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Contents

Development of CCS and Novel Membrane Separation Technologies

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As suggested from recent news about ice melting in the Arctic Ocean etc, global warming problem is getting more and more serious, and it is urgent issue to prevent global warming problem. It is inevitable to develop so called CCS technologies, in which CO_2, a greenhouse gas, is captured from large emission source such as electric power plant and factories and stored either in the onshore or offshore aquifer. Chemical Research Group in RITE is very unique research group which is specialized to develop CO_2 capture technologies, and research and development on chemical absorption, solid sorbent and membranes are being conducted. These technologies are almost at the stage of practical application or demonstration. Development of CO_2 storage technologies are also advanced and large-scale CO_2 storage demonstration is now started. According to Japanese CCS roadmap, practical application of CCS will start in 2020, and CCS related technologies are being developed rapidly.

When practical application of CCS is started, basically the scale of research and development of CCS will be reduced, although modification of technologies and research on safety evaluation will still be needed. So, in Chemical Research Group, development of technologies that don't emit CO_2 is just started as a next stage of global warming problem prevention, in addition to CO_2 capture technologies. Renewable energy, such as solar energy and wind energy, is generated by using solar cells and wind turbine as electrical energy, and is now being used more and more extensively. However, the biggest problems about these energies are that supply of these energies is unstable and that it is impossible to store these energies. To address these issues, the system in which H_2 is generated by electrical energy and H_2 is transported and stored as H_2 carrier is considered promising. When necessary, H_2 is obtained from H_2 carrier, and is used to generate electricity using either fuel cell or H_2 as fuels. And this electrical energy from renewable energy can be used complementarily with conventional electricity supply system. This system can avoid instability of electricity supply, and can reduce CO_2 emission at the same time.

The candidate materials for the H_2 carrier used to be hydrogen storage alloys. Recently, organic chemical hydrides such as methylcyclohexane and ammonia attract a great deal of attention. In order to obtain H_2 from organic chemical hydrides, dehydrogenation and subsequent separation of H_2 and aromatic hydrocarbons (e.g., toluene) are needed. In Chemical Research Group, we set the development of novel membrane reactor that can conduct dehydrogenation reaction and separation at the same time as next important technical challenge as important as CCS technologies, and we have started development.

In development of novel membrane reactor, it is indispensable to develop membranes that can separate H_2 and organic chemical hydride at high temperature. We started to develop inorganic membranes for this purpose. In addition, inorganic membranes can also separate hydrocarbons and organic solvents, so they are expected as energy-saving separation technologies that can potentially replace distillation.

As the gas separation membranes, there have not been practical applications for inorganic membranes yet. Since basic research of inorganic membranes in Japan leads the world, it is not so difficult to establish the world's top inorganic membrane industry. In Chemical Research Group, research and development are conducted with the goal of establishing inorganic membrane industry in Japan in 10 years and also establishing the sustainable society with new environmental and energy technologies. We would like to ask cooperation and support from the readers.

Research Planning Group

Recent Activities and Challenges on Innovative Mitigation Technologies to Prevent Global Warming

1. Introduction

A drastic reduction of CO_2 emissions is required for mitigation of global warming. According to "the Energy Technology Perspective 2012 (ETP2012)"[1)] issued by International Energy Agency (IEA) in January, 2012, global emissions of CO_2 in 2050 should be decreased to 16Gt CO_2/yr, which is almost half of those in 1990, in order to limit long-term global temperature increase to 2°C. This means that 42 Gt CO_2 /yr should be cut from the baseline emissions in 2050, estimated as 58Gt CO_2 /yr. Such a significant reduction cannot be achieved by a sole technology, but combination of technologies with great potential is required. In this context, "Carbon Dioxide Capture and Storage (CCS)" and "Biomass Utilization" are gaining attentions as innovative mitigation options. These two options are both cost-competitive and have stabilities against power fluctuation comparing to photovoltaic or wind power.

At RITE, the following four research groups have been carrying out R&D activities focused on mitigation of global warming. Chemical Research Group is tackling with development of CO_2 capture technology, CO_2 Storage Research Group is striving to develop the technologies to store the captured CO_2 in the subsurface, Molecular Microbiology and Biotechnology Group is coping with development of bio-refinery technologies, and System Analysis Group is working on assessment of global warming mitigation. Before going into the other reports written by each research group, this report provides you of comprehensive overview of the latest progress in CCS and biomass utilization as well as the outline of our research activities and future challenges at RITE.

2. Current status of CCS

2-1. Necessity and perspective of CCS

According to the the 2°C Scenario (2DS) stated in the ETP2012, CCS plays an important role as a vital technology to contribute 17% of the total emission reduction throughout the world as of year 2050 (Fig. 1). Also, CCS is the only option currently available that allows industrial sectors, such as iron and steel, cement and natural gas processing, to meet deep emissions reduction goals, while neither renewable nor nuclear energy can work well in such production processes of those industrial sectors.

As shown in Fig. 2, the cost of CO_2 avoided by CCS is more efficient than those of other measures like photovoltaic, wind power and so on. Therefore, to meet the 2DS without CCS application to power generation and other industrial sectors, IEA points out that an additional 40% investments in electricity are required and it costs an extra USD 2 trillion over the next 40 years. Abandoning CCS as a mitigation option would result in a significant increase of the cost to achieve the 2DS.

In the meantime, CCS is a viable technology in that some of CO_2 capture technologies are already commercially available and most of them can be applied to various sectors.

Thus, CCS is expected to remain as a critical option in the long term. Accordingly, it is pointed out that governments should play a decisive role in switching to efficient and low-carbon technologies.

Fig. 3 shows the cumulative amount of CO_2 captured by region as described in the 2DS by IEA and it shows the region which needs to store the most massive amount of CO_2 is China, the second one is OECD North America in both 2030 and 2050. China should store 40Gt- CO_2, while OECD North America should 21.2Gt- CO_2 by 2050. This means that almost all coal-fired and 36% of gas-fired power generations should be equipped with CCS in OECD North America and nearly two-thirds of coal-fired power generations in China as well (Fig. 4). In the 2DS, it is estimated that the total investment for CCS will be USD 3.6 trillion, equivalent to 300 trillion Japanese yen, by 2050 and it would create an enormous market if CCS would be deployed.

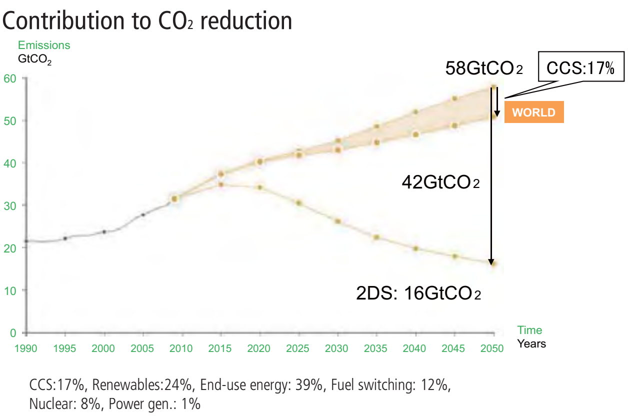


Fig. 1 Contributions of technologies against global warming (IEA "ETP 2012")

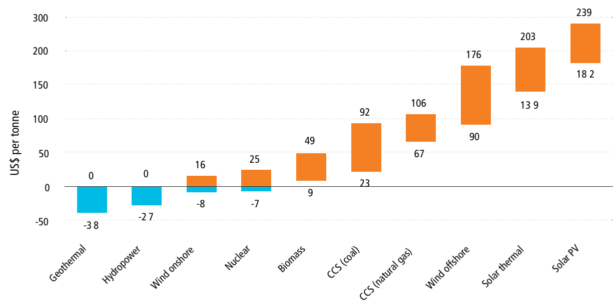


Fig. 2 Costs of CO_2 avoided by technologies
(GCCSI "the global status of CCS 2012")

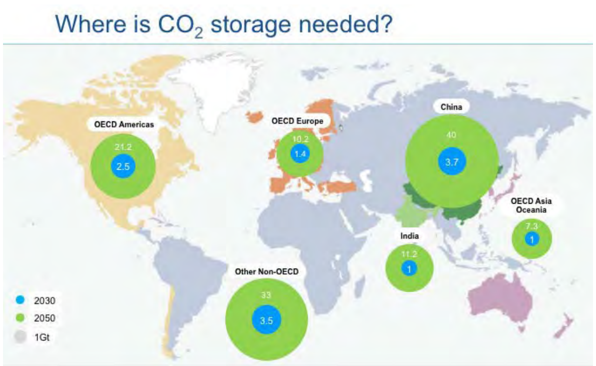


Fig. 3 The cumulative amount of CO_2 captured by region (IEA "ETP 2012")

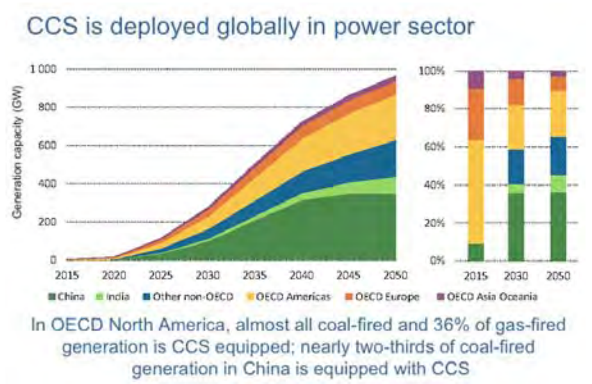
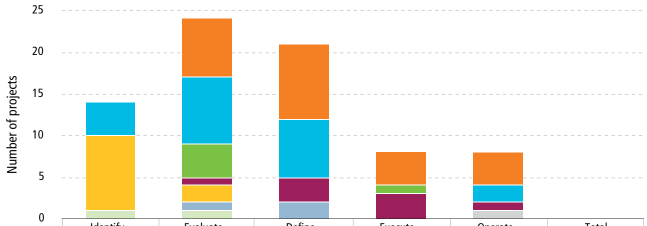


Fig. 4 Electric power generation capacity equipped with CO_2 capture
and the corresponding fraction of capacity by region in 2DS (IEA "ETP 2012")

2-2. The status of CCS projects

The Global CCS Institute (GCCSI) published "The Global Status of CCS: 2012"[2)] which summarizes the recent CCS projects activities in the world. It explains large-scale integrated projects (LSIPs) are classified into the following six stages based on degree of progress: Identify, Evaluate, Define, Execute、Operate, and Closure. Referring to the project lists made by GCCSI, the "Identify" is the stage of site screening, "Evaluate" is site assessment and pre-feasibility study, "Define" is site selection and feasibility study, "Execute" is project execution, design and installation, and "Operate" means asset operation. The "Closure" is the stage that injection is completed and asset is decommissioned.

According to the report, there are 16 LSIPs listed in the Execute and Operate stages, of the total, eight LSIPs are classified as Execute and other eight LSIPs as Operate. The total number of LSIPs including the ones at the stages of planning ('Identify', 'Evaluate', and 'Define') amounts to 75 (Fig. 5). Nine newly-identified projects were added to the listings, while another eight projects have been removed from the list due to being cancelled, put on-hold or restructured compared with a year ago. Five out of nine newly-identified projects are currently under planning in China. Looking at the LISPs by region, there are 24 projects in the USA followed by 21 projects in Europe and 11 in China. Although most of LSIPs in China are classified into 'Identify' stage, considering its future economic growth and energy demands in the country, the future progress of those projects should be closely watched as mentioned by IEA and others. These storage projects in China are investigating Enhanced Oil Recovery (EOR) options (Fig. 6).



	Identify	Evaluate	Define	Execute	Operate	Total
United States	0	7	9	4	4	24
Europe	4	8	7	0	2	21
Australia and New Zealand	0	4	0	1	0	5
Canada	0	1	3	3	1	8
China	9	2	0	0	0	11
Middle East	0	1	2	0	0	3
Other Asia	1	1	0	0	0	2
Africa	0	0	0	0	1	1
Total	14	24	21	8	8	75

Fig. 5 Large scale integrated projects of CCS (GCCSI, "the global status of CCS 2012")

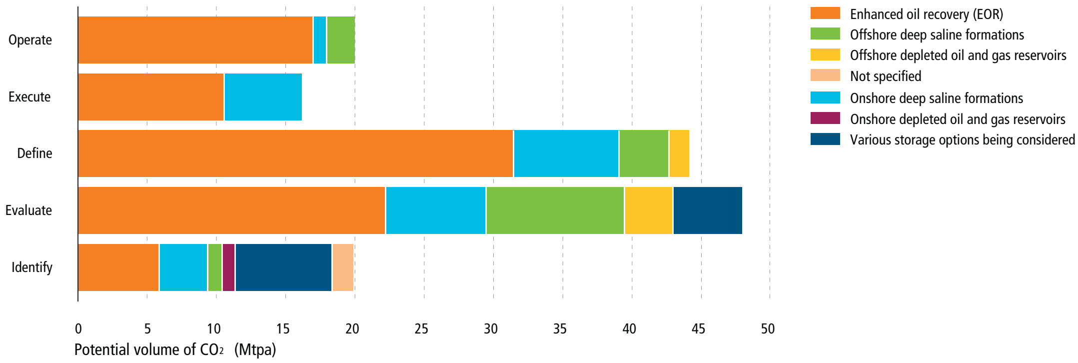


Fig. 6 Potential volume of CO_2 stored by types of CCS (GCCSI, "the global status of CCS 2012")

2-3. The conceptual design and cost estimation of CO_2 geological storage

In an effort to deal with the cost of CCS, RITE has been carrying out a research program, "Total System of Zero-emission Coal-fired Power Generation Project" under entrustment from NEDO. Under this project, the cost estimations of CO_2 storage systems in various cases have been implemented. RITE has been in charge of the conceptual design and cost estimation of CO_2 geological storage. RITE has worked out the approximate costs of offshore storage systems in three promising sites for injecting CO_2 into the sub-seabed saline aquifers off the coast of Japan. As a result of this research, RITE has identified that the total costs of the CO_2 storage systems are between 22 and 31 billion yen on the assumption that the amount of CO_2 injected is 1.5 Mt/y and 30 Mt in total (Fig. 7). Also, it has been elucidated that the costs of the storage systems differ depending on distances from the land and reservoir depths of the storage sites.

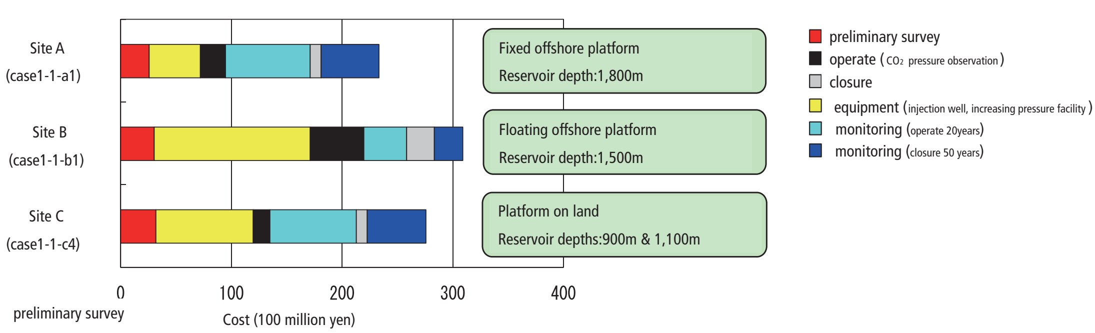


Fig. 7 Example estimation of approximate cost of storage systems (RITE "Feasibility study of total system of coal-fired power with no CO_2 emission")

2-4. International standardization for CCS

With a view to the practical application of CCS, cross-national efforts to establish the international standardization of CCS has been started under the framework of International Organization for Standardization (ISO) to enhance the flexibility of products and to ensure quality and safety of them above a certain level. Once the international standardization is developed, the deployment of CCS will be accelerated in worldwide in conformity with the new standards, which more steadily support the safety and effectiveness of CCS as a measure for CO_2 reduction.

It all started from a proposal by Canada to establish a new ISO Technical Committee (TC) for CCS and it was approved as ISO/TC265 by the Technical Management Board (TMB) of ISO in October, 2011. The first plenary meeting of the TC was held in June, 2012 and the followings were decided:

The title of the TC is "Carbon dioxide capture, transportation and geological storage". The scope of this TC covers construction, operation, environmental planning and management, risk management, quantification and verification, and related activities in the field of CCS. Five working groups are set up under the TC: Capture WG, Transportation WG, Storage WG, Cross-Cutting WG, Quantification and Verification WG and SCC in Canada takes a role as a central secretary.

International standard is developed through open process consisting of Proposal stage, Preparatory stage, Committee stage, Enquiry stage, Approval stage, and Publication stage. International standard is developed normally within three years after New Work Item Proposal (NWIP) is submitted (Fig. 8).

RITE was assigned as the secretariat of the Japanese mirror committee of ISO/TC265 (Fig. 9). The meetings of the mirror committee have already been held three times and the meetings of each working group have been held several times, respectively.

The International standard has been used as an important tool of international business strategy since WTO agreement on Technical Barriers to Trade (WTO/TBT) came into effect in 1995 and WTO agreement on Government Procurement (WTO/GAP) in 1996, respectively. It was banned to produce and to export the products which do not meet the international standards since when these agreements became effective. Under such circumstances, European and American companies had an advantage in that their products met the international standards at that time, while Japanese companies could not satisfy the standards and Japanese products were excluded from international markets. Thus, there were some cases that Japanese companies were forced to withdraw from world markets as they failed to appropriately follow the international standardization, even though there were some success cases.

Japan should keep closely watching and be involved in the processes to develop the international standardization for CCS so that we can promote our original technologies and expertise in the world.

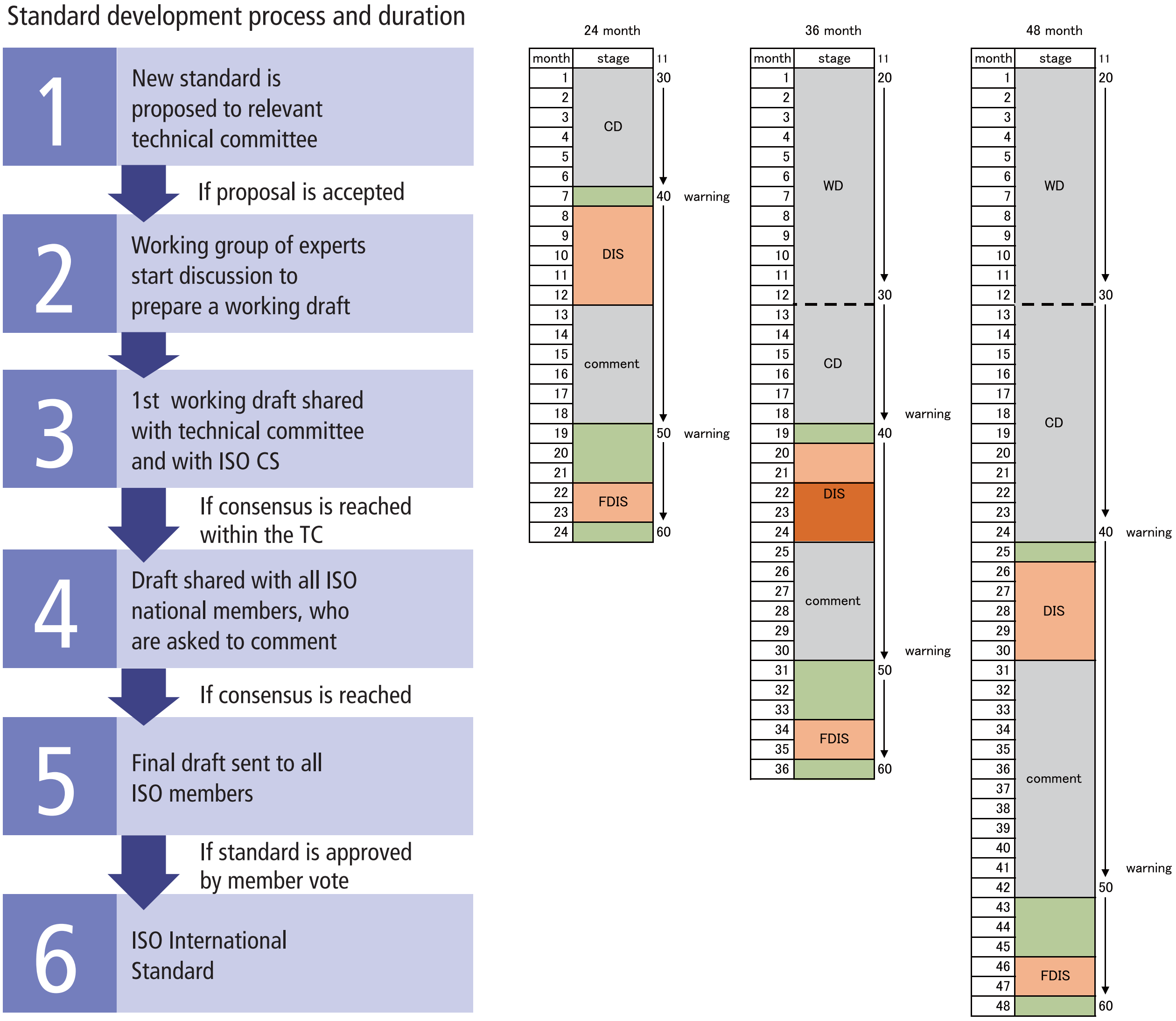


Fig. 8 Standard development processes (ISO&JISC)

2-5. Challenges for the future in CCS

CCS falls under as so-called external diseconomies. CCS cannot be deployed under the principle of the market mechanism because it basically does not contribute to growth of productivity and so on. Therefore, some kinds of systems to internalize external diseconomies should be established including development of regulation on CCS-Ready, subsidy system, preferential tax treatment, feed-in-tariff system and emission trading scheme. The R&D on cost reduction of CCS is also important to facilitate the installation of CCS. The cost of CCS per ton-CO_2 is approximately 7,300 yen/t- CO_2 in total. Of the total, approximately 4,200 yen/t- CO_2 is for CO_2 capture equal to around 60%. RITE has been aiming for a low-cost CO_2 capture technology within the range of 1,500 to 2,000 yen/t- CO_2.

In the course of deployment of CCS in Japan, there would be social concerns, "Is it safe to introduce CCS in Japan, where earthquakes will occur frequently?", "Doesn't CCS cause environmental impact?" Public acceptance is a key to successful CCS implementation, and acquisition of credible data, development of communication tools, human resources development and close communication with stakeholders are required for success.

RITE, as local organizer, held the 11th International Conference on Greenhouse Gas Control Technologies (GHGT-11) at Kyoto International Conference Center from 18th November to 22nd November in 2012. Many experts all over the world participated in this conference and discussed CCS related technologies enthusiastically. GHGT-11 is reported as one of this year's topics in this volume.

As discussed at GHGT-11, governments should take the leading role to decide, address and implement the promotion of CCS as IEA and other international organizations point it out. Decision making and strong support by governments are indispensable as only they can adopt the social system to promote CCS even though it is regarded as external diseconomies.

Japanese Mirror Committee of ISO/TC265 and WG

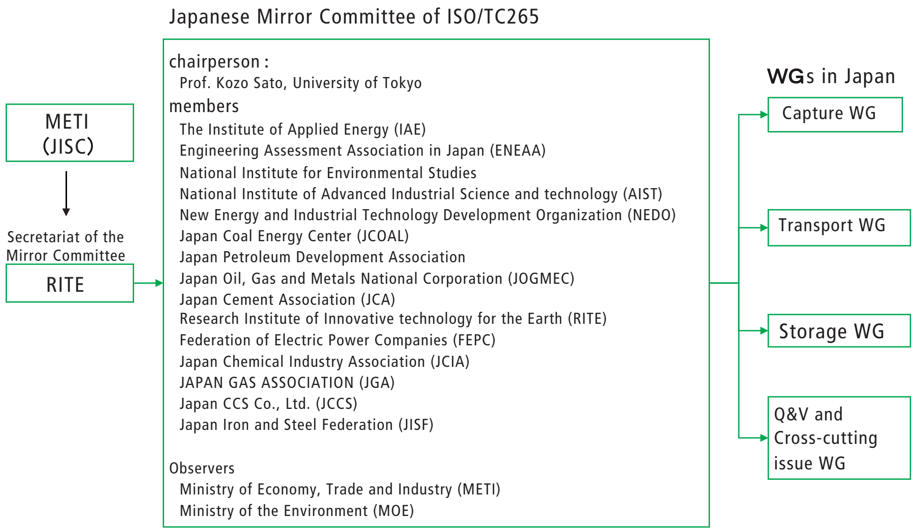


Fig. 9 Organization of Japanese mirror committee (RITE)

3. Biomass Utilization

With respect to the recent bio-fuel production, biomass-based fuels have more than quadrupled since 2000, but from a very low starting point, so that bio-fuels made up only 0.5% of global final liquid fuel demand in 2009 (Fig. 10, 11). Production of Bio-ethanol shares more than half of biomass-based fuels. In terms of the bio-fuel production capacities by region, the United States (around 60% share) and Brazil (30% share) dominate global bio-ethanol production. These two countries provide 90% of global bio-ethanol, while the European countries combined provided around 60% of the global bio-diesel production (Fig. 12, 13).

