. The realization of sustainable development of human society on the earth makes a focal issue in the 21st century. Sustainable development is no longer a mere concept, but appearing as a realistic challenge to be responded.

The Research Institute of Innovative Technology for the Earth (RITE), which was founded for the New Earth 21 Program launched by the government of Japan in 1990, has to contribute to the realization of the sustainable development. While the issue of sustainable development is a theme given to RITE from the society, the theme is too broad for researchers to deal with. The broad research objective should be interpreted as a set of the issues to be addressed as research subjects.

The essence of research lies, after all, in the discovery of new facts and/or the creation of new useful artifacts including not only physical products but also systems in a form of software. RITE has achieved various world leading research outputs such as the technologies for CO_2 capture and storage (CCS), bio-refinery technologies, and the mathematical models for systems analysis of the measures to cope with global warming. These outstanding achievements were resulted from the research activities to tackle with the problems properly derived by interpreting the broad societal needs for realizing sustainable development as concrete research subjects particularly in the field of climate change issues. The staff of RITE should have gained precious experiences, which lead to the proud as researchers, through these achievements in the discovery of new facts and the development of useful technologies and systems.

RITE must meet the expectations from the society as a trustworthy research organization; in addition, RITE should be a place for the staff to enjoy research activities leading to its corporate identity. The staff should exert their ingenuity in individual roles: the management to set a proper research agenda for meeting the social expectations; administrative staff to support research activities and disseminate the results; and researchers to think the implication of research in the society as well as to conduct professional research. While scientific curiosity is an important motivation for the research, recognition of the objective of the research will strengthen the power to develop mew ideas. Joy of research is not enough for researchers to enjoy their research life, recognizing the social context of the research is another important element.

RITE, with the fruitful 20 year history, will continue to be an active research organization to tackle with global environmental issues. We would like to ask for your encouragement and continuing support.

Research Planning Group

Technology Strategy Map on CO_2 Fixation and Effective Utilization

1. Introduction

In the last issue of "RITE Today", we introduced "Technology Strategy Map on CO_2 fixation and effective utilization" drawn up by RITE. In this map, we showed strategies and roadmaps by 2050 in two technology areas, CCS (Carbon dioxide Capture and Storage) and terrestrial storage using large scale afforestation, which were selected as technology areas effective in both reduction potential and cost viewpoint and should be moved to implementation level. This map is revised every year.

In this report, firstly we would like to describe trends in policy and technology in both fields and then introduce the latest "Technology Strategy Map 2010".

2. Trends in CO_2 fixation and effective utilization

This section describes trends in policies and technologies of CCS, and section 2-2 focuses on trends in terrestrial storage using large scale afforestation.

2-1. CCS

1. Policy

In 2008, IEA issued the scenario for Hokkaido Toyako G8 Summit, where 50% reduction in global CO_2 emissions would be achieved by 2050. The followings were described in this scenario:

- Reduction of 48 $GtCO_2$ /yr from the baseline emissions will be required by the year 2050.
- CCS shows the third largest contribution (19%) to 50% reduction in CO_2 emissions by 2050 following energy efficiency (36%) and renewables (21%).
- If CCS is not available, the overall cost will increase by 70%.

Based on these analyses, CCS was concluded to be an essential part of the technology portfolio for achieving substantial global CO_2 emissions reduction.

After considering this report, leaders in Toyako Summit agreed to issue the statement: "We strongly support the launching of 20 large-scale CCS demonstration projects globally by 2010, taking into account various national circumstances, with a view to beginning broad deployment of CCS by 2020".

The next year, IEA published "Technology Roadmap, Carbon Capture and Storage" and showed that around 3,400 projects would be required worldwide by the year 2050 to meet the 50% reduction scenario, nearly half of this total number of projects would be required by the power sector, about 100 projects were needed within the next ten years, and a significant ramp-up from today's levels of CCS deployment was necessary. They also pointed out that CCS development in non-OECD regions became to be very important.

As described above, CCS has been recognized as a very important mitigation option but at the same time we noticed that there were many challenges for implementation of CCS. The first challenge is financing of CCS project. Without setting a carbon price, no income is expected from CCS implementation with some exceptions like EOR or EGR. But nations where carbon tax or emission trading systems being introduced are limited or even if carbon price is already set, for example, in EU nations, it is low or very unstable now. Thus, implementations of large-scale CCS projects have to depend on government's financial supports. As of 2010, public funding commitments were in the range of USD 26.6 billion to USD 36.1 billion.

The second challenge is to establish legal and regulatory frameworks for safe large-scale geological storage of CO_2. Significant progress has been made in the EU (the Directive on the Geological Storage of CO_2 and the EU Emissions Trade Scheme Directive), Australia (Offshore Petroleum Law Amendment), and the US (Safe Drinking Act UIC program). In Japan, the Amendment Act for the Prevention of Marine Pollution and Maritime Disasters was established in May 2008, which provides a legal and regulatory framework on subsea geological storage of CO_2.

As a lifetime of fossil power plant is about 40 years or more, stations which are constructed without retrofit of CO_2 now will continue to emit for such long years – CO_2 unabated for the lifetime of the plant – described as "carbon lock-in". Europe Commissions stated carbon dioxide capture-ready (CCR) mandatory for all new large combustion power stations at or over 300 MWe in CCS Directive. CCR means a design of combustion power stations to allow retrofitting of CCS once CCS technologies have been proven.

In connect with above policy progress, 80 large-scale integrated projects at various stage of development were announced around the world until 2010 with the help of government and private sectors. Many CCS projects in power sector, for example AEP's Mountaineer Project, were also included along with CCS project for natural gas origin.

In Japan, CCS is also considered to be one of the important options for substantial CO_2 emissions reduction. In 2008, the Action Plan for Achieving a Low-carbon Society was issued, which said: "CCS technology has the potential for massive emissions reductions in thermal power generation, which accounts for roughly 30 percent of Japan's emissions, and in the steelmaking process, which accounts for roughly 10 percent. Japan will promote the development of this technology to make the cost of capture and storage in the order of 2,000 yen per ton by around 2015, and to reduce the cost to 1,000 yen or so in the 2020s. At the same time, Japan will commence verification tests on a large scale at an early stage from 2009 onward, with the aim of implementation by 2020. Regarding application, Japan will work to resolve issues such as enhancing environmental impact assessments and monitoring, putting legislation in place, and ensuring public approval. Based on this policy, Japan CCS Co., Ltd. (JCCS) was established to accomplish comprehensive investigations for carrying out CCS total system demonstrations and started preparation of large-scale CCS demonstrations. Finally METI issued the report, "For safe operation of a CCS demonstration project" in August 2009, which gave safety and environmental standards for a large-scale CCS demonstration, including geological considerations in examining candidate sites for CCS demonstration, issues related to CO_2 capture and transport, monitoring items after storage, and remedies for potential problems.

2. Technology

Chemical absorption, physical absorption, and membrane separation etc. are used for capturing CO_2. Chemical absorption was already used for a capture process from the process gas in oil refinery plants in Japan but more cost- and energy-effective processes have been required to apply to various kind of emission sites for mitigating global warming. Such advanced solvents have been developed in Japan for many years and some solvents, for example KS-solvent, has reached a commercial level. In order to develop capture processes for iron and steel making industries, COCS (Cost-Saving CO_2 Capture System) project developed new absorbents with a low regeneration energy in steel works. In 2008 COURSE 50 (CO_2 Ultimate Reduction in Steel-making process by Innovative Technology for Cool Earth 50) project started, where some advanced solvents have been tested in 30t-CO_2 per day capture plant. In the US, "Chilled Ammonia" process is being tested in a pilot scale. Development of polymer and ceramic membrane is also important for capturing CO_2 from high pressured gasses. RITE has been developing molecular-gate membrane since 2006 after the international collaborative investigation on membrane technology with the US DOE's NETL started in 2003.

Geological CO_2 storage is divided to storage in saline aquifer, in depleted oil or gas field, EOR/EGR, and coal-bed methane production. Now, EOR and storage in depleted oil or gas field are conducted in the world and a large-scale injection test into saline aquifer has already begun. In Japan, RITE has conducted CO_2 storage projects which contained 10,000 tons of CO_2 injection into saline aquifer in Nagaoka gas field. As the next step, a large scale demonstration is needed for early establishment of integrated system of CCS including a capture process to accomplish a full-scaled CCS implementation in Japan. Site selection, design of facilities, and feasibility study in candidate sites for large scale demonstrations are conducted by Japan CCS Co. Ltd. Evaluation of environmental impact and safety assesment for increasing reliability of geological storage and estimation of long-termed behavior of stored CO_2 are also important investigation theme for safe CO_2 storage, on which RITE is investigating now.

2-2. Terrestrial storage using large scale afforestation

1. Policy

On the validity of terrestrial storage using large scale afforestation for CO_2 mitigation, "Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 "concluded as follows:

- During the last decade of the 20th century, deforestation in the tropics remained the major factors responsible for emissions. Emissions from deforestation in the 1990s are estimated at 5.8 $GtCO_2$/yr.
- Bottom-up regional studies show that forestry mitigation options have the economic potential at costs up to 100 US$/t$CO_2$-eq to contribute 1.3-4.2 Gt CO_2/yr in 2030. Around 1.6 Gt CO_2/yr can be achieved at a cost under 20 US$/t CO_2. Global top-down models predict far higher mitigation potentials of 13.8 Gt CO_2/yr in 2030 at carbon prices less than or equal to 100 US$/t CO_2.
- Carbon mitigation by forestry contains reducing deforestation, forest management, afforestation, and agro-forestry. In the short term, the carbon mitigation benefits of reducing deforestation are the greatest. Biomass from forestry can be estimated to have a mitigation potential roughly equal to 0.4-4.4 Gt CO_2/yr. In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks will generate the largest sustained mitigation benefit.
- Forestry can make a very significant contribution to a low-cost global mitigation portfolio. However, this has resulted in only a small portion of this potential being realized at present.
- Realization of the mitigation potential requires institutional capacity, investment capital, technology R&D and transfer, as well as appropriate policies and incentives, and international cooperation.

On the basis of this analysis, a new initiative, "the United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) was launched in September 2008, which is managed by three United Nation's organizations (FAO, UNDP and UNE) with the aid of Forest Carbon Partnership Facility at the World Bank and the Tropical Forest Account at Global Environmental Facility. After the discussion at COP/MOP4 in 2008, it was decided to continue efforts to put REDD into the next framework of carbon mitigations. At COP15 in 2009 six countries, Japan, the US, France, Australia, Britain, and Norway decided to give a financial support to REDD. Another effort in terrestrial storage is seen in US DOE's Regional Carbon Sequestration Partnership, which conducts management of forest-, agriculture-, and wet-land, demonstration of CO_2 monitoring, and economical evaluation when carbon credit being introduced.

Progresses in biomass utilization area are as follows: As clean and renewable energy was one of three high prioritized areas in "American Recovery and Reinvestment Act of 2009", US DOE released funding to bio-fuel and bio-refinery projects. In EU "Climate and Energy Package" was agreed by the European Parliament and Council in December 2008 and became law in June 2009, which suggested that the portion of renewables should be increased to 20% of the total energy consumption.

In February 2007, Japanese Government set a goal to extend the amount of bio-fuel production to 6 million kL, (10% of annual gasoline consumption) by 2030 and presented a technology roadmap including cellulosic ethanol production. In order to promote development of innovative technologies for effective cellulosic bio-fuels production in a manner consistent with "Roadmap for increased production of domestic bio-fuels", the Ministry of Economy, Trade and Industry (METI) cooperated with the Ministry of Agriculture, Forestry and Fisheries (MAFF) to develop the "Bio-fuel Technology Innovation Plan" in March 2008 which contained required innovative technologies, milestones, and roadmap. This plan also provided a benchmark for the cost of ethanol production, 40 yen per liter, which should be attained through drastic cost cutting of raw materials and enzymes.

2. Technology

Terrestrial storage using large scale afforestation is the only a technology capable of competing with CCS from a viewpoint of large decrease in CO_2 concentration in the air but more cost cutting is required. In order to increase absorbing amount of CO_2 per unit area and expand vegetation into unsuitable areas for plants like arid area, we should conduct selection of elite plants and soil improvement at early stage and develop genetically-engineered plants step by step, with stimulating information about safety and showing their advantages for CO_2 reduction. Development of adequate monitoring procedures is also necessary. In addition to these, it is important to develop conversion or utilization technologies for industrial and innovative use of biomass.

RITE developed a new effective alcohol production process from cellulose using an engineered strain of growth-arrested *Corynebacterium glutamicum*. This process is much evaluated as it shows a high tolerance against fermentation inhibitors. As further steps, RITE has been developing new production processes for various kinds of energy and chemical products including butanol, lactic acid, and succinic acid from non-food biomass based on this technology.

3. Technology Strategy Map 2010

After considering these trends in policies and technologies, "Technology Strategy Map 2010 on CO_2 fixation and effective utilization" was prepared. In this year, we investigated the number of papers issued (Fig. 1) or cited (Fig.2) in the field of capture, geological storage, ocean sequestration, terrestrial storage using large scale afforestation, and biomass utilization and the position of Japan was grasped in the world by benchmark comparison of Japan to other countries. We also tried portfolio evaluation to clear up the position in CO_2 mitigation technologies.

The roadmap is shown in Fig. 3. In this revised version, "demonstration of integrated processes of CCS" was drawn with a more emphatic.

4. Conclusion

RITE publicizes this roadmap via the Internet, invites opinion from the public, and rolls up the 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.

