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Annual Report

Research Institute of Inovative Tecnology for the Earth

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The Process of Designing Environmental Policy
– Lessons learnt from the cases in UK –

Mitsutsune Yamaguchi
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The United Kingdom, by enacting The Climate Change Act 2008, has introduced legally binding long-term target of 80% Greenhouse Gas (GHG) emissions reduction by 2050 relative to 1990 level for the first time in the world. To achieve the target, the UK government set reduction targets (budgets) for each five year annual average emissions. So far, it is decided in its fourth budget that the target is set as 50% reduction by 2025 (more exactly annual average of 2023-2027). The author of this column thinks this is so challenging and costly, and may not be achievable. On the other hand, the author highly appreciates the process of setting climate policies and targets in the UK. This is the background of this short essay.

In the UK, the independent Committee on Climate Change (CCC) plays a central role in setting the climate policies and targets. In December 2008, the CCC sent its 828-page recommendation to the Government. The recommendation covers wide range of climate related issues including long-term reduction target toward 2050, emission targets for 3 budget periods until 2022, costs, impacts to competitiveness for UK industries and ensuring stable energy supply. This forms the base of current UK climate policy.

As a basis of long-term target, the CCC, acknowledging the necessity to limit the temperature increase below 2 degree since pre-industrialization in order to restrain the adverse impacts of climate change to a certain extent, concluded 50% global emissions reduction is necessary. This roughly corresponds to global per capita emissions in 2050 to 2.1-2.6t/CO_2. For the UK to attain this level, per capita emission must be reduced by 80% in comparison to 1990. This is the logic of 80% reduction target. Setting aside whether this is feasible or not, the basic idea behind is to make global per capita emissions equal.

The CCC also conducted global cost benefit analysis based on the integrated assessment model. The outcome shows that the cost of 50% reduction in 2050 will be 1-3% of GDP and benefit far outweighs cost. After thorough review of academic literatures, discount rates (pure rates of time preference) used here are 0.1-1.5%. For the reference, the CCC also showed that if the rate is bigger than 2.25%, cost will exceed benefit.

Though the author thinks the UK target is too much challenging, the author also feels there are many aspects we should learn in designing Japan's climate policies and targets; several examples include transparent explanation of the necessity of policies, measures to achieve the target and its cost-effectiveness, impact to the economy. The same applies to the Electricity Market Reform just passed the Parliament in December 2013. The UK Government published various papers (including white papers, technical updates, policy overviews and consultations) since 2010 on the necessity of the reform, measures to be taken, cost of the reform etc. and listen to stakeholders' comments from time to time. This contrasts to the way of setting recent Japan's GHG reduction target of 3.8% by 2020 that was decided without any consultation with the Government Council and without showing measures and cost of achieving the target. The author thinks there are many aspects that RITE, one of the leading research institutes in Japan, can play in forming transparent and reasonable climate policy in Japan.

IPCC and its Fifth Assessment Report



President
Yoichi Kaya

Group Leader
Systems Analysis Group
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1. The role of IPCC

Yoichi Kaya, President

It was 1988 when the issue of climate change became a large international policy issue. At the summit of this year issues of global environment had been intensively discussed, of which climate change was a central topic. The first political reaction to this issue was the Framework Convention on Climate Change signed at the United Nations Conference on Environment and Development in 1992. With this Convention as the basis the meeting of countries joining the Convention (Conference of Parties: COP) was held once a year, and Kyoto protocol was signed at Kyoto conference which was COP3. In response to this political movement World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988 for the purpose of illustrating scientifically the situation of climate change.

A number of scholars related to climate change were invited from all over the world, but it is noticeable that IPCC is different in character from ordinary academic societies, as it is organized by many governments in the world. The IPCC is organized in three Working Groups. Working Group I (WG1) deals with the physical scientific aspects of climate change, Working Group II (WG2) assesses the vulnerability of socio-economic and natural systems to climate change, consequences of climate change, and options for adapting to it, and Working Group III (WG3) assesses options for mitigating climate change (through limiting greenhouse gas emissions). This structure has been basically the same since the beginning of IPCC, although the titles of WG's and the coverage by each WG changed slightly.

The author attended the first meeting of WG3 in February 1989. More than 5 hundred participants attended the meeting which started with the address by US secretary of state. IPCC established the principle at its beginning that its role is to compile the most recent information on climate change and pass it to the policy makers. This principle is the fundamental one of IPCC until now. IPCC published 4 assessment reports in total by 2007 and they were quoted frequently by COP. Particularly in case of setting the target of mitigating climate change COP mentioned that they utilized the scientific knowledge of IPCC as the basis.

However the objective of IPCC is, as mentioned as above, just to gather and compile the scientific knowledge but not to recommend any target at all. This is often misunderstood by the public but we stress once again that discussions connected to real policy are the role of COP but not the role of IPCC.

IPCC is now in the process of editing its fifth reports and that of WG1 was already published in September 2013. The outline of this report will be described later and the reports of other two work groups will be published in March and April 2014. All the reports have been prepared by cooperation of a number of scientists and edited several times. For example in case of WG1 report about 800 lead authors and cooperate authors participated in the works of making the report of more than two thousand pages.

2. On the fifth assessment report of WG1

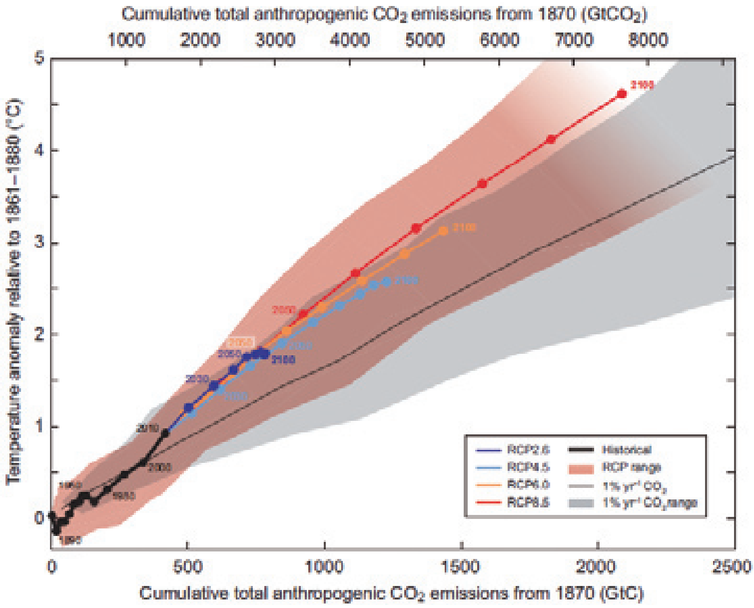
Yoichi Kaya, President

Among the fifth assessment reports the report already published is the one by WG1 which deals with present science of climate change. Here the author quotes two noticeable points from the Summary for Policy Makers (SPM) of the report of WG1.

The first point is that it stresses the climate change of the period particularly after 1950 during which the rise in temperature was large was induced by anthropogenic causes (probability > 95%). You may think this is the matter almost needless to say, but we should notice that there have been a number of skepticisms about climate change science. The above stress is significant in the sense of denying these skepticisms. For example one of well known skepticisms is that by H.Svensmark of Denmark. He believes that changes in solar radiation induce the change in quantity of cosmic ray from the galaxy to the earth, then in the total amount of low layer clouds on the earth and finally of the earth surface temperature. If we follow him the climate change has been induced not by anthropogenic causes but by natural ones. The fifth report of WG1 published this time denies this logic. The SPM describes clearly that solar radiation did not contribute to the rise in global surface temperature at all since 1986.

The second point is that the report indicated the temperature rise is related almost linearly to cumulative emission of CO_2 in the air. According to the analysis in the report the rise in global surface temperature from the past is almost proportional to the cumulative emission of CO_2 (Fig.1). This is a very serious statement, as it means that if we want to stabilize the global surface temperature we have to reduce anthropogenic CO_2 emission to almost zero eventually. (The author believes CO_2 emission should be reduced lower than the level of one tenth of the present emission level but it does not have to be exactly zero. Its detailed discussion is not described here due to space limitation.) From the past the objective of limiting the rise in global surface temperature since preindustrial era to 2 °C has been discussed frequently, and according to the SPM the cumulative emission of CO_2 from the past should be limited to 3010 $GtCO_2$ with the probability of 50%, but anthropogenic cumulative emission of CO_2 already reached 1890 $GtCO_2$.

Since anthropogenic emission of CO_2 emitted every year is, including emission from land use, 38Gt CO_2, the cumulative emission will reach 3010 Gt



source: IPCC AR-5 WG1 Fig. SPM-10

CO_2 within 30 years if we keep the present level of emission. Then the temperature will rise further unless we achieve drastic reduction in anthropogenic CO_2 emission. Actual situation is worse, because global CO_2 emission has been increasing at the rate of 2% per year since 2000. The above simple analysis indicates that the 2 degree target is a very difficult one to achieve. Any way we have to notice that mankind has to make drastic efforts for reducing CO_2 emission in order to limit the future temperature rise to less than a certain level.

Mankind should therefore make the following actions. The first is to consider that the 2 degree target is too difficult to achieve and then to redesign so that the target may be more achievable. Of course it is indispensable in the redesign to investigate how much worsening of the impact on climate change will be induced by that redesign of the target. The author takes these factors into account and has been proposing the 2.5 degree target. However due to the limit of the space of this paper the author has to skip the description of details of this proposal in this paper. The second is to investigate the long term measures for drastic reduction of CO_2 emission, and if possible also those for realizing negative emission (i.e. absorption of CO_2). Development of large scale solar power generation with little output variability (space power generation and solar thermal power generation are candidates) and high efficiency water dissolution by sunlight are good examples of these technologies.

3. Overview of the fifth assessment report of IPCC Working Group 1 and its focal point

Keigo Akimoto, Group Leader, Systems Analysis Group

Since the IPCC was established in 1988, it has provided the world with a clear scientific view on a wide range of complex issues in climate change. The IPCC First Assessment Report was released in 1990 and the previous report, the IPCC Fourth Assessment Report (AR4), was released in 2007. The IPCC is now working on the Fifth Assessment Report (AR5). This article focuses on the overview of the approved and released SPM of the WG1 and underlying reports.

The SPM states that "warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia". It says: "the globally averaged combined land and ocean surface temperature data show a warming of 0.85 [90% likelihood: 0.65 to 1.06)] °C over the period 1880 to 2012. Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass and glaciers have continued to shrink almost worldwide. It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century ("extremely likely" that indicates 95 to 100% likelihood of an outcome or a result)". The corresponding statement in AR4 was "very likely" (90 to 100% likelihood), thus the rating for confidence level raised one-step further.

Regarding projections for future climate change, the SPM admits that the long-term climate model simulations agree with the observed global-mean surface temperature from 1951 to 2012, but there are differences between simulated and observed trends over period as short as 10 to 15 years. Although global mean surface temperature has been increasing continuously, there is a period called a "hiatus (break)", in which the observed global-mean surface temperature increased little during the last 10 to 15 years. The observed warming was almost below the lowest limit or in the lower level of the likely range suggested in the AR4. Many experts think, however, ocean heat content is so great that it is difficult for climate models to reproduce contribution from natural internal decadal variability and eventually long-term increases in observed temperature will be consistent with the model-estimated simulation and not way off the mark. In fact, there are some studies that suggest an increase in deeper ocean heat uptake. Climate models have improved, but many climate phenomena are yet to be reproduced better. Further improvement is required.

As an index to simply show the relations between atmospheric greenhouse gas concentrations and surface temperature increase, equilibrium climate sensitivity (ECS) has been used quite often. The ECS tells us to what degree the global mean surface temperature increases when the atmospheric greenhouse gas concentration doubles and stabilizes. This SPM states that equilibrium climate sensitivity is likely in the range 1.5°C to 4.5°C, extremely unlikely less than 1°C, and very unlikely greater than 6°C. The likely range had been 1.5°C to 4.5°C until the third assessment report (2001), which was raised to 2.0°C to 4.5°C in the AR4 and returned to the original range in this SPM. The lowered range may have reflected on recent observation of retarded global warming, albeit with little difference in climate modeled simulations between AR4 and AR5. In any event, it suggests that uncertainty still remains high and is not expected to be readily reduced. Policymakers are required to make decisions on climate change in the face of continuing uncertainty.

One thing that should be noted in this SPM is that not only the ECS, but also the "transient climate response (TCR)" is discussed. The TCR is defined as the change in global mean surface temperature at the time when the atmospheric CO_2 concentration has doubled in a scenario of concentration increasing at 1% per year (in about 70 years). The TCR is considered more realistic figures than the ECS. The SPM states that the TCR is likely in the range of 1.0°C to 2.5°C and extremely unlikely greater than 3°C. Currently, in addition to stabilization scenarios of atmospheric GHG concentration, overshoot scenarios have been under discussion. In the overshoot scenarios, the concentration is expected to first go beyond 450 ppm to 500 ppm and then go back to 450 ppm. This scenario cannot define the ECS, which is one reason for new discussion.

Another important issue is that this SPM covers the “Transient Climate Response to Cumulative Carbon Emissions (TCRE)”. TCRE approximately shows by what degrees in temperature the planet will warm according to what Gt carbon emissions are accumulated in the atmosphere. Therefore, it is simple and convenient for us to assume temperature increase relative to the accumulated emissions without calculating the atmospheric concentrations. (See the article by Dr. Yoichi Kaya).