According to IEA, liquid bio-fuels provide 18% of global liquid fuel demand in the 2DS in 2050, with around 70% from BTL plants and 30% from advanced ethanol plants using lignocellulosic feedstock (Fig. 14). Bio-butanol, an alcohol with similar production pathways as ethanol, can be a promising alternative to bio-ethanol, since it can be, due to its hydrophobic nature, transported in pipelines.

Capturing CO_2 from bio-fuel production plants and storing it underground becomes an attractive CO_2 mitigation option in the 2DS: during its growth the crop sequesters CO_2 from the atmosphere, which is captured in the bio-fuel plant and then stored underground. This cycle results in a removal of CO_2 from the atmosphere and leads to "negative" emissions for the use of bio-energy in combination with CCS (BECCS). In the 2DS, around 1.3 Gt CO_2 is captured from bio-fuel plants in 2050, which corresponds to around 3% of the total annual CO_2 reductions in 2050 (Fig. 15).

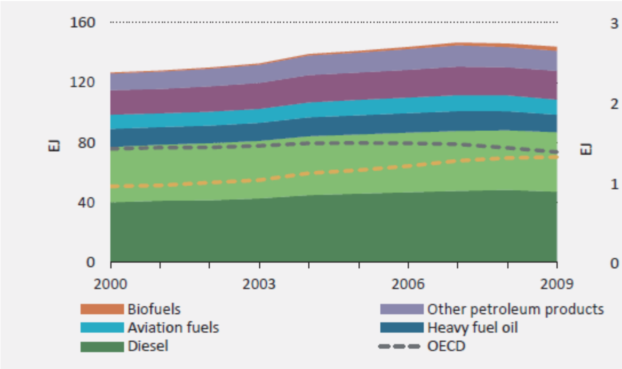


Fig. 10 Global final liquid fuel supply (IEA "ETP 2012")

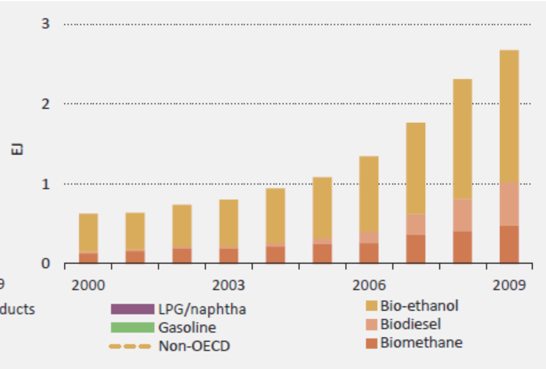


Fig. 11 Global bio-fuel production (IEA "ETP 2012")

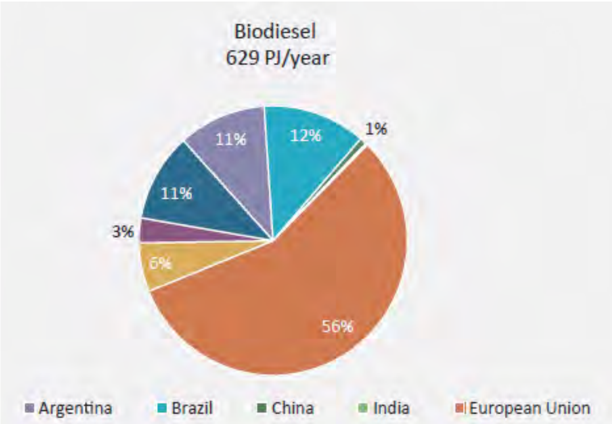


Fig. 12 Global production capacity of bio-diesel (IEA "ETP 2012")

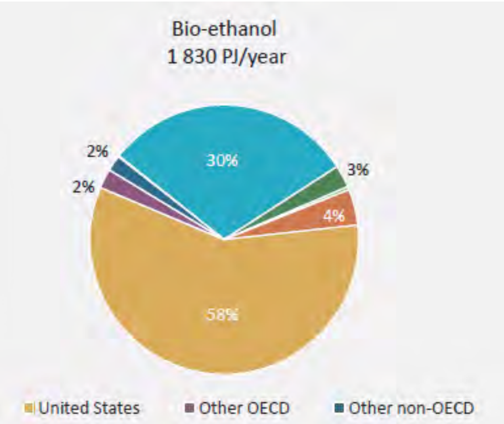


Fig. 13 Global production capacity of bio-ethanol (IEA "ETP 2012")

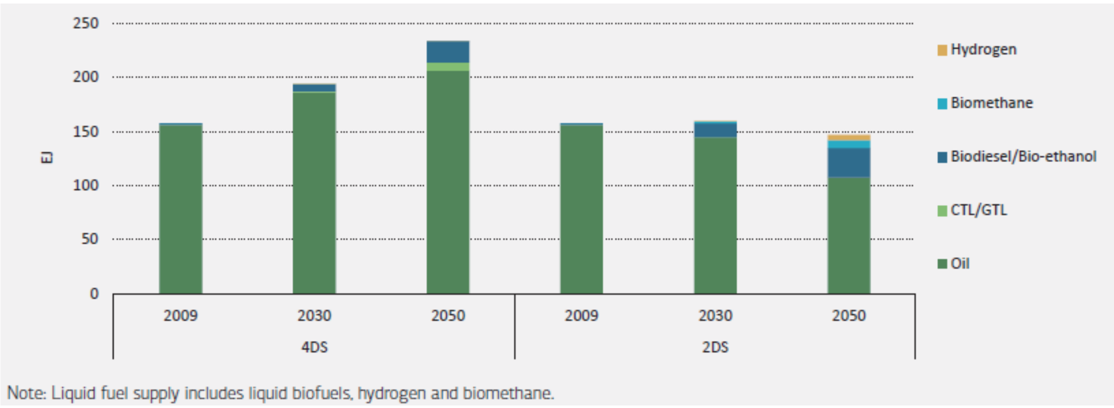


Fig. 14 Global liquid fuel supply in the 2DS and the 4DS (IEA "ETP 2012")

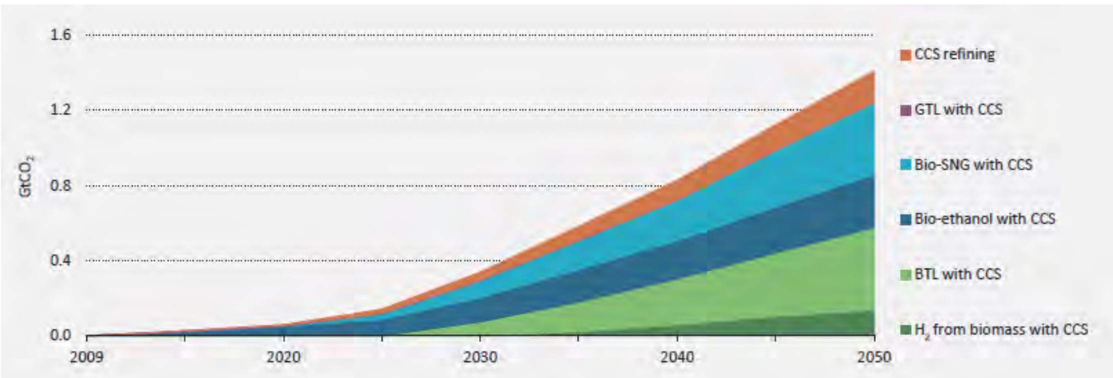


Fig. 15 CO_2 captured in the fuel transformation sector in the 2DS (IEA "ETP 2012")

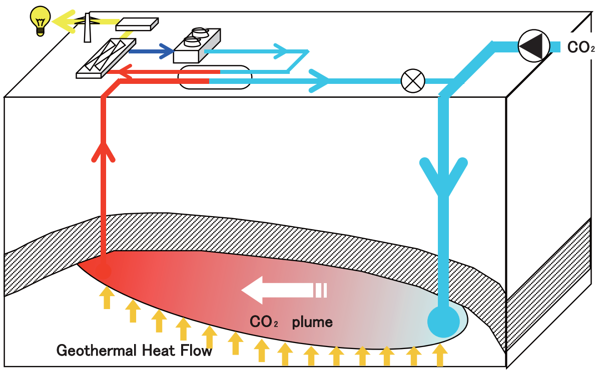
4. The challenges for future in RITE

Since its establishment in 1990, RITE has been implementing researches on various innovative environmental technologies. In light of high-potentials and social needs, RITE focuses on three specific areas of expertise for its research, which are CCS technology, bio-refinery technology and assessment of global warming mitigation. Development and practical application of CCS technology is expected to open the way to substantial reduction of CO_2 emission. Bio-refinery is a renewable and sustainable energy, and further expanded use of bio-energy is a real need. And the urgent need for the assessment of global warming mitigation has been heightened to provide scientifically supporting data for political decision-making process on energy and environment after the accident at TEPCO's Fukushima Daiichi nuclear power plant in March, 2011.

To be a globally competitive research institute, one of RITE's primary missions is to transfer the outcomes of our research to private companies and to make the technologies widely available in industries and society. Therefore, in parallel with implementing its ongoing projects, RITE needs to work out a new research themes and to achieve excellent outcomes so as to keep contributing to the international society in the future as well. Also, RITE should foster and develop new innovative technologies with making use of its own research potentials. It is an essential challenge inherent to RITE as a research institute.

In order to set up a new research target, RITE has investigated and discussed various research themes such as marine renewable energy, geo-engineering, geothermal energy, Enhanced Geothermal System using CO_2 and so on. Eventually, RITE has determind to shed new light on a research on "Enhanced Geothermal System using CO_2" as a new flagship project.

Enhanced Geothermal System using CO_2 is a technology to generate electricity utilizing hot CO_2 extracted from underground storage reservoir (Fig. 16). Using generated electricity for CCS plant or selling it can provide incentives to promotion of CCS. This technology can control the pressure of underground storage reservoir by extracting CO_2 from the reservoir and is also recognized as one of the attractive measures to ensure safety of CCS. Some research institutions in the USA have already started to deal with this technology. Although CO_2 has some disadvantages, for example, specific heat of CO_2 is smaller than that of water, it has many advantages in that there is little precipitation of the scale and it can generate electricity at lower temperature comparing with water. Also, CO_2 works as a promising heat medium for geothermal power generation (Fig. 17).



- Technology of geothermal power generation utilizing CO_2 reserved underground.
- Utilizing generated electrical power for CCS plant or for sale contributes to paying expense of CCS project.
- LBNL in USA leads the research.
- LBNL has finished basic laboratorial research and is applying to DOE for a field test of actual injection to underground

Fig. 16 The concept of enhanced geothermal system using CO_2 (RITE)

Property	Water	CO_2
Chemistry	Powerful solvent for rock minerals, lots of dissolution and precipitation	Non-polar fluid, poor solvent for rock minerals
Mobility	High viscosity, high density	Low viscosity and moderate density
Heat transmission	Large specific heat	Small specific heat
Welbore circulation	Small compressibility, modest expanvisity	Large compressibility and expansivity
Fluid losses	Expansive and unwanted	Credits for GHG mitigation
Availability	Widespread, limited in arid regions	GCS key enabling element
Power plant	Higher capital costs, larger footprint	More compact, lower capital cost

Fig. 17 Comparing CO_2 with water as a heat transmission fluid (LBNL and et al.)

5. Conclusion

CCS is the only technology on the horizon today that would enable industrial sectors to meet deep emissions reduction goals and will be expected to remain as a vital option in the long term. CCS is expected to be deployed all over the world, especially in China and North America. It is in urgent need to establish regulation, subsidy and other systems by governments and to lower the cost of CCS so as to facilitate the deployment of CCS. Firm policy decision and enhancement of government supports are in pressing need for implementation of CCS.

As multilateral efforts to establish international standardization of CCS has already started, Japan should keep closely track of progress of the standardization on CCS to have our technologies and expertise evaluated appropriately.

RITE has decided to start working on a new challenge on "hot dry rock geothermal generation" and will strive to set it up as an official research project.

From November 26 to December 8, COP 18/CMP 8 (the Conference of the 18th Parties to the UNFCCC and the 8th session of the Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol) were held in Doha, Qatar. COP and CMP decisions including the ADP (Ad-Hoc Working Group on the Durban Platform for Enhanced Action) work plan were adopted as the "Doha Climate Gateway". As for emission limitation in the second commitment period, developed countries and developing countries could not reach an agreement. Japan has taken a position of not participating in the second commitment period and it was reflected in the amended Annex B. It is very important to establish international frameworks for implementing measures against global warming and concrete steps to achieve consensus among the nations should be progressed. It is not easy to prospect the energy or economy in future, but promotion of the R&D is as an integral and indispensable part of approaches to reverse climate change. RITE will continue to lead the way in the development of innovative technologies with an aim to achieve the practical application of those technologies in industries in years to come.

References

1) IEA, "Energy Technology Perspective 2012" (2012)
2) GCCSI "The Global Status of CCS: 2012" (2012)

Analysis on Japan's Energy and Environment Strategy

1. Introduction

Radical reforms and reviews for Japan's energy and environment strategy have been required due to the severe accident of the Fukushima-daiichi nuclear power plant caused by the Great East Japan Earthquake and Tsunami. Energy is a basis of our life and economy. CO_2 emissions have strong relationship to energy use, and therefore, energy issues and global warming issues are inseparable so far.

The Japanese government established several committees for the strategy reform, which include the Committee for Verifying Power Plant Costs in the Energy and Environment Council, a committee under the Agency for Natural Resources and Energy of Ministry of Economy, Trade and Industry (METI), a committee under Ministry of Environment (MOE), and a committee under the Atomic Energy Commission. Plural "Options for Energy and the Environment" were developed by the Energy and Environment Council through many discussions in such committees. RITE analyzed economic impacts for the "Options for Energy and the Environment" by using an energy-economy model that had been developed by RITE, according to the requests of the Japanese government.

The Energy and Environment Council, the Japanese government, proposed the "Options for Energy and the Environment"[1)] with the analysis results for economic impacts for each option on June 29, 2012, and wide discussions were deployed to the public. After the discussions, the government decided the "Innovative Strategy for Energy and the Environment"[2)] on the Energy and Environment Council on September 14, 2012. The report for the strategy described "all policy resources will be injected to be possible for achieving zero of nuclear power generations in 2030s". However, the report was introduced on the National Strategy Council on September 18, but was not decided in the council. The cabinet council did not also decide the report of 'Innovative Strategy for Energy and the Environment', and did decide only a short sentence regarding the future plan for energy and environment strategy. One of the reasons avoiding the clear decision will be that the cabinet recognizes there is not a clear pathway to "achieve zero of nuclear power generations in 2030s".

For global warming response measures, the "Innovative Strategy for Energy and the Environment" describes "strong promotions of energy efficiency improvements and renewable energy increases both in domestic and abroad correspond to global warming response measures. Greenhouse gas emission reductions will be promoted with strong supports of the government from the viewpoint of long-term."

The cause of the severe accident of the nuclear power plant remains obscure, and it is difficult to make a clear middle- and long-term energy strategy. The difficult issues how to balance 3E of stable energy supply and energy security, economy, and environment remain. Further considerations including achievability are required with considerations of the economic impacts (Fig. 1).

This report summarizes the economic analyses for the "Options for Energy and the Environment" particularly analyses of RITE.

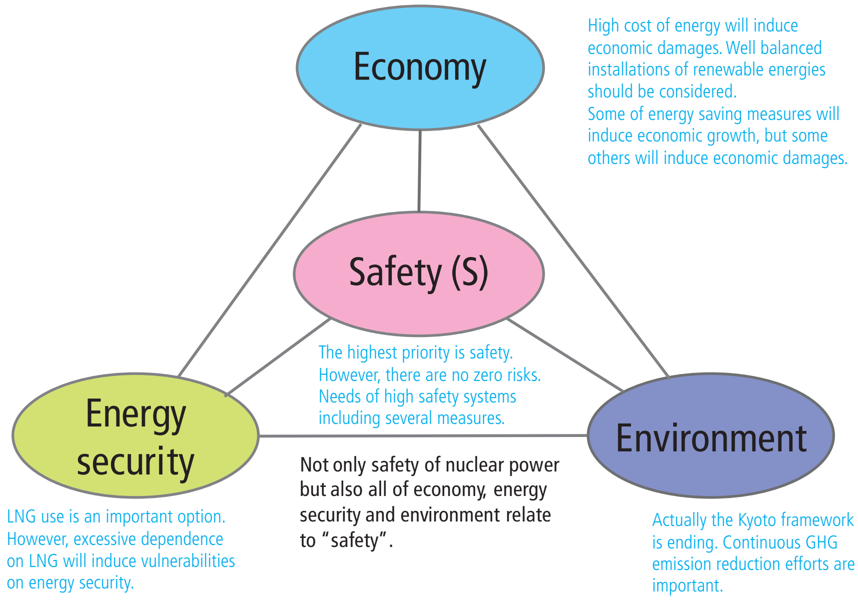


Fig. 1 Balance of 3E (Economy, Energy, Environment) and S (Safety)

2. Overview of the options of Strategy for Energy and the Environment

We summarize the "Options for Energy and the Environment." The following three options, based on the dependences on nuclear energy, are presented by the Energy and Environment Council.

Option 1 is "0% nuclear power" scenario of achieving zero of nuclear power generations by 2030, where the shares of renewable energy and fossil fuels power generations are about 35% and 65%, respectively. PV systems are installed in 12 million houses by 2030, where even if the houses have weak earthquake-resistance strengths, they are reinforced against earthquakes and then PV systems are installed in them. The wind power plants are built in the areas corresponding to 2.2 times as Tokyo metropolitan area. The strict regulations of energy savings, such as the prohibitions of the inefficient electric appliances, are also introduced in this option.

Option 2 is "15% nuclear power" scenario of achieving 15% nuclear power generation share at 2030, where the lifetimes of nuclear plants are assumed to be 40 years and new nuclear plants are not built during the periods. In this option, the share of renewable energy power generations is about 30%. PV systems are installed in 10 million houses, all of which meet the standard of earthquake-resistance strength. The wind power plants are built in the areas corresponding to 1.6 times as Tokyo metropolitan area. The share of fossil fuels power generation is about 55%.

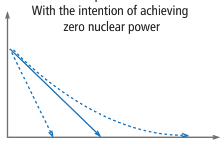
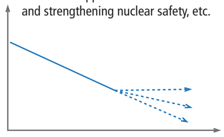
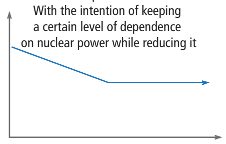
Option 3 is "20%-25% nuclear power" scenario of achieving about 20%-25% nuclear power generation share in 2030, where the shares of the renewable energy and fossil fuels power generations about 25%-30% and 50%, respectively. This option requires new and additional facilities of nuclear power generations by 2030. Through continuous efforts for enhancements of safety and security of the nuclear power, the improvements in the currently negative position to nuclear power are important for achieving this option.

The determined "Innovative Strategy for Energy and the Environment" describes the energy mix in 2030 nearly close to that of the "15% nuclear power scenario." However, substantially because the determined strategy brings zero nuclear power generations at specific target years into view, the strategy is qualitatively similar to the "0% nuclear power scenario."

The analysis on how the economic impacts are estimated for each option was conducted by using energy-economic models. The economic analysis by the government was performed by using the four models developed by four research institutes. The economic models excluding DEARS model by RITE are single-country models focused on Japan. On the other hand, the DEARS model has world 18 disaggregated regions including Japan, which can explicitly evaluate the impacts of internationally sectoral shifts among 18 regions thorough the increases in energy prices and the intensities of the CO_2 emission constraints in Japan. In addition, because the DEARS model has the bottom-up structures for power generations by energy source, the model can reflect the power generation costs by energy source (as well as KEO model developed by Prof. Nomura of Keio University). This report describes the outlooks of economy and CO_2 emission reductions for the three options, based on the results of the DEARS model.

Table 1 shows the main assumptions of the options for economic analyses, requested by the Japanese government.

Table. 1 Assumptions of economic analysis for the options of the Energy and Environment Council

	Reference case (Business as Usual: BAU)	NUC 0% Option 1: With the intention of achieving zero nuclear power  2030	NUC 15% Option 2: After reducing dependence on nuclear power, reviewing based on results of approaches for renewable energy and strengthening nuclear safety, etc.  2030	NUC 20% Option 3: With the intention of keeping a certain level of dependence on nuclear power while reducing it  2030	NUC 25%
Population	2010: 128million people, 2020: 124million people, 2030:117million people				
GDP	2010-2020: 1.1 p.a. 2020-2030: 0.8 p.a.	Calculated endogenously in the model			
Electricity share (2030)	Keeping the shares of 2010	Nuclear 0% Fossil fuel 62% Renewable 38%	Nuclear 15% Fossil fuel 54% Renewable 31%	Nuclear 20% Fossil fuel 48% Renewable 31%	Nuclear 25% Fossil fuel 48% Renewable26%
Power generation	2010-2030: +0.15 p.a.	Calculated endogenously in the model (Electricity demands change by the differences of electricity priceson the assumptions of both electricity shares and CO_2 emission reductions for each option)			
Energy-related CO_2 emissions (compared to 1990) 2020 2030	+2% −6%	−2% −21%	−5% −22%	−6% −25%	−7% −25%
GHG emissions (compared to 1990) 2020 2030	-	−7% −23%	−9% −23%	−10% −25%	

Figures 2 and 3 show electricity generations and capacities, respectively, in 2030 for the options. Here there are the following four important points about the assumptions of the options. The first point is that large potentials of electricity savings are assumed in all the options. Even in the current Basic Energy Plan, the estimated power generation in 2030 was about 1200 TWh, while the large potentials of energy savings were assumed. However, the assumed potentials of energy savings in the options are much larger than those of the current Basic Energy Plan. This point will be mentioned more details afterward.

The second point is that all the options assume the large increases in renewable energies. The current share of renewable energy is about 10% in 2010, where excluding hydro power the share of other renewable energy is only 2%. However, even the 25% scenario includes the assumptions of the renewable energy share of about 25% in 2030. The share in the 0% scenario reaches up to about 35%, where the great extensions of renewable are required for achieving the scenario.

The third is that the considerable increases in auto-producer's power plants and cogeneration are assumed. These increases are important. But the currently small diffusions of cogeneration are explained by the reasons that the cogeneration systems are not well linked to heat demands and the cogeneration costs are high. The considerable increases in cogeneration require the consideration on these problems in detail. The fourth is that the electricity shares with low capacity factors are assumed. This is because of the outlooks of both the increases in renewable energy power plants with low capacity factors and the considerable decreases in electricity demands. The low capacity factors also result from the increases in non-operating fossil fuel thermal power plants because of the rapid changes in electricity shares. As low capacity factors result in high costs, the scenarios with the low factors assume the inefficient usages of the plants.