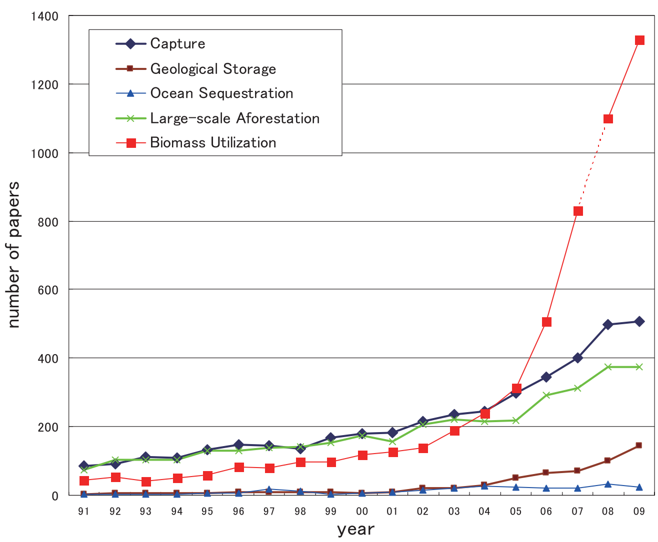


Figure 1 Changes in number of papers released in the related fields (based on research using "Web of Science" by RITE)

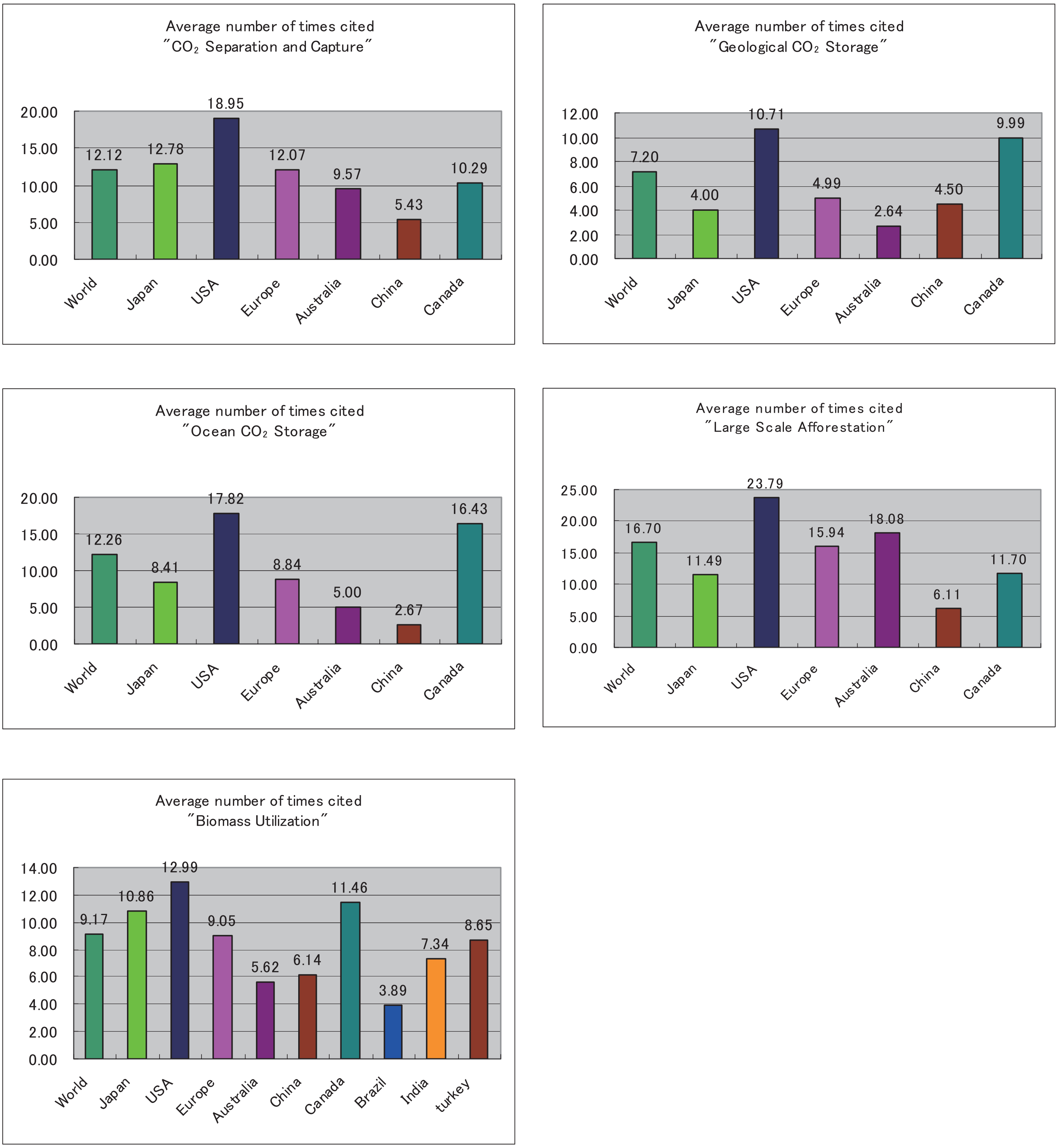
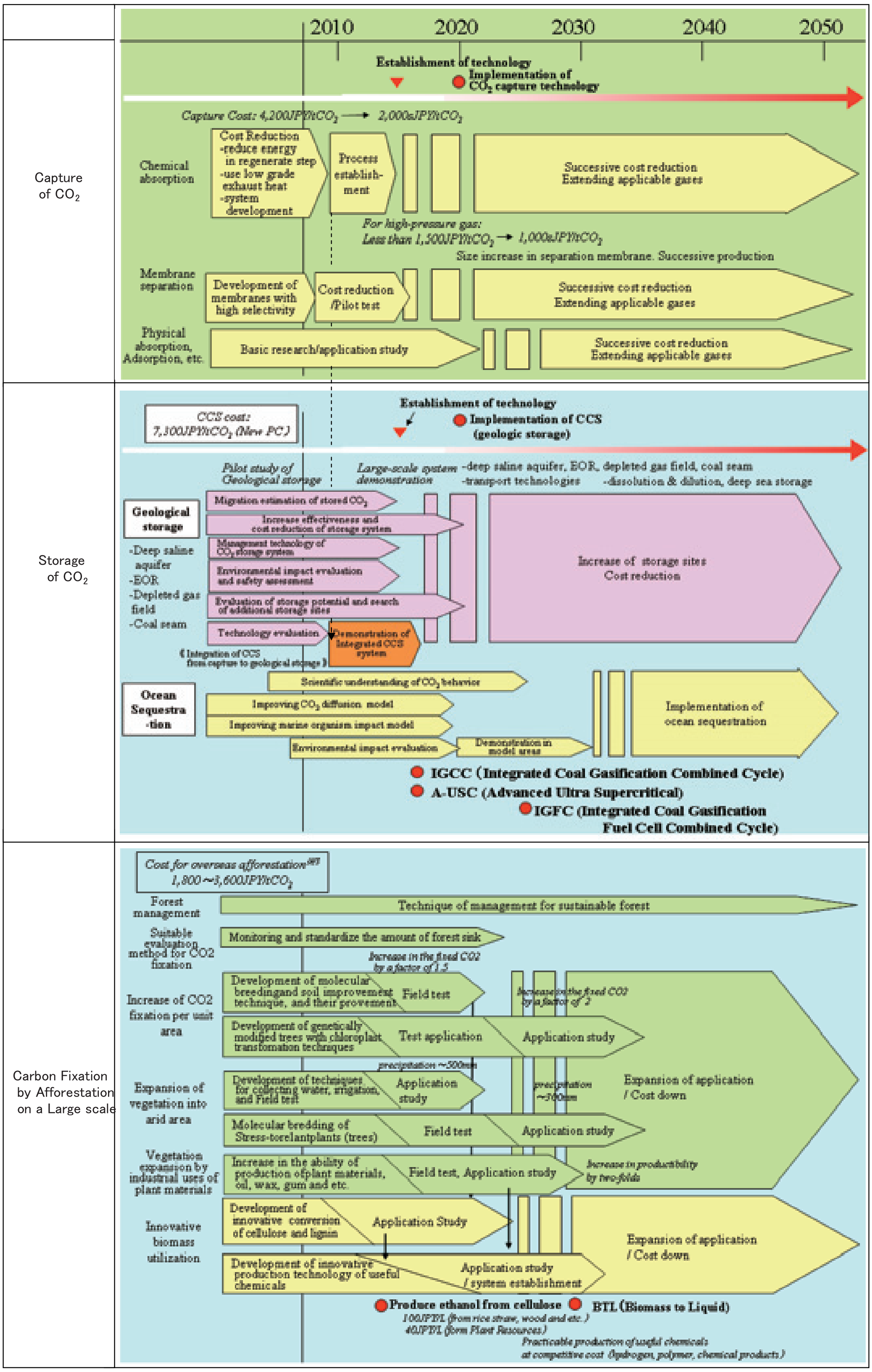


Figure 2 An example of investigation the number of papers cited (based on research using "Web of Science" by RITE)



＊ 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

Figure 3 Strategic Technology Roadmap "CO_2 fixation and effective CO_2 utilization"

Systems Analysis Group

Synthetic Scenario Development for Climate Change Control and Sustainable Development

1. Introduction

RITE has been working on a synthetic scenario development for climate change control and sustainable development in a project called ALternative Pathways toward Sustainable development and climate stabilization (ALPS) since FY 2007. A variety of mitigation scenarios has been developed so far, and made a due contribution to policy making in the context of climate change control. The conventional approaches in modeling exercises for scenario development, however, tend to describe a simplified world in which most cost-effective mitigation measures in the world as a whole are taken. The reality is more complex: different actors have different policy priorities based on their economic levels, natural circumstances and other constraints, which leads to a difficulty in creating a coordinated uniform policy, as observed in the COP15 negotiations and in the domestic policy making process. Climate change is not the only issue on the global agenda, so it should be addressed in a balanced manner under multiple dimensions. Conventional global abatement scenarios may be too simplified to capture richness of detail and context of the real world situation. The results reveal that climate policy with the highly-idealized premises sometimes does not deliver relevant outcomes, or rather causes unduly confusion to the society.

The ALPS project aims at providing alternative plausible future scenarios and through quantification of multiple aspects of society on the assumptions that the real-world society consists of a wide range of values. This approach allows us to inform decision makers of more appropriate strategies toward sustainable development and climate stabilization from longer and wider perspectives. Another focus is to gain a clearer understanding of CO_2 emissions structure on a national, sectoral and technological basis in order to deal with short and mid-term climate challenges. The scenarios on combinations of macro and micro views would generate further insights into climate change mitigation and sustainable development.

This report presents a part of our system development which aims to be implemented in FY2011.

2. Approach

Modeling simulations are powerful tools to support decision making even though they tend to assume perfect information or perfectly rational behavior. At the same time, it is important to bear in mind that the real world is full of variety and complex. The gap between the

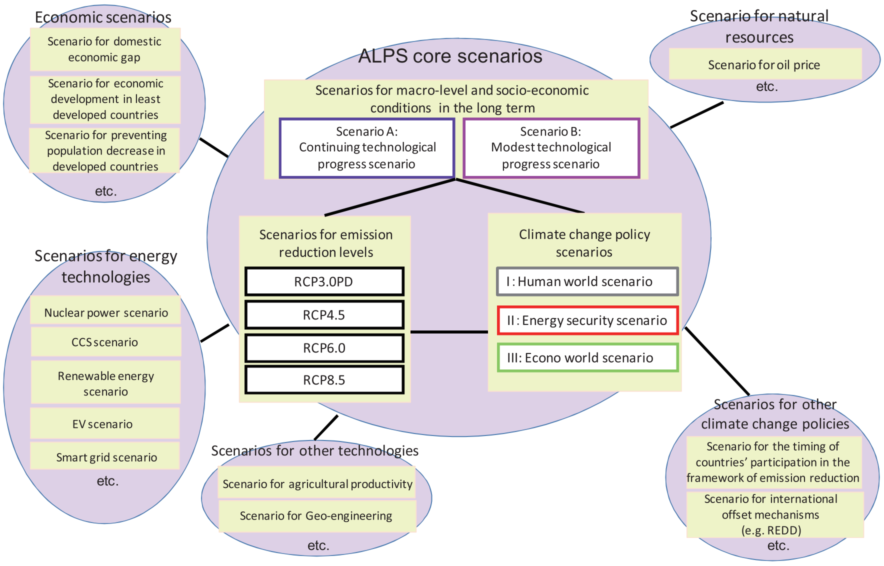


Figure 1 Scenarios to be developed in the ALPS project

Note:
The RCP for scenarios of emission reduction levels are representative concentration pathways, which are emission pathways considered by IPCC. These scenarios are:
RCP3.0PD Radiative forcing peaks at $3W/m^2$ then declines to $2.6W/m^2$ in 2100 (equivalent to 450ppm-CO_2eq.).
RCP4.5 Radiative forcing reaches $4.5W/m^2$ in 2100 (equivalent to 600-650ppm-CO_2eq.).
RCP6.0 Radiative forcing reaches $6.0W/m^2$ in 2100 (equivalent to 700-750ppm-CO_2eq.).
RCP8.5 Radiative forcing reaches $8.5W/m^2$ in 2100.

real world and virtual model world creates a risk of sending a wrong message. Therefore this ALPS project starts from a deep understanding of the current world situation and historical trends in order to avoid such trap. Based on the insights gained from the socio-economic analysis above, narrative storylines with great details are worked out from broader perspectives.

Three different types of qualitative scenarios are developed: 1) Socio-economic scenarios, 2) Climate Change Policy scenarios, and 3) Representative Concentration Pathways (RCP) scenarios. Furthermore sub-scenarios focus on the subject matter of development and diffusion of climate friendly technologies (Figure1).

1) Socio-economic scenarios focusing on uncertainty of technological progress are divided into two scenarios: A) Continuing technological progress scenario and B) Modest technological progress scenario. A new approach is taken for the 2) Climate Change Policy scenarios to reflect various social situations in different climate change context, digging into three categories: I) Human World Scenario, II) Energy Security Scenario, and III) Econo World Scenario.

I) Human World Scenario assumes that human society is built up on the multiple values and diverse communities in nature. A multi-value society usually does not fit well with a uniform framework on climate change while all kinds of economic, social and political barriers exist in the diffusion of climate-friendly technologies. Under the II) Energy Security Scenario each country puts the highest priority on national security, and efforts are made to address climate change in the context of energy security. III) Econo World Scenario is a scenario under which people are rational, and measures against global warming are taken in a cost effective way. This assumption was implicitly adopted by most of the conventional climate change assessment. Given these different natures of the scenarios, mitigation measures and especially their costs may vary significantly even though the same economic conditions are assumed and the same concentration level is pursued. Referring to a range of sustainable development indices, the ALPS project intends to yield deep insights about these scenarios in order to make a contribution to a thorough discussion on climate change.

As for 3) Representative Concentration Pathways (RCP) scenarios, four scenarios (RCP3.0PD, RCP 4.5, RCP 6.0 and RCP 8.5) will be considered as targeted concentration stabilization levels in our analysis.

3. Future socio-economic scenario

CO_2 emissions are closely related to the use of energy. It is important to decouple CO_2 emissions from economic growth, however, it has been shown that there is a statistically significant positive relationship between CO_2 emissions, population and economic growth. For a synthetic scenario development of climate change control and sustainable development, therefore, a careful treatment for projections of population and economic growth is required. This project aims to analyze various indices comprehensively and to develop future scenarios such as about population and economic growth, taking impacts of world financial crisis into consideration. Figure 2 shows global GDP projections in our scenarios A) Continuing technological progress scenario (high scenario) and B) Modest technological progress scenario (medium scenario). Figure 3 shows projections for the share of global GDP by county in Scenario B. The global average of real GDP annual growth assumed to be 2.9% in Scenario A and 2.8% in Scenario B between 2005 and 2020, and 2.7% and 2.4% between 2020 and 2050, respectively. GDP in emerging economies such as China and India will grow significantly and its share of global GDP will further expand toward 2050.

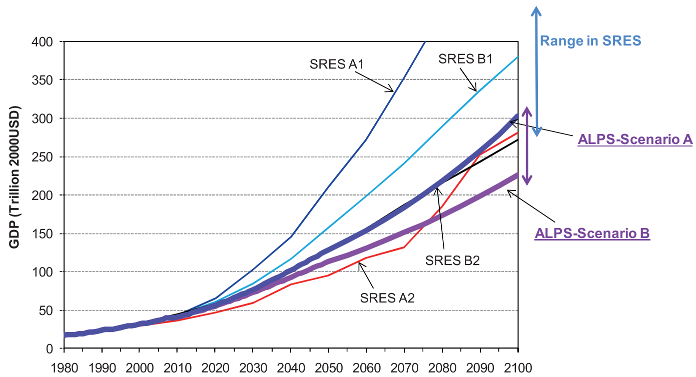


Figure 2 Global GDP scenarios

Note: SRES stands for the scenarios described in IPCC special report on emissions scenarios (2000).