The assessment reports of the WG2 and WG3 are planned to be approved and released soon. What we should do is to understand the contents correctly and to make the most of the knowledge in formulating specific global warming measures, policies, or entering into international negotiations on climate change.

Attending the IPCC Plenary Session

Masato Takagi, Deputy Group Leader, Research & Coordination Group

I attended the 12th session of the WG1 and the 36th plenary session of the IPCC (where SPM of the WG1 was approved and accepted) held on September 23 to 26, 2013 in Stockholm, Sweden. This column gives you a snapshot of the conference.

Let me start with the process until the AR5 is accepted. First, lead authors (LA) contribute to a first order draft, which is reviewed by expert reviewers twice and by governments once. Then the first order draft is re-drafted. In the assessment reports of the WG1, 259 lead authors and 50 review editors from 39 countries got involved. While 669 expert reviewers from 47 countries made a total of 2,100 comments to the first order draft, 800 experts from 46 countries and 26 governments made 31,422 comments to the second order draft. The final order draft of the SPM was reviewed by the governments. To review the about 30-page summary, 32 governments made a total of 1,855 comments.

The 12th session of the WG1 started with greetings from Rajendra K. Pachauri, Chairman of the IPCC and Lena Ek, Swedish Minister of the Environment. Co-chairs of the WG1 Dahe Qin (China) and Thomas Stocker (Switzerland) were appointed to chair the session and discussion started. The revised final order draft of the SPM, which had been revised after the governmental review, was projected on a screen and referring to that, government representatives worked through the text on a line-by-line basis. When the representative wanted to make an objection or a comment, he/she raised the name plate to declare “intervention”. When there is no “intervention”, it was regarded as consensus reached and the text was approved. When governments’ opinions were opposed to halt the negotiations, the co-chairs convened a contact group or a consultation group to discuss the controversial issue. Those group discussions progressed in parallel with the plenary session until a solution was proposed. The proposal was then brought back to the plenary session and approved. As was often the case of the international negotiations, the progress was so slow especially in the first half of consideration. Thus, a “performance-meter”, bar graphs to compare the time passed and the results obtained, was displayed on the screen to visualize the progress. We only found the discussion stumbling on small matters from the very beginning and the results of day 1 reached 5% of the total, day 2 at 10%, and day 3 at about 20%. The session of day 3 closed at 2 o’clock in the night and we sat all night on the final day and saw all the text finally approved at dawn of September 27.

The key points of the discussion were published in ENB report of the IISD (http://www.iisd.ca/download/pdf/enb12581e.pdf). Reference years, hiatus, paleoclimate, sea level rise, ECS, and TCRE each caused a controversy. The sessions were physically and mentally very hard. Still, I think this consideration process is absolutely necessary to revise abstract expressions in the SPM to more specific and scientific ones.

Energy and Environmental Policy in Japan

Kenji Yamaji, Director-General

1. Status as of January 2014

In response to the Fukushima nuclear accident, the Japanese government, then by DPJ, began to review its energy and environmental policy from the ground up.

To review the energy and environmental policy, the Energy and Environment Council comprised primarily of cabinet members was set up to oversee the Advisory Committee for Natural Resources and Energy, the Japan Atomic Energy Commission, and the Central Environment Council, which had conventionally deliberated on the energy and environmental policy. The review was conducted under the initiative of politicians. Under the new framework, each council selected policy options, which were further selected by the Energy and Environment Council to establish a fundamental course for a new policy through nationwide debate. Based on the debate, in September 2012, the national government developed the Innovative Strategy for Energy and the Environment with an aim to achieve zero nuclear power in the 2030s.

However, the DPJ government collapsed after the Lower House general election held in December 2012. On its return to power, the LDP-New Komeito government took the Innovative Strategy for Energy and the Environment back to the drawing board and began to work out another energy and environmental policy, including revising anti-global warming targets for 2020.

The Advisory Committee for Natural Resources and Energy concluded its discussions in December 2013 by submitting a report on a new Strategic Energy Plan where the nuclear option is maintained; and the minister of the environment announced a new, but tentative, GHG reduction target of 3.8% for 2020 from the level of 2005 at COP 19 meeting in November 2013.

2. Frontiers of energy and environmental policy in Japan

Japan's energy and environmental policy is presently at a historical turning point. Although the fundamental goals should be pursued as before to ensure stable energy supply, to sustain the Japanese economy by economical and efficient energy, to work on measures against global warming, and to achieve the three "E" s concurrently, debates are ongoing about the degree of future dependence on nuclear power and targeted measures against anti-global warming for 2020 and thereafter, in order to devise practical and concrete measures.

The author believes that to achieve the fundamental goals, it is important to maintain the widest possible range of Japan's energy and environmental policy options. It is necessary to retain the nuclear power option, further the energy-saving efforts, actively introduce renewable energy, and use fossil fuels cleanly and stably. Among them, as Japan's energy and environmental policy frontiers, it would be important to recognize the options for using positively demand-side resources and for having an international perspective,.

Japan's energy and environmental policy has largely focused on supply-side measures. The core of the energy-saving policy has been improving efficiency in energy use. Policymaking has lacked the perspective of aggressively using energy consumer-side power sources and energy storage equipment for energy supply-demand control. However, to further energy-saving efforts, to massively introduce naturally varying power of solar panels and wind, and to ensure robust energy supply against large-scale disasters such as the Great East Japan Earthquake, it is extremely important for the entire society to share energy supply-demand information and for various demand-side energy equipment to take part in the operation of the entire energy system.

Making the demand side resources active implies a full-scale introduction of distributed resources into energy supply. It is a significant change to the fundamental structure of the conventional energy system designed to enable a centralized supply source to serve distributed consumers through networking. It means building a smart energy system in which information is linked between supply and demand so as to use demand-side energy equipment, such as distributed cogeneration systems, EV storage batteries, and hot water tanks in water heaters, in energy supply-demand control via an information network ("energy cloud"). Also, it requires constructing a high-efficiency energy utilization infrastructure into buildings and urban structures and forming a smart community through the use of the aforementioned integrated network. This is a great challenge and is expected to develop a new social system and to lead to reviving Japan.

On the other hand, Japan's targeted measures against global warming for 2020 are in the final adjustment stage. When taking measures against global warming, an international perspective is specifically important. Japan presently accounts for only 3% to 4% of the world's greenhouse gas emissions. This percentage is forecast to decrease. Consequently, it is extremely important to view the nation's contribution to measures against global warming from an international perspective.

Japan has promoted technology development since the oil crises and has the world's highest level of efficient production technologies in steel and many other industrial fields. In the areas of heat pumps, LED lighting, and other energy-using items, world-leading high-efficiency products are manufactured in the country. Japan can contribute to measures against global warming not only by reduced emissions of greenhouse gases in the country, but also by globally deploying its excellent technologies and products.

A recent trend in determining greenhouse gas emissions in the industrial sector is the assessment of lifecycle emissions, which includes emissions associated with goods and services procured by a company and with the use of the company's products by users, as well as with the company's production activity. Using well-developed techniques of lifecycle greenhouse gas emission assessment, it becomes possible to measure Japan's global contribution to greenhouse gas emission reduction.

Japan's measures against global warming have conventionally placed prime importance on domestic measures and used the Kyoto mechanisms and other international cooperative measures simply as supplementary measures. However, greenhouse gas emission reduction through international cooperative measures should be more positively evaluated. The existing scheme of earning credits emphasized the aspect of buying emission rights and produced financial instruments, obscuring the originally intended contribution to global emission reduction. However, if lifecycle assessment is effective in indicating the extent of reduction achieved through international contribution, Japan's international contribution is expected to gain greater recognition. JCM (joint crediting mechanism or bilateral off-set credit mechanism) could make a first step toward this direction.

Japanese leading-edge technologies, such as superb coal-fired power generation and hydrogen-related technologies, need to be used in wider applications on an international scale. For example, an initiative is announced to introduce low-cost hydrogen produced from Australian brown coal using a Japanese technology. International deployment of Japanese technologies contributes to stable energy supply and improved economy, as well as to measures against global warming.

Economies in the world have been globalized across national boundaries. Japan's energy and environmental policy needs to be aggressively deployed in the international arena.

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The Present States and Prospects of our Efforts for Realization of CCS

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 2012, global emissions of CO_2 in 2050 should be decreased to 16Gt-CO_2/yr, which is almost half of the emissions in 2009, in order to limit long-term global temperature increase to 2°C. This means that 42Gt-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 only a sole technology, but combination of technologies with great potential is required. In this context, "Carbon Dioxide Capture and Storage (CCS)" has been gaining attentions as innovative mitigation options. This option is cost-competitive and has stabilities against power fluctuation comparing to photovoltaic or wind power.

This report provides you of comprehensive overviews of latest progress and issues on CCS which is central focus of our research. Furthermore, we also describe the present states and prospects of our efforts for the realization of CCS.

2. Current status of CCS

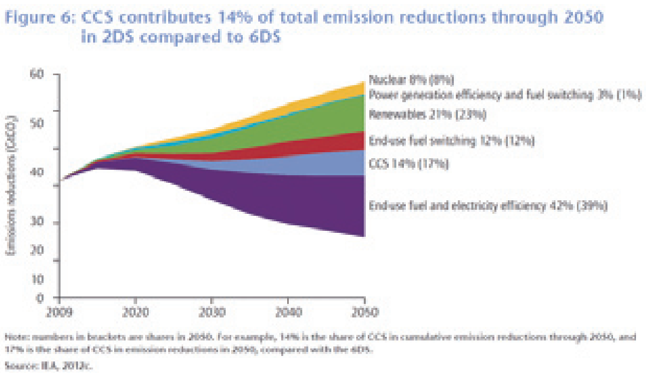
2-1. Necessity and perspective of CCS

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 on the globe through 2050 (Fig. 1).

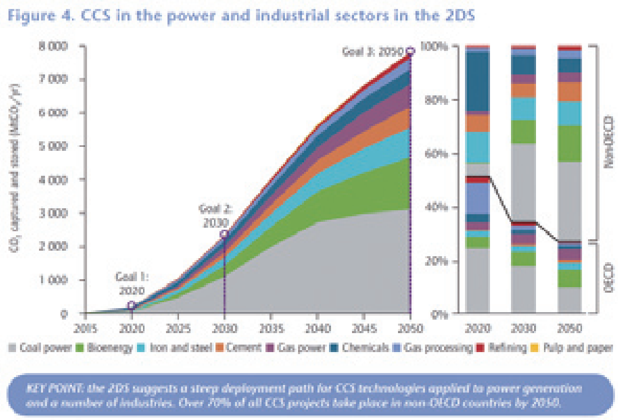
It is necessary to introduce CCS into industrial sectors, such as iron and steel, cement and chemical processing as well as power plant sector, such as coal power and gas power to meet deep emissions reduction goals, while renewable energy and so on cannot work well in such production processes of those industrial sectors. In the 2DS, industrial sectors would account for 45% of the total volume captured and stored between 2013 and 2050.

2-2. The status of CCS projects

The Global CCS Institute (GCCSI) published "The Global Status of CCS:



source: IEA"Technology Roadmap Carbon capture and storage 2013 edition"[2)]
Fig. 1: Contributions of technologies against global warming

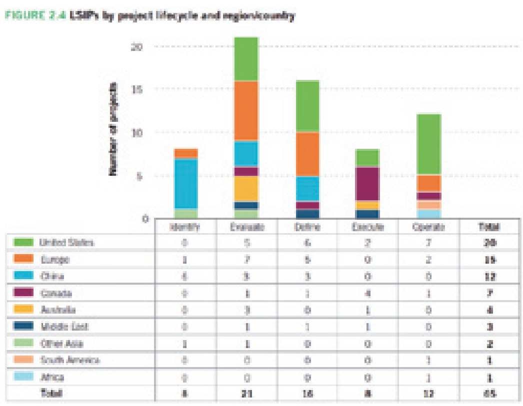


source: GCCSI "the global status of CCS 2012"
Fig. 2: Costs of CO_2 avoided by technologies

2013"[3)] which summarizes CCS projects activities in the world. It shows large-scale integrated projects (LSIPs) are classified into the following six stages based on stages of progress: Identify, Evaluate, Define, Execute, Operate, and Closure. Based on 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 20 LSIPs listed in the Execute and Operate stages, 8 LSIPs of the total are classified as Execute and other 12 LSIPs as Operate. The number of total LSIPs including the planning stages of development ('Identify', 'Evaluate', and 'Define') amounts to 65, decreasing by ten projects compared to the 75 reported in the Global Status of CCS: 2012 (Fig. 3). Although most of LSIPs in China are classified into 'Identify', considering its future economic growth and the corresponding energy demands and IEA perspectives, the future progress of those projects should be closely watched.

In Japan, a large-scale CCS demonstration project is implemented at the Tomakomai site in Hokkaido. Two major facilities, CO_2 capture facility and CO_2 compression & injection facility will be newly designed and constructed by March 2016. 100,000 tons/year or more CO_2 is planned to be stored in two separate reservoirs starting from FY2016. It is also planned to monitor the behavior of CO_2 in the reservoirs to verify neither seepage nor impact is caused by natural earthquake during and after the CO_2 injection comparing to the baseline data obtained before injection.



source: GCCSI, "the global status of CCS 2013"
Fig. 3: Large scale integrated projects of CCS

2-3. The issues of CCS

IEA published "Technology Roadmap Carbon capture and storage 2013 edition" in July 2013. This report highlights key findings they have found and seven key actions needed in the next seven years to create a solid foundation for deployment of CCS starting by 2020.