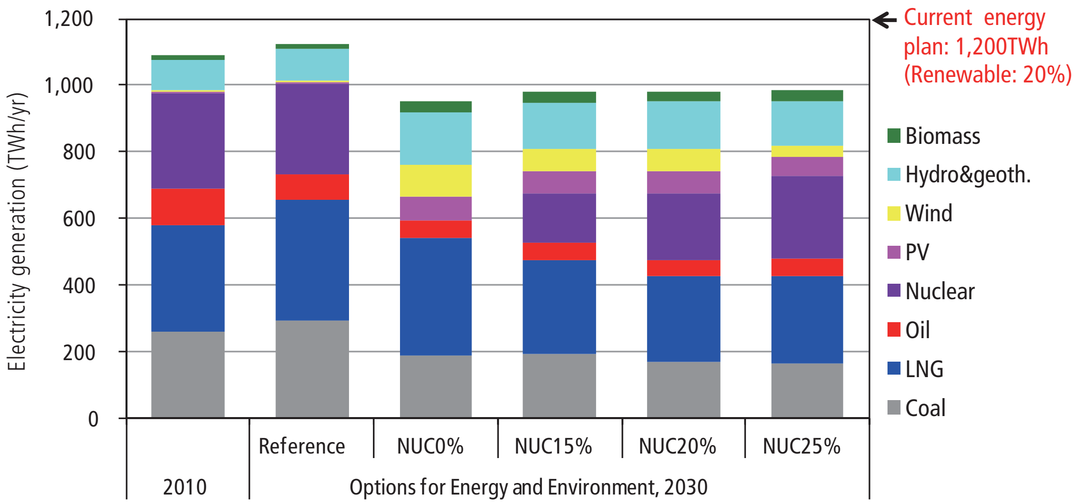


Fig. 2 Power generations scenarios in 2030 for each option

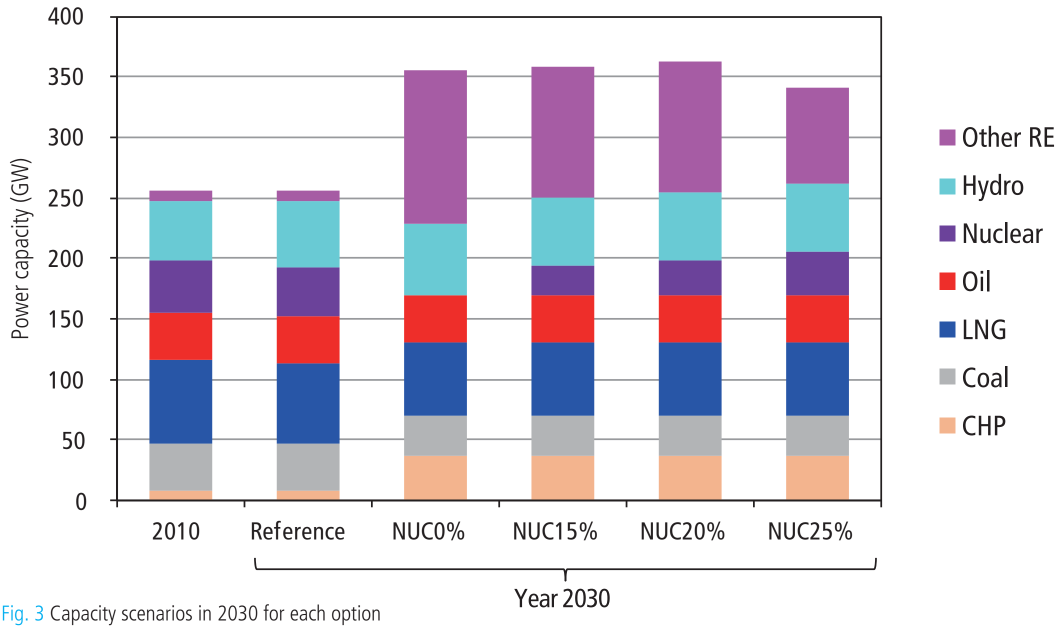


Fig. 3 Capacity scenarios in 2030 for each option

3. Economic analysis on the Options of Energy and the Environment

As mentioned previously, Table 1 shows the main assumptions for each option. The assumed economic growth is about 1% per year (moderate growth scenario) for 2010-2030. The costs of power generations for each source are based on the estimations of the Committee for Verifying Power Plant Costs[3)].

For the economic analysis, we calculate the reference case that is a standard of the model analysis. The main indicators such as GDP, power generations and CO_2 emissions, determined endogenously in the model, correspond to the government's assumptions in Table 1 in such a manner to adjust the parameters such as the total factor productivity. The evaluations of the differences compared to the reference case are important for the interpretations of the model results.

The above assumptions are the assumptions of the options proposed by the government. The GDPs in themselves (or the GDPs compared to the base year) are dependent on the assumptions of the baseline. These GDPs play only a minor role in the economic analysis. For careful analysis, the assumptions of the GDPs should be based on the statistical rationales in terms of validity, probability and consistency. It is noted that the GDPs in the baseline do not derive from the economic models.

We analyze the economic impacts of the options, using the parameters adjusted for the baseline and for the constraints of the electricity shares and the CO_2 emission targets for the options. The constraints on the power generations, the government's assumptions in Fig. 2, are not used for this analysis. Alternatively the CO_2 emissions constraints are employed. The power generations are determined endogenously in the model. Thus, the power generations in the baseline correspond to the government's assumptions but those in the options do not necessarily correspond to the assumptions in Fig. 1. (The electricity shares by energy source in the model are identical to the government's assumptions both in the baseline and the options.)

4. Impacts on electricity charges

This chapter describes the impacts on the electricity charges for each option. Fig. 4 shows the estimated domestic electricity charges. Even in the 25% scenario, the electricity charges increase by 10%-15% compared to the baseline (with same electricity shares as 2010), because the shares of renewable energy increase. The charges for the 15% and 0% scenarios increase by 20%-25% and 35%-40%, respectively. The increases in the electricity charges lead to more electricity savings. However, more stringent mitigation efforts, including more electricity savings, are required for achieving the CO_2 emission reductions targets for each option. In order to achieve the targets, the estimated electricity prices increase by 110%-120% in the 0% scenario, in the case that fossil fuel power plants are imposed on carbon tax and then the tax are added to the electricity price. In this case, the increases in the electricity charges are lower than those in the prices, because these price increases result in additional energy savings. Nevertheless the electricity charges increase by 90%-105%. The increases in industrial electricity charges are much higher than those in domestic ones (Fig. 5).

The RITE's results are based on the estimations by the Committee for Verifying Power Plant Costs[3)] in such that the renewable energy costs steadily decrease during the periods. If the costs do not decrease like those estimations, heavier electricity charges will be estimated.

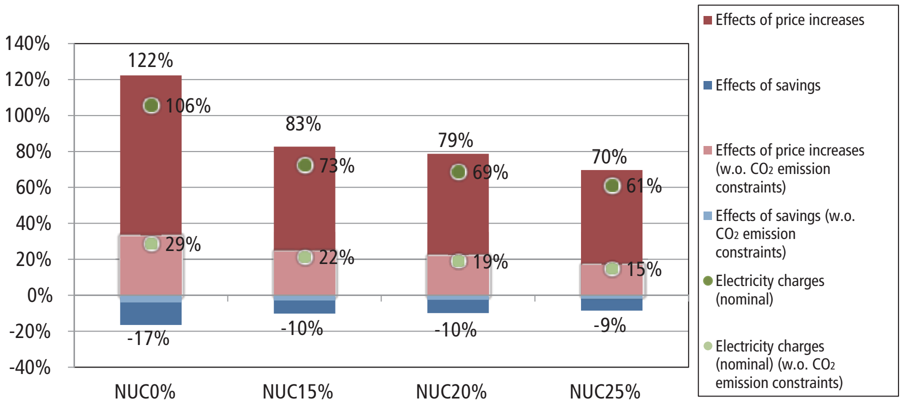


Fig. 4 Domestic electricity charges in 2030 (including the effects of electricity price increases and electricity savings)

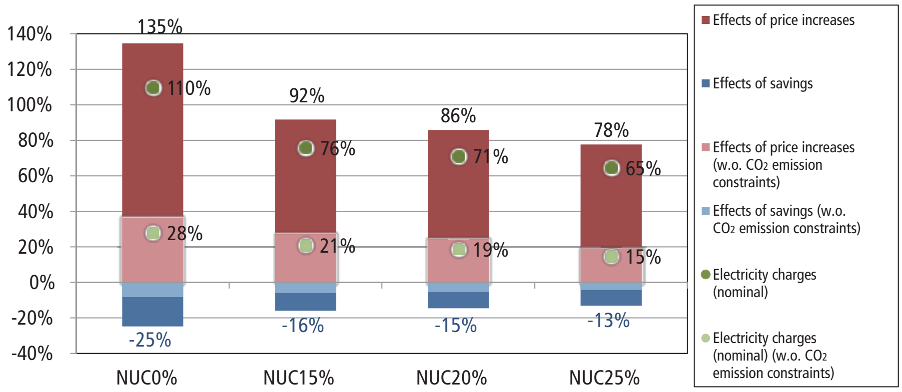


Fig. 5 Industrial electricity charges in 2030 (including the effects of electricity price increases and electricity savings)

5. Impacts on macro economy

The domestic electricity price increases result in consumption decreases. The industrial electricity price increases induce price increases of goods and services, hurt the companies' profits and decrease the investments. Fig. 6 shows the impacts of the whole economy for each option. The RITE's results reveal that GDPs in 2030 in the 15%-25% scenarios decrease by 4.4%-4.9% relative to the reference case. The GDP in the 0% scenario decrease by 7.4%, considerable worse than those in the other scenarios. Because in all the options the stringent energy saving policies and the enormous increases in renewable energy are introduced, the large economic impacts are estimated. In addition, the results indicate that the smaller shares of nuclear power generations are assumed, the severer economic damages are estimated.

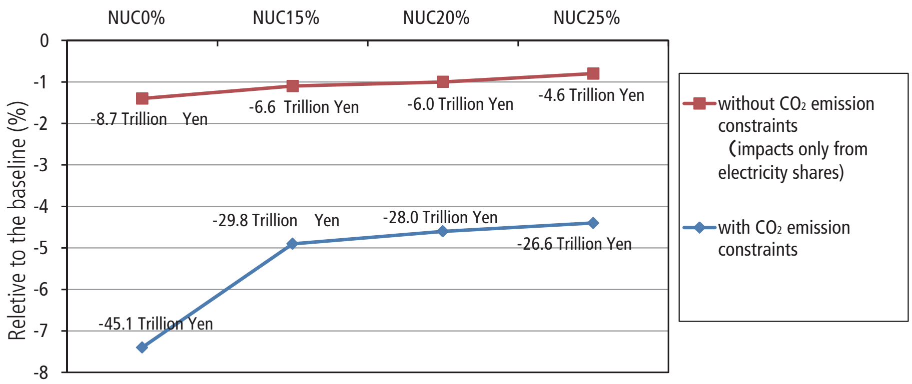


Fig. 6 Impacts on GDP in 2030 (including effects of electricity shares and CO_2 emission constraints)

6. Costs of CO_2 emission reductions

GHG emission reductions in 2030 in the three options are about 23%-25% relative to 1990. The "Innovative Strategy for Energy and the Environment" states that the target of the Japanese GHG emissions in 2030 decrease by about 20% compared to 1990 emission levels.
The CO_2 marginal abatement costs for the reduction targets (23%-25% reductions relative to 1990) of the options are about 34-41 thousand Yen per ton of CO_2 in the 15% and 20%-25% scenarios. In the zero scenario, the costs reach about 40-55 thousand Yen per ton of CO_2 because the more enhancements of energy savings are assumed.

On the other hand, the international levels of carbon prices are $30-50 per ton of CO_2 by 2030, estimated by the previous studies. Although the EU sounds highly motivated for tackling the GHG emissions reductions, even in the EU the outlooks of the carbon prices are €36-61 per ton of CO_2 according to the EU reports. According to the World Energy Outlook (WEO) 2011 Edition by the International Energy Agency (IEA), the estimated prices in 2030 are $40 per ton of CO_2 in the new policies scenario. The estimated carbon prices of all the options provided by the Japanese government reach about ten times as high as those international ones. Such high carbon prices will induce the decreases in domestic consumptions. The significant differences in the prices between Japan and other countries facilitate the overseas shifts of Japanese industry, particularly in the energy-intensive sectors. These shifts do not necessarily decrease the global CO_2 emissions. On the contrary, these shifts probably increase the global emissions because of to the production increases at the inefficient countries in terms of CO_2 emissions.

Needless to say, it is important to tackle the decreases in GHG emissions including CO_2 emissions. Too extreme measures, however, induce serious economic damages. Because the overseas shifts of industry decrease the effectiveness of the emission reductions at a global level, the appropriate measures are required for tackling the global warming issue.

7. Outlooks of electricity savings in the Options for Energy and the Environment

Fig. 7 indicates the strong positive relationship between growths of GDP and power generations. The GDP elasticity of the power generations is just 1.0 for 2000-2010. (The elasticity during for 1990-2010 is higher.) As mentioned previously, the government's options assume that the economic growth rate is about 1%/year for 2010-2030. This assumption leads to the GDP increases in 2030 by +21% compared to 2010. If the GDP elasticity of 1.0, corresponding to the historical trends during the previous ten years, is adopted, the assumption of the power generations increases by +21% in 2030 is highly probable. However, the increase in electricity generation estimated by the government is only 3% in BAU. Thus, the "Options for Energy and the Environment" include the considerable large potentials of the energy and electricity savings. These assumptions on the energy and electricity savings are left outside of the economic analysis by the economic model. This corresponds to the assumptions that the power generation changes from +21% to +3% (compared to 2010) can be achieved without economic damages.

The energy and electricity savings greatly improved after the Fukushima nuclear power plant accident. It was reported that the national average of the energy and electricity savings during the summer (July and August) of 2012, for example, reached about 6% in terms of kWh (estimated by the Agency for Natural Resources and Energy, including the corrections for climate and economic conditions). However, currently, the economic impacts of those energy and electricity savings are uncertain. Assuming that these economic impacts of all the savings are zero and the effects of them are continued, the effects of the savings are expected to be at most 5% on the annual average. Even if it is acceptable that the continuous savings of about 5% after the Fukushima accident, in the savings by power generations changes from +21% to +3%, are interpretable, the economic impacts by the rest of the savings for the options should be investigated carefully. However, this economic analysis, requested by the Japanese government, does not consider the above economic damages. Therefore, we should recognize that the economic analysis for the "Options for Energy and the Environment" results in the underestimated economic damages.

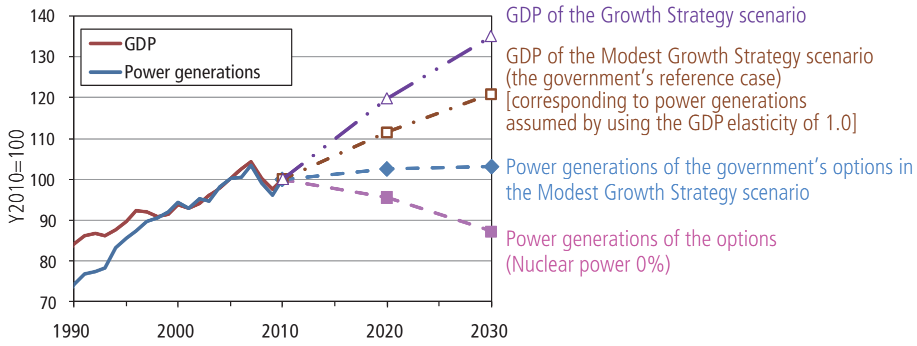


Fig. 7 Assumptions of GDP and power generations

8. Final remarks

The Japanese government decided the 'Innovative Strategy for Energy and the Environment' for our middle- and long-term energy supply and demand strategy after the severe accident of Fukushima-daiichi nuclear power plant attacked the Great East Japan Earthquake and Tsunami. RITE conducted the economic analyses of the "Options for Energy and the Environment", requested by the Japanese government. However, during the discussions toward the decision of the strategy, objective and science-based discussions have been lacked in many times, and it is doubtful that politicians and general public have understood the economic analysis results.

Many public has a negative position to nuclear power after the Fukushima-daiichi nuclear power accident, and therefore, it is impossible to continue past strategies to increase nuclear power plants. Under the situation, further energy efficiency improvements and large increase in renewable energies are necessary. However, the "Options for Energy and the Environment" and the "Innovative Strategy for Energy and the Environment" by the government assume drastic energy efficiency improvements and increase in renewable energies which levels indicate extremely difficult to be achieved economically as discussed in this paper. While a strong positive relationship between GDP growth and electricity demand increase has been observed, the scenarios of the government for the relationship are assumed to be disappeared in the future. There have not been any considerations how to achieve such a decoupling. But the government provided the green growth scenario, which energy uses and CO_2 emissions decrease while GDP increases, and which all people desire. Large savings of electricity have been achieved since March 11, 2011. However, the gap between the assumed electricity savings even in baseline of the options and the strategy by the government is still large, and deeper discussions are needed to fill the gap.

The "Innovative Strategy for Energy and the Environment" states "all policy resources will be injected to be possible for achieving zero of nuclear power generations in 2030s". However, we need to make a better strategy within our limited resources considering several trade-offs. To inject "all policy resources" into a single purpose will induce large negative impacts on our society in the future. A well balanced energy and environment strategy with achievability are required. RITE will continue to analyze energy and environment strategies subjectively using several mathematical models which have been developed, and will provide the analysis results for a better policy making. RITE will also propose more effective measures with reality for more fruitful future.

References

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3) Energy and Environment Council of the Japanese government, "Reports of the Committee for Verifying Power Plant Costs". http://www.npu.go.jp/policy/policy09/archive02_hokoku.html (2012)

Global Biorefinery Trends and Research Overview

1. Introduction

The biorefinery is a relatively recent concept proposed by, among others, the U.S. Department of Energy (DOE) to encompass technologies and industries that enable production of chemicals and liquid fuels from biomass. The biorefinery, along with information technology, has been a key strategic scientific mission of the U.S. since 1990s, with advancement of technologies and industries relevant to the implementation of the biorefinery vision a priority U.S. policy to achieve a sustainable 21st century society less dependent on fossil resources.

The biorefinery is estimated to have the potential to generate as much as $230 billion by 2020 and $300 billion by 2030 (World Economic Forum 2011), with financial investment projected to exceed total investments in IT businesses during the 1990s. Consequently, many biorefinery-related venture businesses established since the second half of the 1990s have succeeded in attracting funds through stock listing over several years.

However, a rapid expansion of biofuel production in the form of large-scale bioethanol production in the U.S. was widely blamed for a worldwide surge in food crop prices, since corn-based feedstocks necessary to sustain the bioethanol production meant that there was a direct competition between bioethanol and the global supply of a major food staple. Further technological developments that hence became necessary to avoid this competition are starting to ensure that non-food agricultural residues (e.g. corn stover) and so-called energy grasses (e.g. switch grass) around the world comprise the major component of biorefinery feedstocks.

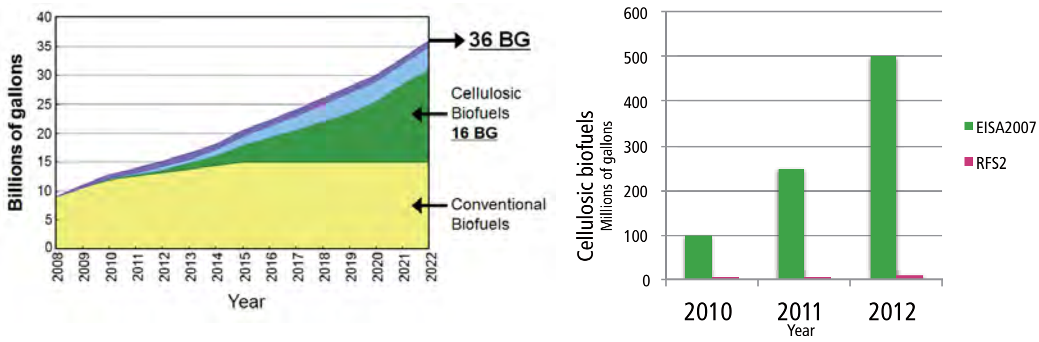
Biomass of plant origin enables a virtuous carbon-neutral cycle of plant growing, processing, harvesting, and burning, meaning that its use does not lead to net changes in the level of atmospheric CO_2. For this reason, it is greatly anticipated that biofuels will provide cleaner fuels through effective reduction of CO_2 emissions.

2. Current state of U.S. bioethanol production and next-generation biofuels

World bioethanol production in 2012 was estimated to be 22.5 billion gallons (F.O. Licht, etc). Even though U.S. bioethanol production was somewhat decreased as a result of the 50-year peak in U.S. corn price after drought damage, it still accounted for ca. 60 % (13 billion gallons) of the global production, and demand is projected to continue to grow following the commencement of the sale of E15 (ethanol-gasoline blends containing up to 15 percent ethanol by volume). Given that as much as 40 % of current U.S. corn crop goes into ethanol production, a shift from grains to cellulosic biomass as raw material is urgently required. The U.S. government has consequently strongly backed biofuel projects which can utilize agricultural residues such as corn stover and so-called energy grasses such as switchgrass.

2-1. Renewable Fuel Standard 2

To increase the production and consumption of renewable fuels in the U.S., the government not only encouraged a feedstock change to avoid undesirable competition with the food-supply but accordingly modified Renewable Fuel Standard (RFS). The original RFS of 2005 was upgraded to RFS2 in the Energy Independent and Security Act of 2007. A turning point to non-food cellulosic materials that should have come around 2010~2011 (Fig. 1, left) never happened, however. On the contrary feedstock conversion progress fully stopped. Thereafter, the U.S. Environmental Protect Association (EPA) has had to revise downward each consequent year's targeted production of cellulosic ethanol from after 2010 (Fig. 1, right).



References: Energy Independence and Security Act of 2007 (EISA2007) Renewable Fuel Standard(RFS2)

Fig. 1 Bioethanol production in U.S.

2-2. Current state and challenges of cellulosic ethanol production

Cost-competitiveness of cellulosic ethanol production has not been achieved despite considerable research funding into technology development by the U.S. government. The two key processes that constitute cellulosic ethanol production, pre-treatment and fermentation entail the generation of side products collectively called fermentation inhibitors in pre-treatment process. The impact that these inhibitors exert on the efficiency of the latter ethanol fermentation process largely determine the efficiency of each cellulosic ethanol production process (Fig. 2).

Under milder pre-treatment conditions (temperature, time, etc.), a relatively large amount of cellulase enzyme used for cellulose saccharification is necessary. Since enzyme cost is a significant cost factor, it directly impacts the overall ethanol production cost. Conversely, harsher pre-treatment conditions lower the amount of cellulase enzyme necessary but generate fermentation inhibitors more liberally, and the efficiency of ethanol fermentation accordingly falls sharply.

Trade-offs between the severity of pre-treatment and the amount cellulose enzyme necessary must therefore be made (Fig. 3). Presently, the cost of cellulase enzyme is estimated at $3 ～5 per gallon ethanol produced, making cellulosic ethanol economically inefficient (ethanol price calculated from the market price of gasoline is ca. $3).

Several attempts to improve the situation, including an engineered approach to inhibitor removal, improved inhibitor tolerance of fermentative microorganisms, etc., have not succeeded in solving the cost performance problems to date. This has resulted in an international major oil company cancellation of a previously announced large-scale plant construction of cellulosic ethanol project in the U.S. Other leading companies have also postponed proposed plant operations until after 2013.

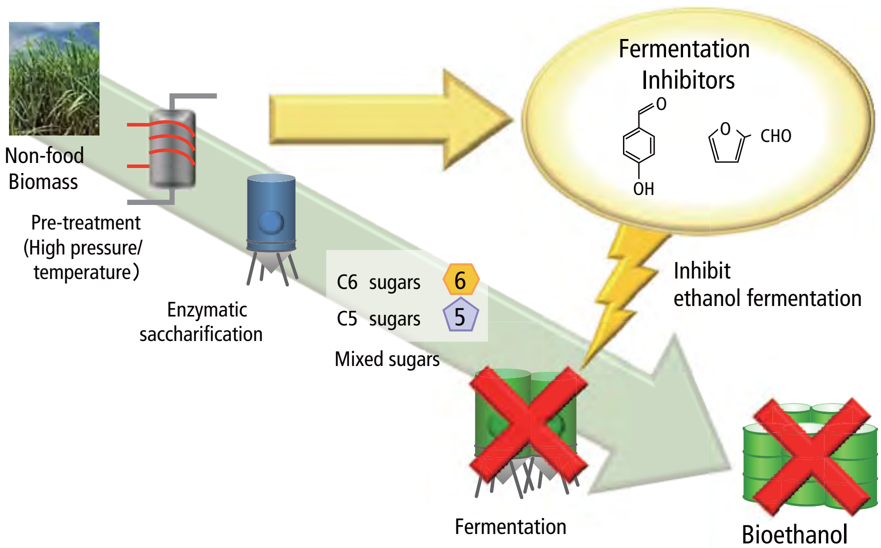


Fig. 2 Obstacles to Industrialization: Fermentation Inhibitors

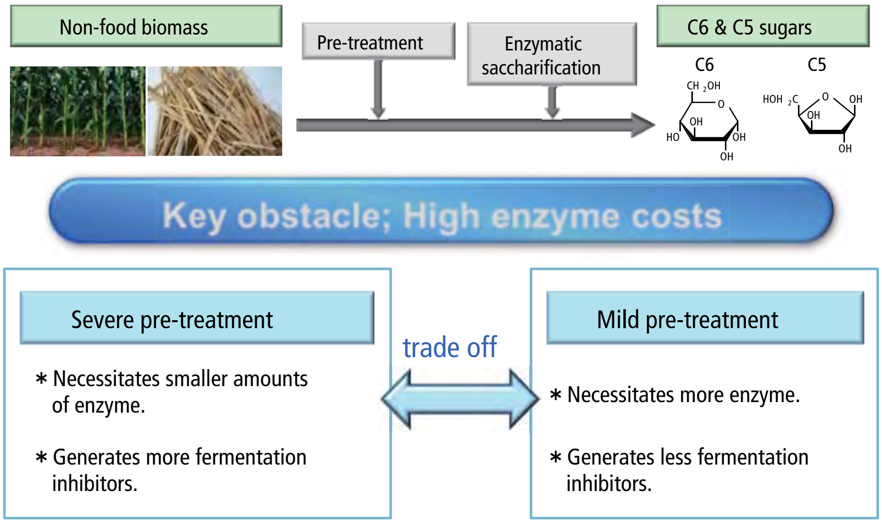


Fig. 3 Obstacles to Industrialization: Saccharification costs

2-3. Outlook of next generation biofuels

According to the International Energy Agency (IEA) biofuels roadmap report of 2011, biofuels can provide up to 27% of world transportation fuels by 2050. Based on these estimates, the next generation biofuel, butanol, receives remarkable attention in the biofuels sector. Compared to ethanol, butanol exhibits several advantages; it has high-energy content while being transportable via existing pipelines after mixing at oil factories with gasoline due to its low water solubility. Industrial production of butanol began early in the 20th by the fermentation method (ABE fermentation) using species of Clostridium bacteria and biomass sugars, and then moved to simpler and cheaper distillation-from-petroleum methods of refining butanol after the 1950s. In recent years, the fermentation from biomass resources has attracted attention once more as biofuel promotion has gained traction.