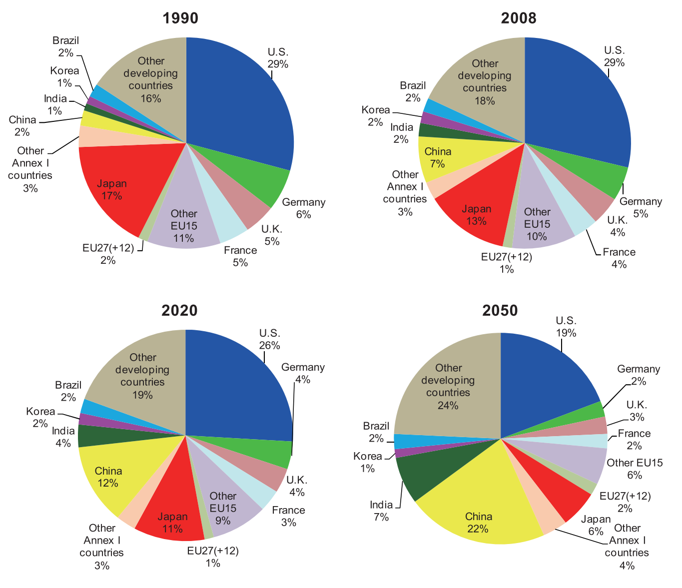


Figure 3 Share of global GDP by county in ALPS Scenario B

4. Global CO_2 emissions projection

Figure 4 shows a projection of CO_2 emissions estimated by the world's most advanced assessment model of GHGs mitigation (DNE21+) developed by RITE on the basis of CO_2 emissions statistics until 2008, economic trends by country and future prospects of economic growth until 2010. This is the projection of business-as-usual CO_2 emissions without additional climate policy, in which B) Modest technological progress scenario (medium scenario) and I) Human World Scenario (in line with a real society) are considered.

Global CO_2 emissions from fuel combustion amount to 2.8 billion tons in 2008, and are expected to reach 3.4 billion tons in 2030 and 5.3 billion tons in 2050. CO_2 emissions in developed countries decreased substantially due to the world financial crisis, however, the trend of increase in emissions in the world as a whole will not change significantly. Furthermore, the share of global emissions by country has largely changed since 1990 and it will continue to change toward 2050. Specifically, the ratio of total emissions of Annex I countries with their reduction targets under the Kyoto Protocol will account for below one-fourth of global emissions (23%) in 2020. It is crucial to pursue the framework of the Copenhagen Accord with participations from major emitting countries in order to achieve an effective CO_2 emission control.

5. Synthetic assessment of socio-economic scenarios for climate change control and sustainable development

Given the diversity in society, a scenario assessment only with indices related to GHGs emissions and mitigation cots is insufficient. The ALPS project develops quantitative scenarios which are consistent with narrative scenarios by using existing models developed by RITE with consistent data among these models. This enables us to conduct an assessment of indices widely related to sustainable development such as not only energy, climate change, but also economic society (see Table 1). An integrated index of the scenarios will be presented, taking into consideration of different priorities for each scenario by weighting key indices.

6. Expected Outcome

Synthetic scenarios toward sustainable development and climate stabilization will be implemented by FY2011 in a consistent and quantitative manner based on the narrative scenarios and group of assessment models. This study provides substantial insight into alternative pathways and catches the implied meaning from the quantitative assessment in order to guide our future actions. Findings and lessons learnt from this research project, including scenario analysis, are returned to society. The results of this study are expected to not only make scientific contribution to the IPCC but also to serve as fundamental information for decision making on global and domestic climate change policy.

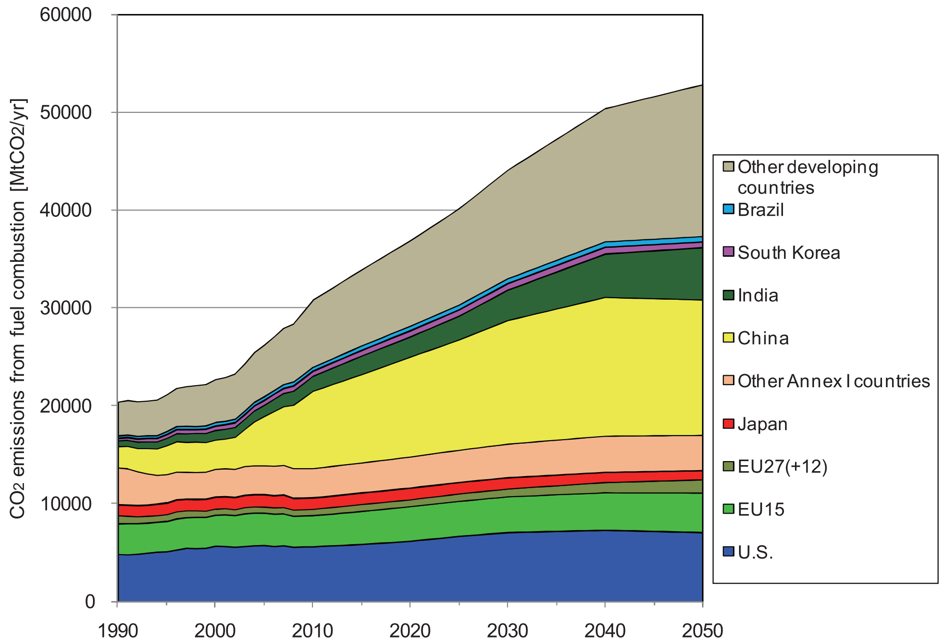


Figure 4 Projection of CO_2 emissions from fuel combustion in major countries and regions in ALPS Scenario B-I

Note: IEA statistics are used until 2008. Other Annex I countries refer to "Other Annex B countries" with reduction targets under the Kyoto Protocol.

Table 1 Key socio-economic indices for synthetic scenario assessments of alternative pathways toward sustainable development and climate stabilization

Items		Variables
Human capital	Working-age population	Ratio of working-age population (between the ages of 15 and 64)
	Education	Literacy rate, (Primary, secondary and tertiary education) Enrollment rate , Investment in education
Economy	Average income	GDP per capita
	Poverty	Proportion of population living in poverty
Global warming	Concentration of GHGs	CO_2 emissions and atmospheric concentrations of CO_2, GHGs emissions and atmospheric concentrations of GHGs, temperature
	Costs of climate change control	Mitigation costs, marginal abatement costs
Basic needs and infrastructure	Nutrition intake	Proportion of population below minimum level of nutrition intake
	Access to water	Proportion of population with sustainable access to an improved water source
	Access to energy	Proportion of population with access to modern forms of energy (electricity and gas)
	Health	Under-five mortality rate
Security	Food security	Ratio of food self-sufficiency
	Energy security	Energy security indicators
	Water security	Proportion of population above certain ratio of water demand and supply
Nature conservation	Land use	Area of land use change, change in the number of species

Molecular Microbiology and Biotechnology Group

Global Biorefinery Trends and Research Overview

1. Introduction

The biorefinery is a relatively recent concept proposed among others by the U.S. Department of Energy (DOE) to encompass technologies or industries that can produce chemicals and liquid fuels from biomass (instead of from fossil feedstock) (Figure 1). Biomass, since it originates from plants and microorganisms, enables a virtuous carbon neutral cycle of harvesting via plant growing, processing, burning, and recycling of CO_2, thus contributing to no net changes in the level of atmospheric CO_2. Since the 1990s, the transitioning from oil petrorefineries to biorefineries has been one of the strategic scientific missions of the U.S. The advancement of technologies relevant to the implementation of the biorefinery vision is therefore a key federal policy to achieve a post-fossil resources sustainable society in the 21st century. The problem is even more urgent that according to the International Energy Association (IEA), the global energy consumption has continued its expansion in spite of the global economical stagnation of 2008-2009, driven to a large extent by the continued strong and fast increasing energy demand of emerging economies such as China, India, Brazil, and Russia (BRIC countries). As a result, the implementation of cost-effective biorefineries constitutes a pressing development need to enable the production of biofuels and green chemicals from biomass. Notably, it is important to make use of non-food biomass resources in order to avoid the food-vs.-fuel/chemicals dilemma.

2. Biofuels

The 2010 world ethanol production is estimated to be 23 billion gallons. This represents more than 15% growth since 2009 and has essentially been achieved by converting corn starch or sugarcane-derived sucrose. However, important technology developments to enable the use of non-food biomass have significantly been achieved in recent years as a means to decrease environment deterioration risks and risks of competition with the global food supply (Figure 2). For example, agricultural residues such as corn stover or so-called energy grasses such as switchgrass, are now expected to represent useful options to produce clean fuels. Notably, their uses can eliminate the competition with foods and effectively reduce CO_2 emissions as demonstrated by Life Cycle Assessment (LCA) analyses. The U.S. DOE has been strongly backing biorefinery projects using non-food biomass. As a result, several demonstration scale cellulosic ethanol plants will be open after 2011 in the U.S. Notably, to promote the market penetration of biofuels, the U.S. government has recently released new regulations, Renewable Fuel Standard 2 (RSF2), and increased to 36 billion gallons the vol-

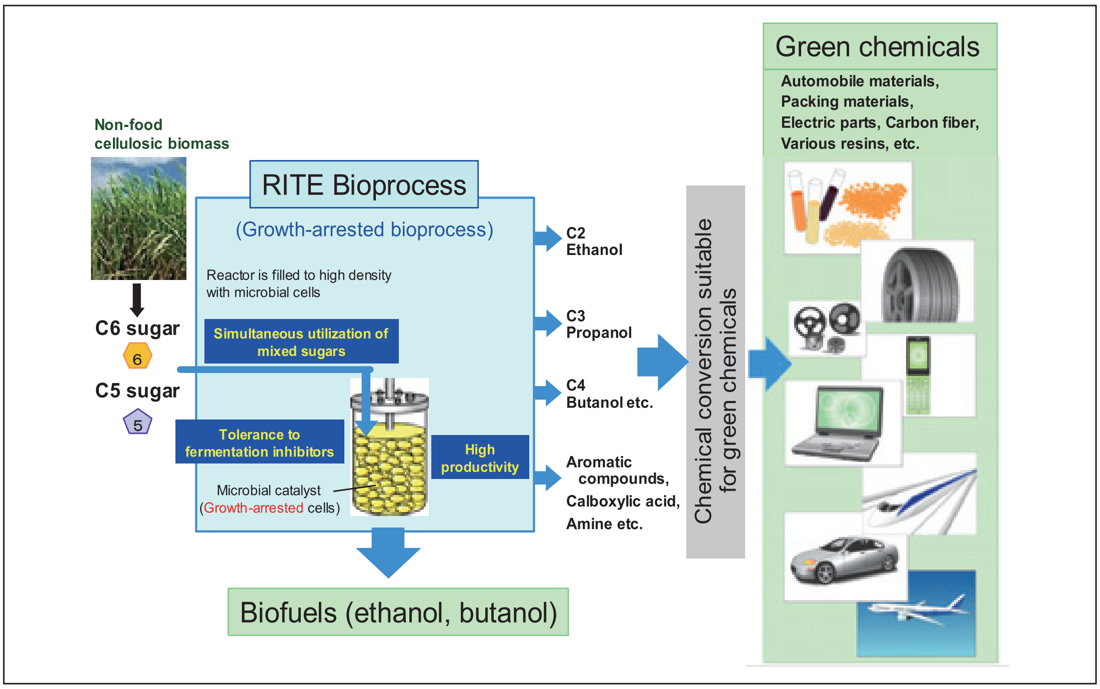


Figure 1 Biorefinery: production of biofuels and green chemicals from non-food biomass

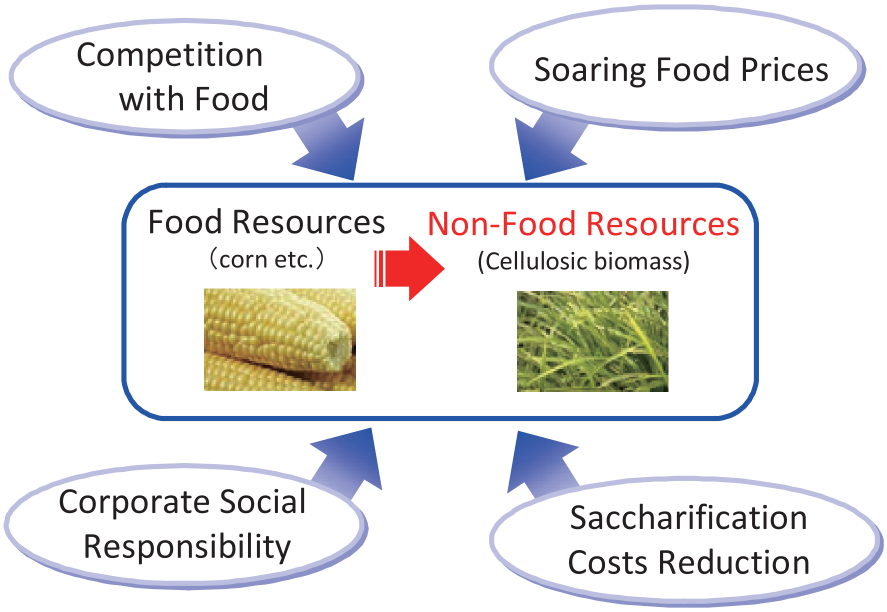


Figure 2 Shift to non-food resources

ume of renewable fuel that is required to be blended into transportation fuels by 2022. Moreover, the use of ethanol-gasoline blends containing up to 15 percent ethanol by volume (E15) was also decided in October 2010 for all vehicles built in 2007 and newer. On the other hand, in Europe, the slow economy and low profitability of 2010 have decreased the growth of biodiesel consumption, which accounts for approximately 80% of the European biofuels consumption. Nonetheless, it is also worth noting that the European Union has set the target to reach 10% biofuels in its transportation energy mix by 2020. In Japan, the Basic Energy Plan revised by the Ministry of Economy, Trade and Industry has established the promotion of renewable energies such as biofuels for transportation, and biofuel targets are included in the key targets for 2030.

3. Green chemicals

In addition to biofuels, strong growth is expected in the field of green (renewable) chemicals produced from biomass. The global market of green chemicals has been growing at around 30%, and will continue to expand to more than $10 billion in sales after 2015. The use of non-food feedstock like corn stover or switchgrass is also an essential requirement for manufacturers (Figure 2). Since saccharification costs have been greatly decreasing with the decrease of cellulose hydrolyzing enzyme (cellulase) costs through technology improvements achieved by enzyme manufacturers, the use of cellulosic biomass hydrolysates that contain mixed sugars has become a promising possibility. Presumably, this prospect is one of the reasons accounting for the fast market growth that is observed today. Green chemicals have sprung an industry-transforming technology trend of substituting sustainable chemicals for the most common oil-derived platform chemicals. Remarkably, the new trend places the emphasis on producing commodity chemicals rather than fine chemicals, which have been the early focus of biochemical engineering. As a result, several manufacturing platforms can be envisaged, such as a C-2 platform from bioethanol, a C-3 platform from biopropanol, or a C-4 platform from biobutanol. In the future, more complex structures comprising for example carboxylic acids, amines, and aromatic compounds should also be amenable to similar platform chemical production processes.