"Key findings and actions" in this report states that "Lack of understanding and acceptance of the technology by the public, as well as some energy and climate stakeholders, also contributes to delays and difficulties in deployment", "Governments and industry must ensure that the incentive and regulatory frameworks are in place and co-operation among governments should be encouraged ", "CCS is not only about electricity generation. Industrial applications such as steel, cement and chemicals must be equipped with CCS ", and so on (Table 1).

Also, "Seven key actions for the next seven years" are stated in this report as following: "Introduce financial support mechanisms for demonstration and early deployment of CCS to drive private financing of projects", "Implement policies that encourage storage exploration, characterization and development for CCS projects", "Develop national laws and regulations as well as provisions for multilateral finance that effectively require new-build, base-load, fossil-fuel power generation capacity to be CCS-ready", "Significantly increase efforts to improve understanding among the public and stakeholders of CCS technology and the importance of its deployment", and so on (Table 2).

Table 1: Key findings we have found

Key findings we have found
Carbon capture and storage (CCS) will be a critical component in a portfolio of low-carbon energy technologies.
Lack of understanding and acceptance of the technology by the public, as well as some energy and climate stakeholders, also contributes to delays and difficulties in deployment.
Governments and industry must ensure that the incentive and regulatory frameworks are in place and co-operation among governments should be encouraged.
CCS is not only about electricity generation. Industrial applications such as steel, cement and chemicals must be equipped with CCS.
The largest deployment of CCS will need to occur in non-OECD countries which will need to account for 70% of the total cumulative mass of captured CO2.
The development of strong business models for CCS, planning and actions which take future demand into account are needed to encourage development of CO2 storage and transport infrastructure

source: IEA"Technology Roadmap Carbon capture and storage 2013 edition"[2)]

Table 2: Seven key actions needed in the next seven years

Leading organization	Seven key actions needed in the next seven years
Government	Introduce financial support mechanisms for demonstration and early deployment of CCS to drive private financing of projects
Government	Implement policies that encourage storage exploration, characterization and development for CCS projects
Government	Develop national laws and regulations as well as provisions for multilateral finance that effectively require new-build, base-load, fossil-fuel power generation capacity to be CCS-ready
Industry	Prove capture systems at pilot scale in industrial applications where CO2 capture has not yet been demonstrated
Government	Significantly increase efforts to improve understanding among the public and stakeholders of CCS technology and the importance of its deployment
Industry／Research institute	Reduce the cost of electricity from power plants equipped with capture through continued technology development and use of highest possible efficiency power generation cycles
Government	Encourage efficient development of CO2 transport infrastructure by anticipating locations of future demand centres and future volumes of CO2

source: IEA"Technology Roadmap Carbon capture and storage 2013 edition"[2)]

2-4. Overseas trends of the regulations about CCS

In September 2013, the U.S. Environmental Protection Agency (EPA), USA proposed New Source Performance Standards on the basis of Climate Action Plan which President Obama issued. The proposed standards require that newly constructed coal fired power plant should meet the CO_2 emission limitation in the range of 500kg/MWh(one- year average) or 480kg/MWh(seven- year average). They also require that newly constructed gas fired power plant should meet the CO_2 emission limitation in the range of 45 kg/MWh(large scale plant) or 50 kg/MWh(small plant). As figure4 shows, meeting this limitation for coal fired power plant cannot be accomplished even if we utilize a technology of the latest IGCC and IGFC in the coal fired power generation. Therefore, new coal fired power plants would be required to capture and storage a portion of their CO_2 emissions. Meanwhile, highly efficient gas fired power plant like combined cycle gas fired power plant will meet this limitation. CO_2 Emission Performance Standard (EPS) which requires CO_2 emission limitation in the range of 50 kg/MWh for coal fired power plant has been endorsed in Canada. Introduction of CO_2 Emission Performance Standard (EPS) has been approved in the parliament in UK.

As for CCS-ready regulation which requires feasibility study for construction of new thermal power plant, EU directive has been entered into effect.

Transportation of EU directive into national law has been completed in some of EU member states, such as Spain, the Kingdom of Denmark and so on. Figure3 explains above mentioned situations.

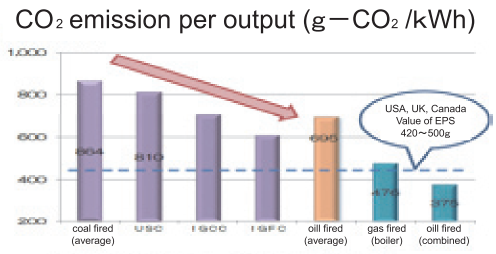


Fig. 4: CO_2 emission per output (g-CO_2/kWh)

Table 3: Outline of overseas regulation on CO_2

State	Outline of overseas regulation on CO2
USA	○New Source Paformance Standard(EPS) draft proposed by EPA: ・New coal fired power : 500kg/MWh(1 year average) , 480kg/MWh(7year average) ・New gas fired power : 450kg/MWh(large scale plant) , 500kg/MWh(small plant) ○EPS regulation(California, Washington, Oregon) ・Base load power : 500kg/MWh
Canada	○EPS regulation : New coal fired .etc : 420kg/MWh
UK	○EPS regulation : New coal fired power : 450kg/MWh ○CCS-Ready : New thermal power : more than 300MW（50MW in Scotland）
EU	○EUCCS Directive(CCS-Ready) : more than 300MW (Adoption had been completed : Spain, Denmark, Netherlands, Italy, France, Lithuania, Malta, Slovenia, Portugal, Romania)

"Chief of the bureau grade meeting report about the thermal power supply bid of Tokyo Electric Power Company concerned" which was agreed between Ministry of Economy, Trade and Industry (METI) and Ministry of Environment (MOE) was published on the 26th of April, 2013. The target that Japan reduces CO_2 emission by 80% until 2050 is mentioned in it. This report sets targets for promotion of CCS as "acceleration of research and development of CCS aiming at commercialization of CCS by around 2020", "Implementing investigation of suitable storage sites for CO_2 reservoir for early realization of CCS introduction", "examining the introduction of CCS into coal fired power plant on a commercial scale by 2030", "developing a legislation for introduction of CCS-ready based on the results of investigation of suitable storage sites and the requirements for CCS-ready regulation".

2-5. International standardization for CCS

With a view to the practical application of CCS, cross-national efforts for the international standardization for CCS has been started under the framework of International Organization for Standardization (ISO). ISO Technical Committee (ISO/TC265) for CCS was establish in October, 2011. Canada leads the committee as a chair-country, participant members of the TC265 are composed of 17 countries, observer members are 10 countries and 6 international organizations participate in the TC265. Six working groups are set up under the TC: Capture WG, Transportation WG, Storage WG, Cross-Cutting WG, Quantification & Verification WG and Enhanced Oil Recovery WG. Japan acts as convener of WG1 and WG3 and secretary of WG1 (Fig. 5).

In response to involvement in this international framework, Japan set up the mirror committee of ISO/TC265. This committee discusses and determines response guideline. RITE was assigned as a secretariat of the Japanese mirror committee of ISO/TC265. Capture WG, Transportation WG, Storage WG and Cross-Cutting, Quantification& Verification WG are set up under the Japanese mirror committee in accordance with the TC265 (Fig. 5). The establishment

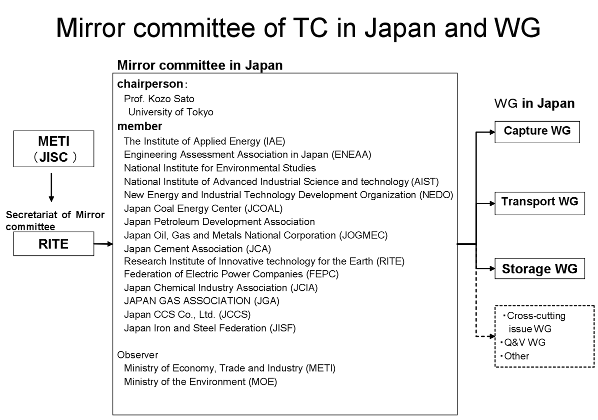


Fig. 5: Organization of Japanese Mirror Committee

of WG for EOR (Enhanced Oil Recovery) is going to be examined on an as-needed basis.

The TC265 has been held three times. At the first meeting of the TC265, the name of TC was decided and at the second meeting five WG were set up and conveners of WG were appointed respectively. The third meeting was held in Beijing in September 2013. 11 participant member countries and 3 international organizations participated in the meeting. 15 delegates from Japan participated in the meeting. At the third meeting, 4 NWIPs (new work item proposals) were approved and International standardization for CCS actually started. The TC265 also decided to set up a new Enhanced Oil Recovery (EOR) WG and an ad-hoc meeting to define clear borders among the WGs. The ad-hoc meeting will deliver a result about the borders by the next meeting of TC265. The next meeting of the TC265 will be held in Berlin, Germany from 31th March through 4th April, 2014. In response to these circumstances, the Japanese mirror committee has discussed and decided how to cope with the next meeting in Berlin so that the technology and knowledge that Japanese companies had developed will be evaluated appropriately.

Table 4: Activities of each ISO WG

WG	NWIP	Activities	Publish (Target)
WG1 (Capture)	Approved	Technical report(TR) International standard(IS) (Capture technology, process)	TR:2015 IS:2017
WG2 (Transport)	Approved	International standard(IS) (Pipeline transpotation)	2016
WG3 (Storage)	Approved	International standard(IS) (Storage onshore and offshore)	2017
WG4 (Q & V)	under consideration	Technical report(TR) International standard(IS) (Quantification & verification)	under consideration
WG5 (Cross-cutting Issue)	Approved	International standard(IS) (Vocabulary)	2016
WG6 (CO2-EOR)	under consideration	under consideration	under consideration

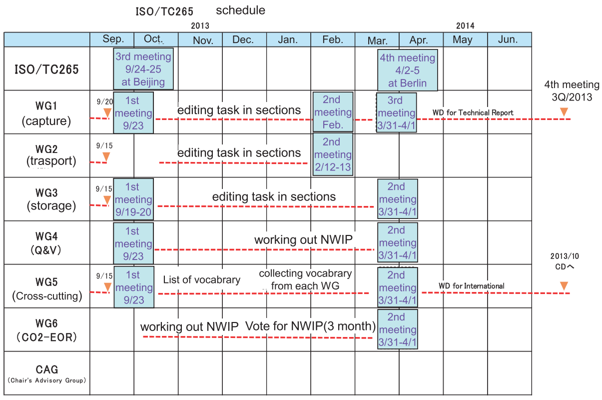


Fig. 6: Schedule of ISO/TC265

3. The outcomes of Zero-emission Coal-fired Power Generation Project

RITE implemented "Conceptual design of CO_2 storage system and evaluation of the potential reservoir of CO_2" under "Innovative zero-emission coal thermal power generation project" in cooperation with OYO Corporation under entrustment from NEDO from FY2008 through FY2012. RITE has established the way of evaluation of CO_2 reservoir, investigated CO_2 storage engineering and evaluated nationwide CO_2 reservoirs. Based on these results, RITE selected three candidate sites, site A, B and C as the CO_2 storage sites. RITE performed the conceptual design of CO_2 storage systems and calculated the estimated costs of CO_2 storage systems on a demonstration scale (240kt-CO_2/year) and a commercial scale (1.54Mt-CO_2/year). In addition, RITE selected site D for a large scale CO_2 storage and performed the conceptual design of CO_2 storage systems and calculated an estimated cost of a CO_2 storage system for a large scale demonstration (10Mt-CO_2/year). As a result, it is proved that the cost of a large-scale system is more cost-effective than those of more than one small scale system's. Also, RITE developed an economic evaluation tool for CO_2 storage based on the findings.

Table 5 shows the brief summary of each candidate site selected in this project. Among the four sites A to D, the site A is the nearest one from the coast and in alphabetical order, the locations of other sites are getting farther away from the coast and deeper. As for the CO_2 storage system, site A is intended for an inclined well from the land, site B is for a jack-up platform, which is located on the sea with its bottom attached to the seabed, and both sites C and D are for semi-submersible platforms, that is, a platform floating on the sea. Estimated cost of CO_2 storage facility on a commercial scale (1.54Mt-CO_2/year) is within a range of 26 to 38 billion yen. The farther the site is apart from the coast, the higher the cost increases. According to our estimation, the construction cost of a large-scale storage system (10Mt-CO_2/year) at site D will be at 89.4 billion yen if the whole system is constructed at a time, in the meantime, the cost will increase to 112.1 billion yen if the components of the total system are built separately. In contrast, the cost of CO_2 storage system (1.54 Mt-CO_2/year) at site D will be at 31.6 billion yen, therefore, in case of a system for 10 Mt-CO_2/year, the total construction costs of the smaller systems will run to approximately 180 billion yen, which is equal to about six times of 1.54Mt level. Therefore, it proves that the cost of a single large-scale system is more economical than those of assembled small-scale ones.

RITE has developed an economic evaluation tool on CO_2 reservoir in this project (Fig. 7). When full-scale CCS is deployed in the future, it is necessary to evaluate the economy as well as the safety and the quantity of the potential site in order to select the CO_2 storage site. In the screening stage of the CO_2 storage sites, it is not easy to evaluate the economy including transportation cost. RITE developed "the economic evaluation tool for CO_2 storage" to support selection of CO_2 storage sites. RITE expects to provide our data on CCS by utilizing this database tool in future.