There are two main approaches to efficient biobutanol production process under current development. The first is the improvement of traditional ABE fermentation process while the other one introduces biosynthesis pathways into industrial microbes such as *Escherichia coli*, yeasts, etc. to produce biobutanol. RITE previously announced introduction of butanol synthesis genes into *E. coli* in a pioneering study. The more recently announced possibility of isobutanol synthesis through intermediate chemicals of the branched-chain amino acid biosynthesis triggered technology developments in a variety of microbes from these intermediates.

At present, major oil and chemicals companies, ventures companies, etc., have recognized the early industrialization potential of the biobutanol business, where non-food biomass resources should play an important role in future large-scale production. Noteworthy is the issue of fermentation inhibitors, which must be overcome also in biobutanol production.

3. Green chemicals

The field of green (renewable) chemical production via bioprocessing greatly differs in outlook from that of biofuels. Although green chemical production requires more advanced technologies to produce compared to those required for biofuels, a variety of high-value product groups and integrated market size are predicted and an easier business model than that of biofuels seems can be created. The future market size of green chemical is estimated to generate $100 billion by 2020, and many ventures have been established the world over. Several venture companies with cellulosic ethanol production as the main business plan changed plans to produce green chemicals as an immediate goal. In these business plans, they use C6 sugars derived from food-based biomass like corn as a raw material because economical volumes for green chemicals are considerably smaller than those required for biofuels, leading to little criticism. Nevertheless, the use of non-food biomass like corn stover or switchgrass is eventually an essential requirement for sustainability, just as with biofuels.

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

RITE has developed an efficient biomass utilization technology based on intrinsic characteristics of coryneform bacteria. The so-called "RITE Bioprocess" (a growth-arrested bioprocess) has so far enabled elevated productivities of green chemicals and biofuels. This pioneering technology enables the simultaneous utilization of mixed sugars from cellulosic biomass in biorefinery settings. In a collaboration with a private company, its application in a cellulosic ethanol production system earned the Grand Prize at the 18th Nikkei Global Environment Award (see RITE Today 2009). What is more, the process has evoked the interest of international academia and their researchers, earning our group leader the 2011 fellowship award from The Society for Industrial Microbiology and Biotechnology (SIMB), the first Japanese scientist to receive the prestigious award (see Topics). Starting in 2011, collaboration work on cellulosic biofuels with NREL (National Renewable Energy Laboratory) founded by U.S. Department of Energy has yielded interesting results (see later).

Moreover a research group based in Germany has followed our footsteps and carried out additional research using coryneform bacteria; they have 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 described in the following paragraphs.

4-1. Technological attributes of the RITE Bioprocess

In the RITE Bioprocess, coryneform bacteria are engineered to have an optimum metabolic pathway for a particular target chemical. The cells are grown on a large scale and packed to very high densities in a reactor in order to maximize the catalyst/volume ratio at the production stage (Fig. 4).

Sugars are subsequently added to initiate bioconversion as a substrate under oxygen deprivation; the tight packaging effectively ceases growth of the 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 without any additional natural rich medium or external energy. 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 those of chemical processes.

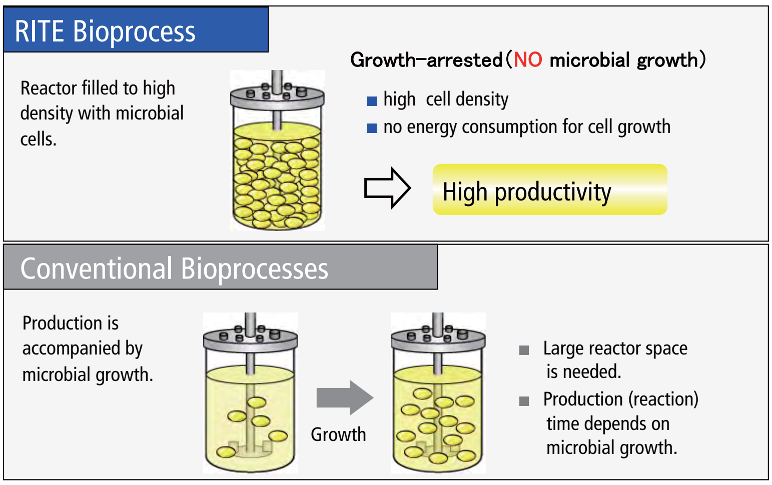


Fig. 4 Comparison of RITE Bioprocess with conventional bioprocess

4-2. Simultaneous utilization of C_6 and C_5 sugars

Lignocellulosic biomass hydrolysates constitute complex mixtures of different sugars (Fig. 5). They compose pentoses (C5 sugars such as xylose and arabinose) derived from hemicelluloses, as well as hexoses (C6 sugars such as glucose and fructose). By comparison, starch from food grains such as corn, wheat etc. and sugar from sugarcane contain only hexoses. Therefore, for achieving a high yield per substrate, it is essential for microorganisms used in biofuel processes to to simultaneously utilize both pentoses and hexoses. Several genes involved in the catabolism of C5 sugars into have been introduced into coryneform bacteria, and the resultant recombinant bacteria applied to the bioprocess. These modifications allow for efficient utilization of cellulosic materials, and faster conversions with essentially no lag phase.

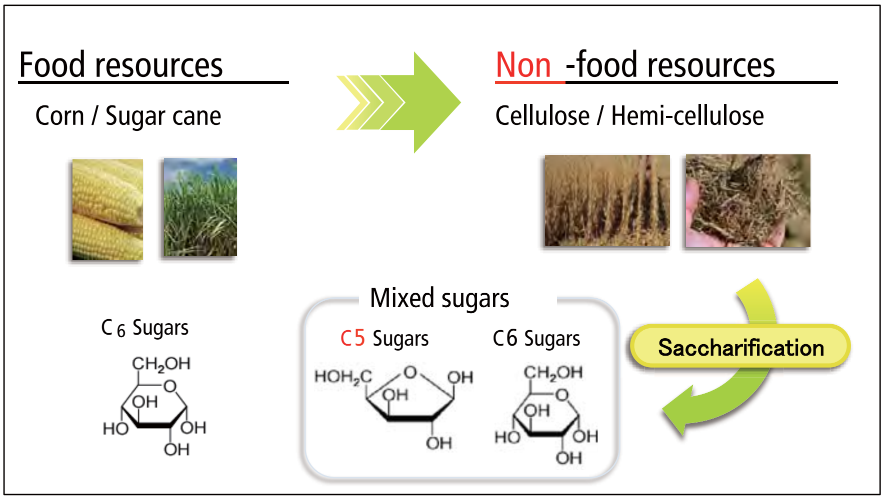


Fig. 5 Expanding usage of mixed sugars from non-food biomass

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 (Fig. 2). 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. As mentioned in chapter 2, 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, the RITE Bioprocess has been demonstrated to be insensitive to these fermentation inhibitors, since their action is to inhibit cell growth, which is a separate phase from the production phase in the RITE Bioprocess. Furthermore, it has been 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. 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 compounds comprising butanol, aromatic compounds, and amino acids (Fig. 6).

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 leading Japanese companies to become building blocks for advanced products such as electric devices, hardware, and automobiles. In addition, the RITE Bioprocess shows higher cost performance than conventional fermentation processes such as amino acids manufactured by aerobic fermentation. Because aerobic processes require air compressors and agitation motors to ventilate and mix liquids, respectively, aerobic processes involve additional equipment and expensive operational cost. We have already begun to develop production processes for several amino acids by using the RITE Bioprocess

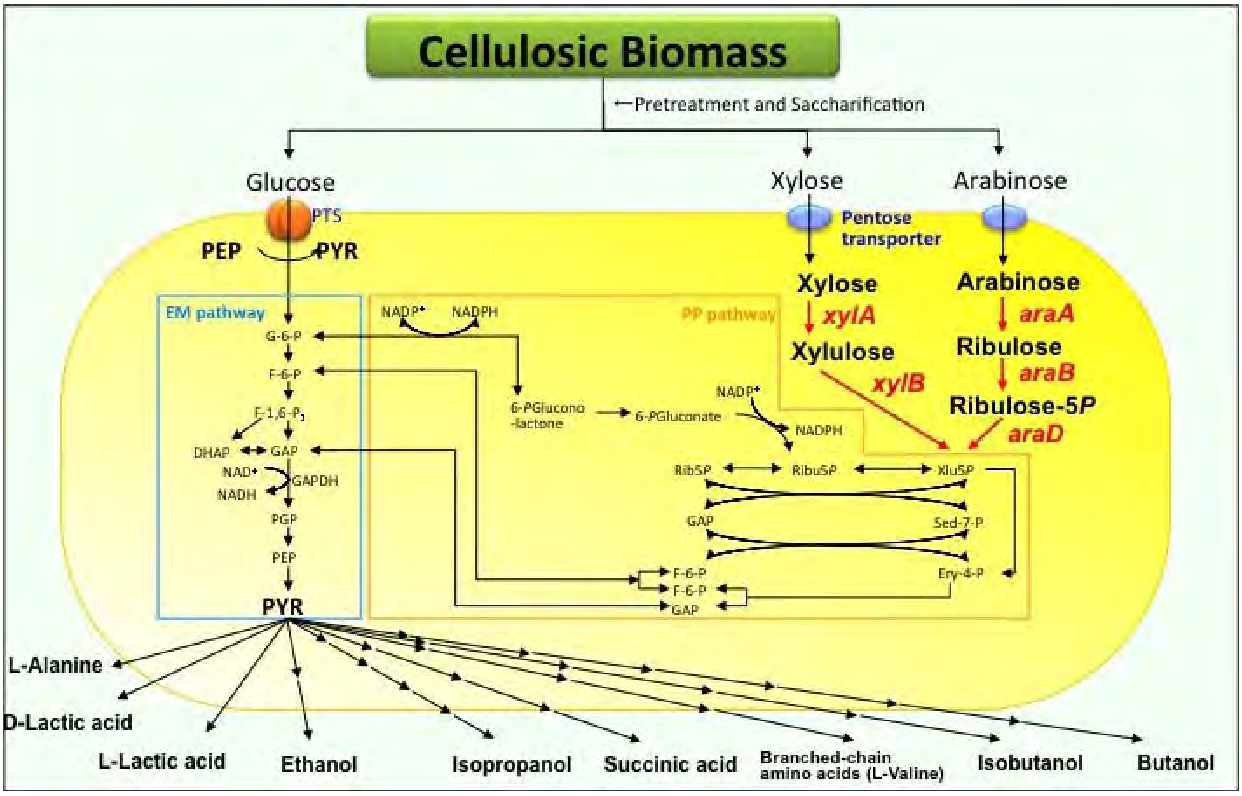


Fig. 6 Production pathways of coryneform bacteria designed for acyclic chemicals and biofuels

5. RITE's effort for industrialization

5-1. Establishment of a venture company

As described earlier, the RITE Bioprocess has unique features such as high productivity, simultaneous utilization of mixed sugars and tolerance against fermentation inhibitors, evoking the interest of national as well as international industry powerhouses. In response to many requests and in order to accelerate the realization the industrialization of the biorefinery, we established Green Earth Institute Co., Ltd. in September 2011 as a world-reading venture company to provide biofuels and green chemicals through the RITE Bioprocess. The overarching goal of establishing GEI is not simply industrialization of the RITE Bioprocess but to contribute to the conservation of global environment through efforts against global warming and hence the realization of sustainable post-fossil resources society (http://www.gei.co.jp/index.html).

5-2. Joint research for cellulosic ethanol production with NREL

NREL (U.S. National Renewable Energy Laboratory), founded by DOE in 1974, is the only national laboratory solely dedicated to advancing renewable energy and energy efficiency technologies. It has accumulated good research data regarding mixed sugar preparations from various cellulosic materials and holds significant expertise in pre-treatment technologies applicable to them. As described earlier, solution of the problem of fermentation inhibitors is indispensable for cost-effective production of cellulosic ethanol. The joint research between RITE, NREL and a private company established in 2011 and based on the RITE Bioprocess aims to tackle fermentation inhibitors head on. The prospects of solving the problems at a basic research level by combining our mutual research are apparent. In several years, our efforts with the participation of GEI, should lead to actualization of an economically efficient production process for cellulosic ethanol.

6. Ending remarks

Immediate goals for the joint research with NREL are the economically efficient production of fuel ethanol from non-food biomass resources, and it should make impact on other chemicals other than fuel ethanol. For example, the manufacture of as wide a range of green chemicals as possible must be attained when a supply of low cost mixed sugars from non-food biomass becomes available and to be used for biorefinery. Based on the joint research with NREL, we hope to make efforts for the realization and expansion of biorefinery industry which contributes towards global warming prevention, environmental protection and construction of a sustainable society (Fig. 7).

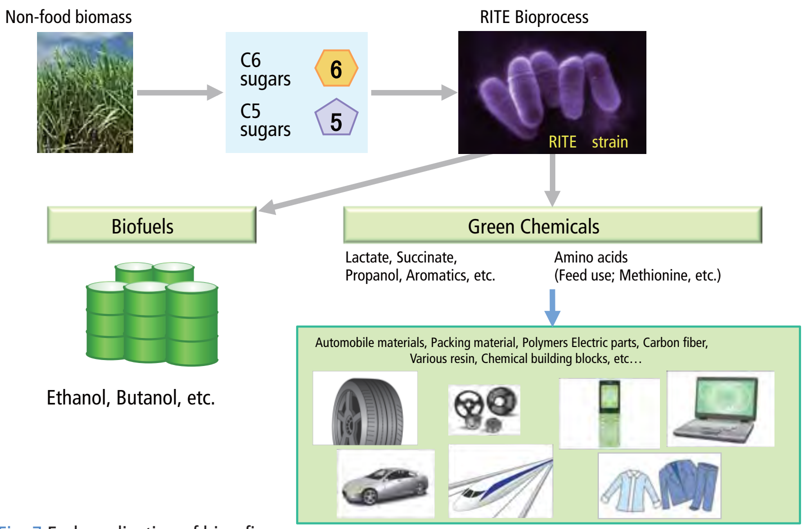


Fig. 7 Early realization of biorefinery

Chemical Research Group

Challenges for Advanced Industrializing CO_2 Capture Technologies and CO_2 Emission Reduction Technologies

1. 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.

Chemical research group studies various CO_2 capture technologies, with a special focus on chemical absorption, membrane separation and adsorption methods, and obtained the outcomes that lead the world. Materials development, processing and system investigation are conducted in the group.

In the development of chemical absorbents, we developed innovative chemical absorbents that can reduce the CO_2 capture cost to half under COCS project and we have been developing new chemical absorbents with the further high performance, under COURSE50 project in steel-making industry.

As the net results, in FY 2012 (final year of COURSE50 project), we achieved the CO_2 capture energy consumption 2.0GJ/t-CO_2 which is our target of this project, not only that, came up the development of breakthrough absorbents which enables CO_2 regeneration from absorbents at less than 100℃ compared with 120℃ necessary as it is.

By developing molecular gate 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 (by 2015).

We discovered that new types of dendrimer /polymer hybrid membranes show excellent separation performance for separating CO_2 from H_2 gas mixtures. Recently, we succeeded in improving separation performance further by changing polymer materials from PEG to PVA etc., and world's largest CO_2/H_2 separation factor (>500) was obtained under atmospheric conditions. RITE and three private companies have established the technology research association, developing membrane modules and separation systems for the practical application.

We started to develop novel solid sorbents and to establish evaluation standards CO_2 capture using liquid amine solvents. We are now endeavoring to find more efficiently new solid sorbents (CO_2 capture energy: 1.5 GJ/ton-CO_2) which are appropriate for the project. It has been confirmed that a new RITE-solvent based solid sorbent synthesized in our study desorbed CO_2 at lower temperature compared with traditional solid amine sorbent. Evaluation for the practical use is now under way.

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 chemical absorption process, baroplastics that have low temperature flow under high pressure state, etc., to be used for various purposes. Especially the membrane/absorption hybrid CO_2 capture technology has been used practically in a private company.

2. 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. For the last decade, we have been developing highly efficient CO_2 absorbents that can decrease the consumption energy of CO_2 separation, which is the main concern for chemical absorption systems.

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

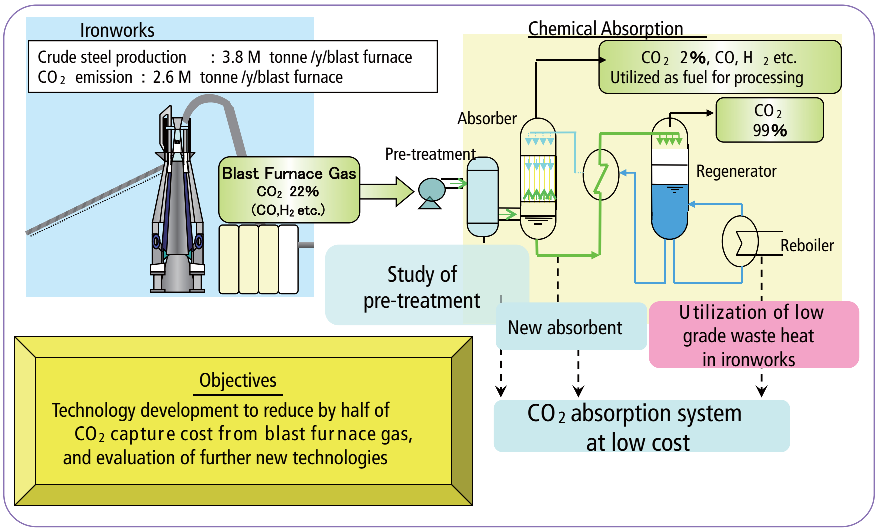


Fig. 1 Outline of cost saving CO_2 capture system (COCS project)

In this project, we developed various types of high performance absorbents. The CO_2 capture energy consumption of absorbents (named RITE solvent) developed in this project is drastically reduced in comparison with that of MEA (monoethanolamine)-based absorbent used as a benchmark.

These outcomes were succeeded by new project, “CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50” (COURSE50, five years from FY 2008), aiming at CO_2 capture in steel-making industry.

We have been developing more efficient amine-based absorbents taking advantage of acquired R&D techniques, knowledge and the latest computational chemistry with Nippon Steel & Sumitomo Metal Corporation and The University of Tokyo, and evaluating the test results with 1t and 30t-CO_2/day scale pilot equipment (Fig.2 and 3) using BFG (blast furnace gas) under the cooperation with Nippon Steel & Sumikin Engineering Co., Ltd.

As the net results, in FY 2012 (final year of COURSE50 project), we achieved the CO_2 capture energy consumption 2.0GJ/t-CO_2 which is our target of this project, not only that, came up the development of breakthrough absorbents which enables CO_2 regeneration from absorbents at less than 100℃ compared with 120℃ necessary as it is.

Furthermore, as the further outcomes of R&D on highly energy-efficient absorbents, we have already developed new chemical absorbents with excellent CO_2 absorption and dissociation performances which enables CO_2 regeneration under high pressure, and now we are developing CO_2 absorption with the further high performance.

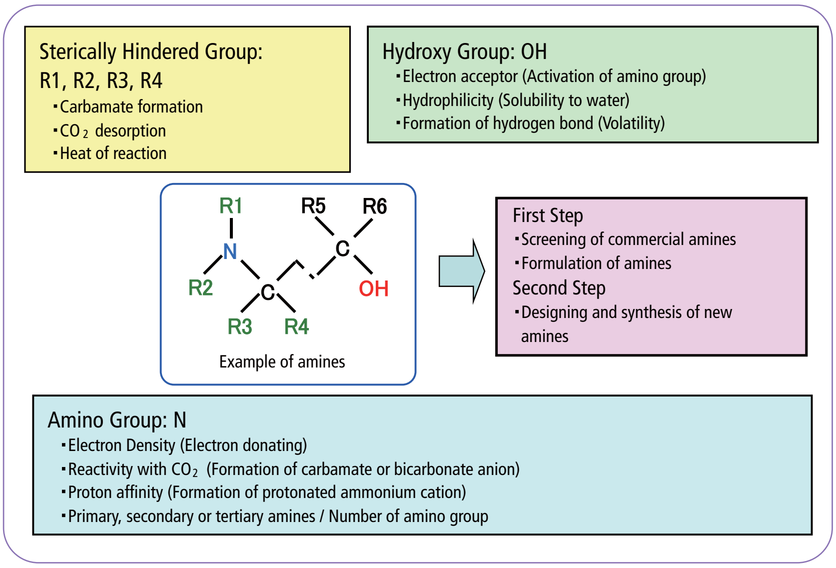


Fig. 2 Development of new absorbents

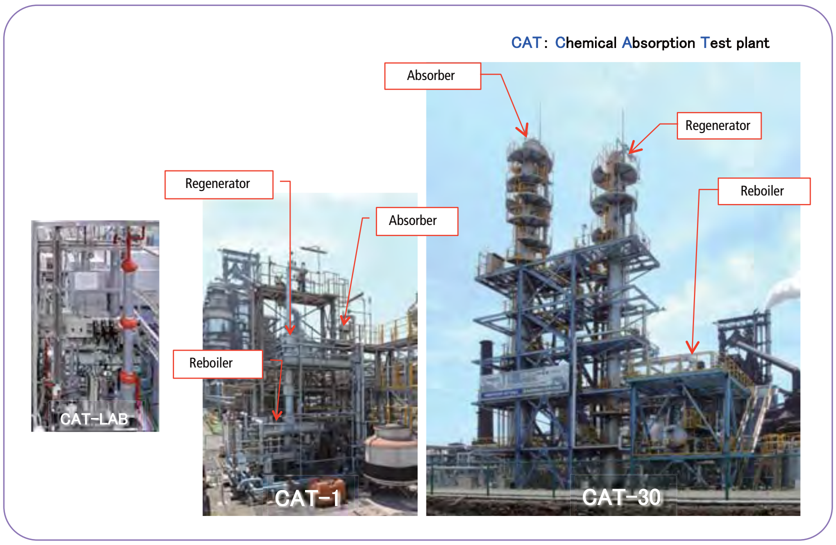


Fig. 3 Snapshots of test equipment

3. 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) **(Fig.4). 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. 5 shows the basic outline of the CO_2 molecular gate function. The pathway for gas molecules is occupied solely by CO_2, which acts as a gate to block the passage of other gases. Consequently, the amount of N_2 or H_2 permeating to the other side of the membrane is greatly limited and high concentrations of CO_2 can be obtained.