4. Technology development: the RITE Bioprocess (Growth-Arrested Bioprocess)

Our group has developed an efficient biomass utilization technology based on intrinsic characteristics of coryneform bacteria. The process was named “RITE Bioprocess” (Growth-arrested bioprocess), and it has so far enabled elevated productivities of organic acids and biofuels. This pioneering technology enables the simultaneous utilization of mixed sugars from cellulosic biomass in biorefinery settings. In collaboration with a private company, we applied it in a cellulosic ethanol production system, earning the Grand Prize at the 18th Nikkei Global Environment Award (see RITE Today 2009). What is more, our process has evoked the interest of international public and private researchers. In particular, a German group has been following our footsteps and carried out additional researches using coryneform bacteria; they independently confirmed the capabilities and attributes of our innovative bioprocess, which is characterized particularly by a clear separation between product production and the growth phase of the bacteria catalysts. The main technological features of the RITE Bioprocess are given in the following paragraphs.

4-1. Technological attributes of the RITE Bioprocess

The RITE Bioprocess addresses fundamental problems of conventional bioprocesses. In the first step that occurs in the laboratory, coryneform bacteria are designed and engineered to have an optimum metabolic pathway for a particular target chemical. At the production plant stage, cells are grown at a large scale and packed to very high densities in a reactor in order to maximize the catalyst/volume ratio. The substrate is subsequently added to initiate bioconversion under oxygen deprivation; this has the effect to cease the growth of these bacteria while keeping them metabolically active. As a result, the target chemical is produced by growth-arrested cells, with a larger share of the substrate being converted into useful products. The key to achieving high efficiency and high productivity is the effective separation of the microbial growth phase from the production phase of the target compound. This manner of using bacterial cells as if they were simple chemical catalysts enables one to produce large amounts of chemicals in short periods of time, and unlike conventional bioprocesses, the productivities reached, expressed as space-time-yield (STY), are comparable to that of chemical processes.

4-2. Simultaneous utilization of C6 and C5 sugars

Lignocellulosic biomass hydrolysates constitute complex mixtures of different sugars. They comprise pentoses (C5 sugars such as xylose and arabinose) derived from hemicelluloses, as well as hexoses (C6 sugars such as glucose and fructose); whereas corn starch and sugarcane-derived sucrose hydrolysates contain only hexoses. Therefore, for achieving a high yield per substrate, it is essential for microorganisms used in biofuel processes to exhibit the ability to simultaneously utilize both pentoses and hexoses. We introduced several genes relative to the catabolism of C5 sugars into coryneform bacteria, and applied these recombinant bacteria to our bioprocess. These modifications made the utilization of cellulosic materials efficient and faster conversions thus became possible since we could achieve without any lag phase the simultaneous utilization of all the sugars present in the reaction medium.

4-3. Tolerance against fermentation inhibitors

Fermentation inhibitors include phenols, furans and organic acids such as acetic acid. These compounds are by-products formed during the pre-treatment of lignocellulosic biomass. As exemplified by hydrothermal treatment, such treatments are typically very harsh but are necessary to break the recalcitrant biomass fiber and thereby facilitate enzymatic hydrolysis. Their strong inhibition has been known for many years to be a cause of concern to the biofuel manufacturer and they represent one of the biggest problems associated with conventional bioprocesses. However, we demonstrated that these fermentation inhibitors essentially do not affect the RITE Bioprocess, since their action is to inhibit cell growth while our process separates the cell growth phase from the product production phase. Furthermore, we extensively demonstrated that the main metabolic pathways necessary to produce compounds of interest on the one hand remain active under the conditions of the growth arrested RITE Bioprocess and on the other hand are virtually not affected by the presence of fermentation inhibitors in quantities that would hinder conventional processes.

4-4. Future technology development

We are constantly expanding the range of product options that the RITE Bioprocess can support. To this end, we implement global analysis tools including system biology based on metabolome analysis, metabolic pathway design, and genome engineering based on the genome database of coryneform bacteria. Figure 3 shows the synthetic pathways from pyruvate of a variety of compounds using cellulosic biomass hydrolysates as raw materials. In addition to the successful production of ethanol, or L- and D-lactic acids and succinic acid, we are developing a whole range of new targets addressing large market needs or high value added, comprising butanol, aromatic compounds, and amino acids. Although the economical production of aromatic compounds has been a challenge when using conventional fermentation technologies, their production by industrial biotechnology is still an important aim since these materials, once made from sustainable raw materials such as biomass, are expected by Japanese leading companies to become basic materials for advanced products, such as electric device, hardware, and automobiles. In addition, we revisit with the RITE Bioprocess the production of compounds conventionally manufactured by aerobic fermentation such as amino acids. There is an important cost component that can be exploited here: the production of amino acids by conventional fermentation processes requires air compressors and agitation motors for carrying out forced ventilation and mixing liquids, respectively. These equipments and their operations result in significant capital and variable expenses. We have already begun to develop anaerobic production processes for several amino acids by using the RITE Bioprocess. We will announce these in the future.

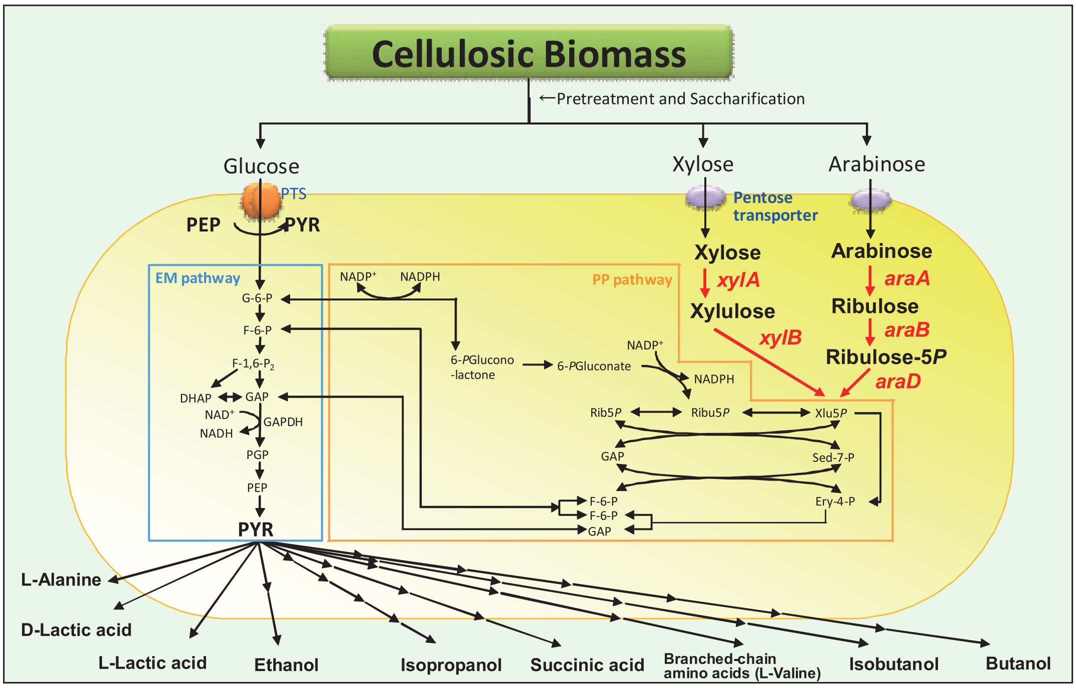


Figure 3 Production pathways of coryneform bacteria engineered for acyclic chemicals and biofuels biosynthesis

4-5. Development for industrialization

Last year, we have established several partnerships with private companies to accelerate our research and development, in addition to the collaborative work for the cellulosic ethanol production system described elsewhere (see RITE Today 2008~2010). A recent legal change in Japan makes that no more than 2 unrelated legal entities are necessary to establish a venture having corporate status, with the important specification that joint research is now also possible between companies and public R&D agencies. The ability to pursue such partnerships will help us develop and evolve cooperative entities to quickly commercialize our developments. In addition to the associations established last year, "Green Phenol Technology Research Association" and "Bio-Butanol Technology Research Association", new associations with other goals are in preparation.

5. Ending remark

Last November, the World Meteorological Organization announced that, globally, the average atmospheric CO_2 concentration reached a record level in 2009. Although the reasons why the levels of warming gases have steadily increased in the atmosphere over the past few years are still being debated, the competition for technology development in the field of biorefinery (one of the conceptually very effective means against global warming) is intensifying worldwide. As reported in the preceding paragraphs, in the field of biofuels, demonstration-scale cellulosic ethanol plants have been and are being constructed, and their productions are scheduled to go on line in the U.S. after 2011. Green chemicals such as aromatic compounds are expected to become essential materials; a strong know-how in this arena will undoubtedly help boost the competitiveness of Japanese leading industries. To contribute in achieving early the establishment of a competitive commercial-scale biorefinery, we hope to continue to aggressively expand our base of collaborative researches with industry to further the chemical scope and industrial deployment of the RITE Bioprocess platform technology.

Chemical Research Group

Challenges for Advanced Industrializing CO_2 Capture Technologies

CO_2 capture and storage (CCS) is composed of CO_2 capture from fossil fuel combustion gases and its injection into geological formations for storage or sequestration.

The current CO_2 capture cost from emission sources is estimated to be about 60% of CCS costs. Therefore reduction of CO_2 capture costs is important aspect for practical application of CCS.

Our Chemical Research Group studies various CO_2 capture technologies, with a special focus on chemical absorption and membrane separation methods.

We developed a COCS project aimed at reducing the CO_2 capture cost in ironworks by chemical absorption, in which we developed an innovative chemical absorbent that reduced the CO_2 capture cost for flue gas to 3000 JPY/ton-CO_2. We are continuing to develop a chemical absorbent to further reduce this CO_2 capture cost to 2000 JPY/ton-CO_2.

Moreover, we have developed an excellent CO_2 absorbent that is effective for pressurized gas, and are planning to put this into practical use.

By developing molecular gate type membrane technologies to capture CO_2 selectively from H_2-containing pressurized gases such as that in the integrated coal gasification combined cycle (IGCC), we are aiming for a CO_2 capture cost target of 1500 JPY/ton-CO_2.

We have discovered that new types of dendrimer polymers have excellent properties for separating CO_2 from H_2 gas mixtures, and are therefore developing membrane modules incorporating dendrimeric materials. Furthermore, we have begun testing module performance using simulated gas of coal gasification gas.

For CO_2 capture technology using adsorption processes, we have developed new solid adsorbents that do not lose CO_2 capture efficiency even in the presence of water vapor. We are planning to develop a low-cost CO_2 capture process by eliminating the requirement for a dehumidification tower.

Above all, we have begun to develop new solid sorbents, onto which amine is immobilized, for the purpose of developing low-cost CO_2 capture technology.

As mentioned above, we are promoting innovative CO_2 capture technologies, which lay the foundations for the next generation, while developing practical technologies that are acceptable to industries.

Moreover, we have seed technologies such as CO_2 separation by zeolite membranes, H_2 separation by palladium membranes, a hybrid CO_2 capture system that combines membranes with a wet scrubbing system, baroplastics that have low temperature flow under high pressure state, etc., to be used for various purposes.

Development of CO_2 capture technology by chemical absorption systems

CO_2 capture by chemical absorption is a prospective technology for separating CO_2 from a CO_2-containing gas by means of thermal dissociation of CO_2 that is chemically absorbed in an amine-based solution. This is suitable for CO_2 separation from the normal pressure gas generated on an industrial scale. Our objective is to develop new, efficient absorbents that will decrease the CO_2 separation cost, which is the main concern for chemical absorption systems.

We planned and coordinated, from FY 2004 until FY 2008, a “Cost-saving CO_2 Capture System” (COCS) project to capture and separate CO_2 from ironworks blast furnace gas at half the previous cost of a chemical absorption system, and achieved this goal (Fig. 1).

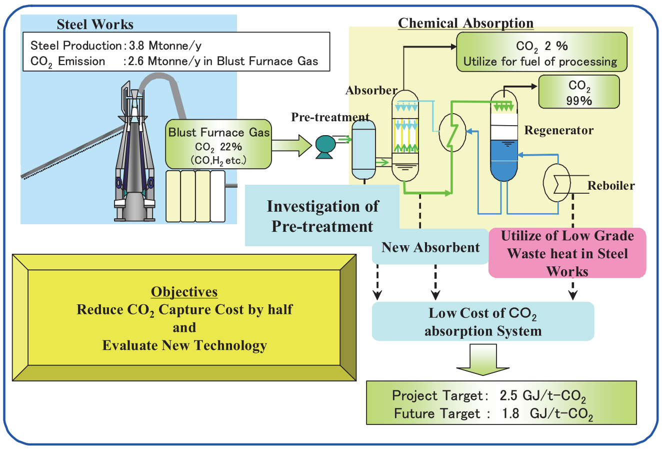


Figure 1 The outline of cost saving CO_2 capture system (COCS project)

The characteristics required of new absorbents to capture and separate CO_2 are lower heat of reaction and dissociation energy for CO_2 and a higher CO_2 absorption capacity. In particular, amines possess excellent characteristics in this regard.

In the first step of the COCS project, hundreds of amines were chosen from commercially available amines. We studied their basic characteristics, such as CO_2 absorption rate in solution, heat of reaction, CO_2 absorption capacity and so on, in a laboratory scale and determined the relationship between the chemical structure of the amines and their characteristics as absorbents. Furthermore, as a result of exploring amine composition and combining the characteristics of various amines, we developed several new efficient types of absorbent solution

(RITE-3 and 4 series) (Fig. 2). In the second step, we also developed more efficient absorbents (RITE-5 and 6 series) by designing, synthesizing and evaluating various kinds of amines using a methodology of computational chemistry based on our acquired data and quantum chemistry. The best performance for CO_2 capture energy of the absorbents developed in this project is 2.5 GJ/ton-CO_2, compared with the CO_2 capture energy of MEA (monoethanolamine) used as a standard of 4.0 GJ/ton-CO_2. We thus achieved the project target (Fig. 3).

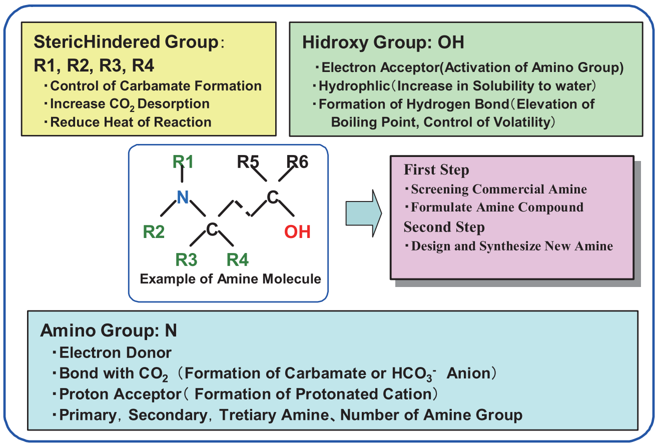


Figure 2 Development of new absorbents

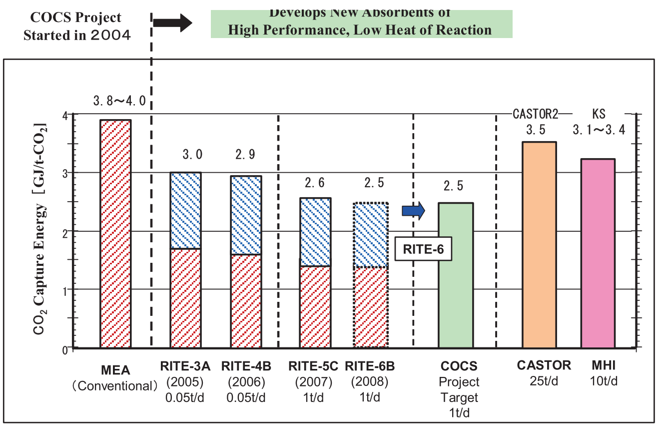


Figure 3 Reduction of CO_2 capture energy by new absorbents

The outcomes of the COCS project were succeeded by another project, "CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50" (COURSE50, from FY 2008 until FY 2012), aiming at CO_2 capture from the ironworks process gas.