Table 5: Outline of each site selected in this project

	A site	B site	C site	D site
location	Northeastern Sea of Japan side area along the shore	East Japan Pacific side area along the shore	West Japan continental shelf offing	West Japan continental shelf offing
Distance to the shore	1.5km	5km	app.30km	app.140km
depth of water	approx.50m	approx.15m	approx.120m	approx.120m
depth of reservoir	900, 1500m	1800m	1500, 2500m	1500m
capacity of reservoir (Mt-CO2)	～200	～900	～2700	～4900
Storage system	inclined well from the land	Jack-up platform	Semi-submersible platform	Semi-submersible platform for large scale storage
the estimated cost of storage (1.54Mt-CO2/year)	approx. 26 billion yen	approx. 21 billion yen	30～38 billion yen	approx. 31 billion yen

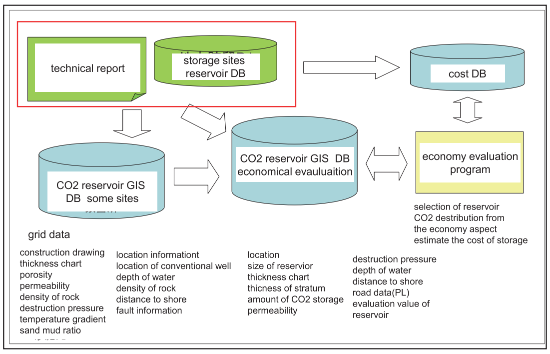


Fig. 7: Development of "the economical evaluation tool for CO_2 storage"

In addition, RITE has compiled our future challenges of CCS storage and proposals for the future. (Table6, Table7) Out of this proposal, "prioritization of the CO_2 storage site development and further exploration based on the priorities", "compiling information about the CO_2 storage sites into a database and making it accessible to the persons concerned", "developing a technique and a tool to perform exploration of the CO_2 storage sites more effectively" are important in particular.

Table 6: Future challenges of CCS storage

future challenges on CCS storage
1. Exploration of CO2 storage sites New nationwide invetigation is nescessary from the point of view of CO2 storage
2. Demonstration in Japan and improvement of the CO2 storage layer design skill through the overseas cooperation Sharing the experience of the large-scale demonstration plant enough, establishment of a close network with overseas large-scale demonstration plant and taking in the majority experience in the large-scale demonstration plant.
3. Optimized planning of the total CCS system The planning that foresee a problem of the energy supply in the site, the choice of the system which is cheaper and more effective, and the future.
4. Clarification of the route for the CCS practical use and Concrete program planning of the large-scale project Making of a more practical plan to perform for a concrete emission source, the concrete CO2 storage site.
5. Disseminate an excellent technique of our country more Polishing a technique in a demonstration plant in our country, enhancing the cooperation with foreign countries, active participation in international standardization of CCS.

Table 7: Proposals for future about CCS storage

proposals on CCS storage for future
1. Push forward the exploration of the large-scale CO2storage sites because the are more advantageous than developing a lot of CO2storage sites of the small scale. The large-scale sedimentation layer from the San-in offing to North Kyushu is in particular an influential candidate.
2. Carry out a more detailed investigation in the northern Kyushu area, carry out concrete program planning and feasibility study of the large-scale CO2 storage project because there is a promising spot in CCS in the northern Kyushu area.
3. Prioritize the CO2 storage site development and further exploration according to it, compile information about the CO2 storage sites into a database and make it accessible to the person concerned, develop a technique and a tool to perform exploration of the CO2 storage sites more effectively
4. Promote the enforcement of the demonstration in our country,build the network with many overseas organizations and projects, share knowledge, the experience. In addition, Polish a technique in demonstration in our country and assume it the basic data for overseas advances. Strengthen the cooperation with Asian countries in particular and promote spread enlightenment activity through the personnel training business. Enhance the presence in the other country of Japan and promote infrastructure system export.
5. Guarantee safety of CCS and maintain the environment where fair competition is enabled by promotion of the international standardization of CCS. In addition, based on an international standard, promote enforcement of CCS in the countries where the maintenance of laws and regulations is undeveloped.

4. Storage & Utilization of CO_2 for Coexistence of Economical & Safe System (SUCCESS)

More economical and safer CCS technology is necessary to expand the candidate sites for CO_2 storage. Storage & Utilization of CO_2 for Coexistence of Economical & Safe System is one of the more economical and safer CCS technologies and we call it “SUCCESS” by short. The concept of this system has been developed on the basis of “Enhanced Geothermal System using CO_2" reported in the previous issue of the RITE Today last year. “SUCCESS” is a next-generation CO_2 storage system which has three advantageous effects (geothermal heat utilization, stratum pressure relaxation, injection rate increase) (Fig. 8).

First of all, this system has an advantage in that it boosts economic efficiency of the CCS business and secures income by utilizing geothermal energy. A mechanism of this system is to utilize thermal energy from the discharged high-temperature ground water. After an aquifer is filled with CO_2 injected, the system will circulate CO_2 and utilize a geothermal energy. LBNL, USA is planning a verification test of the geothermal heat use with CCS, and RITE intends to promote a collaborative research with LBNL. Secondly, this system has a possibility to serve as a tool for safety measures to avoid abnormal elevation of the stratum pressure by depressurizing the aquifer at the injection.

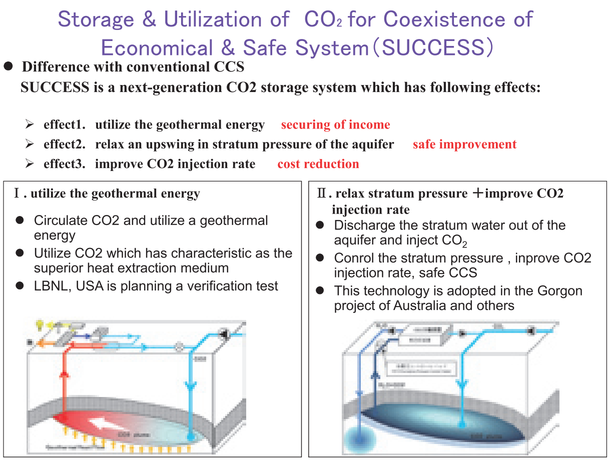


Fig. 8: Outline of SUCCESS

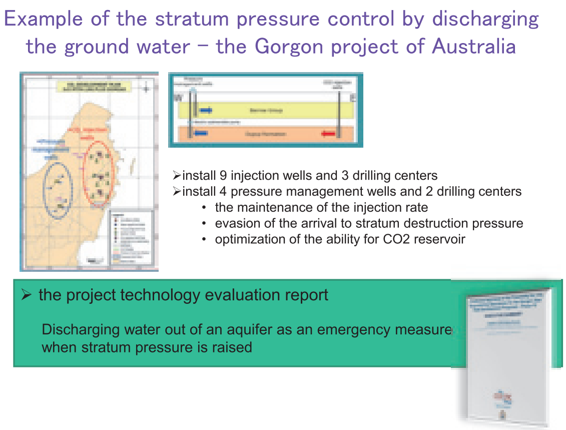


Fig. 9: Example of the stratum pressure control by the discharge of the ground water

In this way, we can expect the effect of safety improvement by this system. The third promising effect is that this system enables to raise the rate of CO_2 injection per one well resulting from relaxation of a rise in stratum pressure. As a consequence, it leads to cost reduction arising from more efficient injection with increased volume of CO_2.

Some similar systems are slated to be in operation abroad. For example, in the case of the Gorgon project in Australia, they will inject CO_2 into the injection wells and concurrently discharge water out of the pressure management well so that they can adjust stratum pressure. As a result, positive effects such as maintaining the injection rate, avoiding to reach stratum destruction level of the pressure and optimizing the ability of CO_2 reservoir are expected. In the technology evaluation report of the project, discharging water out of the aquifer is mentioned as an emergency measure when stratum pressure increases (Fig. 9).

5. Conclusion

Among limited technical options for the future, CCS is focused to play a critical role to substantially reduce CO_2 emissions. Therefore, toward introduction of CCS, it is required creating incentives such as introduction of financial supports, further exploration of CO_2 storage sites, development of regulations including CCS-ready conditions, implementation of demonstration tests of capture systems for industrial application, promotion of public understanding, acceleration of researches on CCS technologies. In some overseas countries, certain regulations to mandate CCS-ready and the new Emission Performance Standard (EPS) are ready or have been in force. In addition, International standardization for CCS has been in progress steadily.

As for CO_2 storage, based on a the result of Zero-emission Coal-fired Power Generation Project, it is necessary to work on exploration of CO_2 storage sites, optimization of the total CCS system and concrete planning on a large-scale project to accelerate promotion of CCS. Especially, prioritizing development of CO_2 storage sites and further exploration, and compiling information on CO_2 storage sites into a database and making it accessible by the persons concerned, are important.

The more economical and safer CCS technology is necessary to expand the potential CO_2 storage sites. SUCCES is a next-generation CO_2 storage system to bring some non-conventional effects such as utilization of terrestrial heat, relaxation of stratum pressure, improvement of injection rate by discharging the ground water from the aquifer and RITE will continue to implement feasibility study on this approach in future.

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International Integrated Assessment Model Comparison Projects

1. Introduction

The IPCC 5th Assessment Report (AR5) are scheduled to be completed in 2014. The Working Group III assesses mitigation options and the report "Climate Change 2014: Mitigation of Climate Change", will be released in April 2014 after the approval in the 39th Session of IPCC. Scenario analysis and modeling exercise by the integrated assessment model (IAM) provide a key element in the AR5 report. A number of international inter-model comparison projects are formulated mainly in the United States and EU countries in an effort to make contribution to the IPCC AR5 report. RITE have been involved in many of those projects and provided the assessments using our models.

This article introduces the climate challenges that the IAMs are currently addressing based on the outcomes of the international IAM comparison projects.

2. Inter-model comparison studies

IAMs cover wide variety of issues that often involve significant uncertainty, leading to the broad range of different results across models. Inter-model comparison projects help better understanding where the differences in model behaviour come from and considering plausible policy implications. Table 1 presents the list of ongoing or recently completed international model comparison projects that RITE joined.

The integrated assessment models are powerful tool to evaluate mitigation strategy, but it represents nothing more than a simplified world. Complex real world phenomena cannot be captured fully in such a simplistic approach. For example, it is often emphasized that only moderate global GDP losses of several % are estimated for deep GHG emissions cuts and the IPCC AR4 report[1)] presented more or less consistent results with that estimation. These results, however, are

Table 1: International model comparison projects that RITE joined

	Host Organization	Objective/Overview
AME	JGCRI/PNNL(US)	Asia Modeling Exercise (AME) was initiated in 2010 and completed in late 2012. Funded by US EPA, EMF, EPRI and others. The goal of AME was to bette' articulate the role of Asia, most important region in addressing global climate change. 23 energy and integrated assessment models participated in. Papers are published in the special issue of the Energy Economics[2].
EMF27	Stanford University, EMF (US)	The Energy Modeling Forum 27 (EMF27) study focuses on "Technology Strategies for Achieving Climate Policy Objectives" Project duration; 2010-12. Study results are published in the special issue of Climatic Change[3].
AMPERE	PIK (Germany)	AMPERE is an EU-funded international project in the period of 2011-2014. The project assesses the impact of the uncertainty of climate projection, the role of mitigation technology and delayed and fragmented climate policy. The results have been published in a special issue of the international journal Technological Forecasting and Social Change[4]. The AMPERE consortium comprises 22 institutions from Europe, Asia and the United States.
ADVANCE	PIK (Germany)	The ADVANCE project started in 2013 and continues until the end of 2016, funded by EU. One of the project objectives is to improve model representation of end-use technologies and consumer choices in order to make contribution to the IPCC AR6.
EMF30	Stanford University, EMF(US)	The EMF30 started in October 2013. This study considers the implications of the relationship between climate policy and air quality regulations, and of non-Kyoto radiative forcing projections uncertainties on climate policies, and makes a comprehensive assessment of a major increase in the use of modern bio-energy.

often based on the assumptions that ever country, including developing countries, makes the same GHG emissions reduction efforts with a universal carbon price (equal marginal abatement cost) under perfect global cooperation. Such assumptions, however, are characterized by unrealistically simplified world interpretation. It should be noted that, without this understanding, only the model results are cited and the misunderstanding is spread in the process of their secondary use.

With that in mind, the impacts of climate policy under a broader range of more realistic assumptions close to the real world situation have been scrutinized, especially after the publication of IPCC AR4. EFM27 and AMPERE projects introduced below are the cases of such efforts.

3. EMF27

The Energy Modeling Forum (EMF) organized by Stanford University has conducted energy-environmental inter-model comparison studies over the nearly last four decades since 1976. Significant number of the results learned from the exercise have been referred in the IPCC reports. The 27th EMF study explored global "Technology Strategies for Achieving Climate Policy Objectives" in conjunction with region specific sub-projects; EMF 24 focusing on the United States and EMF 28 for the EU. 19 energy-economy and integrated assessment models of universities and academic institutions from around the world, including RITE's DNE21+ model, participated in the EMF27.

The EMF 27 scenario matrix consists of 32 different technology and policy assumptions. The results gained from the participating models produced the following topic focused papers: renewable energies, traditional fossil fuel resources, bio-energy, energy efficiency, aerosols, and nuclear power. The EMF27 assessed the impacts of the variation of different assumptions about future technology availability and cost combined with different levels of climate policy, such as 550 ppm CO_2-eq target and 450 ppm CO_2-eq target.