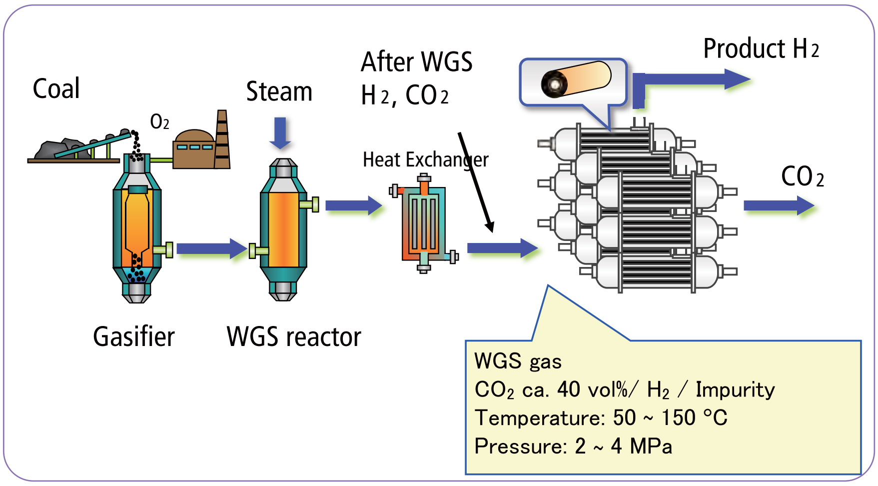


Fig. 4 Schematic of IGCC with CO_2 Capture

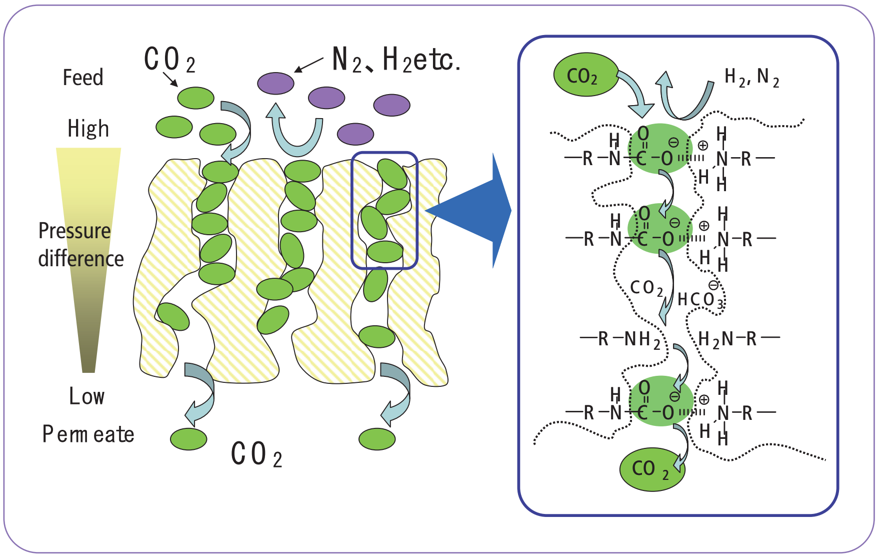
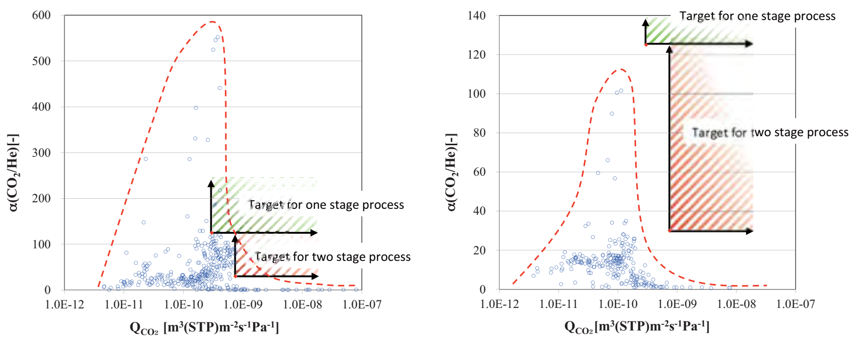


Fig. 5 Conceptual diagram of the molecular gate membrane

We discovered that new types of dendrimer /polymer hybrid membranes show excellent separation performance for separating CO_2 from H_2 gas mixtures. Recently, we succeeded in improving separation performance further by changing polymer materials from PEG to PVA etc., and world's largest CO_2/H_2 separation factor (>500) was obtained under atmospheric conditions (Fig. 6).



(a) Separation performance at atmospheric pressure

(b) Separation performance at 0.7MPa

Fig. 6 Separation performance of PVA-based molecular gate membranes (QCO2：CO_2 permeance, α：selectivity)

* Ministerial-level international climate change initiative that is focused on the development of improved cost-effective technologies for the separation and capture of carbon dioxide (CO_2) for its transport and long-term safe storage.

Based on these materials, modification of membrane materials, membrane thickness control etc. are ongoing to improve CO_2 separation performance further.

In the development of a commercial membrane module using the PAMAM dendrimer/polymer hybrid material, RITE, Kuraray Co., Ltd., Nitto Denko Corporation and Nippon Steel & Sumikin Engineering Co., Ltd. established Molecular Gate Membrane module Technology Research Association, and membranes, membrane modules and separation systems are being developed (Fig. 7).

In developing this CO_2 molecular gate membrane, 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.

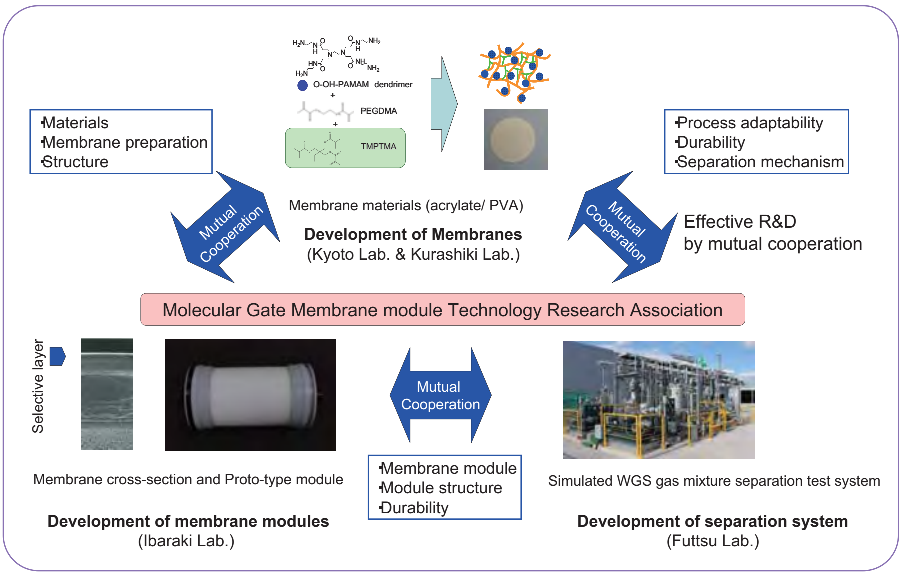


Fig. 7 Development of membrane modules in cooperation with private companies

4. 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. We are now endeavoring to find more efficiently new solid sorbents (CO_2 capture energy: 1.5 GJ/ton-CO_2) which are appropriate for the project (Fig. 8) .

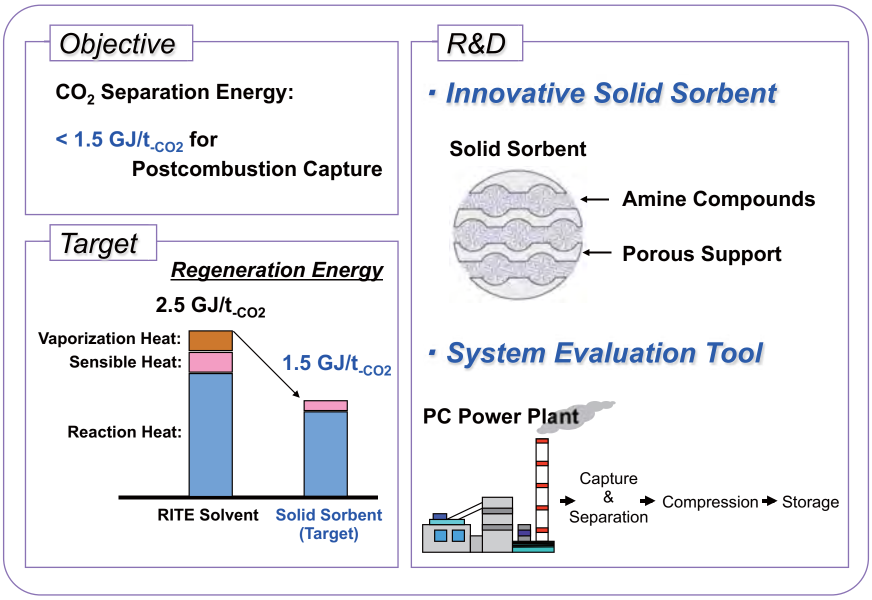


Fig. 8 Project for Development of CO_2 Solid Sorbent

With respect to solid sorbents, amines can be immobilized onto a support or encapsulated within a porous substrate (Fig. 9). 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. In addition, energy efficiency of a power plant with post-combustion CO_2 capture can be improved at about 2% by the solid sorbent technique instead of by an advanced liquid amine solvent technique (Fig. 10).

RITE has investigated novel solid sorbents using RITE-developed solvents through cooperative R&D activities with NETL under the CRADA concluded in May 2012 between RITE and NETL. NETL has started to evaluate the potential of the RITE-developed solvent for solid sorbent fabrication. It has been confirmed that a new RITE-solvent based solid sorbent synthesized in our study desorbed CO_2 at lower temperature compared with traditional solid amine sorbent. Evaluation for the practical use is now under way.

In addition, RITE has carried out process simulation study so as to more accurately estimate energy and cost for CO_2 capture from a coal-fired power plant. CO_2 capture with an advanced amine solvent was modeled with consideration of amine-CO_2-H_2O reaction mechanism and the calculation result of the process simulation with that model was well accorded with the experimental data obtained from 10t-CO_2/d pilot plant operation. Now we have extended the simulation study based on the solvent scrubbing process to evaluation of the solid sorbent process.

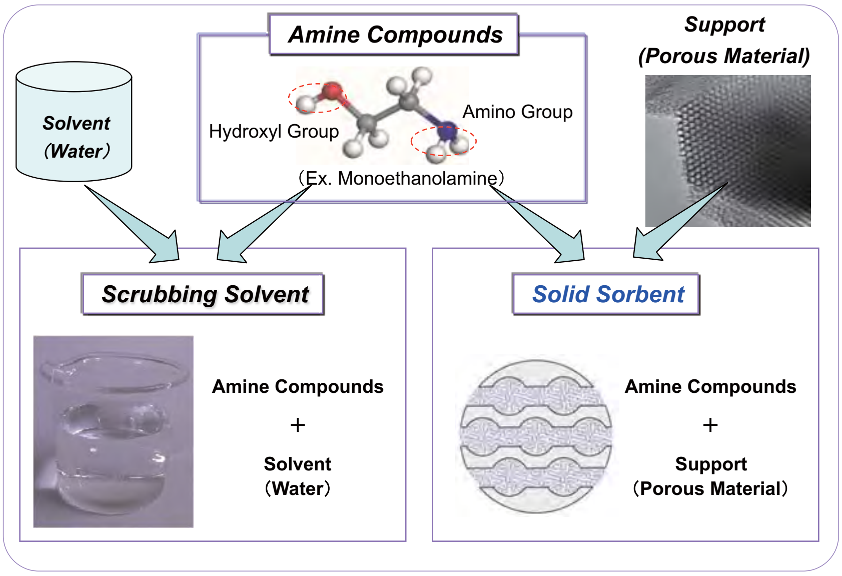


Fig. 9 Conceptual Image of Solid Sorbent

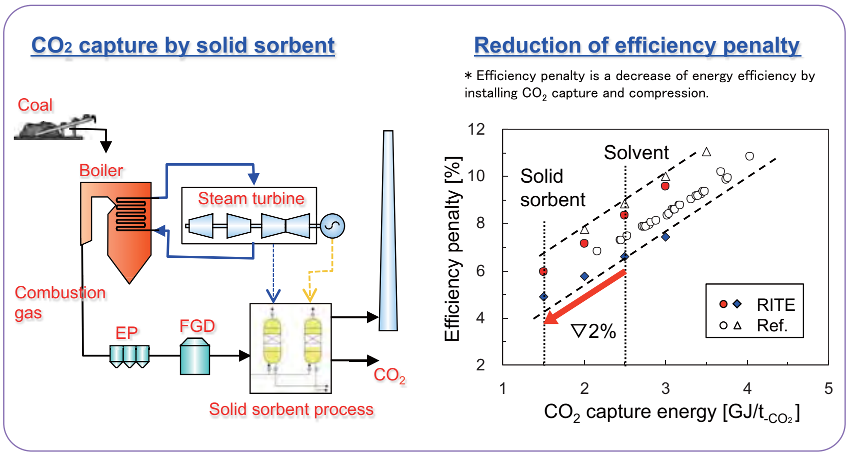


Fig. 10 Effect of CO_2 capture by solid sorbent on a power plant

5. Challenges for CO_2 emission reduction technologies

In chemical research group, we have developed various CO_2 capture technologies for CCS. In the future, we will study on technologies for reducing CO_2 emission itself. For example, we will study on process in which H_2 from renewable energy sources such as natural energy, biomass etc. is used as the energy without emission of CO_2. For this purpose, we will start to develop H_2 selective inorganic membranes.

In addition, we will start to study on energy-saving membrane technologies for separation of organic solvents and hydrocarbons in place of energy-consuming distillation.

CO_2 Storage Research Group

Developing CO_2 Storage Technologies Aimed at Practical Application

1. Overview

Controlling emissions of carbon dioxide (CO_2), a primary component of greenhouse gases, is an imminent issue. Carbon capture and storage or CCS is a series of techniques that enable separation and capture of CO_2 from large-scale emission sources, such as power stations and oil refineries, and its storage underground. CCS is considered as an important option to mitigate global warming, as well as the other efforts to control CO_2 emissions, including fuel energy efficiency, alternative fuel, and increased use of renewable energies. In order to halve greenhouse gas emissions by 2050, the International Energy Agency (IEA) suggested in the roadmap that 100 CCS projects need to be deployed by 2020, 850 projects by 2030 and 3,400 projects by 2050 in the world.

In this context, Japan launched a large-scale demonstration project in Tomakomai, Hokkaido, aiming at establishing technologies necessary for deployment of CCS. Japan CCS Corporation in charge of the project has already started drilling works. In the demonstration, CO_2 will be captured from a large-scale emission source and more than 100 thousand tons of CO_2 will be annually injected into two geological formations (Moebetsu formation at the depth of 1,100 to 1,200 meter and Takinoue formation at the depth of 2,400 to 3,000 meters). Monitoring activities are planned to be carried out to ensure the safety of stored CO_2.

Currently, RITE undertakes research and development of geological storage of CO_2, Japan-China CCS-EOR project, partnership with international bodies and survey of global CCS activities. By applying the outcome of our activities to the large-scale demonstration project, RITE hopes to help facilitate implementation of CCS in Japan.

2. Research and Development of geological storage of CO_2

Geological storage of CO_2 includes CO_2 injection into oil fields to enhance oil recovery (EOR); CO_2 injection into coal seams to enhance methane recovery (ECBM); CO_2 sequestration into depleted gas fields; and CO_2 storage in deep saline aquifers. In CO_2 storage in deep saline aquifer, impermeable caprock formations (mudstone layer) having high sealing properties immediately above a reservoir (sandstone layer) enable injected CO_2 to be contained stably and safely for a long period of time.

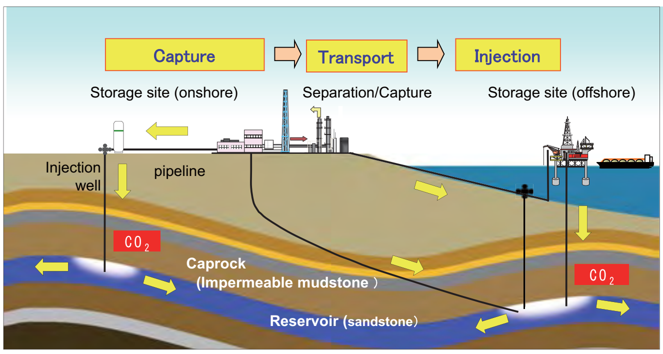


Fig. 1 Concept of geological storage of CO_2

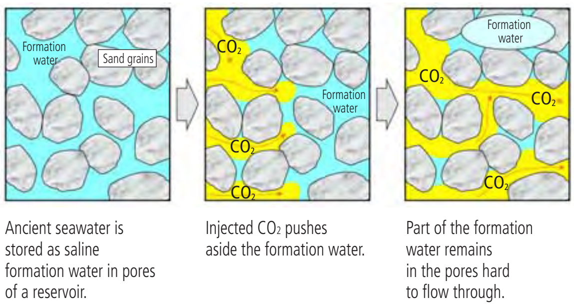


Fig. 2 Images of CO_2 in reservoir

As shown in Fig. 3, specific technical issues RITE works on in terms of research and development of geological storage of CO_2 are as follows: techniques of evaluating storage performance (building geological models), analyzing CO_2 behavior in reservoir (monitoring techniques and numerical simulation of CO_2 behavior), and analyzing CO_2 migration from reservoir (numerical simulation of CO_2 migration and methodology of offshore environmental impact assessment). Furthermore, RITE is preparing a series of best practice manuals based on the outcome of our work and what we have learned from prior projects in and outside Japan.

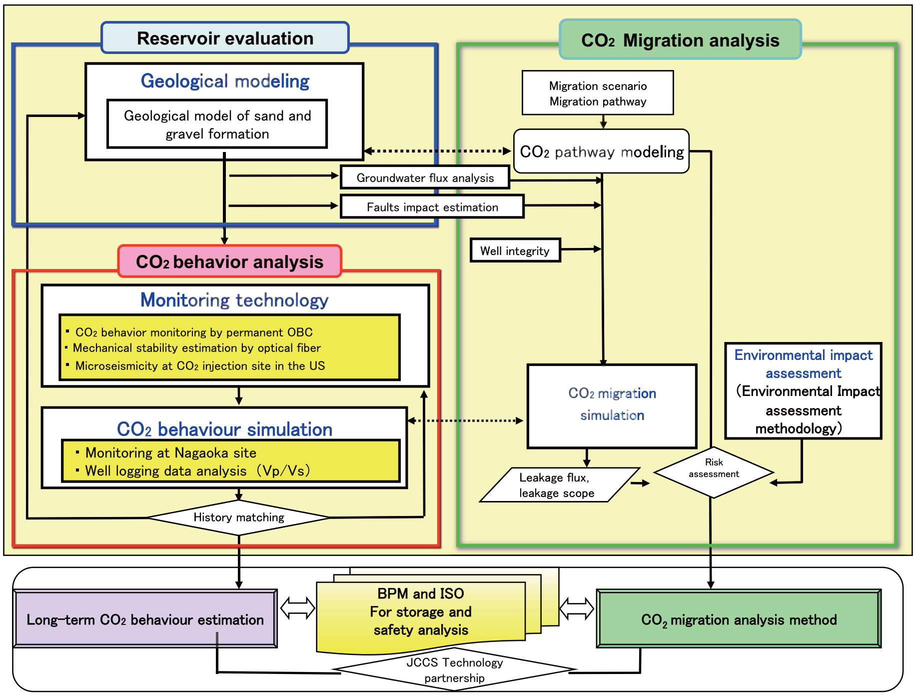


Fig. 3 Technical issues RITE works on in geological storage of CO_2

(1) Development of techniques of evaluating storage performance

Since a large volume of supercritical CO_2 is injected into a reservoir in geological storage of CO_2, it requires different techniques for evaluating storage performance and monitoring from those used in the fields of oil and natural gas exploitation. Among them, the most important part is building a geological formation model that will be used as the initial input (a geological model of a reservoir). When building a geological formation model of a region where no oil or natural gas exploitation has been made, we need to heavily depend on the past geological surveys of the ground surface or literature research, which are limited geological information to build a model. Since CO_2 injection might increase the pressure of a reservoir in geological storage of CO_2, numerical simulation of CO_2 behavior should be based on good understanding of physical properties of the rocks. To that end, it is very important to build a geological model that reflects the physical properties of the rocks.

From July 2003 to January 2005, RITE injected in total 10,400 tons of CO_2 into a deep saline aquifer at the depth of 1,100 meter in Nagaoka CO_2 injection demonstration test site (Iwanohara base, Nagaoka, Niigata Pref. owned by Inpex Corporation). In order to understand post-injection CO_2 behavior, various field measurements have been continuously conducted by using the wells at the site. Those data and results of physical properties test of core samples are used to develop a methodology of building a geological model that reflects complex geological formations unique to Japan, such as a sand-and-mud alternate formation or a sand-and-gravel formation.

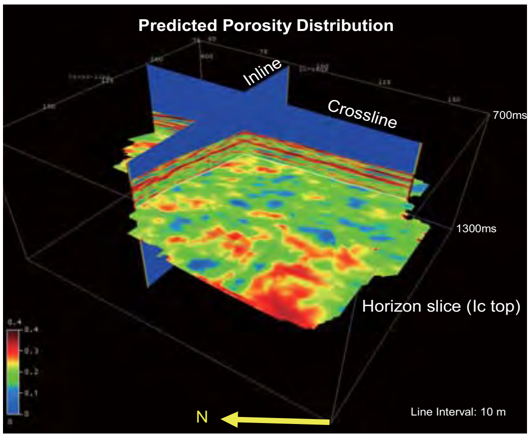


Fig. 4 Predicted porosity distribution on the top surface of Nagaoka reservoir

(2) Analyzing CO_2 behavior within reservoir

To facilitate commercialization of geological storage of CO_2, it is important to monitor CO_2 injected in a deep underground reservoir and verify that it is safely stored. Thus, RITE works on clarifying CO_2 storage mechanisms and improving numerical simulation of long-term CO_2 behavior by comprehensively analyzing various data obtained from physical loggings in Nagaoka. RITE is also developing a permanent ocean bottom cable system(OBC) that is effective for monitoring CO_2 behavior in offshore storage site.

- Analyzing CO_2 behavior at Nagaoka site

To monitor CO_2 behavior, RITE has continuously conducted physical loggings and cross-well seismic tomography at Nagaoka CO_2 injection site. The physical loggings allow us to measure changes in physical properties around the observation wells and to estimate a timing of CO_2 reaching the observation well, distribution of CO_2 in a depth direction, or a state of CO_2 (whether it remains in a supercritical state or dissolved into the formation water).

In the year 2012, RITE conducted the physical logging to examine the storage state of CO_2 during the post-injection period. Based on the results, we carried out history matching to calibrate the numerical simulation for long-term CO_2 behavior. It should be noted that among many geological storage demonstrations in the world, Nagaoka site is the only project where CO_2 behavior is continuously monitored even after the end of CO_2 injection. Therefore, its outcome has drawn great attention worldwide.

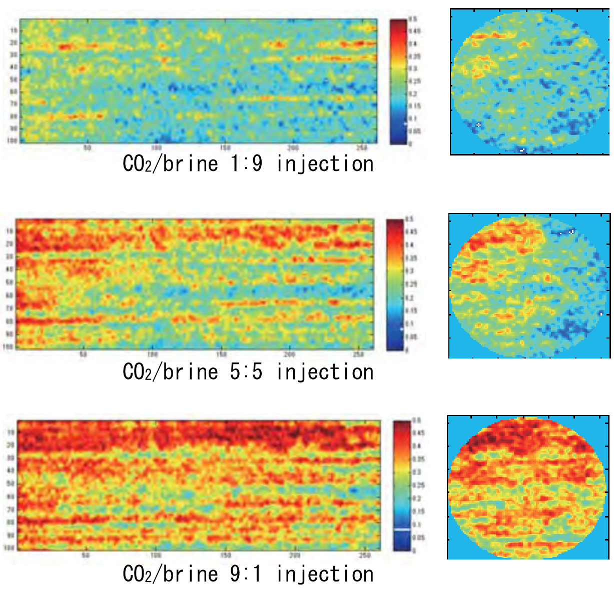


Fig. 5 Visual images of CO_2 distribution in core sample

- Visualizing CO_2 distribution by X-ray CT scanner

Evaluating the safety of injected CO_2 in a deep underground reservoir requires good understanding of how complex geological structures of the reservoir affect CO_2 behavior and how a storage mechanism of CO_2 works. A residual gas trapping is a well known mechanism in the fields of oil and gas exploitation and is essential to assess a long term stability of CO_2 in the reservoir.