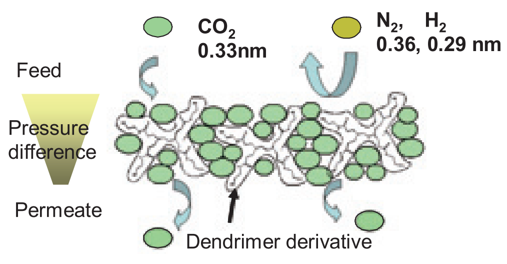
We are now endeavoring to find new, more efficient, absorbents (CO_2 capture energy: 2.0 GJ/ton-CO_2) that are appropriate for the above-mentioned project and are also conducting tests of these absorbents in a process evaluation plant (30 ton-CO_2/d processing capacity).

From FY 2007 to FY 2009, we worked on the research and development of appropriate absorbents for CO_2 capture under high-pressure conditions, based on our accumulated research experience and found amine-based absorbents with excellent CO_2 absorption and dissociation performances. We will propose a chemical absorption system using these amine absorbents as a new technology for CO_2 capture from gases under high pressure.

CO_2 and H_2 separation with a polymeric membrane

Japan's government declared a goal to reduce CO_2 emissions to half of those in 2005 as the objective "Cool Earth 50". One promising means of reducing CO_2 emission is the development of an integrated coal gasification combined cycle with CO_2 capture & storage (IGCC-CCS). In the IGCC-CCS process, CO_2 separation membranes will play an important role for reducing CO_2 capture costs. Estimates indicate that the CO_2 capture cost from a pressurized gas stream using a membrane might be 1500 JPY/ton-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. 4 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 N2 or H_2 permeating to the other side of the membrane is greatly limited and high concentrations of CO_2 can be obtained. An RITE dendrimer, which possesses excellent CO_2/H_2 selectivity, is fixed stably in a cross-linked polymer matrix to form the separation membrane. Fig. 5 shows a conceptual diagram of a material incorporating PAMAM dendrimer and its CO_2/H_2 separation properties, along with the data reported in Science and other high-impact journals. Our PAMAM dendrimer/polymer hybrid material shows the world's 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.

Figure 4 Conceptual diagram of the CO_2 molecular gate

In the development of a commercial membrane module using the PAMAM dendrimer/polymer hybrid material, RITE has recently involved four major membrane companies, Daicel Chemical Industries, Ltd.; Kuraray Co., Ltd.; Nitto Denko Corporation; and Toray Industries. RITE and Nippon Steel Engineering Co., Ltd. will test trial membrane modules with a recently developed simulator and demonstrate the utility of the membrane module for capturing CO_2 from a pressurized gas stream such as that in coal gasification (Fig. 6).

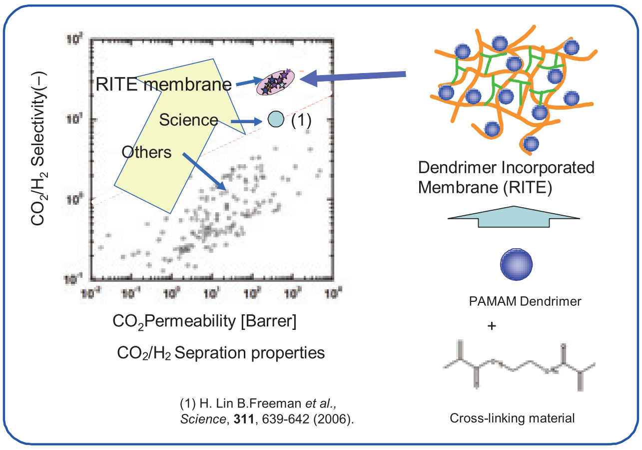


Figure 5 Dendrimer incorporated membrane and its performance

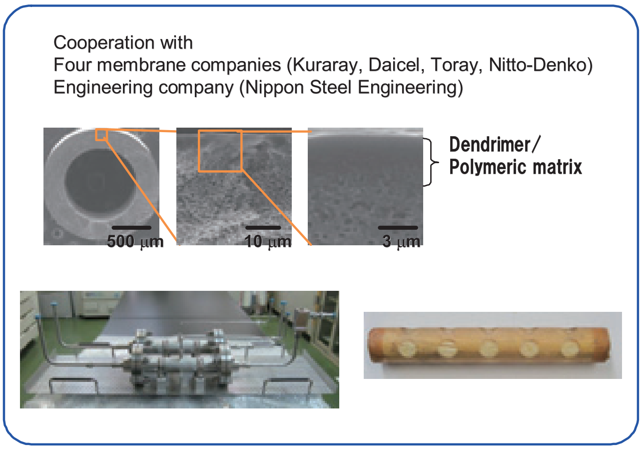


Figure 6 Development of membrane modules in cooperation with private companies

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) in a recognized project for the Carbon Sequestration Leadership Forum (CSLF), the University of Texas at Austin and the Norwegian University of Science and Technology.

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

Novel hydrophobic adsorbents have been proposed as CO_2 adsorbents for the separation of CO_2 from high-pressure gas. CO_2 adsorption capacities of 13X zeolite and new synthetic adsorbents are shown in Fig. 7.

It has been confirmed that the adsorbent synthesized

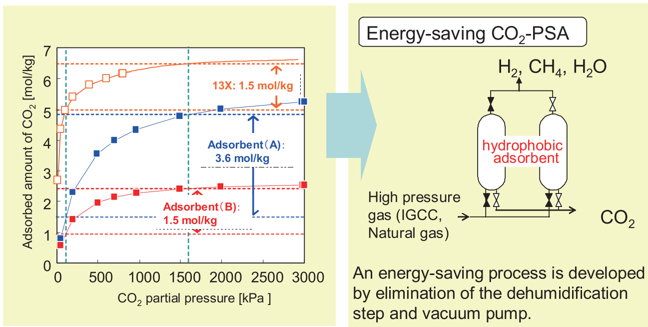


Figure 7 Development of an energy-saving CO_2-PSA process

in our study adsorbed considerable amounts of CO_2 at high pressure. It was also confirmed that they adsorbed CO_2 even in the presence of water vapor. From CO_2 separation experiments using CO_2-H_2 mixed gas flows, it was confirmed that the new adsorbent was effective for separating CO_2 from the gas flow in the presence of water vapor. Evaluation of the process cost is now under way.

Advanced stage of technology development on CO_2 capture by amine-based absorbents

CCS is a highly viable technology for tackling global warming. It is strongly desirable that this be implemented in the market as soon as possible. Recent R&D on CCS has focused on energy-saving, low-cost CO_2 capture technologies, demonstration and feasibility studies of commercial-scale systems, and so on. RITE began a new project funded by METI in 2010FY, in which the research objectives were to develop novel solid sorbents and to establish evaluation standards CO_2 capture using liquid amine solvents.

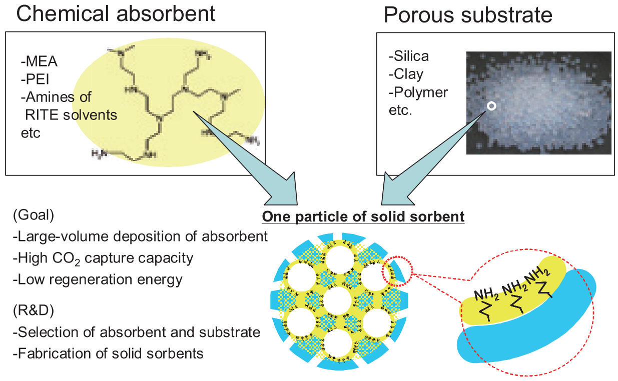


Figure 8 Development of novel solid sorbents

With respect to solid sorbents, amines can be immobilized onto a support or encapsulated within a porous substrate (Fig. 8). Although solid sorbent techniques use amine-based absorbents, similar to liquid amine solvent methods, it has the advantage of a lower anticipated heat duty for regeneration. RITE investigates novel solid sorbents using RITE-developed solvents through cooperative R&D activities with NETL, from which major research on the solid sorbents has already been presented.

Improved evaluation techniques are required to accelerate commercialization of liquid amine solvent methods. Process simulation for advanced amine solvents must be established and improved so as to more accurately estimate the performance of scaled-up processes. Also, the environmental impact of amine-based absorbents has become a crucial issue.

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

RITE has conducted developmental work entitled "Sub-nano structure controlled materials: development of innovative gas separation membranes" as part of the Global Climate and Energy Project (GCEP) of Stanford University, USA.

Under the theme of advanced CO_2/H_2 separation materials incorporating active functional agents, supercritical and subcritical CO_2 acts as a structure-directing agent for CO_2 affinity materials. Fig. 9 shows a schematic of the concept. Excellent CO_2 separation membranes will be obtained by strict morphology regulation at the molecular scale. In the figure, supercritical CO_2 regulates the CO_2 affinity membrane materials into a morphology that is preferential for CO_2 permeation (State A). After removing supercritical CO_2, the preferential morphology will be maintained to form an excellent CO_2 separation membrane.

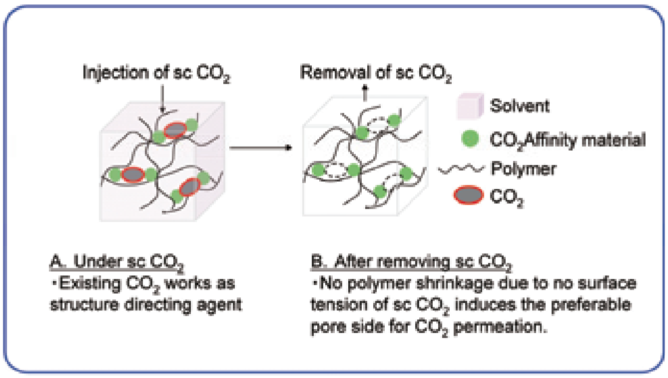


Figure 9 Concept of super critical (sc) CO_2 structure directing method

CO_2 Storage Research Group

CO_2 Storage Technology Development for Practical Application

CO_2 Geological Storage Project

CO_2 geological storage technology is a technology for safely containing CO_2, one of greenhouse gases, underground without releasing them in the air. It includes EOR for enhancing oil recovery by injecting CO_2 into oil reservoirs; CO_2 sequestration into depleted gas fields; ECBM for enhancing methane recovery by injecting CO_2 into coal seams; and storing CO_2 in saline aquifer consisting mainly of porous sandstone. RITE has been working on storing CO_2 in the saline aquifer, where CO_2 could be stably stored for long period of time because of the presence of mudstone layer above the sandstone of the aquifer, which is capable of blocking gas and liquid with high sealing properties.

RITE has been developing basic technologies concerning geological characterization of saline aquifer, monitoring CO_2 behavior, and predicting long-term CO_2behavior. Partnership with relevant research institutes, such as Japan CCS Co., Ltd (JCCS) and National Institute of Advanced Industrial Science and Technology (AIST) have been further encouraged and this year RITE has also started a joint study with US national research laboratory (on developing technique for predicting CO_2 behavior).

Followings are RITE's research results for FY 2010.

• Permanent OBC test study in real waters

RITE conducted performance assessment of permanent OBC (undersea cable) system for seismic wave exploration, which has been developed by RITE for last three years, in real waters off Tomakomai, Hokkaido in July through August, 2010. This test study gave us hands-on experience and know-how about how the cables should be installed and removed and two-month consecutive measurement data, as well as observation data of natural micro-seismicity occurred in near and far areas of the test study site. After taking economic factors into account, RITE will move forward with deployment of the permanent OBC system as a method that is suitable for monitoring CO_2 behavior stored in offshore aquifer.

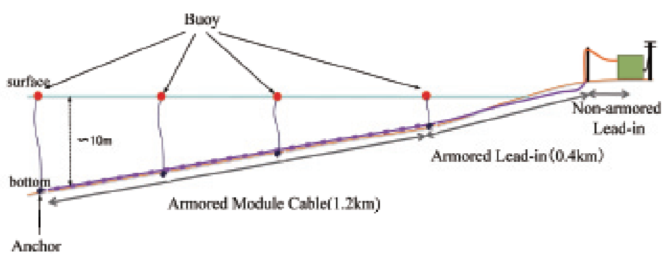


Figure 1 Outline of OBC test study

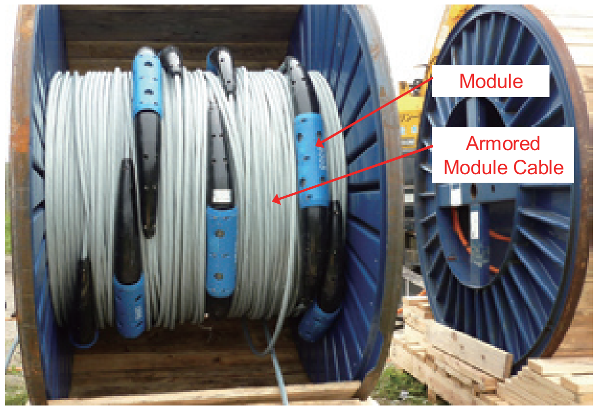


Figure 2 Photo of OBC

• Monitoring CO_2 behavior in Nagaoka site

From July 2003 to January 2005, 10,400 tons of CO_2 were injected into saline aquifer 1000 meters below the ground surface of Iwanohara, Nagaoka site, Niigata Prefecture (Inpex Corporation). Even after the end of injection, RITE continues various on-site measurements of wells to grasp CO_2 behavior underground. This year, RITE conducted physical logging, cement bond logging and crosshole seismic tomography and confirmed CO_2 was safely stored. Among many demonstration projects worldwide, only Nagaoka project keeps monitoring CO_2 behavior even after the end of injection and for that reason, its monitoring results have drawn attention from all over the world.