Fig. 1 shows development of shares in global final electricity use and global electricity share in final energy over time in the Base case, 550 ppm CO_2eq. and 450 ppm CO_2eq. scenarios. As mitigation policies become more stringent, total amount of electricity used in the world gets relatively smaller toward 2050, but it rather increases in 2100. In terms of the share of electricity in final energy, there is a general trend toward electrification, especially after 2050 under the stringent climate policy. Robust results across models show that increased electrification with its de-carbonization is necessary to reduce CO_2 emissions significantly for

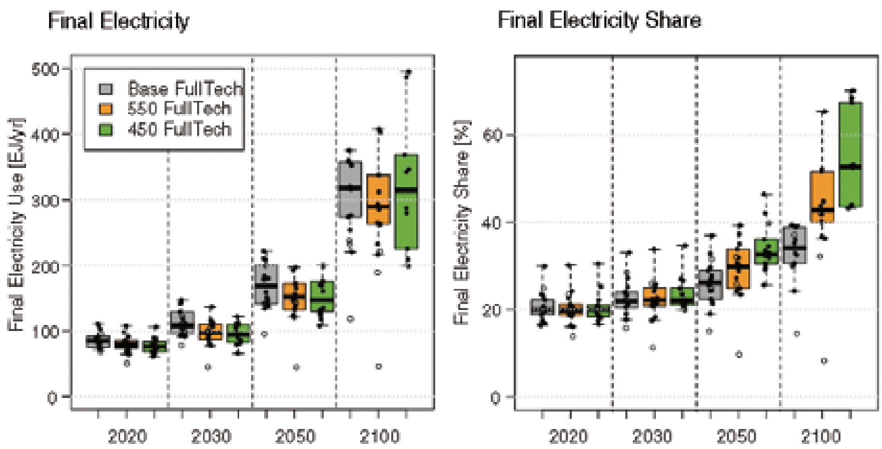

Fig. 1: Global final electricity use in the Base, 550 ppm CO_2eq., 450 ppm CO_2eq. scenario (EMF27)[3]

(a) Feasibility matrix of technology variation scenarios for different climate targets

	FullTech	LowEI	NoCCS	NucOff	LimSW	LimBio	Conv	EERE	LimTech
Baseline	13/13	13/13		11/11	11/11	13/13	13/13	13/13	11/11
550 ppm	13/13	13/13	12/12	11/11	11/11	13/13	13/13	12/12	6/9
450 ppm	10/11	9/10	4/11	9/10	9/10	9/11	8/11	6/11	0/10

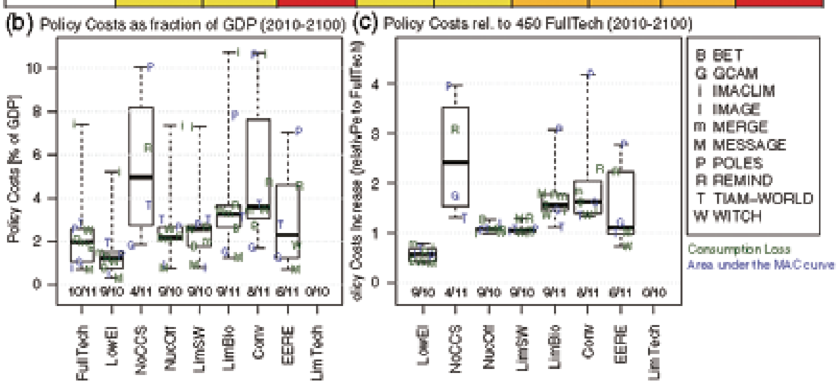

Fig. 2: Feasibility matrix of technology variation scenario for different climate target (a) and Policy costs for 450 ppm CO_2eq. scenario (b, c) (EMF27) [3]

Note: "FullTech" full suite of technologies represented in models, "LowEI" low energy intensity compared to the reference case, "NoCCS" CCS excluded from technology portfolio, "NucOff" phase out of nuclear energy, "LimSW" share of electricity production from solar and wind is limited, "LimBio" primary bio-energy supply is limited, "Conv" wind, solar and bio-energy supply are limited, "EERE" combination of low energy intensity, no CCS, and nuclear phase out, "LimTech" limitations of all energy mitigation technologies, including CCS, nuclear, solar, wind and bio-energy

450 ppm CO_2eq. target.

Fig. 2 illustrates feasibility matrix of technology portfolio for the Baseline, 550 ppm CO_2eq., and 450 ppm CO_2eq. scenarios (a), and policy costs for 450 ppm CO_2eq. scenario (b, c). 10 models out of 11 models indicate feasibility for 450 ppm CO_2eq. scenario with full technology deployment. Without CCS, however, only 4 models produce feasible technology solutions for 450 ppm CO_2eq. scenario. Even with the feasible solutions of the no-CCS scenario, mitigation costs jump up to 2.5 times higher relative to the reference scenario with full technology portfolio. If global primary bio-energy potential is limited to 100 EJ/yr (LimBio), mitigation costs to meet 450 ppm CO_2eq target increase to 1.5 times higher than the policy costs for the reference scenario. There are the ranges in the estimates of cost effects across models due to different configuration of each model, robust results can be obtained through inter-model comparison exercises. For the RITE's DNE21+ model, the most expensive case was "No-CCS" scenario followed by "EERE", the scenario for the combination of low energy intensity, no CCS, and nuclear phase out. There are some variations in the assessment of mitigation costs, the overall implications of technology availability on mitigation costs are consistent across models.

4. AMPERE

AMPERE（Assessment of Climate Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates） project is led by the Potsdam Institute for Climate Impact Research (PIK) and funded by the European Commission (external partners join on an in-kind contribution basis). Along with EMF27 exercise, the feasibility of significant emissions reduction for a variety of mitigation technology portfolios is assessed in the AMPERE. Below is the case assessment for the scenario of the resulting global GHG emission levels from the near-term pledges by 2020 and extrapolated the mitigation effort to 2030.

The pathway in green of the Fig. 3 indicates the development of global GHG emissions for the 450 ppm CO_2eq. scenario under the optimal condition assuming immediate introduction of global wide climate policies. Global emissions resulting from the pledges are subject to uncertainty, since some country pledges are associated with conditions or are defined relative to an uncertain business as usual path. Then, the blue trajectory follows a high ambition pledge pathway by 2030 and the red one follows a low ambition pledges by 2030, and thereafter both scenarios are adjusted to meet the 450 ppm CO_2 eq. target in the long term. Fig. 4 shows the average annual rate of CO_2 emission growth/reduction between 2030-2050 and 2010-2050 in the 450 ppm CO_2.eq scenarios (horizontal bars) and historical distribution of annual emission reduction rates across different countries of the world (20 year average between 1900 and 2009). With significant emission reduction until 2030, the required annual emission reduction to meet 450 CO_2eq. target diverges from the historical rates of change. If the emissions pathways are locked into the low ambitious Copenhagen pledges to 2030, further improvement is required after 2030. According to the analysis by RITE's DNE21+

model, more rapid emission reductions are required after 2030 thorough 2050, compared to the results of other models. There are many non-feasible results to meet the stringent target in model calculation, if there are technological constraints in the availability of CCS, nuclear and renewable energy.

There are two major policy implications. First of all, further global efforts toward 2030 would be necessary. The other would be that more feasible and moderate target could be on the table of negotiation because 450 ppm CO_2eq. corresponding to 2 degree target, often discussed as a long term target after the IPCC AR4, is not realistically feasible, given the various barriers in our world.

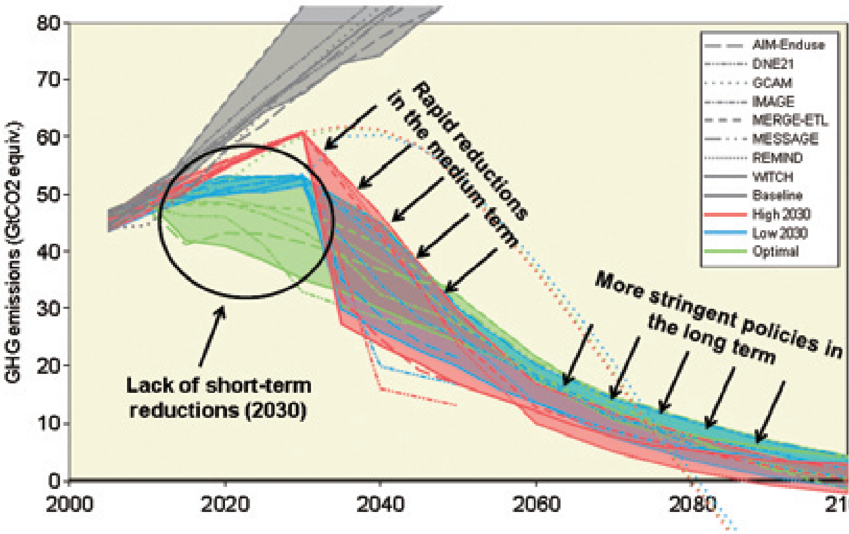

Fig. 3: Development of global GHG emissions for the 450 ppm CO_2eq scenarios[4] Optimal (Green), Low emissions with high ambition pledges (Blue), and High emission with low ambition pledges (Red)

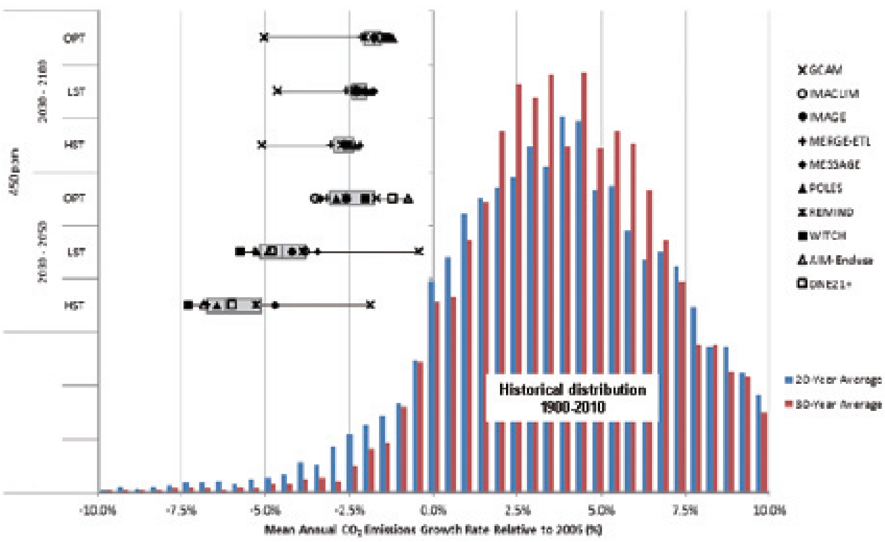

Fig.4: Historical annual emission reduction rates and average annual rate of CO_2emission reductions for the 450 ppm CO_2 eq. scenario[4]

5. Integrated Assessment Modeling Consortium (IAMC)

The Integrated Assessment Modeling Consortium (IAMC) created in 2007 is an organization of scientific research organizations that facilitates to coordinate interactions between IAMC members [5] and members of other scientific research communities studying climate change such as the Climate Modeling (CM) and the Impact, Adaptation, and Vulnerability (IAV). In the annual IAMC meetings, the members discuss future direction of climate change research. Membership is open to any organizations that conduct climate research, and RITE, as a member of the IAMC, has made contribution to the community since its inception.

RITE will continuously participate in the international model comparison projects to provide the results of RITE's model assessment and to disseminate relevant information internationally.

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Global Biorefinery Trends and Research Overview of the Molecular Microbiology and Biotechnology Group

1. Introduction

The biorefinery is a relatively recent concept to encompass technologies and industries that enable production of chemicals and liquid fuels from biomass. Its market may have the potential to generate as much as $300 billion by 2030. The biorefinery, along with information technology (IT), has been a key strategic mission of the U.S. since the 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. Similar to how IT-related ventures have contributed to expand their IT businesses, many biorefinery-related venture businesses established since the second half of the 1990s have succeeded in attracting funds through stock listing over several years. The financial outlay of biorefinery ventures may exceed total investments in IT businesses during the 1990s. The U.S. biofuel sector attracted substantial support from the U.S. government and benefited from the continued high price of crude oil. Over 200 corn-based ethanol plants were constructed and the biofuel market expanded rapidly, consuming around 40% of corn produced in the U.S.

However, the rapid expansion of large-scale bioethanol production was widely blamed for a worldwide surge in food crop prices since corn-based feedstock necessary to sustain the bioethanol production meant that there was a direct competition between bioethanol and the global supply of a major food staple. Therefore technological developments to avoid this competition with food materials have been carried out to use non-food agricultural residues (e.g. corn stover) as the major component of biorefinery feedstock, with most governments in the world also supporting these R&D efforts. Since cellulosic biofuels are more effective at reducing GHG (greenhouse gases) emissions compared to food-based biofuels, and cellulosic materials are abundant in many countries, cellulosic biofuels are greatly anticipated to underlie cleaner fuels for global warming prevention.

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

Global bioethanol production in 2013 was estimated to be 22.5 billion gallons (F.O. Licht, etc), an increase of 1.5% from the previous year. Bioethanol production in the U.S. was also somewhat increased and it still accounted for ca. 60 % (13.5 billion gallons) of the global production.