RITE uses an X-ray CT scanner to visualize distribution of CO_2 displacing with brine water in a highly heterogeneous core sample to study the residual CO_2 trapping. Our method of visualizing the distribution of CO_2 while measuring the physical properties of rock, such as seismic wave or specific resistance, successfully clarified a correlation between CO_2 distribution and physical properties of rock. RITE now studies the application of our method to actual data obtained from physical loggings or seismic surveys at CO_2 injection site.

- Development of technology of monitoring stability of geological formation during CO_2 injection

An optical fiber in the optical fiber sensing technology is capable of constantly monitoring pressures and temperatures in a depth direction of the earth by installing it underground. In the field of CCS, the optical fiber is further expected to measure deformation of a reservoir or caprock formations caused by CO_2 injection.

RITE has undertaken basic studies using rock or cement samples in the laboratory to develop methods of evaluating stability of geological formation or methods of detecting CO_2 leakage in a very early stage. They successfully resulted in establishing the basic techniques to measure deformation of geological formations at a measurable level and to grasp the movement of

CO_2 based on a change in rock deformation by using the optical fiber. Furthermore, RITE designed specifications of an optical fiber suitable for installing in casing cement of a well and has made prototypes. In view of the experiment results in the laboratory, we started a field test, where the optical fiber was installed in a boring hole drilled to the sedimentary layer and monitoring work is underway to see the deformation of geological formations during CO_2 injection.

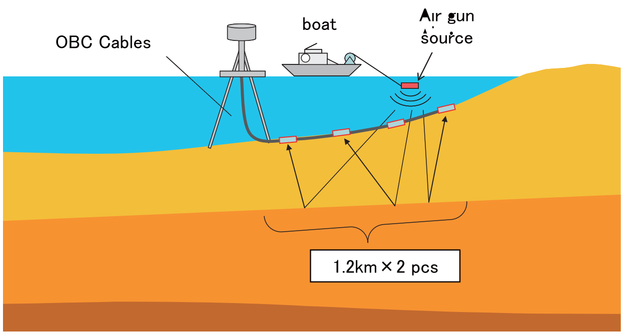


Fig. 6 Permanent OBC System test off the coast of Hiratsuka

- Permanent OBC long-term field observation

In order to facilitate commercialization of the geological storage of CO_2, monitoring the behavior of injected CO_2 is one of the most important issues to study. A well known technique is "repeat 3D seismic" which has been developed in exploiting natural resources such as oil and natural gas. To apply the "repeat 3D seismic" in offshore geological storage of CO_2, we found a permanent ocean bottom cable (OBC) system is very effective. The OBC system is accurate, cost competitive and capable of collecting data all the time by installing the system on the sea bottom in the area of the storage site.

This year again, RITE conducted a seawater test of the system in the coast off Hiratsuka in Kanagawa prefecture. The seismic surveys were conducted with airguns and the stability and endurance of the system were examined for long use. The challenges facing commercial use were identified.

- Impacts on geological formations during CO_2 injection

Probabilities of occurrence of microseismicity induced by geological storage of CO_2 have been at issue. According to observation in energy development sites overseas, CO_2 injection would induce microseismicity only at a very low level. However, from the viewpoint of public acceptance and safety assessment of geological storage of CO_2, monitoring microseismicity is indispensable.

Under collaboration with the Lawrence Berkeley National Laboratory and the Bureau of Economic Geology, the University of Texas at Austin, RITE installed six geophones at the CO_2 injection site of the United States Regional Carbon Sequestration Partnership in Cranfield oil field (Mississippi, USA). Observation started in December 2011. The data has been analyzed on an event of microseismicity and correlations between each event and CO_2 injection are evaluated.

(3) Analyzing CO_2 migration from reservoir

When implementing a CCS project, we need to carefully conduct various preliminary surveys of potential storage sites before determining a reservoir that can stably contain CO_2 for a long term. However, public concern remains very high about CO_2 leakage from the reservoir. In order to advance public understanding of CCS and to promote wider deployment of the technology, it is important to evaluate the impact of possible CO_2 leakage on the environment and to demonstrate that CCS is a safe and stable technology. RITE carries out numerical simulation of CO_2 escaping from a reservoir as part of a project of developing methodologies of safety assessment of CCS.

When CO_2 is expelled from an offshore reservoir to seabed, it is expected to migrate through geological formations via a sediment layer to seabed. and spread into seawater. Thus simulating CO_2 leakage requires three numerical models: one for the geological formations, one for the unconsolidated sediment layer, and one for the seawater. The model for geological formations simulates CO_2 changing a phase from supercritical, gas, liquid to dissolved state by taking possible CO_2 pathways such as a fault into account. The model for sedimentary layer simulates CO_2 moving upwards while spreading within the layer and receiving influences of chemical reactions, biological activities and others. The seawater model simulates how CO_2 escaping from the seabed diffuses in seawater advection and what distribution of CO_2 concentration is generated. RITE constructs a database of the environmental impact of the changes of CO_2 levels in seawater on marine organisms.

To learn more about the impacts of CO_2 leakage on the marine environment, RITE participates in QICS (Quantifying and Monitoring Potential Ecosystem Impacts of Geological Carbon Storage) project in the UK and joined in the field experiment where CO_2 was deliberately released from the seafloor. Time-lapse underwater cameras were installed to observe changes in behavior of large-size benthic marine organisms. Furthermore, various measurements were conducted to know the impact on aerobic-ammonia-oxidation activities of benthic microorganisms.

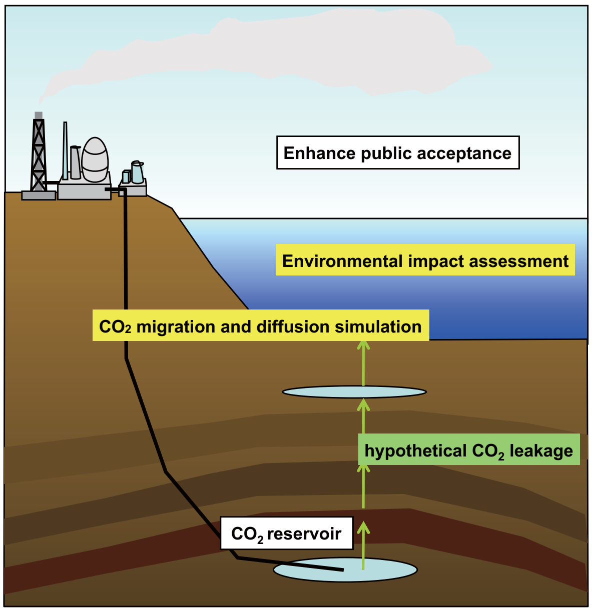


Fig. 7 Concept of CO_2 migration and diffusion simulation

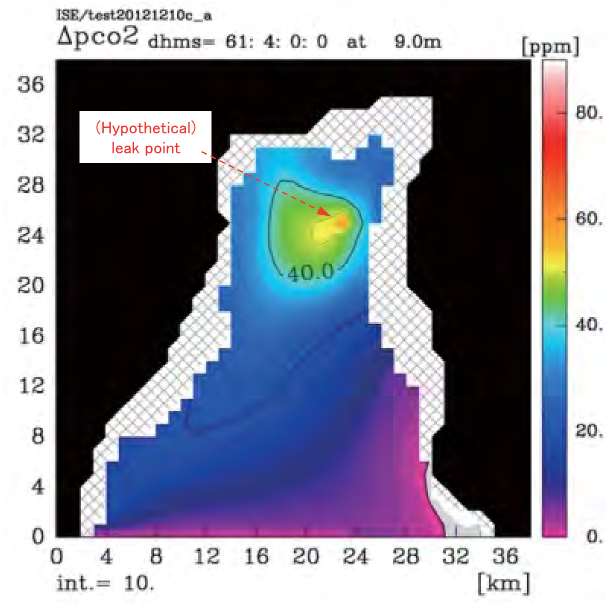


Fig. 8 CO_2 diffusion simulation in seawater
(showing increase in CO_2 concentration after leakage)

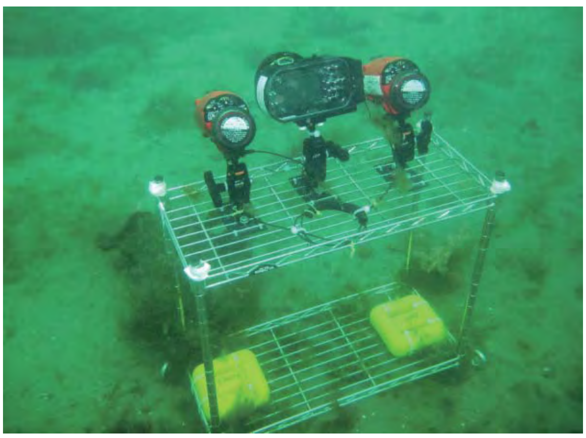


Fig. 9 Time-lapse underwater camera

Fig. 10 Measurement of aerobic ammonia oxidation activity of benthic micro-organisms

(4) Preparing CCS Best Practice Manuals

It has been 16 years since the world's first CO_2 storage started at Sleipner, Norway, in 1996. Since then, the world has seen a lot of CO_2 geological storage projects start. Lessons learned were started to gather around 2008 in the form of best practice manuals (BPM), technical manuals or guidelines for more general use. In Europe the European Commission issued CCS Directive. It stipulates the rules of implementation of CCS to Member States and as a reference, a set of four Guidance Documents were released to assist each country to transpose the Directive into its own legal framework. Likewise, experience and knowledge associated with CCS demonstrations have been organized to prepare for a full-fledged onshore or offshore geological storage of CO_2.

In Japan, the Ministry of the Environment (MoE) enacted the "Act on Prevention of Marine Pollution and Maritime Disaster and related legislation". The Ministry of Economy, Trade and Industry (METI) , in view of a large-scale demonstration of CCS, released "For safe operation of a CCS demonstration project". This document describes a standard desired to be followed from the safety and environmental viewpoints in implementing the large scale CCS demonstration. Regarding the research and development of CCS, Japan has gained great knowledge through Nagaoka CO_2 injection demonstration and the like.

For full-fledged deployment of CCS in future, it is important to document the expertise of demonstration projects in and out of Japan in an effective manner. Thus, RITE works on drafting a series of best practice manuals of CCS as technical references for developers of CCS demonstration projects. The best practice manuals are expected to include the outcome of research and development in Japan and actual deployment cases overseas

Table 1 Guidelines and guidance on CCS

	Organization	Published guidelines and guidance
United States	EPA	Guidelines for CO_2 storage wells (12 documents)
	DOE/NETL	BPM for CO_2 Storage (6 documents)
Canada	CSA	CCS international standardization
Europe	EC	Guidance for CCS directives (4 documents)
Japan	Ministry of the Environment	Guidelines for applying offshore CO_2 storage
	METI	Document for Large-scale demonstration
International organizations	CSLF	Comparison of BPM
	WRI	Comparison of regulatory framework of EU,IEA, and EPA
	IEAGHG	BPM on Weyburn project
Private organization	DNV	Recommendation on certifying CCS project

Table 2 Objectives and image of CCS best practice manuals

	Contents
Objectives	1. - Demonstrate technically-safe and economically-feasible implementation of CCS -Cost-effectiveness, safety, legal compliances, consensus building - Address barriers of further deployment of CCS 2. Assist stakeholders to promote, deploy and spread Japanese technologies overseas - Entrance into overseas market and participation in joint research - International standardization and partnership with international organizations
Images of best practice manuals	Target users: CCS operator How to be used: Guidelines for deploying CCS technology Mode: Organize technologies developed by Japan and overseas practices Cases: Nagaoka demonstration, overseas cases, other practices in Japan

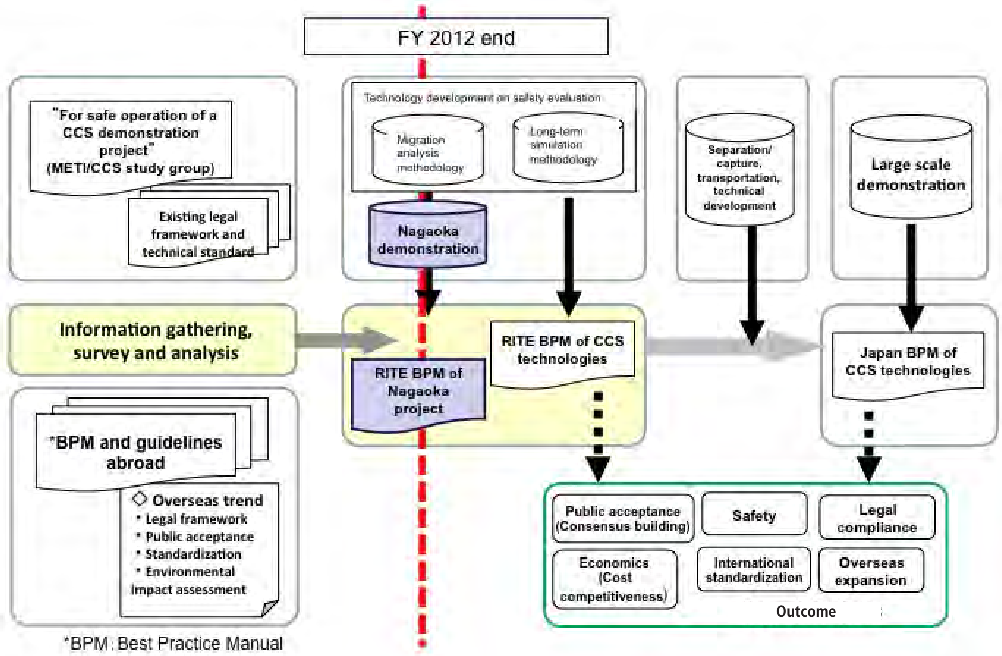


Fig. 11 Scheme of drafting best practice manuals of CCS

Fig. 11 shows a development scheme to prepare RITE's best practice manuals of CCS. It mainly comprises 1) collecting, organizing and analyzing information in and out of Japan; 2) organizing Nagaoka demonstration case as a domestic project; 3) preparing RITE's best practice manuals; and 4) preparing the best practice manuals for Japan. RITE has already collected and organized major information on CCS in the year 2011. Thus, in the year 2012, we updated the information especially on CCS projects overseas, drafting the best practice manuals focusing on Nagaoka demonstration project, and organizing information for the best practice manuals of CCS.

3. Japan-China CCS-EOR project

CCS is a technology to capture CO_2 emissions from fossil fuels combustion and store it underground. It is considered as an essential option to mitigate global warming. The concept of CCS-EOR combining CCS with enhanced oil recovery or EOR makes profits through operation, thus its earlier deployment is considered very likely. In the United States, CCS-EOR has been already commercially implemented using natural CO_2 in the order of 60 million tons of CO_2 per year. CCS-EOR is expected to further advance in foreseeable future to utilizing CO_2 emissions from coal-fired power stations which emit relatively large volume of CO_2 for each basic unit of generation (1kWh).

China is the top CO_2 emitter in the world and still increasing emissions every year due to the rapid economic growth. Japan ranks the fifth CO_2 emitter in the world. Thus bilateral collaboration in the joint research on CCS-EOR has a great significance in preventing global warming.

RITE co-hosted CCS-EOR workshops (in 2009 and 2010) and Saving Energy, Environmental Protection, GHG reduction Workshop (2011) with China National Petroleum Corporation (CNPC). The tie has been strengthened through mutual visits to CCS/CCS-EOR related facilities/sites in both countries. RITE and CNPC signed "the Memorandum of Understanding on Japan-China collaboration themes" in Beijing on September 28, 2011 and selected the following three categories as the theme of Japan-China Collaboration: (1) Research on entire CCS-EOR (CCUS) system, (2) Research on reservoir characterization techniques, and (3) Research on microbial restoration of methane deposits with subsurface CO_2 sequestration into depleted oil fields.
In the year 2012, RITE measured petro-physical properties using elastic wave velocity and X-ray CT images of the rock samples from China and studied the applicability of reservoir characterization techniques developed by RITE to oil fields in China.

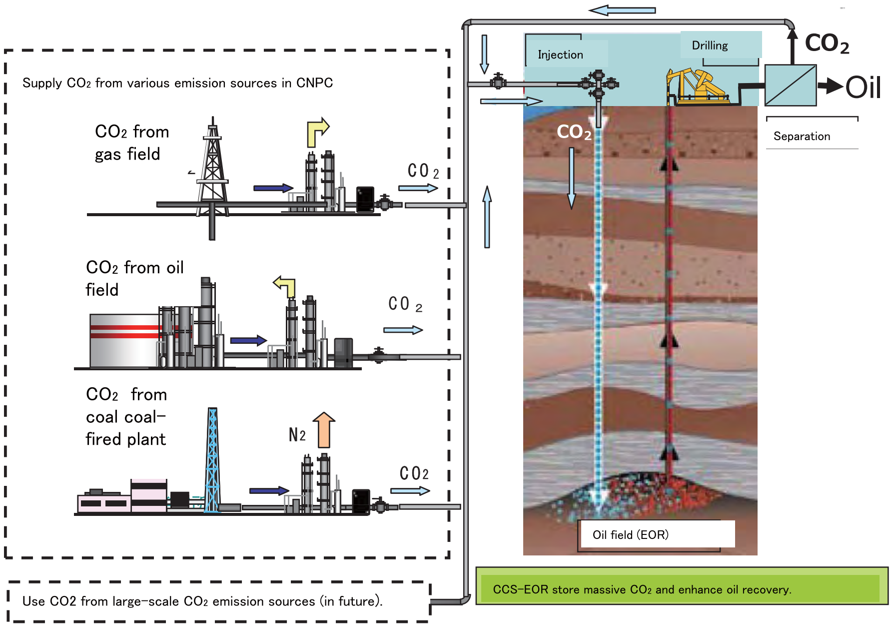


Fig. 12 Concept of CCS-EOR

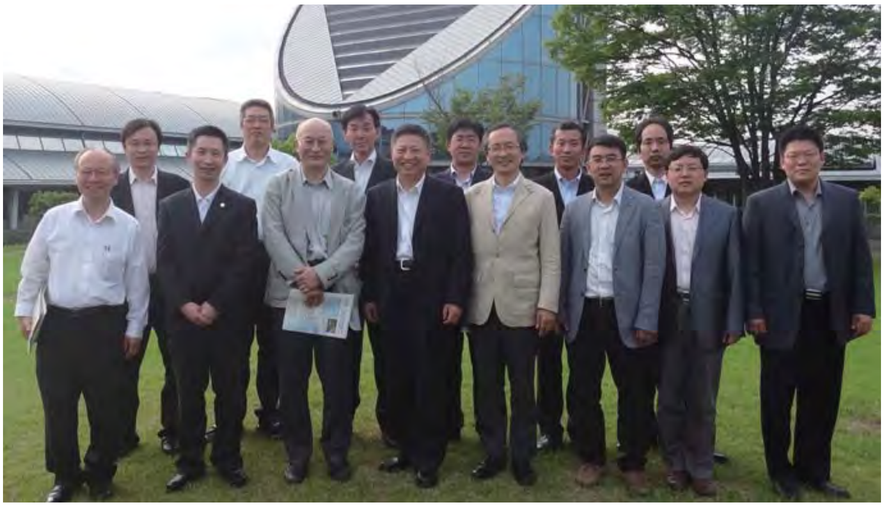


Fig. 13 CNPC visits to RITE (June, 2012)

4. Work with International Bodies and Survey of Global CCS Activities

RITE works closely with international bodies that make efforts to facilitate CCS deployment and also monitors CCS activities in the world. There are a number of challenges in CCS implementation, including economics, policies, regulations and public acceptance. It is therefore essential to collaborate and share knowledge with overseas through these international organizations.

The following are an outline and updates of the international bodies with which RITE has been working together – the Carbon Sequestration Leadership Forum (CSLF), the IEA Greenhouse Gas R&D Programme (IEAGHG) and the London Convention – and recent topics in the global CCS community.

- CSLF and its Recent Activities

The Carbon Sequestration Leadership Forum (CSLF) is an international initiative to promote research, demonstration and commercialization of CO_2 capture and the geological storage and industrial utilization of the captured CO_2 (CCUS) through international co-operation. Its activities include organizing a ministerial meeting every two years. The organization was established in 2003. The establishment was led by the USA and the US Department of Energy takes the role of Secretariat. CSLF is currently composed of 25 members, including developed countries such as Japan, emerging economies, oil producers and the European Commission. Its activities are conducted by two groups: one is the policy group that consists of policy-makers; and the other is the technical group that has representatives from private companies and research institutes. RITE has been a member of the technical group since 2009.

In 2011, CSLF agreed to incorporate the utilization of captured CO_2, in particular, for enhanced oil recovery (EOR) in its scope in addition to geological storage. The decision was made with a thought that since the number of the initiation of CCS projects is much smaller than expected, the promotion of CO_2 use projects that are more commercially feasible can reduce capture costs and will lead to future acceleration of CCS deployment consequently. EOR will be a prime theme in the next ministerial meeting to be held in Texas in the USA in autumn 2013. As part of preparation for the meeting, CSLF is updating a CCS technology roadmap in a way of including short-term challenges to be addressed.

- IEAGHG and its Recent Activities

The IEA Greenhouse Gas R&D Programme (IEAGHG) was established in 1991 as an implement agreement under the International Energy Agency (IEA). IEAGHG is aimed at evaluating greenhouse gas reduction technologies, promoting the deployment of these technologies, disseminating outcomes from evaluation studies and promoting international collaboration. Among the low-carbon technologies, the focus has been placed on CCS. IEAGHG has a variety of members, including 21 member countries, the European Commission and the Organization of Petroleum Exporting Countries (OPEC) as well as 24 multinational industrial sponsors. RITE has represented Japan in its Executive Committee since 2009 to contribute to activities planning and reviewing.

Major activities in IEAGHG include networking CCS experts and hosting workshops for the networks as well as organizing international conferences. With a progress of actual CCS projects, a new expert network was launched to look into environmental research in 2012. Most of the workshops have been organized for individual networks such as modeling, monitoring and risks for carbon storage but more efforts have come to be made on a joint meeting for multiple networks. Such a joint meeting was held for the four storage-related networks in 2012 and two joint workshops will be held in 2013 – one is for modeling and risk management; and the other is for monitoring and environment research. As an IEAGHG-hosted international conference, RITE co-hosted the 11th International Conference on Greenhouse Gas Control Technologies (GHGT-11) in November 2012 and made a success of the event. In 2013, IEAGHG plans two international conferences on capture technologies.

- London Convention and its Recent Activities

The London Convention supports CO_2 storage under the seabed. The international treaty is aimed at preventing marine pollution by dumping of wastes and other matters mainly from ships and was amended to allow offshore storage in 2007. CCS related topics such as transboundary CCS activities have still been under discussion. RITE is a member of the Japanese delegation in contracting parties meetings and also scientific meetings that are to share information underpinned by science.

Transboundary activities consist of two issues: CO_2 export for injection and migration of injected CO_2. The London Convention was amended to incorporate these activities in 2009 but the amendment hasn't come into force yet due to shortage of the number of parties who has ratified. Since then, efforts to set up two guidelines – one for export and the other for migration – and the later one was completed and approved in 2012.

- CCS Activities Update

The CCS roadmap released by IEA in 2009 points out that it is required to deploy 100 large-scale CCS projects by 2020 to achieve a scenario to halve CO_2 emissions from a current level by 2050. According to the Global CCS Institute (GCCSI), there are, however, only eight projects of this kind under operation currently and taking account of those which will come into operation within a few years, the number is still 16. Among those, 12 projects are operated or planned in North America so that we can say the region takes the lead in large-scale projects. 14 use industrial plants which require lower additional costs for CO_2 capture as CO_2 emission sources and 10 employ a business model to sell captured CO_2 for enhanced oil recovery (EOR) operation. These imply that a key issue in successful project implementation is to secure project economics. CCS projects for coal-fired power plants are limited to two, namely, Boundary Dam and Kemper, again, in North America. The both projects are making good progress toward commissioning in 2014 and their completion will draw great attention from the viewpoint of demonstration of capture technology forCO_2 from commercial-scale power plants.

Europe has been enthusiastic in tackling global warming and has placed the focus on the promotion of large-scale CCS projects for coal-fired power stations, which has the high potential to contribute to intensive reduction in CO_2 emissions when equipped with CCS. However, their programmes have not shown good progress. The European Commission initiated two schemes for financial support to capital investment in 2008 and 2009. However, due to the recent economic turmoil and much lower prices of carbon credits, which were expected to be incentives for CCS, there have been neither deployed projects and nor final investment-decided projects since two Norwegian projects, Sleipner and Snøhvit, were initiated in 1996 and 2008. Under the circumstance, Norway established a test centre where capture technologies can be verified at a relatively large scale in 2012. The facility has raised expectation for its prospective contribution to reduction in capture costs. A new scheme that the UK Government has decided to introduce has also drawn strong attention as an economic incentive alternative to carbon prices. The policy is a feed-in-tariff system for electricity generated by low-carbon technologies, including not only renewable and nuclear but also CCS.