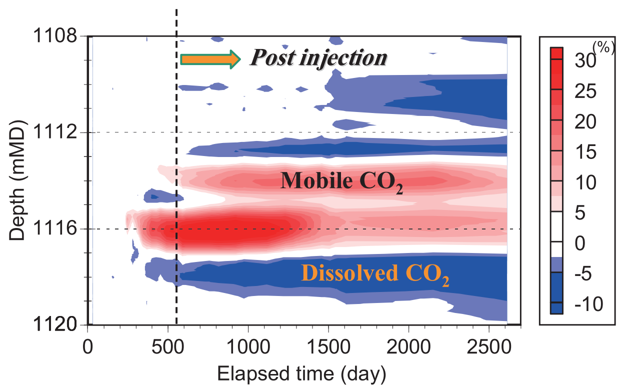
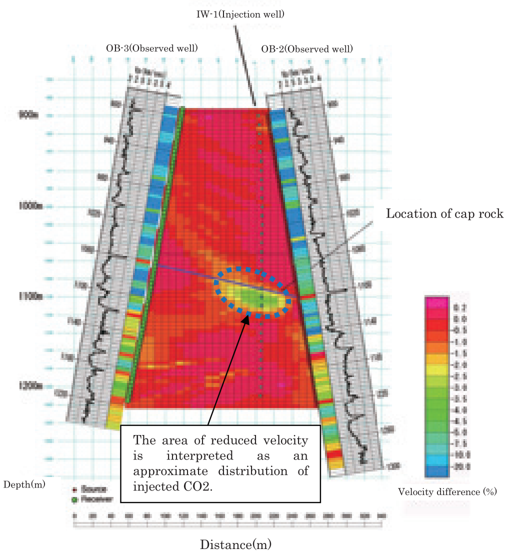


Figure 3 Physical logging



In order to image the distribution of injected CO2, time-lapse croswell tomography was conducted. This figure shows velocity difference tomographs of survey results in the 69th month after the injection ended. The latest survey shows that the velocity difference remain unchanged from just after the injection results. This means injected CO2 is stored safely in the aquifer.

Figure 4 Crosshole seismic tomography

- Installation of X-ray CT scanner

To estimate how CO_2 is stored after injected into pronouns sandstone formation of saline aquifer, RITE introduced X-ray CT scanner that is capable of visualizing CO_2 behavior and distribution in the pronouns structure of sandstone. The state-of-the-art X-ray CT scanner enables us to observe microscopic structure of sandstone in real time, so that we could estimate CO_2 behavior into more detail by combining this experiment system with the existing physical measurement techniques RITE has developed.

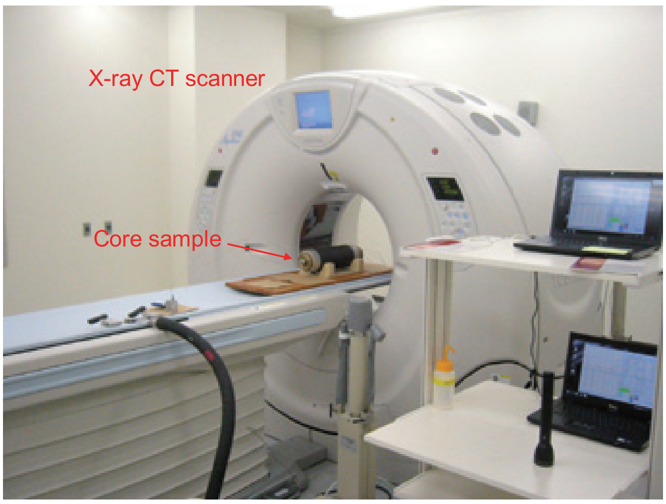


Figure 5 Photo of X-ray CT scanner

Based on the research results, RITE will focus on the followings in next fiscal year:

- To address technical issues arising in large-scale demonstration projects (in partnership with Japan CCS Co., Ltd).

RITE has established technical partnership with Japan CCS Co., Ltd, the operator of implementing the large-scale CCS demonstration projects. In this fiscal year, we have started physical measurements of core samples extracted at prospective pilot sites of Japan CCS. Applying this measurement technique to site characterization of possible large-scale demonstration sites, RITE tries to standardize methods for reservoir characterization and physical measurements.

- To promote joint study with research laboratory in the US (US-Japan joint study)

In a joint study with Lawrence Berkeley National Laboratory, RITE has been studying the method for characterizing CO_2 long-term behavior and the impact on geological formation at the time of CO_2 injection by using data obtained in Nagaoka site or CO_2 injection pilot sites in the US. We have started preparatory study and researches for the joint study this year. In the years after the next fiscal year, it is scheduled to conduct physical measurements, including on-site observation of microseismic waves at CO_2 injection sites.

IZEC (International Zero Emission Coal)Project

Combining technology of high-efficiency coal power generation with technology of CCS (CO_2 capture and storage), which enables zero emission, has been developed widely in the US, Canada, Europe, Australia, China and others and its large-scale demonstration projects have been planned and implemented in many places. While each technology and its know-hows are accumulated and improved through international partnership, such as CSLF (Carbon Sequestration Leadership Forum), the efforts to demonstrate the technology need to be proceeded. Considering no economic incentives are expected from the CCS technology (except for EOR etc.), it is necessary for the government to support the implementation as a national project, while collaborations between public and private sectors are required to be reviewed for lasting operation of the project in the future.

In view of the situation above, this project is aimed at gathering information on state-of-the-art technology trend of zero-emission coal fired power plant with CCS (CO_2 Capture and Storage) projects and at helping making policies for the implementation of technology. RITE has engaged in the following activities as part of FutureGen project since 2009 and IZEC (International Zero Emission Coal) project since 2010.

(1) Gathering and analyzing information on high-efficiency coal fired power plant with CCS projects in the world

(2) Gathering and organizing information on legal

framework, approval criteria and approval authorities in terms of CCS-ready in the world

(3) Hearing and discussion with experts from overseas through the workshop to be held in Japan

As for CCS projects, we have been conducting a survey of current status of more than 60 pilot- and demonstration projects mainly in Europe, the United States and Australia. As for strategies for introducing CCS, we have been conducting research on policies and strategies of the UK, Norway, the Netherland, Germany, the United States, Canada and Australia etc. It is noteworthy that the UK requires a new coal-fired power plant to be CCS-ready when its construction is approved and permitted, and other EU member states need to incorporate requirement of CCS-ready into domestic laws in June, 2011. In Japan, a draft of Strategic Energy Plan of Japan clearly states that coal-fired power plants for future planning are required to review possible equipment of CCS technology by 2030, so we conduct a survey of CCS-ready trend in Europe in that context. Our 2010 research will focus on detailed information on approval criteria and progress toward the implementation, particularly, in the UK and Germany.

"Zero-emission coal-fired plant (IZEC) workshop" is scheduled to be held in February, 2011, where the regulatory authorities in EU member states and operators of large-scale demonstration project are invited to discuss their efforts and update progress toward CCS implementation and exchange opinions on such issues.

China CCS-EOR Project

CCS, the technology to capture and store CO_2 from fossil fuel, is essential as countermeasures against global warming before 2100. In particular, CCS-EOR which can bring commercial advantage by increasing oil recovery is expected to be implemented at early stage.

In the United States, CCS-EOR utilizing natural CO_2 has already been developed in a scale of 60 million-tons per year. CCS-EOR is further expected to target CO_2 emissions from coal-fired power stations which releases large amount of CO_2 emissions for energy unit.

In recent years, China's CO_2 emissions have been increasing year by year and become the largest in the world in 2008. Japan also emits a large amount of CO_2 which corresponds to the 4th largest one. Therefore, the collaboration between China and Japan in CCS-EOR study has a very significant meaning from the viewpoint of preventing global warming internationally.

As part of technical exchange with China National Petroleum Corporation (CNPC), RITE held the 2nd CCS-EOR workshop in April in Tokyo, following the 1st one in last fiscal year, and discussions and exchange of opinions were made on the technical themes below:

(1) CO_2 Storage Basic Research
(2) CO_2 Monitoring
(3) CO_2 Simulation
(4) CO_2 Capture Technology
(5) Progress on EOR development
(6) Case study of demonstration projects
(7) CCUS/System integration

Technical exchange with CNPC has been deepened this year to the extent that RITE conducted research into CCS-EOR pilot sites of CNPC's Jilin oil fields in June. Based on the research results, RITE has chosen the following three themes for China-Japan CCS-EOR collaboration

(1) Research on CCS-EOR (CCUS) whole system
(2) Research on reservoir characterization technique
(3) Research on Microbial Restoration of Methane Deposits with Subsurface CO_2 Sequestration into the Depleted Oil Fields

RITE will carefully study each theme to contribute to realizing low-carbon society and ensuring energy security.

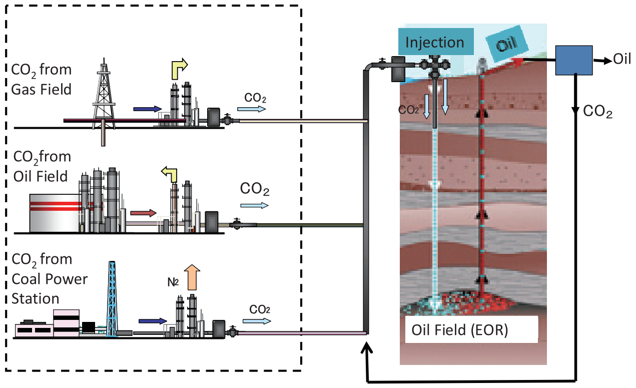


Figure 6 Outline of CCS-EOR

Commemorative Ceremony of the 20th Anniversary of RITE
"Gift for Future Generation - Low Carbon Society for the Beautiful Earth"

Marking the 20th year since RITE was founded here in Kyoto in July 1990 receiving support and cooperation from the government, industrial community, and universities to play a role to realize New Earth 21 program proposed by the Japanese government to the world, we held commemorative events on November 2nd, 2010.

Facility tour of our headquarters held in the morning was attended by around 40 guests. At the start of the tour, Senior Managing Director Takashi Honjo made an address saying "Our technologies accumulated over 20 years are now going to blossom" and introduced R&D activities of each group. After that, participants visited the laboratories in J&S memorial building etc.

In the afternoon, memorial lecture, commemorative ceremony, and reception were held at Hotel Granvia Kyoto. Attendance of some 250 people from industry, government, and academia made the events successful.

[Memorial lecture]

Kyoto University President Dr. Hiroshi Matsumoto delivered a lecture titled "Ars Vivendi and Use of Space Energy."

[Commemorative ceremony]

Chairman Takashi Imai made a speech on behalf of RITE saying "We will continue to work actively on developing innovative technologies to find a breakthrough in the global environmental issues and promote their practical application" and introduced the slogan to commemorate our 20th anniversary, "Gift for Future Generation - Low Carbon Society for the Beautiful Earth." Following that, remarks by guests of honor were given, namely, by Economy, Trade and Industry Minister Akihiro Ohata (read by Deputy Director-General for Industrial Science and Technology Policy Junya Nishimoto), Kansai Economic Federation Chairman Hiroshi Shimozuma, and Kyoto Prefecture Governor Keiji Yamada. Then, a brief overview of activities of RITE was provided.

[Reception]

President Yoshihisa Akiyama made an opening address on behalf of RITE, and Kyoto Culture Foundation President Teiichi Aramaki, who had given support in establishing RITE as then-governor of Kyoto prefecture, made a congratulatory speech. Following the speeches, kagami-biraki (breaking the circular lid of a sake barrel with a wooden mallet to celebrate the beginning of an event) was performed and former President of RITE Shoichiro Kobayashi, Adviser of the Kansai Electric Power Co., Inc., proposed a toast. After that, the participants enjoyed the reception in a relaxed atmosphere. To conclude the party, Senior Vice President Yoichi Kaya thanked the guests for their attendance, and asked their kind support to RITE in future.

Facility tour of our headquarters

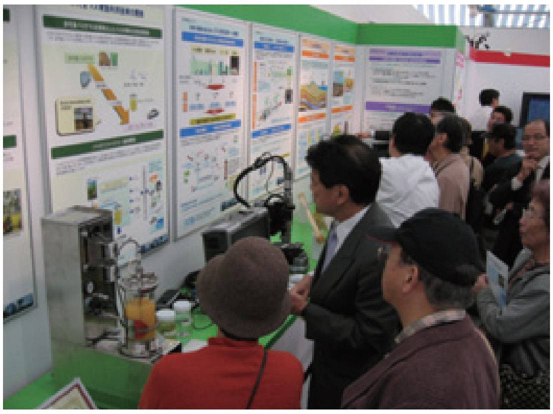
Commemorative ceremony

The 1300th Anniversary of Nara Heijo-kyo Capital
Technologies developed in Kansai Science City -See the future from Heijo Palace Site-

Planning, Survey, and Public Relations Group

The technologies developed in Kansai Science City-See the future from Heijo Palace Site- was held at the Heijo Palace Site on November 5 to 7, 2010.

Nine research institutes including RITE participated in this event to promote an understanding of the activities on going at Kansai Science City. The popularity of the celebration of the 1300th Anniversary of Nara Heijo-kyo Capital boosted the attendance to reach 11,000 visitors in three days.



RITE exhibited poster and showpieces about global warming countermeasure technologies such as CCS and biorefinery, scenario-making for global warming mitigation, industry-institute cooperation/public relations.

The RITE promotion video was shown and RITE staff gave a quiz show about environmental problems to introduce RITE's activities and social impact.

Symposium on Innovative Environmental Technologies
-The Realization of Low Carbon and Sustainable Society-

Planning, Survey, and Public Relations Group

The symposium entitled "Symposium on Innovative Environmental Technologies ~The Realization of Low Carbon and Sustainable Society~" was held on December 2, 2010 at Nadao Hall in Tokyo.

The symposium was organized by RITE, and supported by the Ministry of Economy, Trade and Industry(METI)/the Chemical Society of Japan/the Society of Chemical Engineers, Japan/the Japan Society for Bioscience, Biotechnology, and Agrochemistry/the Japan Society of Energy and Resources/the Japan Institute of Energy. A total of 406 attendees from METI, the Ministry of the Environment as well as industry and academia from various fields gathered to hear the latest advances in evironmental technologies.

The symposium was opened by Dr. Yoichi Kaya who delivered the keynote address. Rite experts from each research groups reported the outcomes and outlooks of their researches such as CCS technology, biorefinery technology and scenarios for mitigating global warming, with the current trends of the world.

IIASA-RITE International Symposium 2010

Systems Analysis Group

The IIASA-RITE International Symposium 2010 was held at Nadao Hall in Tokyo on February 8th, 2010. 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 including Prof. Detlof von Winterfeldt, a director of the IIASA, Prof. Nabojsa Nakicenovic from the IIASA, Dr. Seita Emori from the National Institute for Environmental Studies, Prof. Nobuo Mimura from Ibaraki University, Ms. Junko Edahiro from e's Inc., Yoichi Kaya, a director general of RITE, and Keigo Akimoto from RITE. They introduced the latest research outcomes, focusing on the necessity of system analysis to solve climate change, the importance of scientific views and decision making under uncertainty, the necessity of not only mitigation measures but also its best mix with adaptation measures, and the necessity of a long-term view/a view of international fairness for sustainable development.

We had an attendance of 230 people from industries, ministries and universities. Their active discussion motivated us to dedicate further efforts to our research and development.

Many visitors attended our seminar and exhibition booth at BioJapan2010 (World Business Forum)

Molecular Microbiology and Biotechnology Group

The World Business Forum organized by the BioJapan Organizing Committee and Nikkei Business Publications Inc. was held at Pacifico Yokohama from 29th September to 1st October 2010. Director, Dr. Hideaki Yukawa, moderated the seminar on "Green Innovation" and our group displayed the highly efficient bio-conversion technology 'RITE-Bioprocess', along with posters and a video presentation, which allowed to introduce in our activities in detail. In addition, our corporate strategic alliance partners joined the exhibition and their panels were displayed also in the RITE booth. We are planning to present and participate in the exhibition at BioJapan 2011 too where we will show our latest progress and achievements.