2-1. Renewable Fuel Standard 2 and modification of 2014 target

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 the Renewable Fuel Standard (RFS). The original RFS of 2005 was upgraded to RFS2 in the Energy Independent and Security Act of 2007 (Fig. 1). A turning point to non-food cellulosic materials 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 after 2010 (Fig. 2). However, actual production volume of cellulosic biofuels has not reached to the modified volumes since 2010.

In November 2013, EPA released modified targets of the 2014 application of the RFS2, where it proposed cutting the biofuels mandate for 2014 by 16% to 15.21 billion gallons (total renewable fuels). This reduction is considered to be due to an increase of U.S. oil production by shale energy revolution and a decrease of gasoline consumption. At the same time, the EPA increased cellulosic biofuel target to 17 million gallons, which is ca. 3 times larger than the previous year (6 million gallons). The increased cellulosic ethanol target of 2014 depends on the starting of large-scale ethanol plants (10~20 million gallons per year) by

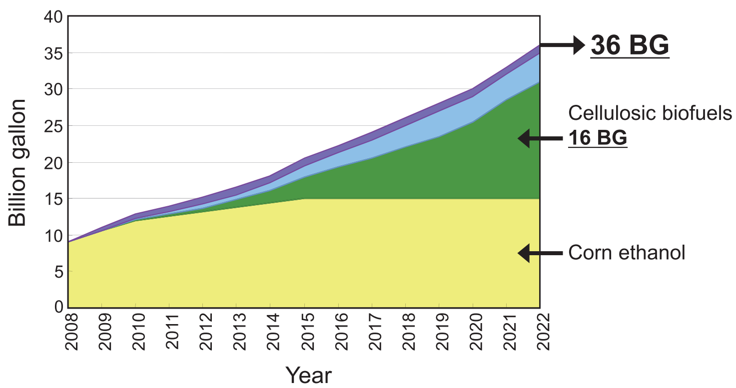
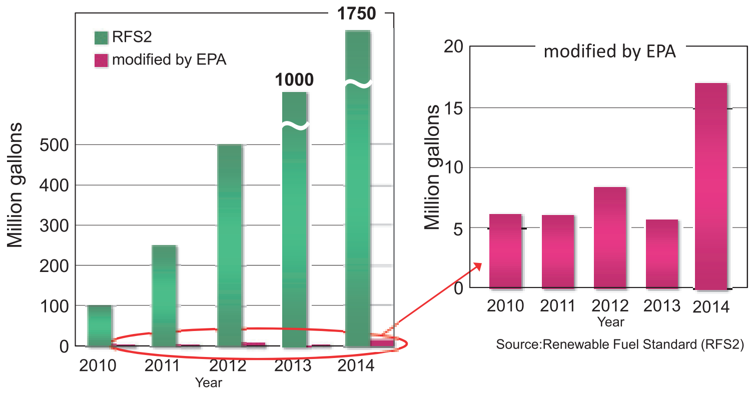


Fig.1: RFS2 biofuel mandate in U.S.



Source: Energy independence and security act of 2007(EISA2007), Renewable Fuel Standard(RFS2)

Fig.2: RFS2 cellulosic biofuels mandate and modification

global major chemical companies or their venture businesses which use agricultural residues such as corn stover. Nevertheless, the start of operations is behind schedule by 3 to 4 years. The following chapter describes the reasons for the delay.

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. 3).

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.

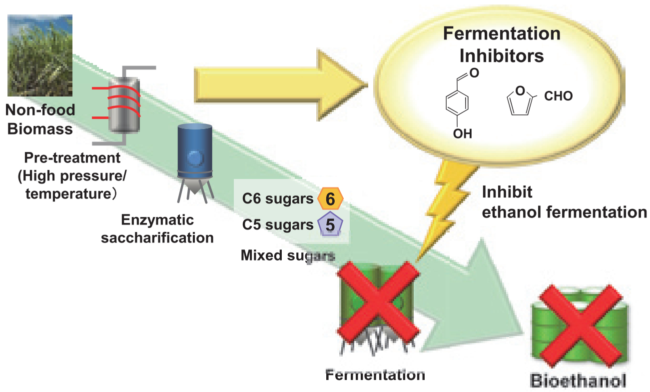


Fig. 3: Obstacles to industrialization: Fermentation inhibitors

Trade-offs between the severity of pre-treatment and the amount cellulose enzyme necessary must therefore be made (Fig. 4). 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.

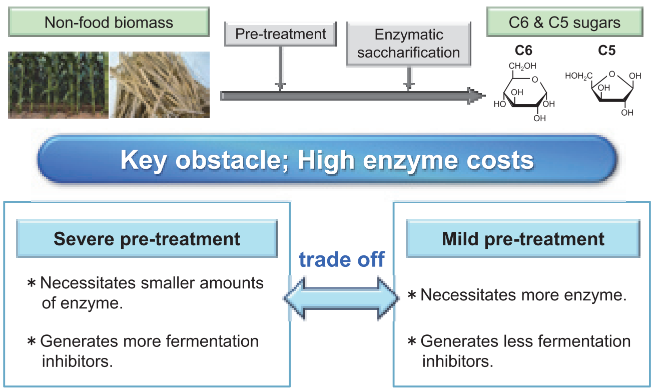


Fig. 4: Obstacles to industrialization: Saccharification costs

2-3. Outlook of next generation biofuel Butanol

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.

There are two main approaches to efficient biobutanol production process under current development. The first is the improvement of traditional ABE fermentation process using species of Clostridium bacteria and biomass sugars, while the other one introduces biosynthesis pathways into industrial microbes such as *E. 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.

Recently, biobutanol is starting to attract attention as one component of biojet fuels. According to an IEA report (IEA Energy Technology Perspective 2010), CO_2 emissions from the aviation sector will become most significant, contributing 40% of total CO_2 emission of the global transportation sector. Currently, worldwide flights by aircrafts contribute 20% of the CO_2 emissions of the global transportation sector, but it is not easy to reduce these CO_2 emissions from the aircrafts fundamentally. Therefore it is considered that the CO_2 emissions of aircrafts must continue increasing with an increase in the number of passengers from emerging countries and LCC (low cost carriers), even if technologies for weight saving of the aircraft body progress. For this reason, utilization of sustainable biofuels in place of crude oil-based jet fuels is expected to reduce the proportion of CO_2 emissions by the worldwide airline industry (Fig. 5).

Since butanol can be easily converted to jet fuels by oligomerization and hydrogenation (Fig. 6), some venture businesses in the U.S. have started technology developments and collaboration works of biobutanol production at commercial scale. Irrespective, the use of non-food biomass is eventually as essential a requirement for sustainability as the cellulosic ethanol production.

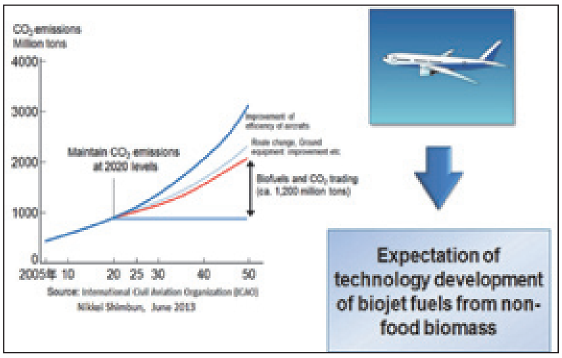


Fig. 5: Measures against CO_2 emissions of international aviation

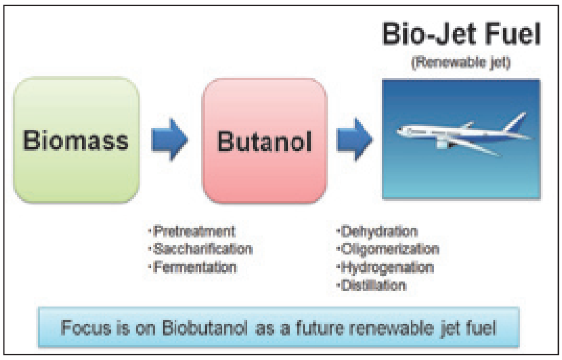


Fig. 6: Biobutanol toward materials for biojet fuels

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.

Global major chemical companies are constructing production systems by using renewable resources as raw materials. These efforts are considered to aim at making sustainable production systems to reduce the dependence on fossil resources. Therefore, these companies have launched collaboration works with venture businesses which have advanced technologies, and started technology developments to replace their fossil resources with renewable ones.

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 (SIM), the first Japanese scientist to receive the prestigious award (see RITE Today 2012, 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 RITE Today 2013, Topics).

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. 7). 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.

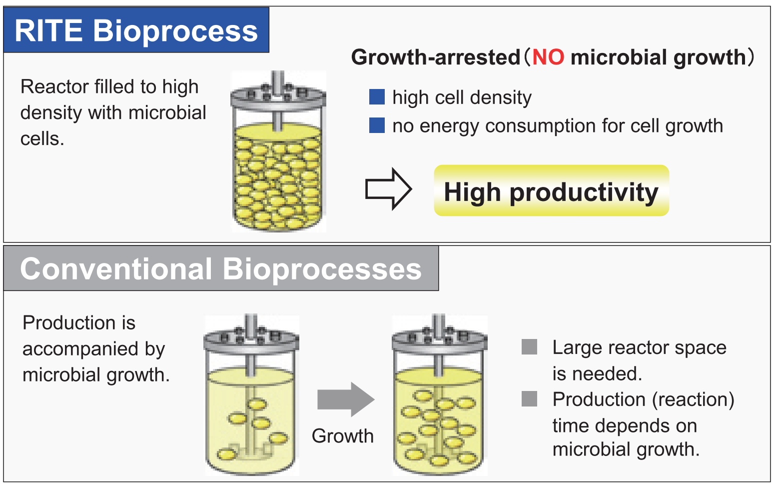


Fig. 7: Comparison of RITE Bioprocess with conventional bioprocess

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.

4-2. Simultaneous utilization of C6 and C5 sugars

Lignocellulosic biomass hydrolysates constitute complex mixtures of different sugars (Fig. 8). 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 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.

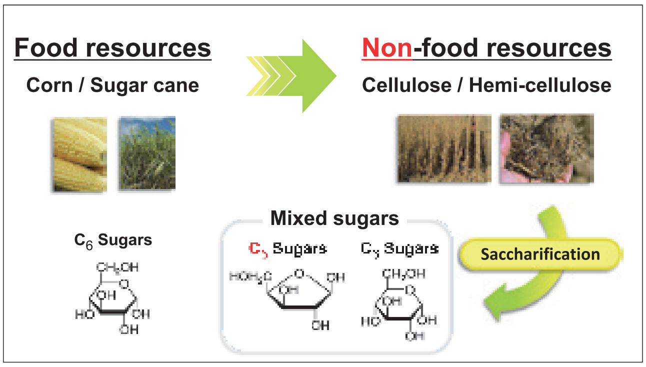


Fig. 8: Expanding usage of mixed sugars from non-food biomass

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. 3). 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. 9).

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.

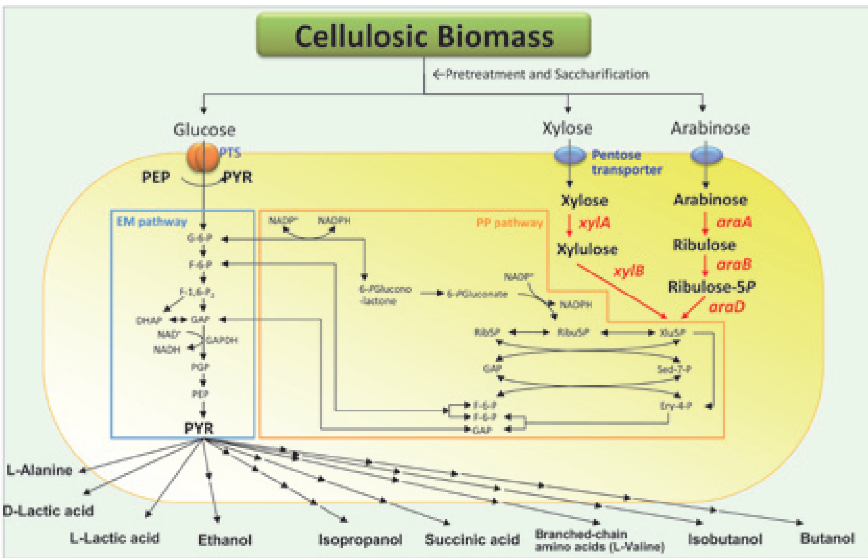


Fig. 9: Production pathways of coryneform bacteria designed for acyclic chemicals and biofuels

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 of 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).

In January 2014, a new research center (Green Earth Research Center), which has a pilot production facility, opened at the Kazusa Akademia Park in Chiba prefecture, where the production of chemicals is going to be demonstrated by using non-food biomass (C5 & C6 sugars) toward a large scale production.

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

NREL, founded by DOE (U.S. Department of energy) 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.

NREL started joint research with RITE based on our RITE Bioprocess in 2011, because NREL paid attention to our attempts to reduce the effect of fermentation inhibitors. Consequently, the prospects of solving the problems of fermentation inhibitors at a research level by combining our mutual research results are apparent. Now we have set up efforts with the participation of GEI, targeted at early actualization of an economically efficient production process for ethanol using non-food biomass.