In Australia, a private consortium is developing an offshore gas field as a CCS project. The Gorgon Project is to capture and store over three million tonnes of CO_2 generated in processing of natural gas produced there. Its construction has kept on its schedule toward commissioning in 2015. Australia has a setting suitable for CCS promotion: a carbon tax scheme was implemented in July 2012 and the Federal and State Governments are positive to investment in CCS projects. It is, however, likely to take many years to see a next project after Gorgon. There are two large-scale projects, South West Hub and Carbon Net, in which multiple emitters will participate. Both projects are in a phase of feasibility study and the commitment of the Governments on funding is limited to the studies.

Projects in Asia have recently drawn more attention. The Japanese Government is preparing for a full-chain CCS demonstration in Tomakomai, Hokkaido. In China, two CCS projects with a capture rate of 100,000-tonne level are under operation and another two with 100,000 to 300,000-tonne level are under construction.

Topics

11th International Conference on Greenhouse Gas Control Technologies(GHGT-11) held in November 2012

GHGT-11 was held from 18th to 22nd November 2012 at the Kyoto International Conference Center and hotels in Kyoto city. The GHGT conference series has established itself as the principal international conference on greenhouse gas mitigation technologies especially on CCS, and are held every two years rotating between North America, Europe and Asia. GHGT-11 was its first visit to Japan in the past ten years, again organized by RITE and IEAGHG.

The previous event GHGT-10, which was held in Netherlands, drew more than 80% of its attendance from Europe and North America. GHGT-11 attracted 1293 participants from 48 countries, featured as many as 526 participants from Asia, including 346 from Japan, 61 from China, and 60 from Korea. GHGT-11 was funded by 19 donators and sponsors, exhibition booths arranged by 25 entities, as well as supported by METI, Kyoto prefecture, Kyoto city, Kyoto Convention Bureau, and Kyoto Chamber of Commerce and Industry, for all of which we thank you very much.

The conference was composed of the three sections, that is, Plenary sessions (keynote talks and the final panel discussion etc.), Technical sessions (oral and poster presentation)" and Social Programmes.

The official GHGT-11 Conference Summary in English language, which includes key messages from both the plenary and technical sessions, has been made available at www.ghgt.info. Papers presented at the technical sessions are to be included in the conference online proceedings and published by Elsevier around March 2013, for which the link will be distributed to all the participants by e-mails.

During the breaks between sessions, many enjoyed walking in the garden, viewing reddening autumn leaves, and learning how to create Japanese origami figures.

Social Programme was mainly composed of two events, the first one being the Welcome reception held on Sunday 18th November at Hotel Granvia Kyoto, where a traditional Japanese ceremony called "Kagami-biraki (sake barrel opening ceremony) " was performed to celebrate the success of the conference. The second and the concluding one was the Conference Dinner organized on Wednesday 21th November held at the Westin Miyako Kyoto, where Kyo-mai (elegant dancing by Maiko and Geiko) entertained the delegates much. At the same occasion the Greenman award was given to Dr. Sally Benson, professor at Stanford University and GHGT-11 Technical Programme Committee member by Dr. Kelly Thambimuthu, the chair of the Executing Committee of the IEAGHG (at right of the same photo) to reward her long-term great contribution to CCS R&D activities and also to the GHGT conference series.

Plenary and Technical Sessions in GHGT-11

GHGT-11 had plenary sessions consisting of opening, three keynote, six presentations, final panel discussions and closing and technical sessions where around 300 oral and 600 poster presentations were made.
In this conference we had vigorous discussions on mainly Carbon dioxide Capture and Storage (CCS) under a key theme, "CCS: Ready to forward" during 5 days. In this article, outlines of these plenary and technical sessions are introduced.

1. Attending countries

Attendees were 1,293 from 48 countries. The number is; Japan 346, the United States 172, Norway 118, the United Kingdom 97, Australia 72, China 61, South Korea 60, and Canada 57. Largest party was the host country, Japan, and was followed by the United States, Norway, and the United Kingdom. Many participants joined from Asian countries like China and South Korea because this conference was held in Asia.

2. Plenary sessions

The key theme of the conference was "CCS：Ready to Move Forward", which was followed with the theme, "From research to reality" in GHGT-10 two years ago. This theme implied that "CCS is already ready to realize. Why don't we move forward! " However, many challenging issues including today's slumping economy are standing before us. The conference repeatedly strengthened that leaderships of government in each country were necessary to get over these walls.

The following three keynote speech was given on the first day:

- Mr. Atsuoka Nishida, Chairman of the Board, Toshiba: "Aiming for True Harmony between Energy and Environment"
- Mr. Brad page, CEO, Global CCS Institute: "International Progress on CCS: Current Status and Recommendations for the Future"
- Dr. Jay Braitiszh, Senior Advisor, Office of Fossil Energy USDOE: "CCS Projects are Becoming Reality –the USDOE Demonstration Program"

President Nishida introduced green activities of Toshiba group in process, product technology and market fields. The next presenter, Mr. Brad Page introduced Global CCS Institute's recent report, "Global Status of CCS, 2012" and talked on current status of CCS and recommendations for the future. Finally, Dr. Jay Braitiszh of MIT introduced CCS demonstration projects supported by USDOE.

From the second day two plenary presentations were given in every morning. Presenters and titles are as follows:

- Mr. Juho Lipponen, Head of CCS Unit, IEA: "A Global Vision for CCS –Revising the IEA CCS Roadmap"
- Dr. Frank O'Sullivan, Executive Director, Energy and Sustainable Challenge Programme, MIT: "The Global Gas Supply –Scale, Cost and implications for CCS"
- Dr. Kozo Sato, Director, Frontier Research Center for Energy and Resources, The University of Tokyo: "GHGT101: Carbon Storage in Japan"
- Mr. Henk Reimink, Executive Director, Energy Sustainability Challenge Programme, Word Steel Association: "Deployment of CO2 Capture Technology in Energy Intensive Industry –Challenges Ahead: A Case Study for the Steel Industry"
- Mr. Chris Hendriks, Managing Consultant, Ecofys: "Overview and Recent Developments on CO_2 Transport Infrastructure"
- Dr. Kieigo Akimoto, Chief Researcher and Group Leader of the System Analysis Group, RITE: "Beyond Kyoto –More effective Framework for Climate Change"

In Final Panel Discussion, Dr. Kenji Yamaji chaired and four panelists, Juho Lipponen (IEA), James A. Edmonds (PNNL), Takeo Kikkawa (Hitotsubashi University), and Yoshiharu Tachibana (CRIEPI) joined to discuss under the theme, "As a Countermeasure to Global Warming –Best Mix on Energy Portfolio and Enhancing International Cooperation". The discussion was concluded by the following messages: CCS is necessary to mitigate Global Warming. It is important that we are staking experiences through implementing many demonstration projects and sharing knowledge together. It is also necessary to well communicate with stakeholders and appeal strongly that CCS is a very attractive mitigation technology.

3. Technical sessions

Technical sessions have 77 oral sessions. Among them, capture sessions were 21 and storage sessions including other storage options were 23, both of these two constituting more than half of all. The number of policy sessions (policy, legal issues, and public perception) was only five, giving an impression that it was a little small.

In five system integration sessions, technical assessment on cost and risk, operational flexibility, system integration (power system, infrastructures, and others) were presented. For demonstration, five sessions were allocated: storage, USRCSP, policy related issues, capture and transport, and post combustion. In this storage session, a large scale demonstration at Tomakomai, Hokkaido was introduced.

Technical sessions	Number
Capture	21
Storage (inc. other options)	23
Transport	3
Integrated Systems	5
Demonstration	5
Industrial Sources	2
Policy (policy, legal issues, public perception)	5
Commercial issues	1
Education	1
Utilization of CO_2	4
Negative CO_2 Emissions	1
Panel Discussion	6
Total	77

Capture sessions

Capture technologies are mainly classified into three categories: Post-, Pre-, and Oxyfuel-Combusition. In this conference presentations on Post-Combustion were given in 12 sessions, which were more than half of all capture sessions. As Pre-Combustion had two and Oxyfuel had three sessions, the number of sessions on Post-Combustion was remarkably large and this gave us information that Post-Combustion was widely examined for an earliest available technology. Presentations on Post-Combustion were covered in wider fields including basic study like new innovative solvents development, engineering topics like selection of packing materials for absorber or corrosive issues, process simulations, and demonstration projects. Especially remarkable topics were that three sessions were allocated for environmental impacts of Post-Combustion process. Degradations of amines which are main components of absorbing solvents, its behaviors in environments, and impacts to environment were presented by Norway and Australia. Besides, Norway also showed emission standard of amines in demonstration plants.

Recent Progresses in the following demonstration projects were introduced: Technology Center Mongstad (Norway), Munmorah Coal Power (Australia), Wilhelmshaven Power (Germany), Ferrybridge (UK) for Post-Combustion, Puertollano IGCC (Spain) for Pre-Combustion, and Callide Oxyfuel Project (Australia, Japan), Vattenfall Oxyfuel (Germany), Compostilla Power (Spain), Eni's FCC Oxyfuel (Italy) for Oxyfuel-Combustion.

Advanced technologies including membranes, sorbent system, and chemical looping were presented. Industrial sectors (Iron & Steel, cement, etc.) are also important area for CO_2 capture. Two sessions named "Industrial Sources" were assigned, giving information on progresses in these industrial fields. COURSE50 project was also introduced from Japan in these sessions.

Storage sessions

Storage sessions covered a wide variety of themes. There were presentations on storage capacity estimation in the world and specific areas (offshore the Netherlands and south Queensland, Australia), and site characterization and selection procedures in offshore sites such as Norway, Denmark, and Tomakomai, Japan. In modeling and numeric simulations, uncertainties in reservoir model were discussed. For CO_2 infectivity, Snøhvit case was introduced and pressure control procedures with additional water production wells were discussed. In monitoring sessions, geochemical monitoring for CO_2 leakage, detailed results in monitoring pilot projects, In Salah (micro seismic), Otway, Nagaoka, and Weyburn (CO_2 leakage) were presented. Regarding safety issues, QUICS project which investigated impacts of released CO_2 to the marine environment was introduced. Besides, there were other three sessions on "Risk Assessment and Management" and "Contingency planning & remediation".

In the field of CO_2 use (CCUS), there also presented enhanced hydrocarbon recovery (EOR、EGR、ECBM) and combination of CCS with geothermal.

Policy Sessions

Policy sessions were two in which the following topics were discussed: CDM of CCS (formal acceptance in UNFCCC, modalities and procedures), carbon market and CCS, effectiveness of EUETS, and how to go CCS forward under today's slumping economy. In a legal issues session, current situations in transposition of CCS Directive into national laws in Europe were introduced. Investigations on public perception in the Netherlands, Spain, Poland, Scotland, China, and the US RCSP were also reported.

Molecular Microbiology and Biotechnology Group

Joint research with NREL towards cellulosic ethanol production

NREL (U.S. National Renewable Energy Laboratory) founded by DOE is the only national laboratory solely dedicated to advancing renewable energy and energy efficiency technologies. In the U.S., the industrial production of biofuels from non-food cellulosic biomass resources is slowing down due to technological problems caused by "fermentation inhibitors" (see text). In this joint research by RITE, NREL and a private company, we aim overcome these technological problems by sharing our respective research results and findings, namely pre-treatment and saccharification technologies developed by NREL and the high tolerance for the fermentation inhibitors inherent in the RITE Bioprocess. Green Earth Institute Co., Ltd., a venture company established by RITE, will join in the second part of this year to spearhead demonstration experiments for cellulosic ethanol production.

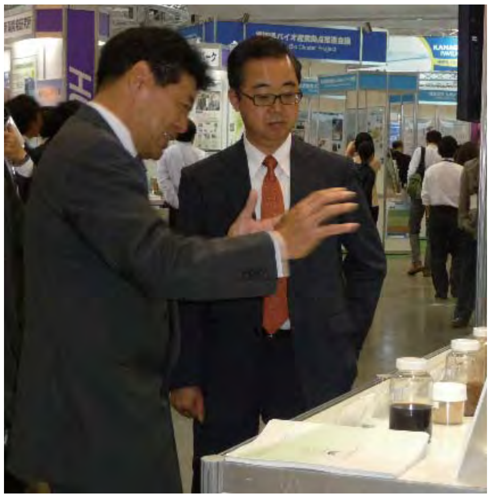
National Renewable Energy Laboratory (NREL)

Dr. Yukawa presenting the joint research results at the SIMB (Society for Industrial Microbiology and Biotechnology) Annual Meeting (Aug. 2012)

A rendering of Kazusa biorefinery facility which begins demonstration experiment for cellulosic ethanol production (Chiba prefecture)

Many visitors attended our seminar and exhibition booth at BioJapan2012 (World Business Forum)

BioJapan 2012 (World Business Forum) organized by the BioJapan Organizing Committee and ICS Convention Design, Inc. was held at Pacifico Yokohama from 10th to 12th October 2012. RITE hosted the forum as a sponsor organization since 2011. RITE Director, Dr. Hideaki Yukawa moderated the seminar on "Green Innovation Summit", this time in its fourth year, which many participants attended. RITE and GEI, jointly exhibited the "RITE-Bioprocess" and its strategy for industrialization along with posters and video presentations. Our corporate strategic alliance partners also joined the exhibition, with their panels displaying products which were produced using the RITE-Bioprocess. We thank all those who visited of our booth very much.



Mr. Ikuro Sugawara, center, Director-General, Manufacturing Industries Bureau of Minister of Economy, Trade and Industry, stopped by our booth.

RITE/GEI joint exhibition booth

Chemical Research Group

Symposium for Innovative CO_2 Membrane Separation Technology - Recent Trend of Membrane Separation Technology Contributing to the Prevention of Global Warming -

On September 28th 2012, Symposium for Innovative CO_2 Membrane Separation Technology "Recent trend of membrane separation technology contributing to the prevention of global warming" was held at Dai-ichi Hotel Tokyo, sponsored by Molecular Gate Membrane Module Technology Research Association, co-sponsored by Ministry of Economy, Trade and Industry (METI) (supported by Japan CCS Co., Ltd.(JCCS), Global CCS Institute(GCCSI), Japan Association for Chemical Innovation (JACI), The Membrane Society of Japan, and The Society of Chemical Engineers, Japan(SCEJ)). 147 related persons attended from companies, universities, research institutes and government agencies.

Molecular Gate Membrane Module Technology Research Association was established by Kuraray Co., Ltd., Nitto Denko Corporation, Nippon Steel & Sumikin Engineering Co., Ltd., and RITE in order to commercialize a molecular gate membrane module, which was pioneered by chemical research group of the RITE.

The purpose of this symposium was to report the recent research trend of CO_2 separation membrane technologies, which the Association have been developing, and the overview of its research and development in overseas, and then widely provide people interested in CO_2 separation with the latest information to help them understand R&D activities for CO_2 reduction required for both public and private sectors. The first symposium was held last year, and this time was the second symposium.

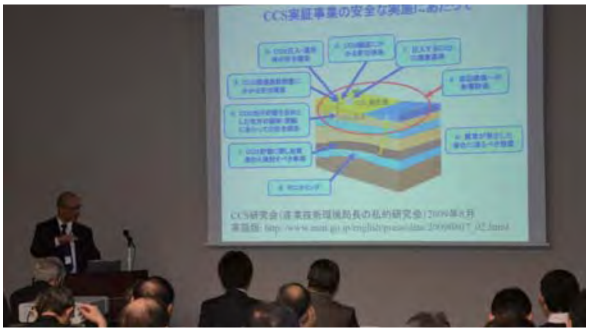
The speakers were Kenji Yamaji, Director-General of RITE, "Energy/Environmental Problems and CCS"; Toshinori Tsuru, Professor of Hiroshima University, "Current status and future perspective of membrane separation technology"; Tim Merkel, Director of Research and Development Group, Membrane Technology& Research, Inc. (MTR) U.S.A., "Development of Membrane Technology for CO_2 Capture from Power Systems at MTR"; Jaap Vente, Group Leader and Technology Transfer Manager, Energy research centre of the Netherlands (ECN), "Technological possibilities for the separation of hydrogen from carbon dioxide"; Shin-ichi Nakao, Professor of Kogakuin University, Group Leader of Chemical Research Group of RITE, "Next-Generation Membrane Module".

Membrane modules and posters, etc. were displayed by the Association.

A survey of visitors was conducted. As a result, a good response was received from 80% of respondents.

CO_2 Storage Research Group

CCS Technical Workshop - Approaches to Address Concerns over CO_2 Seepage from Reservoirs -



RITE, in association with the Ministry of Economy, Trade and Industry (METI), hosted a CCS Technical Workshop with a theme of "Approaches to Address Concerns over CO_2 Seepage from Reservoirs" in Belle Salle Yaesu in Tokyo on 24 January 2013. The efforts to secure safety of CCS projects have been increasingly recognized important as Japan launched a full-chain CCS demonstration in 2012 and more and more CCS projects are going to commence across the world. In the workshop, approximately 140 participants from governments, businesses, universities and research institutes discussed efforts of this kind and ways of securing safety of CCS through presentations from four overseas and Japanese experts, facilitated by Professor Toru Sato, the University of Tokyo.

The event was kicked off by Dr Jun Kita, RITE, who introduced case studies of regulations for safety and environment impacts assessment. Then, Professor Robert J. Finley from the Illinois State Geological Survey talked about approach to prevent CO_2 leakage, introducing site characterization and monitoring plan and results in the Decatur Project in USA. The third speaker, Dr Keisuke Uchimoto, RITE, presented a methodology to assess impacts if CO_2 leaks from a reservoir under the seabed. Finally, Dr Katherine Romanak from the University of Texas at Austin explained a field survey for an alleged seepage in the Weyburn Project in Canada. Key findings through discussions include an environmental impacts process contributes greatly to improvement in public acceptance; a monitoring program enables not only researchers but also regulators and the general public to confirm that there is no leakage and the site is safe; and setting up an incident response protocol prior to a CCS project is essential. Finally, Professor Sato concluded the workshop by emphasizing that not only in CCS but also in other large developments it was important to take both the viewpoint of economic development and that of environmental impacts and that countermeasures against environmental impacts should be recognized as an added value.

Systems Analysis Group

ALPS International Symposium 2012

The ALPS International Symposium 2012 was held at Nadao Hall in Tokyo on February 7th, 2012. This symposium was hosted by the Research Institute of Innovative Technology for the Earth (RITE) with support from the Ministry of Economy, Trade and Industry, Japan (METI). The symposium was titled "the Addressing Climate Change Harmonized with Sustainable Development."

We are honored to have a variety of leading experts including Prof. Nabojsa Nakicenovic and Prof. Arnulf Grübler from the International Institute Applied Systems Analysis, Prof. John P. Weyant from the Stanford University, Dr. Rob Dellink from the Organisation for Economic Co-operation and Development, Taikan Oki from the University of Tokyo, Taishi Sugiyama from the Central Research Institute of the Electric Power Industry, Shuzo Murakami from the Building Research Institute, Yoichi Kaya from the President of RITE, and Keigo Akimoto from RITE. We discussed sustainable development and climate change response measures, and their scenario analyses from long-term and multiple perspectives.

We had an attendance of 200 people from industries, ministries and universities. Their active discussion motivated us to dedicate further efforts to our research and development.

The ALPS International Symposium 2013 will be scheduled to take place in February 27th, 2013 in Tokyo (Hosted by RITE and co-hosted by METI). Distinguished experts from Japan and abroad will be invited as guest speakers to talk about the trend and outlook on sustainable climate change actions and the frameworks for them.

Planning, Survey, and Public Relations Group

Innovative Environmental Technology Symposium 2012 - Toward the realization of green growth -

The symposium entitled "Innovative Environmental Technology Symposium 2012 - Toward the realization of green growth -" was held on December 5, 2012 at Ito Hall (The University of Tokyo).

This 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・Japan Society for Bioscience, Biotechnology, and Agrochemistry・Japan Society of Energy and Resources・The Japan Institute of Energy.

The symposium started with RITE's Director-General, Dr. Yamaji's lecture entitled "Expectations and challenges for green growth" which focused on measures to realize green growth that contributes to industrial and economic development. Then, Mr. Tsuzuku, Director, Research Planning Group, reviewed the global trend and international standardization for CCS and future challenges for RITE.

The experts from each research group reported the outcome and outlook of their researches such as biorefinery technology, scenarios for mitigation global warming and CCS technology, within the context of current global trends and the specific situation in Japan.

With a total of 287 attendees from a variety of institutions and governmental agencies including participants from METI and various fields of industry and academia, this symposium illustrated the impact that the work performed at RITE can have in the marketplace and for the general public.

Environmental education for children in Keihanna

RITE is contributing to the awareness about global warming of the children who study in the Keihanna area. We welcomed junior high school students in Seika town and delivered a lecture on the topic of global warming and our research and development. Furthermore, we cooperated the "Science-Rally for Kids in the Yamashiro Area", an event organized by the Yamashiro regional education office.

Through such seminars, students of all ages learned about the causes of global warming and its effects on the environment, and on the other hand how the R&D conducted at RITE can be implemented to reduce the CO_2 concentration in our atmosphere. Notably, numerous students expressed their interest and amazement for newly discovered technologies such as CCS. It is our hope that by giving children a chance to learn about global warming, about our research, and about our innovations would help them increase their interest in science and in the global problems of our time.