RITE exhibition booth at BioJapan 2010

The Second Japan-China CCS-EOR Workshop

CO_2 Storage Research Group

The second Japan-China CCS-EOR workshop was held on April 5 and 6, 2010 at Grand Palace, in Tokyo, which was co-hosted by RITE and China National Petroleum Corporation (CNPC) and aimed at exchanging information on CCS-EOR technologies between Japan and China. About 70 stakeholders from Japan and China attended the workshop.

Following opening statements from the governments (Coal Division of the Ministry of Economy, Trade and Industry and Department of Climate Change of the National Development and Reform Commission), experts from Japan and China reported on CO_2 Storage Basic Research; CO_2 Monitoring; CO_2 Simulation; CO_2 Capture Technology; Progress on EOR development; Case study of demonstration projects; and CCUS/System integration over two days. Active discussions were taken place on each issue.

Based on the results of the first and second workshops, Japan and China have agreed to collaborate on the following three themes on CCS-EOR:

- Research on CCS-EOR (CCUS) whole system
- Research on reservoir characterization technique
- Research on Microbial Restoration of Methane Deposits with Subsurface CO_2 Sequestration into the Depleted Oil Fields

Opening statement of Organizer

CCS Technical Workshop 2010, CO_2 Monitoring Technology

CO_2 Storage Research Group

On December 9th 2010, CCS Technical Workshop 2010 was held at Hotel Granvia Kyoto organized by RITE and supported by the Ministry of Economy, Trade and Industry (METI) National Institute of Advanced Industrial Science and Technology (AIST), Central Research Institute of Electric Power Industry (CRIEPI), Japan Society of Energy and Resources (JSER) and Japan CCS Co., Ltd. (JCCS). 169 related persons attended from companies, universities, research institutes and government agencies.

The speakers were Tip Meckel, The University of Texas on "Summary of current regional carbon sequestration partnerships activities, USA"; Wawan Gunawan A. Kadir, Institute Technology Bandung on "Energy policies, geophysical challenges and 4D microgravity development for reservoir monitoring during EOR (water and CO_2 injection) in Indonesia" ; Masanori Abe, JCCS on "Japan is moving forward to large-scale CCS demonstrations" ; Milovan Urosevic, Curtin University on "Otway basin project stage I: results of seismic monitoring" ; Rob Arts, TNO on "Fourteen years' experience of monitoring CO_2 injection in the Utsira Sand at Sleipner, offshore Norway" ; Takahashi Akihisa, Geo-Science Laboratory on "Toward offshore CCS seismic monitoring -Development of permanent OBC system-" ; and Ziqiu Xue, RITE on "Development of the technology to evaluate CO_2 storage based on seismic survey data".

Researchers in RITE also delivered poster presentation. Fruitful discussion was made about CO_2 monitoring technology in CCS field among the participants.

Opening statement of Organizer

GHGT-11 to be held in Kyoto in 2012

Office for GHGT-11

The 11th International Conference on Greenhouse Gas Control Technologies (GHGT-11) will be held in Kyoto in November 2012. The GHGT conferences are international conferences guarded by IEA Greenhouse Gas R&D Programme (IEAGHG), which was established as an Implementing Agreement under the International Energy Agency, and in which RITE participates to represent Japan.

When GHGT-6 was held in Kyoto in October 2002, RITE took the lead in hosting the conference. The GHGT conferences are held every two years rotating between North America, Europe and Asia. The series will return to Asia after ten years, GHGT-11 again being held in Japan and co-organized by RITE and IEAGHG.

The GHGT conference series has established itself as the principal international conference on greenhouse gas mitigation technologies especially on CCS (CO_2 Capture and Storage), drawing experts from across the world. GHGT-11 will be a four-day conference that includes keynote speeches, plenary sessions, around six parallel technical sessions and poster sessions. The sessions will allow about 250 oral presentation to be made, and 700 posters to be presented.

Call for paper will open in the autumn of 2011. Further schedule and detailed information on GHGT-11 will be put on the websites of RITE and IEAGHG. GHGT-10 held in Amsterdam in September 2010 was attended by some 1,600 delegates, but only 200 of them were from Asia. In order to increase Asia's presence at GHGT-11 to be held in Japan, we would like to invite all of you who are working on global warming to submit papers and attend the conference, to enhance global cooperation on research and development for greenhouse gas control technologies.

1. Overview of GHGT-11
   (1) Dates: Sun. November 18 - Thur. November 22, 2012
       (Venue: Kyoto International Conference Center)
   (2) Estimated number of attendees: 1,600
   (3) Organized by: RITE & IEAGHG
   (4) To be supported by METI etc.
   (5) Programme
       November 19: Keynote addresses (Plenary session)
       November 19-22: around 6 parallel Technical sessions, Poster sessions
       November 22 PM: Conclusions, Closing session
   (6) Social events
       Welcome Reception (November 18)
       Networking Reception (November 20)
       Conference Dinner (November 21)

Themes of Technical Sessions at GHGT-10 (September 2010, Amsterdam)

Capture	Pre-Combustion, Post-Combustion, Membranes, Techno-Economic Comparisons, Oxy-Combustion, Novel Systems, etc.
Utilisation	ECBM and other Uses, EOR
Storage	Modelling Tools, Coal Bed Storage, Risk Assessment, Seals, Saline Aquifer, Field Studies, Capillary and Solubility Trapping, etc.
Integrated	Integrated CCS Systems, System Flexibility: Need for Flexibility, CO_2 Transportation, Health and Safety Issues, etc.
Demonstrations	Demonstration Projects, New Developments, Experience with Storage, Lessons Learnt
Policy	Scenarios, Policy Instruments
Negative Emissions	Capture from Air - Biomass and CCS, Capture from Air - Mineralisation Routes
Legal	Legal Issues and Regulatory Frameworks
Public Perception	Public Perception and CCS, Learning from Projects, Communication and CCS

2. Schedule Outline (subject to change)
   (1) Call for Papers / Development of Technical Programme
   - Autumn of 2011: Call for Paper open (abstracts submittable)
   - Summer of 2012: Notification of paper acceptance or rejection
   - October 2012: Full paper due / Final programme established and listed on web site

   (2) Registration
   - Spring and summer of 2012: Early bird registration open
   - From the next day that Early bird registration closes: Late registration open

Web pages on GHGT-11
* For information in Japanese, please visit our web site
  http://www.rite.or.jp/Japanese/ghgt11/ghgt11.html
* For information in English, please visit http://www.ghgt.info/

GHGT-11 invitation video

Systems Analysis Group

■2010 Original Paper

	Title	Researchers	Journal
1	Land Use-Transport Model for Impact Assessment of Urban Policies on Carbon Dioxide Reduction and Sustainability	Masanobu Kii, Keigo Akimoto	Journal of Japan Society of Energy and Resources Vol.31 No.1, pp.16-22
2	Introduction of Subsidization in Nascent Climate-friendly Learning Technologies and Evaluation of its Effectiveness	Ullash Kumar Rout, K. Akimoto F. Sano, T. Tomoda	Energy Policy, Vol. 38, Issue 1, January 2010, pp.520-532
3	Estimates of GHG Emission Reduction Potential by country, Sector and Cost	K. Akimoto, F. Sano, T. Homma	Energy Policy, Vol.38 Issue 7, 2010, pp.3384-3393

■2010 Other Paper (e.g. Review, Comment)

	Title	Researchers	Forum
1	Response to Global Warming	Keigo Akimoto	China Research Center, Japan Science and Technology Agency, 'Monthly Science and Technology Newsletter of China' http://www.spc.jst.go.jp, January 2010
2	Global Warming Mitigation and CO2 Reduction Technologies	Keigo Akimoto	Monthly Chemical Engineering, January 2010
3	Challenges for the Future', the First Step to Establish a New Social System, Seminar -Environment/CSR-, JST Symposium	Keigo Akimoto, et al.	Monthly Global Environment, February 2010
4	Global Warming Measures and Sustainable Development	Keigo Akimoto	ELECTRICAL REVIEW, June 2010
5	Kyoto Protocol and Copenhagen Accord	Fuminori Sano, Keigo Akimoto	ELECTRICAL REVIEW, July 2010
6	Consumption-based Measurement of CO2 Emissions by Country	Takashi Homma	ELECTRICAL REVIEW, August 2010
7	Comparable Energy Efficiency for Key Sectors across Countries	Junichiro Oda	ELECTRICAL REVIEW, September 2010
8	Overview of Global Warming Mitigation and Role of Nuclear Power; Toward Sustainable Measures against Global Warming	Keigo Akimoto	ATOMOZ、October 2010, Atomic Energy Society of Japan
9	Mid- and Long-term Scenarios for Global Warming Mitigation	Keigo Akimoto	ELECTRICAL REVIEW, December 2010

■2010 Oral Presentation (Domestic Conference)

	Title	Researchers	Magazine, Newspaper, etc.
1	Analyses of Equitable Emission Reduction Targets with a World Energy Systems Model	Fuminori Sano, Keigo Akimoto, Takashi Homma, Junichiro Oda	26th Conference on Energy, Economy and Environment, January 26, 2010
2	Evaluation of Climate Change Mitigation with Cost of Stabilization of Power System for Inducing PV and wind Power Generation	Fuminori Sano, Keigo Akimoto	26th Conference on Energy, Economy and Environment, January 26, 2010
3	Land Use-Transport Model for Impact Assessment of Urban Policies on Carbon Dioxide Reduction and the Sustainability	Masanobu Kii, Keigo Akimoto	26th Conference on Energy, Economy and Environment, January 26, 2010
4	A Study on Marginal Abatement Cost Curve and Payback Periods	Keigo Akimoto, Fuminori Sano, Junichiro Oda	26th Conference on Energy, Economy and Environment, January 27, 2010
5	Analyses on GHG Emissions and Sustainable Development from Statistics Data	Kohko Tokushige, Keigo Akimoto, Junichiro Oda	26th Conference on Energy, Economy and Environment, January 27, 2010
6	Analysis of Economic Impacts of Mid-term CO2 Emissions Reduction Targets of Annex I Countries Considering International Industrial Relationships	Takashi Homma, Keigo Akimoto	26th Conference on Energy, Economy and Environment, January 27, 2010
7	Impact Assessment Method of Urban Policies on Carbon Dioxide Reduction Using Land Use-Transport Model	Masanobu Kii, Keigo Akimoto	26th Conference on Energy, Economy and Environment, January 27, 2010
8	Energy Efficiency in Iron & Steel Sector by Region and Potentials of CO2 Emission Reductions	Junichiro Oda, Keigo Akimoto, Fuminori Sano	26th Conference on Energy, Economy and Environment, January 27, 2010
9	Estimations of Water Resources and Demand by Country for Assessments of Sustainable Water Use	Ayami Hayashi, Keigo Akimoto, Takashi Homma, Fuminori Sano, Junichiro Oda	26th Conference on Energy, Economy and Environment, January 27, 2010
10	RITE Model Analyses on the Mid-term Target -Issues and Remarks-	Keigo Akimoto	Society for Environmental Economics and Policy Studies, September 11, 2010
11	Investment for Competitive Power Plants under Uncertainty of Allocation Scheme	Junichiro Oda	The 5th National Conference on Real Options, November 13, 2010

■2010 Oral Presentation (International Conference)

	Title	Researchers	Magazine, Newspaper, etc.
1	Analyses on GHG Mitigation Cost and Measures and their Implications	Keigo Akimoto	International Conference on Post-Kyoto Climate Change Mitigation Modeling, Seoul, Korea, June 17, 2010
2	Baseline Scenarios and Comparability	Kenichi Wada	The third Asian Modeling Exercise Meeting , September 13-15, 2010
3	Role and Issues of CCS in Long-term Sustainable Emission Reductions and toward Sustainable Development	Kohko Tokushige	GHGT10, Amsterdam, Netherlands, September 20-23, 2010
4	An Analysis of CCS Investment under Uncertainty	Junichiro Oda	GHGT10, Amsterdam, Netherlands, September 20-23, 2010

■2010 Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Assessment of Economic Impacts of Japan's Mid-term Target on Industrial Competitiveness	Takashi Homma	DBJ Research Center, Development Bank of Japan, January 6, 2010
2	Global Warming Issues: the Latest situation, Technology Trends and Development Perspectives	Keigo Akimoto	Research Council for Project Vitalization in Kansai Area, Japan Machinery Federation, February 16, 2010
3	Global Warming Measures: Low-Carbon Cities and Pursuit of Co-benefit	Keigo Akimoto	Community-based Environment Assembly, 'Low-Carbon City Directions: Sustainable Environment Innovations ' , March 11, 2010
4	Challenges for the Future', the First Step to Establish a New Social System, Seminar -Environment/CSR-, JST Symposium	Keigo Akimoto	JST (Japan Science and Technology Agency) Symposium, March 13, 2010
5	Necessity of Integrated Analyses of Materials and Energy, and Policy and Measures	Keigo Akimoto	Energy- and Environment-Specific Symposium, The University of Tokyo, June 3, 2010
6	Perspectives on Global Warming Measures: Feasibility of the Mid- and Long-term Target and Assessment of the Mid- and Long-term Roadmap	Keigo Akimoto	The First Project Meeting, Resource and Environment Committee, Kyushu Economic Federation, June 25, 2010
7	RITE Model Analyses and Mid-term Target -Issues and Views	Keigo Akimoto	Society for Environmental Economics Model, Japan Center for Economic Research, July 7, 2010
8	Analyses of Emission Reduction Costs	Keigo Akimoto	Task Force Meeting, Political Measures Working Group, Global Environment Subcommittee, Environment Committee, Industrial Structure Council, September 1, 2010
9	Analyses of Emission Reduction Costs	Keigo Akimoto	Political Measures Working Group, Global Environment Subcommittee, Environment Committee, Industrial Structure Council, September 13, 2010
10	The Mid- and Long-term Climate Policy Scenario	Miyuki Nagashima	The Second Lecture Meeting, Global Environment Technology Forum, Osaka Science & Technology Center, September 13, 2010
11	Impacts of Carbon Leakage by Climate Policies in Japan	Keigo Akimoto	British Embassy Tokyo, October 7, 2010

Molecular Microbiology and Biotechnology Group

■2010 Original Paper

	Title	Researchers	Journal
1	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)
2	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.
3	Xylitol production by recombinant *Corynebacterium glutamicum* under oxygen deprivation.	M. Sasaki, T. Jojima, M. Inui and H. Yukawa.	Appl. Microbiol. Biotechnol. 86:1057-1066. 2010.
4	A novel redox-sensing transcriptional regulator CyeR controls expression of an old yellow enzyme family protein in *Corynebacterium glutamicum*.	S. Ehira, H. Teramoto, M. Inui and H. Yukawa.	Microbiology 156:1335-1341. 2010.
5	Engineering of sugar metabolism of *Corynebacterium glutamicum* for production of amino acid L-alanine under oxygen deprivation.	T. Jojima, M. Fujii, E. Mori, M. Inui and H. Yukawa.	Appl. Microbiol. Biotechnol. 87:159-165. 2010.
6	Characterization of a 24-kb plasmid pCGR2 newly isolated from *Corynebacterium glutamicum*.	Y. Tsuchida, S. Kimura, N. Suzuki, M. Inui and H. Yukawa.	Appl. Microbiol. Biotechnol. 87:1855-1866. 2010.
7	Regulation of expression of genes involved in NAD de novo biosynthesis in *Corynebacterium glutamicum*.	H. Teramoto, M. Suda, M. Inui and H. Yukawa.	Appl. Environ. Microbiol. 76:5488-5495. 2010.
8	Antisense-RNA-mediated plasmid copy number control in pCG1-family plasmids, pCGR2 and pCG1, in *Corynebacterium glutamicum*.	N. Okibe, N. Suzuki, M. Inui and H. Yukawa.	Microbiology 156:3609-3623. 2010.
9	Regulation of genes involved in sugar uptake, glycolysis and lactate production in *Corynebacterium glutamicum*.	H. Teramoto, M. Inui and H. Yukawa.	Future Microbiol. 5:1475-1481. 2010.