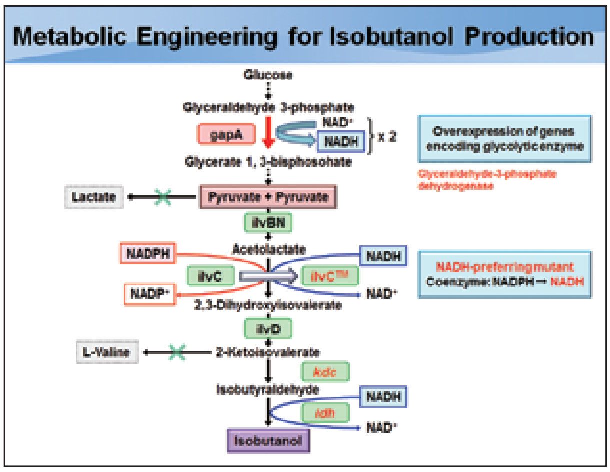


Fig. 10: Metabolic engineering for butanol production

5-3. Research on biobutanol

As described in the previous section, we conduct the development of a highly efficient technology to produce butanol from non-food biomass by using RITE Bioprocess with coryneform bacteria harboring butanol biosynthesis ability. In order to obtain high conversion rates (sugar-based yield) to butanol from mixed sugars derived from cellulosic biomass, we investigated improved performance of the cells by metabolic engineering, achieving high STY with respect to the butanol production (Fig. 10).

It is known that butanol has strong cell toxicity against cell growth and inhibits microbial butanol production, but coryneform bacteria show much better tolerance to butanol than other industrial microbes. Therefore high production performance is expected for the coryneform bacteria. In addition, we started a new R&D project aimed at materials for biojet fuels based on non-food biomass as raw materials (see Topics).

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. 11).

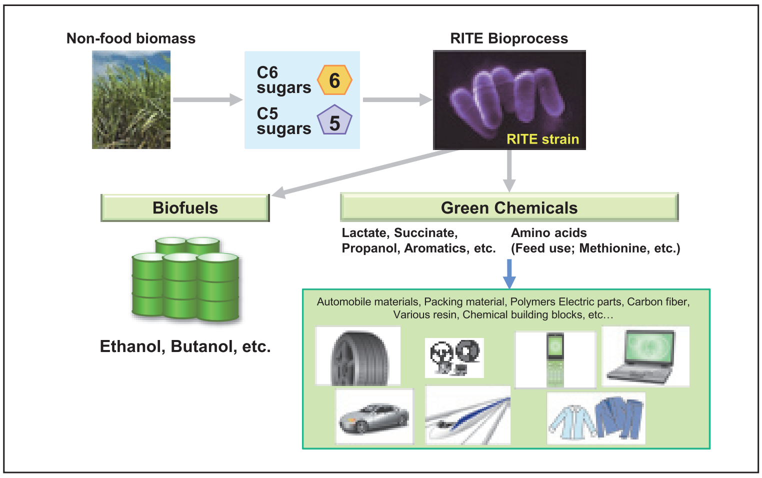


Fig. 11: Early realization of biorefinery

Chemical Research Group

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Challenges for Advanced Industrialization of CO_2 Capture Technologies and Development of Inorganic Membranes and Membrane Reactors for H_2 Energy Production

1. CO_2 capture technologies

CO_2 capture and storage (CCS) entails CO_2 (a greenhouse gas) capture from fossil fuel combustion gas emissions from large emission sources such as electric power plants and factories, and subsequent containment of the captured CO_2 into geological formations for storage or sequestration.

Current CO_2 capture costs from emission sources are estimated to be about 60% of the CCS costs. Therefore, reduction of CO_2 capture costs is an important aspect for practical application of CCS.

The Chemical Research Group studies various CO_2 capture technologies, with a special focus on chemical absorption, membrane separation, and adsorption methods that have generated significant outcomes for the progress of worldwide research in this particular field. Materials development, processing, and system investigation are conducted in the group.

We developed innovative chemical absorbents under the Cost Saving CO_2 Capture System by Utilizing Low-grade Waste Heat (COCS) project and the CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50 (COURSE 50) project that enabled a CO_2 capture energy consumption of 2.0 GJ/t-CO_2 and CO_2 regeneration from the absorbents at temperatures of less than 100°C that are lower than the required temperature of 120°C as featured in the steel-making industry.

One of the outstanding developed absorbents was selected for application in a commercial CCS plant owned by a private Japanese company.

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

Our investigations demonstrated the excellent separation performance of new types of dendrimer/polymer hybrid membranes for separating CO_2 from CO_2/H_2 gas mixtures. RITE and three private companies have established a joint research association for developing membrane modules and separation systems for practical application.

Recently, we succeeded in further improving the separation performance by modification of polyvinyl alcohol (PVA) polymer materials; the target separation performance was obtained at 0.7 MPa.

Based on our technologies, we are also investigating solid sorbents for CO_2 capture to efficiently reduce energy costs and methods for evaluation of the CO_2 capture process. We are currently examining the synthesis of novel solid sorbents capable of achieving a 1.5 GJ/t-CO_2 for regeneration energy. We have successfully developed a new solid sorbent that can be regenerated at low temperatures. Evaluation for practical use is now underway.

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

Moreover, we have developed seed technologies such as CO_2 separation by zeolite membranes, H_2 separation by palladium membranes, a hybrid CO_2 capture system that combines the membrane technology with chemical sorption processes, and baroplastics that have low-temperature flow under high pressures for various purposes. More specifically, the membrane/absorption hybrid CO_2 capture technology has been used 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, CO_2 is chemically absorbed in an amine-based solution and released by heating the solution. This technology is suitable for CO_2 separation from normal-pressure gases generated in industries.

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

Between 2004 and 2008, the implementation of the COCS project was assessed for capturing and separating CO_2 from steel-making blast furnace gases. Various types of high-performance absorbents were developed under this project. The CO_2 capture energy consumption of the absorbents (termed as RITE solvent) was significantly reduced when compared with that of the MEA (monoethanolamine)-based solvent that is typically used as a benchmark (Fig. 1).

A follow-up project (COURSE 50) was examined between 2008 and 2012 that was aimed at capturing CO_2 in the steel-making industry. Under this project, we achieved our target CO_2 capture energy consumption of 2.0 GJ/t-CO_2. Moreover, the development of breakthrough absorbents that enabled CO_2 regeneration at temperatures (<100°C) lower than the conventional temperature (120°C)

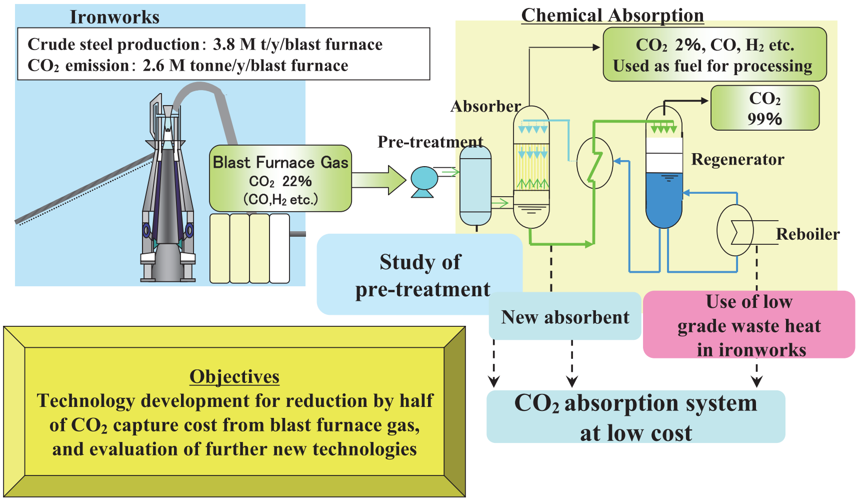


Fig. 1: Cost-saving CO_2 capture system scheme (COCS project)

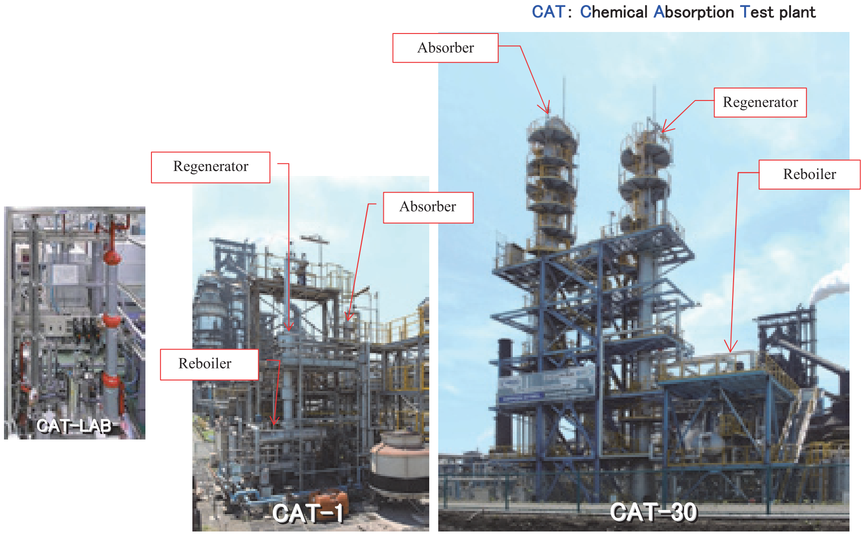


Fig. 2: Snapshots of the testing units

was successfully achieved (Fig. 2).

Starting in 2013 and intending to finish in 2017, we are conducting the COURSE 50 Step 2 project where we develop absorbents with higher performances, enabling a reduced CO_2 capture cost in the steel-making industry.

As additional outcomes of the research and development (R&D) on highly energy-efficient absorbents, we developed chemical absorbents with excellent CO_2 absorption and desorption performances, which enable CO_2 regeneration under high pressures.

The newly developed solvent shows a high-CO_2 recovery and high-CO_2 absorption and desorption rates. This suggests that the solvent can recover CO_2 with reduced energy consumption under high pressures. The total energy for CO_2 separation and capture, including the compression process, has been estimated to be lower than 1.2 GJ/t-CO_2.

3. CO_2 and H_2 separation using polymeric membranes

The government of Japan has set a goal to reduce CO_2 emissions to half of the current emission levels by 2050 under the project “Cool Earth 50”. One promising means of reducing CO_2 emissions is the development of a joint integrated coal gasification combined cycle and CO_2 capture and storage system (IGCC–CCS) (Fig.3).

In the IGCC-CCS process, membranes are used for CO_2 separation, and 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 is 1500 JPY/t-CO_2 or less.

We are currently developing a CO_2 molecular gate membrane, with the goal of producing a high-performance separation membrane. Fig. 4 shows a schematic illustration of the working principles of a CO_2 molecular gate. The pathway for gas molecules is solely occupied by CO_2, which acts as a gate to block the passage of other gases. Consequently, the amount of N_2 or H_2 diffusing to the other side of the membrane is greatly reduced and high concentrations of CO_2 can be obtained.

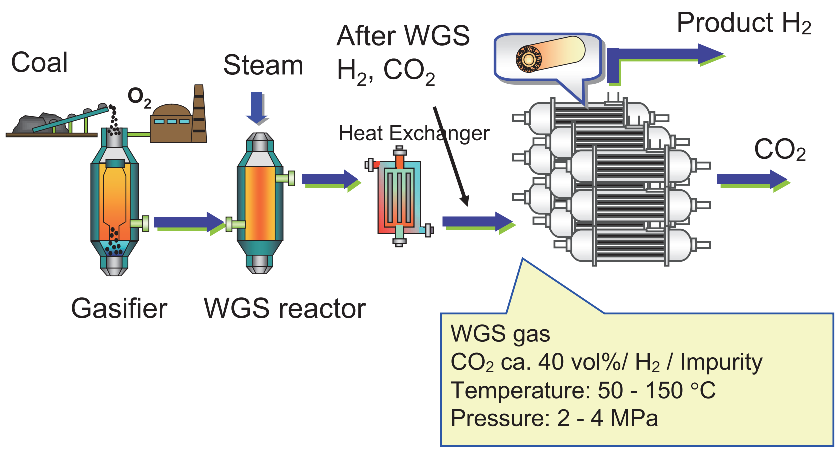


Fig. 3: Schematic of IGCC-CO2 capture system

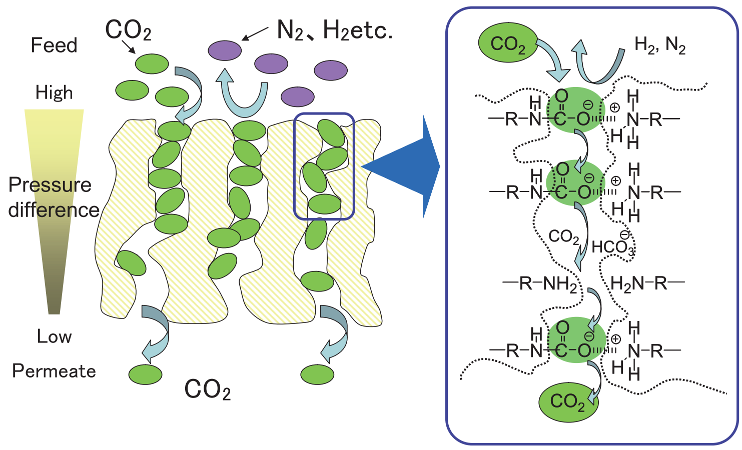
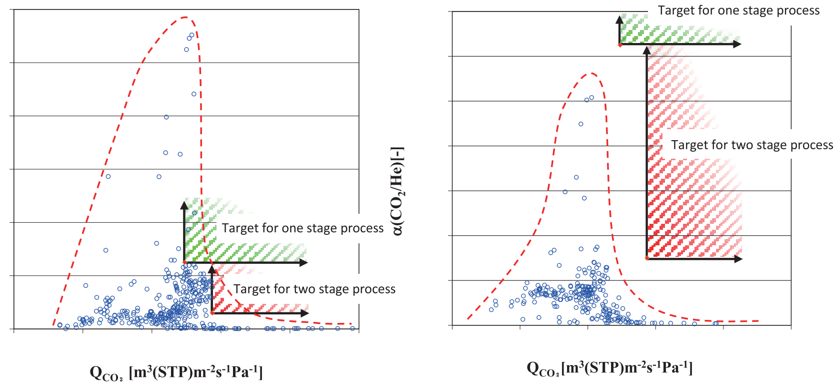


Fig. 4: Schematic diagram of the molecular gate membrane



(a) Separation performance at atmospheric pressure

(b) Separation performance at 0.7MPa

Fig. 5: Separation performance of PVA-based molecular gate membranes (Q_{CO_2}: CO_2 permeance; α : selectivity)

Furthermore, new types of dendrimer/polymer hybrid membranes with an excellent separation performance for separating CO_2 from CO_2/H_2 gas mixtures were successfully developed, enabling high CO_2 permeance and CO_2/H_2 selectivity (Fig. 5).