Systems Analysis Group

◆2012 Original Paper

1. J. Oda, K. Akimoto, T. Tomoda, M. Nagashima, K. Wada, F. Sano. International comparison of energy efficiency in power, steel and cement industries, Energy Policy Vol.44 pp.118-129, May 2012
2. K. Akimoto, F. Sano, T. Homma, K. Wada, M. Nagashima, J. Oda. Comparison of marginal abatement cost curves for 2020 and 2030: longer perspectives for effective global GHG emission reductions, Sustainability Science Vol.7 No. 2 pp.157-168, July 2012
3. K. Akimoto, F. Sano, A. Hayashi, T. Homma, J. Oda, K. Wada, M. Nagashima, K. Tokushige, T. Tomoda. Consistent assessments of pathways toward sustainable development and climate stabilization, Natural Resources Forum Vol.36 No.4 pp.231-244, November 2012
4. T. Homma, K. Akimoto, T. Tomoda. Quantitative evaluation of time-series GHG emissions by sector and region using consumption-based accounting, Energy Policy Vol.51 pp.816-827, December 2012
5. K. Wada, K. Akimoto, F. Sano, J. Oda, T. Homma. Energy-efficiency opportunities in the residential sector and their feasibility, Energy Vol.48 Issue 1, pp.5-8, December 2012
6. K. Wada, F. Sano, K. Akimoto, T. Homma, K. Tokushige, M. Nagashima, T. Tomoda. Assessment of Copenhagen pledges with long-term implications, Energy Economics Vol.34 Supplement 3, S481-S486, December 2012
7. A. Hayashi, K. Akimoto, T. Tomoda, M. Kii. Global evaluation of the effects of agriculture and water management adaptation on the water-stresses population, Mitigation and Adaptation of Strategies for Global Change, in press
8. M. Kii, K. Akimoto, A. Hayashi. Risk and hunger under climate change, social disparity, and agroproductivity scenarios, Environmental Modeling and Assessment, in press
9. K. Akimoto, F. Sano, A. Hayashi, T. Homma, J. Oda, M. Nagashima, K. Tokushige, T. Tomoda. Trade-offs and synergies of sustainable development and climate stabilization in Asian regions, Edited Volume of Environment Policy in Asia (National University of Singapore (NUS)), in press

◆2012 Other Paper

1. Keigo Akimoto. Chapter 3: Mitigation target, Chapter 5, Cost of mitigation, Chapter 8: Potential for energy efficiency improvement and barriers. Climate Change Mitigation -A Balanced Approach to Climate Change- (Springer), January 2012
2. Keigo Akimoto. Primary consequences of nuclear power phase-out and condensation -the impacts on economy, household budgets and CO_2 emissions-. Energy Forum Vol.58 No.686, February 2012
3. Kenichi Wada. Implication of climate change policies from emissions trading, renewable energy and energy conservation policies in EU, Electrical Review, August 2012
4. Keigo Akimoto. Global warming and energy outlook : Greenhouse gas emissions and global warming impacts, Journal of the Japan Institute of Energy, pp.605-607, July 2012
5. Keigo Akimoto. Trying to understand 'Options for Energy and the Environment' correctly and deeply, Japan Chamber of Commerce and Industry News, September 2012
6. J. Oda, K. Akimoto. The iron and steel industry of Japan, maintaining superior energy efficiency in the world, International Environment and Economy Institute, http://ieei.or.jp/2012/10/expl121025/, October 2012
7. Keigo Akimoto. Power supply and policy challenges in the future from the perspective of global warming, Electrical Review, December 2012

◆2012 Oral Presentation (Domestic Conference)

1. Keigo Akimoto. Global warming and energy outlook : Greenhouse gas emissions and global warming impacts, Group seminar on "Energy Studies", the Japan Institute of Energy, Jan. 23, 2012
2. K. Akimoto, A. Hayashi, F. Sano, T. Homma, J. Oda, K. Wada, M. Nagashima, K. Tokushige, T. Tomoda. Analyses on scenarios for global response measure and sustainable development, 28th Conference on Energy, Economy and Environment, Jan. 31, 2012
3. K. Tokushige, K. Akimoto, J. Oda, T. Homma. Outlook of possibility for meeting the Kyoto Target of Japan, 28th Conference on Energy, Economy and Environment, Jan. 31, 2012
4. M. Nagashima, K. Akimoto, K. Wada, J. Oda, F. Sano. A study on implicit cost for investment in environmentally-friendly and energy-saving equipments, 28th Conference on Energy, Economy and Environment, Jan. 31, 2012
5. A. Hayashi, T. Homma, K. Akimoto, F. Sano. Analyses of land use agriculture under climate change, 28th Conference on Energy, Economy and Environment, Jan. 31, 2012
6. F. Sano, K. Akimoto, A. Hayashi, T. Homma. An evaluation of biomass energy and forestation in climate change mitigation with land-use constraints, 28th Conference on Energy, Economy and Environment, Jan. 31, 2012
7. K. Wada, K. Akimoto, F. Sano, M. Nagashima, J. Oda, K. Tokushige. Bounded rationality and risk perception in human behavior, 28th Conference on Energy, Economy and Environment, Jan. 31, 2012
8. T. Homma, A. Hayashi, F. Sano, K. Akimoto. Regional food security under CO_2 emission reduction policies, 28th Conference on Energy, Economy and Environment, Jan. 31, 2012
9. J. Oda, K. Akimoto, F. Sano, K. Wada. Energy security index by country under CO2 emission constraints, 28th Conference on Energy, Economy and Environment, Jan. 31, 2012
10. Keigo Akimoto. The future perspective of Japan's energy system considering global warming response measures, The 77th Annual Meeting, the Society of Chemical Engineers, Japan, Mar. 16, 2012
11. K. Akimoto, F. Sano, T. Homma, J. Oda. Analyses on Japanese mid- and long-term power supplies and global warming mitigation measures, 31st Annual Meeting, Japan Society of Energy and Resources, Jun. 5, 2012
12. F. Sano, K. Akimoto, K. Wada. Impacts of model representation of climate change mitigation technology options on the evaluation of CO_2 emission reduction, 31st Annual Meeting, Japan Society of Energy and Resources, Jun. 5, 2012
13. J. Oda, K. Akimoto, K. Wada, M. Nagashima, F. Sano. Study of the competitiveness of small-and-medium-sized steel plants in China, 31st Annual Meeting, Japan Society of Energy and Resources, Jun. 6, 2012
14. K. Akimoto, F. Sano, A. Hayashi, T. Homma, J. Oda, K. Wada, M. Nagashima, K. Tokushige, T. Tomoda. Analyses on scenarios for global response measures harmonizing sustainable development, 17th Annual Meeting, Society for Environmental Economics and Policy Studies, Sep. 16, 2012
15. A. Hayashi, K. Akimoto, F. Sano. A scenario analysis for potential of global energy-crop production, 2012 Annual Meeting, Society of Environmental Science, Japan, Sep. 14, 2012
16. Keigo Akimoto. Policy analysis and evaluation of CO_2 reduction and energy strategy in Japan, P&D Seminar, The Society of Chemical Engineers, Dec. 14, 2012

◆2012 Oral Presentation (International Conference)

1. Kenichi Wada. Co-benefits of energy efficiency in the context of climate change mitigation, IGES International Workshop on a Co-Benefits Approach, Feb. 13, 2012

2. F. Sano, K. Akimoto, T. Homma, J. Oda, K. Wada. Analysis of Asian long-term climate change mitigation in power generation sector, 3rd IAEE Asian Conference, Kyoto, Japan, Feb. 20, 2012

3. J. Oda, K. Akimoto, F. Sano, M. Nagashima, K. Wada, T. Tomoda. Assessment of Asian energy security index in the context of global CO_2 mitigation, 3rd IAEE Asian Conference, Kyoto, Japan, Feb. 20, 2012

4. K. Wada, F. Sano. Solar and wind representation in DNE21+ model for EMF27 study, EMF 27, Stanford University, US, May 1, 2012

5. Keigo Akimoto. Trade-offs and synergies of sustainable development and climate stabilization in Asian regions, Policies for Environmentally Sustainable Development: Asia's Perspective an International Workshop, Singapore, May 24, 2012

6. K. Wada, F. Sano. DNE21+'s study results and energy policy debate in Japan, AMPERE Project Meeting in Venice, Italy, May 23, 2012

7. T. Homma. Analysis of economic impacts including poverty under global CO_2 emissionreduction targets, GTAP Conference 2012, Centre International de Conférences Genèva, Switzerland, June 29, 2012

8. J. Oda, K. Akimoto, F. Sano, T. Homma, A. Hayashi, M. Nagashima, K. Wada, T. Tomoda. Comprehensive evaluation of sustainable development and climate stabilization: ALPS Project, IIASA 40th Anniversary Conference, Austria, October 24, 2012

9. A. Hayashi, K. Akimoto, F. Sano, T. Homma, J. Oda, K. Wada, M. Nagashima, T. Tomoda, K. Tokushige. Global evaluation of land area required for food production and water stress, IIASA 40th Anniversary Conference, Austria, October 24, 2012

10. K. Akimoto, K. Wada, F. Sano, A. Hayashi, T. Homma, J. Oda, M. Nagashima, K. Tokushige, T. Tomoda. Consistent analysis of different scenarios of climate stabilization and sustainable development, IAMC (Integrated Assessment Modeling Consortium) 2012 Annual Meeting, Netherlands, November 12, 2012

11. K. Wada, F. Sano. Decomposition analysis of emission reduction scenarios with DNE21+ model, AMPERE Project Meeting in Utrecht, Netherlands, November 14, 2012

12. J. Oda, K. Akimoto, F. Sano, M. Nagashima, K. Wada, T. Tomoda. Analysis of CCS impact on Asian energy security, GHGT-11, Nov. 20, 2012, Kyoto, Japan

13. F. Sano, K. Akimoto, K. Wada, M. Nagashima. Analysis of CCS diffusion barriers for CO_2 emission reduction considering technology diffusion barriers in the real world, GHGT-11, Nov. 20, 2012, Kyoto, Japan

14. M. Nagashima, K. Akimoto, F. Sano, A. Hayashi, T. Homma, J. Oda, K. Wada, K. Tokushige, T. Tomoda. Comprehensive analysis of measures towards sustainable development and climate stabilization:ALPS Scenarios, GHGT-11, Nov. 20, 2012, Kyoto, Japan

15. Keigo Akimoto. Beyond Kyoto - More effective framework for climate change, GHGT-11, Nov. 22, 2012, Kyoto, Japan

◆2012 Non-Journal Publication

1. Keigo Akimoto. Japan's strategy for the realization of true green growth, 5th High-tech Top Seminar, Keihanna, Feb.15, 2012

2. Keigo Akimoto. Impact of energy issues on the Japanese economy, General meeting, Nagano Chamber of Commerce and Industry, Mar. 26, 2012

3. K. Akimoto, T. Homma, F. Sano. Economic impact analysis in 2030 using RITE energy and economic models, Fundamental Issues Subcommittee, Advisory Committee on Energy and Natural Resources, METI, May 9, 2012

4. Keigo Akimoto. The cost of nuclear power and economic research, Study Session of Democrats parliamentary group, Tokyo Metropolitan Assembly, May 14, 2012

5. K. Akimoto, T. Homma, F. Sano. Economic impact analysis in 2030 using RITE energy and economic models (2), Fundamental Issues Subcommittee, Advisory Committee on Energy and Natural Resources, METI, May 21, 2012

6. K. Akimoto, T. Homma, F. Sano. Economic and CO_2 impact analysis in 2030 using RITE energy and economic models, Joint Meeting of Subcommittee on the Post-2013 Countermeasures and Global Environment Committee, Central Environment Council, May 28, 2012

7. Keigo Akimoto. Toward the establishment of a new climate change framework, Exploratory Committee on a New Climate change Framework, IGES, Jul. 2, 2012

8. Keigo Akimoto. Energy and environmental strategy impact on economy and industry, Academic Forum sponsored by Science Council of Japan, "Now, a strong step to reconstruction -considering the post-quake energy and industrial reconstruction-", Jul. 3, 2012

9. Keigo Akimoto. New strategy for energy and CO_2 emission reduction, "Energy & Environment" Technical Committee, Japan Techno-Economics Society, Jul. 11, 2012

10. Keigo Akimoto. Energy and environment strategy in the future, RITE Companionship Board, Jul. 13, 2012

11. Keigo Akimoto. Analysis of the energy and environment council options & potential alternative strategy, Symposium on Japan's Energy Policy, Toward a National Debate on Options -the Nature of Energy and Environment Policy-, Jul. 23, 2012

12. Keigo Akimoto. Trends of developing IPCC integrated scenarios and overview, IPCC WG3, National Executive Committee, METI, Aug. 3, 2012

13. Keigo Akimoto. RITE analysis of energy and environmental strategy options and points of concern, Economic Model Debate on Energy and Environmental Strategy Options, Kankeiren, Aug. 10, 2012

14. Keigo Akimoto. FOD status: IPCC WG3 Chapter 6 Assessing Transformation Pathway, Workshop on Industrial Chapter, IPCC WG3, METI, Aug. 21, 2012

15. Keigo Akimoto. Toward the establishment of a new international framework for the post-Kyoto Protocol era, International Environment Strategy WG, Keidanren, Aug. 29, 2012

16. Keigo Akimoto. Energy and environment strategy in Japan, Lunch Meeting, Ministry of Finance Japan, Sep. 4, 2012

17. Keigo Akimoto. RITE ALPS project and trends of IPCC integrated scenarios, The first scenario initiative meeting, Central Research Institute of Electric Power Industry, Sep. 10, 2012

18. Keigo Akimoto. Energy policy movements, Kiryu Chamber of Commerce and Industry, Sep. 27, 2012

19. Keigo Akimoto. Economic impact and issues of the energy and environment council options, Press Seminar, International Environmental Economic Institute, Sep. 24, 2012

20. Junichiro Oda. Japanese steel industry: world leaders in energy efficiency, Heavy Industry Press Club, Oct. 3, 2012

21. Keigo Akimoto. Economic impacts and issues of options for energy and environment provided by the Japanese Government, Opinion exchange meeting for invited overseas researchers, Japan Institute for Social and Economic Affairs, Oct. 24, 2012

22. Keigo Akimoto. Peaceful use of nuclear power seen from the public living environment, Workshop, National Council for Peace and against Nuclear Weapons, Oct. 24, 2012

23. Kenichi Wada. Evaluation, diagnostics and uncertainty in Integrated Assessment Model / AMPERE project, The second scenario initiative meeting, Central Research Institute of Electric Power Industry, Dec. 12, 2012

24. Keigo Akimoto. IMAC report, Energy-water-land interactions, The second scenario initiative meeting, Central Research Institute of Electric Power Industry, Dec. 12, 2012

Molecular Microbiology and Biotechnology Group

◆2012 Original Paper

1. X. Peng, S. Yamamoto, A.A. Vertès, G. Keresztes, K. Inatomi, M. Inui and H. Yukawa. Global transcriptome analysis of the tetrachloroethene-dechlorinating bacterium *Desulfitobacterium hafniense* Y51 in the presence of various electron donors and terminal electron acceptors. J. Ind. Microbiol. Biotechnol. 39:255-268. 2012.
2. S. Hasegawa, K. Uematsu, Y. Natsuma, M. Suda, K. Hiraga, T. Jojima, M. Inui and H. Yukawa. Improvement of the redox balance increases L-valine production by *Corynebacterium glutamicum* under oxygen deprivation conditions. Appl. Environ. Microbiol. 78:865-875. 2012.
3. K. Uematsu, N. Suzuki, T. Iwamae, M. Inui and H. Yukawa. Increased fructose 1,6-bisphosphate aldolase in plastids enhances growth and photosynthesis of tobacco plants. J. Exp. Bot. 63:3001-3009. 2012.
4. H. Teramoto, M. Inui and H. Yukawa. NdnR is an NAD-responsive transcriptional repressor of the *ndnR* operon involved in NAD *de novo* biosynthesis in *Corynebacterium glutamicum.* Microbiology 158:975-982. 2012.
5. K. Uematsu, N. Suzuki, T. Iwamae, M. Inui and H. Yukawa. Alteration of photosynthate partitioning by high-level expression of phosphoglucomutase in tobacco chloroplasts. Biosci. Biotechnol. Biochem. 76:1315-1321. 2012.
6. S. Yamamoto, W. Gunji, H. Suzuki, H. Toda, M. Suda, T. Jojima, M. Inui and H. Yukawa. Overexpression of genes encoding glycolytic enzymes in *Corynebacterium glutamicum* enhances glucose metabolism and alanine production under oxygen deprivation conditions. Appl. Environ. Microbiol. 78:4447-4457. 2012.
7. A.A. Vertès, M. Inui and H. Yukawa. Postgenomic approaches to using corynebacteria as biocatalysts. Annu. Rev. Microbiol. 66:521-550. 2012.
8. K. Uematsu, N. Suzuki, T. Iwamae, M. Inui and H. Yukawa. Expression of Arabidopsis plastidial phosphoglucomutase in tobacco stimulates photosynthetic carbon flow into starch synthesis. J. Plant. Physiol. 169:1454-1462. 2012.
9. H. Teramoto, M. Inui and H. Yukawa. *Corynebacterium glutamicum* CsoR acts as a transcriptional repressor of two copper/zinc-Inducible P_{1B}-type ATPase operons. Biosci.
10. Y. Tanaka, S. Ehira, H. Teramoto, M. Inui and H. Yukawa. Coordinated regulation of *gnd*, which encodes 6-phosphogluconate dehydrogenase, by the two transcriptional regulators GntR1 and RamA in *Corynebacterium glutamicum*. J. Bacteriol. 194:6527-6536. 2012.
11. H. Teramoto, M. Inui and H. Yukawa. *Corynebacterium glutamicum* Zur acts as a zinc-sensing transcriptional repressor of both zinc-inducible and zinc-repressible genes involved in zinc homeostasis. FEBS J. 279:4385-4397. 2012.
12. T. Jojima, T. Igari, W. Gunji, M. Suda, M. Inui and H. Yukawa. Identification of a HAD superfamily phosphatase, HdpA, involved in 1,3-dihydroxyacetone production during sugar catabolism in *Corynebacterium glutamicum*. FEBS Lett. 586:4228-4232. 2012.
13. K. Watanabe, H. Teramoto, N. Suzuki, M. Inui and H. Yukawa. Influence of *SigB* inactivation on *Corynebacterium glutamicum* protein secretion. Appl. Microbiol. Biotechnol. (in press)
14. S. Hasegawa, M. Suda, K. Uematsu, Y. Natsuma, K. Hiraga, T. Jojima, M. Inui and H. Yukawa. Engineering of *Corynebacterium glutamicum* for high-yield L-valine production under oxygen deprivation conditions. Appl. Environ. Microbiol. (in press)
15. T. Kubota, Y. Tanaka, K. Hiraga, M. Inui and H. Yukawa. Characterization of shikimate dehydrogenase homologues of *Corynebacterium glutamicum*. Appl. Microbiol. Biotechnol. (in press)
16. K. Toyoda, H. Teramoto, M. Inui and H. Yukawa. Involvement of regulatory interactions among global regulators, GlxR, SugR, and RamA in expression of *ramA* in *Corynebacterium glutamicum*. J. Bacteriol. (in press)

◆2012 Oral Presentation (Domestic Conference)

1. Yuya Tanaka, Masayuki Inui, Hideaki Yukawa. Regulation of PTS gene expression in *Corynebacterium glutamicum*, Annual Meeting of the Japan Society for Bioscience, Biotechnology, and Agrochemistry, 2012, 23-25 March 2012
2. Masako Suda, Shogo Yamamoto, Wataru Gunji, Yasuhiro Moteki, Kazumi Hiraga, Masayuki Inui, Hideaki Yukawa. Phenol production by metabolically engineered *Corynebacterium glutamicum* I: Metabolic design of phenol biosynthesis pathway, Annual Meeting of the Japan Society for Bioscience, Biotechnology, and Agrochemistry, 2012, 23-25 March 2012
3. Shogo Yamamoto, Masako Suda, Keiro Watanabe, Yasuhiro Moteki, Kazumi Hiraga, Masayuki Inui, Hideaki Yukawa, Phenol production by metabolically engineered *Corynebacterium glutamicum* II: Phenol production under oxygen deprivation, Annual Meeting of the Japan Society for Bioscience, Biotechnology, and Agrochemistry, 2012, 23-25 March 2012
4. Koichi Toyoda, Haruhiko Teramoto, Masayuki Inui, Hideaki Yukawa, Transcriptional regulation of GlxR regulon genes in *Corynebacterium glutamicum*, Annual Meeting of the Japan Society for Bioscience, Biotechnology, and Agrochemistry, 2012, 23-25 March 2012
5. Taku Nishimura, Haruhiko Teramoto, Masayuki Inui, Hideaki Yukawa, Role of the SOS response during anaerobic nitrate respiration in *Corynebacterium glutamicum*, Annual Meeting of the Japan Society for Bioscience, Biotechnology, and Agrochemistry, 2012, 23-25 March 2012
6. Haruhiko Teramoto, Masayuki Inui, Hideaki Yukawa, Transcriptional regulation of NAD *de novo* biosynthesis operon in *Corynebacterium glutamicum*, Annual Meeting of the Japan Society for Bioscience, Biotechnology, and Agrochemistry, 2012, 23-25 March 2012
7. Toshihiro Tsujimoto, Koichi Toyoda, Haruhiko Teramoto, Masayuki Inui, Hideaki Yukawa. Transcriptome analysis of isobutanol stress response in *Corynebacterium glutamicum*, 90th anniversary meeting of the Society of Biotechnology of Japan, 24-26 Oct. 2012

◆2012 Oral Presentation (International Conference)

1. Hideaki Yukawa. Advances in Oxygen-deprived Production of Organic Acids by *Corynebacterium glutamicum*, Symposium on Bio-based Production of Organic Acids, 11 May 2012
2. Nancy Dowe, Hideaki Yukawa and Daniel J. Schell. Corynebacterium as a biocatalyst for production of ethanol from biomass sugars, SIMB Annual Meeting, 14 Aug. 2012

◆2012 Non-Journal Publication

1. Hideaki Yukawa, Masayuki Inui(eds.), Microbiology Monographs: Biology and Biotechnology of *Corynebacterium glutamicum*, Springer, Berlin. 2012.
2. M. Sasaki, M. Inui and H. Yukawa, Microorganisms for xylitol production: focus on strain improvement. p.109-131. In S.S. da Silva and A.K. Chandel (eds.), D-Xylitol: Fermentative Production, Application and Commercialization, Springer. 2012.

Chemical Research Group

◆2012 Original Paper

1. Shin Yamamoto, Hiroshi Machida, Yuichi Fujioka, Takayuki Higashii, Shingo Kazama. Novel amine solution development for high pressure CO_2 capture and application examination to IGCC gas, ACS Symposium Series, "Recent Advances in Post-Combustion CO_2 Capture Chemistry", Vol.1097, pp.87-98, 2012
2. Kazuya Goto, Satoshi Kodama, Hiromichi Okabe, Yuichi Fujioka. Energy performance of new amine-based solvents for CO_2 capture from blast furnace gas, ACS Symposium Series, "Recent Advances in Post-Combustion CO_2 Capture Chemistry", Vol.1097, pp.71-85, 2012
3. Kazuya Goto, Firoz Alam Chowdhury, Satoshi Kodama, Hiromichi Okabe, Yuichi Fujioka. CO_2 absorption characteristics of 2-Isopropylaminoethanol(IPAE) aqueous solution, ACS Symposium Series, "Recent Advances in Post-Combustion CO_2 Capture Chemistry", Vol.1097, pp.317-331, 2012
4. Manabu Miyamoto, Ayato Takayama, Shigeyuki Uemiya, Katsunori Yogo. Study of Gas Adsorption Properties of Amidoamine-Loaded Mesoporous Silica for Examining Its Use in CO_2 Separation, Journal of Chemical Engineering of Japan, Vol.45, No.6, pp.395-400, 2012
5. Hidetaka Yamada, Takayuki Higashii, Firoz A. Chowdhury, Kazuya Goto, Shingo Kazama. Experimental study into carbon dioxide solubility and species distribution in aqueous alkanolamine solutions, WIT Trans. Ecol. Envir. 157, pp.515-523, 2012
6. Ikuo Taniguchi, Yuka Ootera, Firoz A, Chowdhury, Kin-ya Tomizaki, Teruhiko Kai, Shingo Kazama. Polymeric Membranes Composed of Polystyrenes Tethering Amino Acids for Preferential CO_2 Separation over H_2, Polymer Bulletin, Vol.69, Issue 4, pp.405-415, 2012
7. Ikuo Taniguchi, Shingo Kazama, Hiroshi Jinnai. Structural analysis of poly (amidoamine) dendrimer immobilized in cross-linked poly(ethylene glycol), Journal of Polymer Science PartB:Polymer Physics, Vol.50, Issue 16, pp.1156-1164, 2012
8. Ikuo Taniguchi, Nathan G. Lovell. Low-temperature processable degradable polyesters, Macromolecules, 45 (18), pp.7420-7428, 2012
9. Manabu Miyamoto, Yuichi Fujioka, Katsunori Yogo. Pure Silica CHA Type Zeolite for CO_2 Separation Using Pressure Swing Adsorption at High Pressure, Journal of Materiasl Chemistry, 22 (38), pp.20186-20189, 2012
10. Shuhong Duan, Ikuo Taniguchi, Teruhiko Kai, Shingo Kazama. Poly (amidoamine) dendrimer/poly(vinyl alcohol) hybrid membranes for CO_2 capture, Journal of Membrane Science, Vol.423-424, pp107-112, 2012

◆2012 Oral Presentation

1. Yuichi Fujioka, Kazuya Goto. Decreasing energy of CO_2 recovery for CO_2 capture & storage, International Institute for Carbon-Neutral Energy Research (I2CNER) International Workshop(Kyushu Univ.), 2 Feb. 2012
2. Teruhiko Kai. Poly(amidoamine) Dendrimer/Polymer Hybrid Membranes for CO_2 Capture, International Institute for Carbon-Neutral Energy Research (I2CNER) International Workshop(Kyushu Univ), 2 Feb. 2012
3. Shuhong Duan, Teruhiko Kai, Ikuo Taniguchi, Shingo Kazama. Development of Poly(amidoamine) Dendrimer/Poly(vinyl alcohol) Hybrid Membranes for CO_2 Separation, AMS7(The 7th Conference of Aseanian Membrane Society)(Pusan, Korea), 6 July 2012
4. Ikuo Taniguchi. Room-temperature processable degradable plastics, Asian Workshop on Polymer Processing 2012(Kyoto Institute of Technology), 29 Aug. 2012
5. Masataka Hino, Ikuo Taniguchi, Teruhiko Kai. Low-temperature processable degradable polymers from renewable materials, Asian Workshop on Polymer Processing 2012(Kyoto Institute of Technology), 30 Aug. 2012
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6. Makiko Takagishi, Tsutomu Hashimoto, Shigeo Horikawa, Kinichiro Kusunose, Koichi Takizawa, Ziqiu Xue. Micro seismic monitoring at CO_2 geological storage site - Initial data results observed at Cranfield in the U.S.-, Japan Geoscience Union meeting 2012, 20 May 2012

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