■2010 Oral Presentation

	Title	Researchers	Forum
1	Technology and Innovation for Production of Cellulosic Biofuels	Toru Jojima and Hideaki Yukawa.	UNEP-GEC Regional Workshop on Waste Agricultural Biomass, March 4, 2010
2	Involvement of L-lactate-responsive transcriptional regulator LldR in controlling of expression of the *ldhA* gene encoding L-lactate dehydrogenase in *Corynebacterium glutamicum*	Koichi Toyoda, Haruhiko Teramoto, Masayuki Inui, and Hideaki Yukawa.	SIM Annual Meeting, August 2, 2010
3	Identification of a second beta-glucoside phosphoenolpyruvate, carbohydrate phosphotransferase system in *Corynebacterium glutamicum* R	Yuya Tanaka, Haruhiko Teramoto, Masayuki Inui, and Hideaki Yukawa.	SIM Annual Meeting, August 2, 2010
4	Biorefinery: Today and Tomorrow	Hideaki Yukawa	2nd Asian Core Program Joint Seminar on Capacity Building and Development of Microbial Potential and Fermentation Technology towards New Era, November 20, 2010

■2010 Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	L-aspartic acid	S. Okino, M. Inui and H. Yukawa.	Encyclopedia of Industrial Biotechnology: Bioprocess, Bioseparation, and Cell Technology. John Wiley and Sons, Inc
2	L-isoleucine	T. Jojima, M. Inui and H. Yukawa.	Encyclopedia of Industrial Biotechnology: Bioprocess, Bioseparation, and Cell Technology. John Wiley and Sons, Inc
3	Advanced fermentation technologies	M. Inui, A.A. Vertès and H. Yukawa.	Biomass to Biofuel: Strategies for Global Industries. John Wiley and Sons, Ltd

Chemical Rsearch Group

■2010 Original Paper

	Title	Researchers	Journal
1	Heats of reaction and vapor-liquid equilibria of novel chemical absorbents for absorption/recovery of pressurized carbon dioxide in IGCC-CCS processes	Kin-ya Tomizaki, Shinkichi Shimizu, Masami Onoda, Yuichi Fujioka	Ind. Eng. Chem. Res. 49, 1214-1221 (2010)
2	13C-NMR Studies on the dissolution mechanisms of carbon dioxide in amine-containing aqueous solvents at high pressures toward an IGCC-CCS process	Kin-ya Tomizaki, Shinkichi Shimizu, Masami Onoda, Yuichi Fujioka	Ind. Eng. Chem. Res. 49, 1222-1228 (2010)
3	Prediction of the basicity of aqueous amine solutions and the species distribution in amine-H_2O-CO_2 system using the COSMO-RS method	Hidetaka Yamada, Shinkichi Shimizu, Hiromichi Okabe, Firoz Alam Chowdhury, Yuichi Fujioka	Ind. Eng. Chem. Res. 49, 2449-2455 (2010)
4	Preliminary estimations of energy and cost for CO2 recovery by a membrane flash process utilizing waste thermal energy	Kazuhiro Okabe, Hiroshi Mano, Yuichi Fujioka	International Journal of Greenhouse Gas Control 4(.4), 597-602 (2010)
5	Hydrogen separation membrane encapsulating Pd nanoparticles in a mesoporous silica layer	katsunori Yogo, Manabu Miyamoto, Yuichi Fujioka, Kensuke Nagata (NAIST)	Desalination and Water Treatment 17, 233-241 (2010)

■2010 Oral Presentation

	Title	Researchers	Forum
1	Development of novel Poly(amidoamine) dendrimer membranes and their CO2 Separation Properties	Teruhiko Kai, Shuhong Duan, Firoz Alam Chowdhury, Shingo Kazama, Tomoyuki Kato(NAIST)	NAMS/ICIM2010 (Washington D.C., USA The Mandarin Oriental Hotel) 19 July 2010
2	Synthesis and selection of hindered new amine absorbents for CO2 capture	Firoz Alam Chowdhury, Hiromichi Okabe, Hidetaka Yamada, Masami Onoda, Yuichi Fujioka	10th International Conference on Greenhouse Gas Control Technologies(GHGT-10) (RAI Amsterdam, The Netherlands) 20 September 2010
3	Quantum chemical analysis of carbon dioxide absorption into aqueous solutions of moderately hindered amines	Hidetaka Yamada, Hiromichi Okabe, Shinkichi Shimizu, Yuichi Fujioka, Yoichi Matsuzaki(Nippon Steel Corporation)	10th International Conference on Greenhouse Gas Control Technologies(GHGT-10) (RAI Amsterdam, The Netherlands) 21 September 2010
4	High efficiency CO2 capture with amine solution from high pressure gas	Hiroshi Machida, Shin Yamamoto, Satoshi Kodama, Kazuya Goto, Shinkichi Shimizu, Hiromichi Okabe, Yuichi Fujioka	10th International Conference on Greenhouse Gas Control Technologies(GHGT-10) (RAI Amsterdam, The Netherlands) 21 September 2010
5	Development of an energy-saving CO2-PSA process using hydrophobic adsorbents	katsunori Yogo, Tsuyoshi Watabe, Yuichi Fujioka, Yosuke matsukuma, Masaki Minemoto (Kyusyu Univ.)	10th International Conference on Greenhouse Gas Control Technologies(GHGT-10) (RAI Amsterdam, The Netherlands) 21 September 2010
6	Development of Molecular Gate Membrane Module for CO2 Capture from Pressurized Gas Stream	Shingo Kazama, Takashi Yamaguchi, Shin-ichi Minegishi, Takuji Shintani, Toshihiro Terauchi, Yoshiki Nobuto, Kazunari Tanaka, Mikihiro Hayashi(Nippon Steel Corporation)	10th International Conference on Greenhouse Gas Control Technologies(GHGT-10) (RAI Amsterdam, The Netherlands) 21 September 2010
7	Effects of membrane properties on CO2 recovery performance in a gas absorption membrane contactor	Hiroshi Mano, Yuichi Fujioka, Nobuhide Takahashi, Yusuke Furuta, Hiroshi Fukunaga, Toru Takatsuka(Shinshu Univ.)	10th International Conference on Greenhouse Gas Control Technologies(GHGT-10) (RAI Amsterdam, The Netherlands) 21 September 2010
8	Development of a Low Cost CO2 Capture System with a Novel Absorbent under the COCS Project	Kazuya Goto, Firoz Alam Chowdhury, Hiromichi Okabe, Shinkichi Shimizu, Yuichi Fujioka	10th International Conference on Greenhouse Gas Control Technologies(GHGT-10) (RAI Amsterdam, The Netherlands) 23 September 2010
9	Development of Poly(amidoamine) Dendrimer/ Poly(vinyl alcohol) Membrane for CO2 Capture	Shuhong Duan, Ikuo Taniguchi, Teruhiko Kai, Shingo Kazama	AMS-6(Sydney, Australia) 24 November 2010
10	Gas permeation properties of amine loaded mesoporous silica membranes for CO2 separation	Katsunori Yogo, Manabu Miyamoto, Ayato Takayama, Shigeyuki Uemiya (Gifu Univ.)	AMS-6(Sydney, Australia) 24 November 2010
11	CO2 absorption characteristics of 2-isopropylaminoethanol(IPAE) aqueous solution	Kazuya Goto, Firoz Alam Chowdhury, Satoshi Kodama, Hiromichi Okabe, Yuichi Fujioka	pacifichem 2010(Honolulu, Hawaii) 16 December 2010
12	Absorption rate and plant performance of novel amine solvents for CO2 capture	Kazuya Goto, Satoshi Kodama, Hiromichi Okabe, Yuichi Fujioka	pacifichem 2010(Honolulu, Hawaii) 16 December 2010
13	Novel amine solution development for high pressure CO2 capture and application examination to IGCC gas	Shin Yamamoto, Hiroshi Machida, Hiromichi Okabe, Yuichi Fujioka	pacifichem 2010(Honolulu, Hawaii) 16 December 2010
14	Polymeric membranes containing poly(amidoamine) (PAMAM) dendrimer for preferential CO2 separation over H2	Ikuo Taniguchi, Ryosuke Shimizu, Shuhong Duan, Teruhiko Kai, Shingo Kazama	pacifichem 2010(Honolulu, Hawaii) 18 December 2010

CO_2 Storage Rsearch Group

■2010 Original Paper [R & D project of CO2 Storage Technology]

	Title	Researchers	Journal
1	Experimental study on CO2 monitoring and quantification of stored CO2 in saline formations using resistivity measurements	Yoshihiro Nakatsuka, Ziqiu Xue, Henry Garcia, Toshifumi Matsuoka	International Journal of Greenhouse Gas Control, Volume 4, Issue 2, March 2010, Pages 209-216
2	Supercritical CO2 core flooding and imbibition in Tako sandstone - Influence of sub-core scale heterogeneity	Shi Ji-Quan, Xue Ziqiu, Durucan Sevket	International Journal of Greenhouse Gas Control, in press, 2010
3	Reservoir Simulation Verification of CO2 injection into an Onshore Aquifer, Nagaoka, Japan	Henry García, Ziqiu Xue , Zhejun Pan, Toshifumi Matsuoka	International Journal of Greenhouse Gas Control, submitted
4	Monitoring and simulation studies for assessing macro- and meso-scale migration of CO2 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 press, 2010
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 press, available online 28 Oct. 2010
6	Seismic monitoring of residual super critical CO2 in a water-satulated porous sandstone	Keigo Kitamura ,Ziqiu Xue	Journal of the Mining and Materials Processing Institute of Japan, submitted

■2010 Oral Presentation [R & D project of CO2 Storage Technology]

	Title	Researchers	Forum
1	Comparative assessment of CCS with other technologies mitigating climate change	Toshihiko Miyagawa, Ryuji Matsuhashi, Shigeo Murai, Motoshi Muraoka	10th International conference of Greenhouse Gas Control Technologies, September 2010, Amsterdam, The Netherlands
2	Scenario analysis on hypothetical site condition for geological CO2 sequestration in Japan	Koichi Takizawa, Hironobu Komaki, Eiji Hayashi, Shigeo Murai, Shinzo Ueta, Kohei Yamaguchi, Makoto Tsuchiya	10th International conference of Greenhouse Gas Control Technologies, September 2010, Amsterdam, The Netherlands
3	Life Cycle Assessment Performed on a CCS Model Case in Japan and Evaluation of Improvement Facilitated by Heat Integration	Satoshi Nagashima, Toshihiko Miyagawa, Masaki Matsumoto, Satoshi Suzuki, Hironobu Komaki, Masato Takagi, Shigeo Murai	10th International conference of Greenhouse Gas Control Technologies, September 2010, Amsterdam, The Netherlands
4	The Data base of investigation result of saline aquifers for CO2 storage in Japan.	Masao Ohoka,Shinichi Hiramatu,Kazuo Koide,Nakanishi Shigetaka,Akasaka Chitoshi,Eiji Hayashi,Hideaki Miida	10th International conference of Greenhouse Gas Control Technologies, September 2010, Amsterdam, The Netherlands
5	CO2 sequestration monitoring in a low formation water salinity reservoir	Doug Murray, Tadash Horie, Tukasa Yoshimura, Saeko Mito	IOGCEC (International Oil & Gas Conference and Exhibition in China), SPE
6	Ultrasonic velocity monitoring of CO2 migration and formation of residual trapping in porous sandstones	Keigo Kitamura, Ziqiu Xue, Tatsuya Yamada, Toshifumi Matsuoka	SEG development and Production Forum 2010, Boston
7	Review of evaluation methodology for storage capacity using heterogeneity geological model	Ikuo Okamoto, Hiroshi Okuma, Yukiko Obuchi, Akihiko Sato, Kameichiro Nakagwa	Spring meeting of the Mining and Materials Processing Institute of Japan, 2010
8	Development of reservoir structure evaluation technology of micro array survey	Kameichiro Nakagawa, Yukihiro Mizuochi, Ikuo Okamoto, Tetsuya Kogure, Hisao Hayashi, Tatsuro Matsuoka	Spring meeting of the Mining and Materials Processing Institute of Japan, 2010
9	The Role of rock mechanics for CO2 geological storage	Ziqiu Xue	Fall meeting of the Mining and Materials Processing Institute of Japan, 2010
10	Simultaneous measurement of Vp and Vs of Tako sandstone	Keigo Kitamura, Ziqiu Xue, Osamu Nishizawa	Society of Exploration Geophysicists of Japan Conference 2010
11	Repeated multi-electrode resistivity measurements of a small-scale carbon dioxide gas injection experiment	Takakura, Shinichi;Tosha, Toshiyuki	Japan Geoscience Union meeting 2010
12	Research and Development Activity of Marine Environment AssessmentTechnology for CCS in RITE (invited)	Michimasa Magi	IEAGHG CO2 Natural Rerease, Germany, 2010

■2010 Others [R & D project of CO2 Storage Technology]

	Title	Researchers	Forum
1	Development of prediction methods of CO2 influence to marine environment, plankton and benthos around seabed	Michimasa Magi, Yukihiro Yazaki	10th International conference of Greenhouse Gas Control Technologies, September 2010, Amsterdam, The Netherlands
2	Outcome of the Ocean Sequestration Project, and Technical Evaluation of CCS as Mitigation Measure of Increase Atmospheric CO2 and Ocean Acidification	Michimasa Magi , Shigeo Murai	10th International conference of Greenhouse Gas Control Technologies, September 2010, Amsterdam, The Netherlands

■2010 Oral Presentation [R & D project of CO2 Long Term Predictions]

	Title	Researchers	Forum
1	Post injection monitoring of stored CO2 at he Nagaoka pilot site: 5 years time-lapse well logging results	Saeko Mito, Ziqiu Xue	10th International conference of Greenhouse Gas Control Technologies, September 2010, Amsterdam, The Netherlands
2	Post-injection monitoring at the Nagaoka site	Saeko Mito, Ziqiu Xue	IEA GHG 6th monitoring network meeting, 2010
3	The activities of RITE and Japan in the field of geological storage of CO2 and collaboration with the EU	Saeko Mito, Ziqiu Xue	CO2 GeoNet Open Forum, Venice, Italy, May 2010
4	Trapping mechanisms in CO2 geological sequestration -case study at the Nagaoka site-	Saeko Mito	Japan German Research and Innovation Forum 2010
5	Integrated well-based monitoring of injected CO2 at the Nagaoka pilot site (invited)	Ziqiu Xue	16th Formation Evaluation Symposium of Japan, 2010

■2010 Oral Presentation [Japan China CCS-EOR]

	Title	Researchers	Forum
1	Development of CCS technologies in Japan (invited)	Shigeo Murai	Fifth Japan-China Energy Conservation Forum, Tokyo, Japan, 2010

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