Based on these materials, RITE, Kuraray Co., Ltd., Nitto Denko Corporation, and Nippon Steel & Sumikin Engineering Co., Ltd. established Molecular Gate Membrane Module Technology Research Association, whereby membranes, and membrane modules and separation systems are being developed (Fig. 6). Kuraray Co., Ltd. and RITE are collaborating to develop membranes with a target CO_2 capture cost of 1500 JPY/t-CO_2.

Recently, we succeeded in improving separation performance by modification of PVA polymer materials, and the target separation performance was achieved at 0.7 MPa.

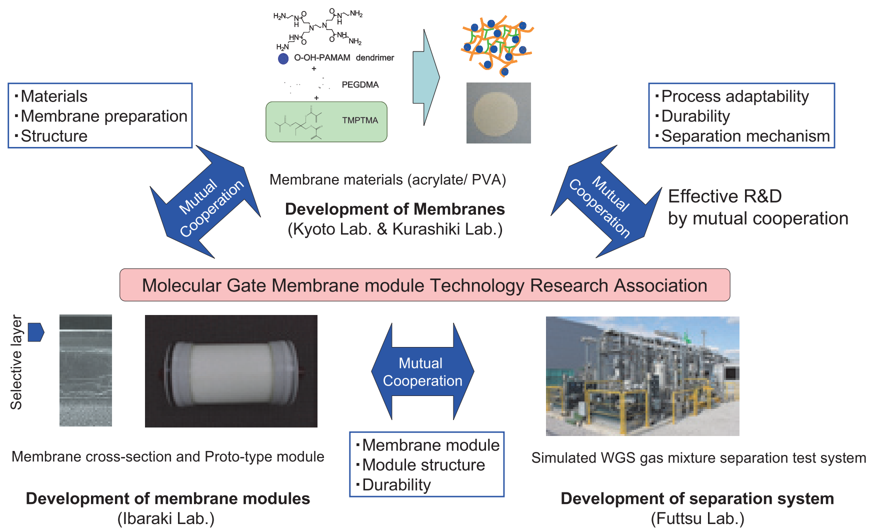


Fig. 6: Development of membrane modules in collaboration with private companies

In the future, we will investigate the effect of pressure on the membrane modules for practical use.

During the development of CO_2 molecular gate membranes, RITE conducted a joint research with the US Department of Energy National Energy Technology Laboratory (NETL) under a recognized project for the Carbon Sequestration Leadership Forum (CSLF)*.

*CSLF is a ministerial-level international climate change initiative that is focused on the development of improved cost-effective technologies for the separation and capture of CO_2 for its transport and long-term safe storage.

4. Advanced development of CO_2 capture by solid sorbents

The imminent commercial implementation of the CCS technology is strongly desirable. Recent R&D on CCS has focused on demonstration and feasibility studies of commercial-scale systems. However, a low-cost CO_2 capture technology with lower energy consumption is required. RITE has conducted a project funded by the Ministry of Economy, Trade and Industry (METI) since 2010.

The research objectives are to develop solid sorbents for an energy-saving CO_2 capture system and to establish evaluation standards of CO_2 capture systems. We are endeavoring to fabricate novel solid sorbents that are applicable to CO_2 capture from coal-fired power plants with a target capture of 1.5 GJ/t-CO_2 (Fig. 7).

Solid sorbents prepared from amines and porous supports exhibit similar CO_2 sorption characteristics to those of liquid amine solvents. Additionally, solid sorbents have the advantage of a lower expected heat duty for regeneration processes. Following exchange of information on solid sorbents with NETL, RITE has started to develop new solid sorbents using amine compounds, as synthesized by RITE.

The relationship between amine structures and their CO_2 desorption per-

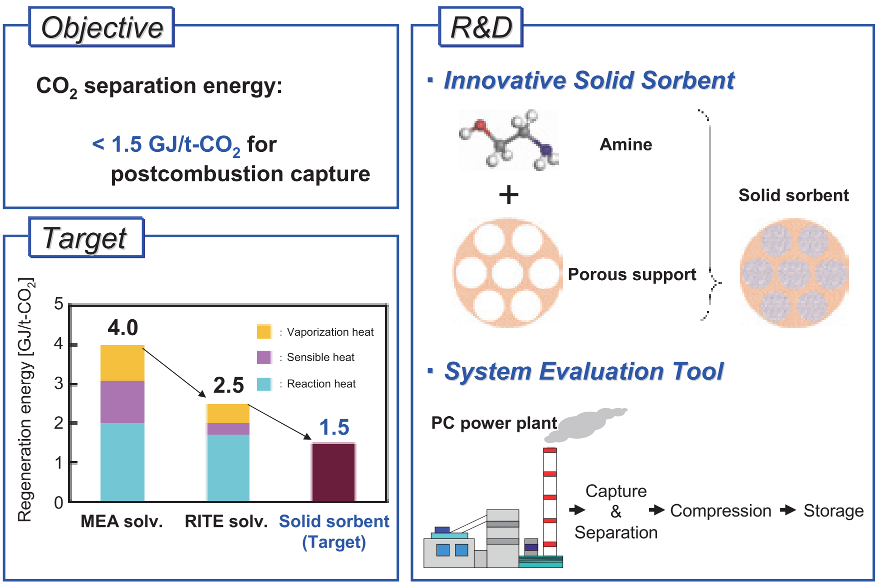


Fig. 7: Development of a CO_2 solid sorbent scheme

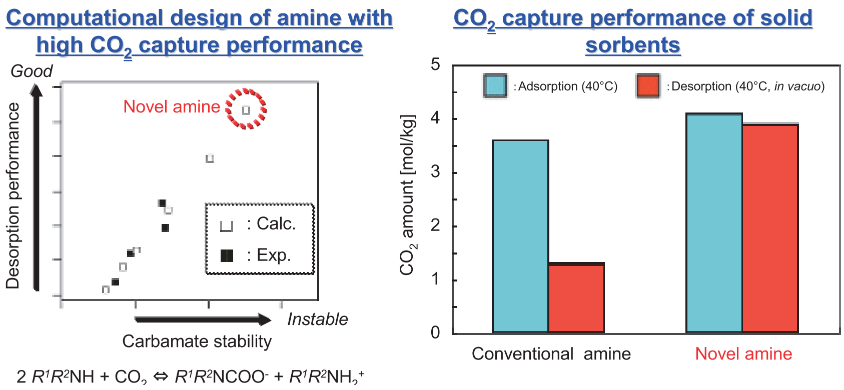


Fig. 8: Performance of a CO_2 solid sorbent system

formances was established by computational chemistry. The finding led to the fabrication of a more efficient solid sorbent in terms of desorption performance and the sorption capacity (Fig. 8).

RITE conducted simulation studies to accurately estimate the energy and cost of CO_2 capture from coal-fired power plants (Fig. 9). The CO_2 capture process was modeled based on amine–CO_2 chemical reactions. The energy efficiency of a power plant with a CO_2 capture system was estimated to improve by about 2% when a solid sorbent was alternatively used over an advanced liquid amine solvent.

Currently, we are evaluating the solid sorbent process using a lab-scale adsorption/regeneration test apparatus, and also carrying out simulation studies on the resulting efficiency penalty of power generation. Examination of the practical use of the RITE-developed solid sorbent is underway.

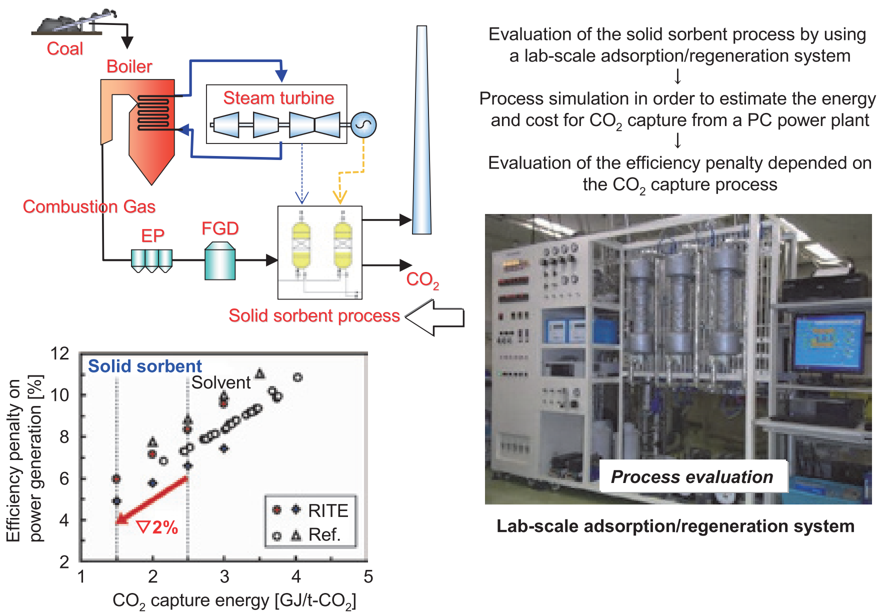


Fig. 9: Performance of a CO_2 capture solid sorbent system implemented in power plants

5. Development of inorganic membranes for H_2 energy production

The Chemical Research Group has developed various CO_2 capture technologies for CCS. In the future, we will study technologies for reducing CO_2 emissions. For example, we will study H_2 production processes, from renewable energy sources (e.g., natural energy and biomass), that generate negligible CO_2 emission levels. To this effect, RITE started to develop H_2 selective inorganic membranes.

In 2013, RITE began a new project funded by Ministry of Education, Culture, Sports, Science and Technology (MEXT). In this project, we develop H_2 selective inorganic membranes (e.g., chemical vapor deposition-prepared silica membranes, Pd membranes) in collaboration with Hiroshima University, Yamaguchi University, Utsunomiya University, Kogakuin University, and National Institute of Advanced Industrial Science and Technology (AIST) for H_2 separation from H_2 carrier gas (e.g., methylcyclohexane, ammonia). We also investigated methods for evaluating the pore size distribution of the inorganic membranes.

In the same year, RITE also began another project funded by METI. For this project, RITE collaborates with Chiyoda Corporation to conduct feasibility studies on membrane reactors for compact and low-temperature operation systems for H_2 generation from methylcyclohexane.

In the COURSE 50 Step 2 project, chemical vapor deposition-based silica membranes will be developed as membrane reactors (water gas shift reaction and H_2 separation) for H_2 generation from blast furnace gas.

CO_2 Storage Research Group

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Moving toward Commercialization of CO_2 Storage Technologies

1. Overview

Controlling the emissions of carbon dioxide (CO_2), a dominant component of greenhouse gases (GHG), is an imminent issue. Carbon capture and storage (CCS) is a series of technologies for separating, capturing and geologically storing CO_2 emitted from large emission sources, such as thermal power stations and steel mills. CCS is considered as one of the effective CO_2 mitigation options, together with fuel energy efficiency, alternative fuel use, and renewable energies.

The International Energy Agency (IEA) positions CCS as an important decarbonising energy technology. Its "Energy Technology Perspectives 2012 (ETP 2012)" requires 17% contributions from CCS to CO_2 emission reductions in 2050 to achieve the globally agreed-upon target of limiting average global temperature increase to 2°C.

In this context, Japan launched the large-scale CCS demonstration project in Tomakomai, Hokkaido. Currently, Japan CCS Corporation advances drilling works and other preparations for the project start. In the demonstration project, more than 100 thousand tons of CO_2 will be captured from a large-scale emission source and injected into two geological formations (Moebetsu formation at 1,100 - 1,200 meter depth and Takinoue formation at 2,400 - 3,000 meter depth) annually, while being monitored to ensure the safety of the project.

RITE carries out a wide range of research and development programs on geological storage of CO_2, a Japan-China CCS-EOR project, and a global CCS trend survey program in partnership with international bodies. RITE aims to apply the outcome of our programs to the large-scale CCS demonstration project and to facilitate the implementation of CCS in Japan.

2. Research and Development of geological storage of CO_2

Geological storage of CO_2 includes injecting CO_2 into oil fields to enhance oil recovery (EOR); injecting CO_2 into coal seams to enhance methane recovery (ECBM); sequestrating CO_2 in depleted gas fields; and storing CO_2 in deep saline aquifer. The deep saline aquifer for storing CO_2 has impermeable caprock formations (mudstone layer) with high sealing properties above the aquifer (sandstone

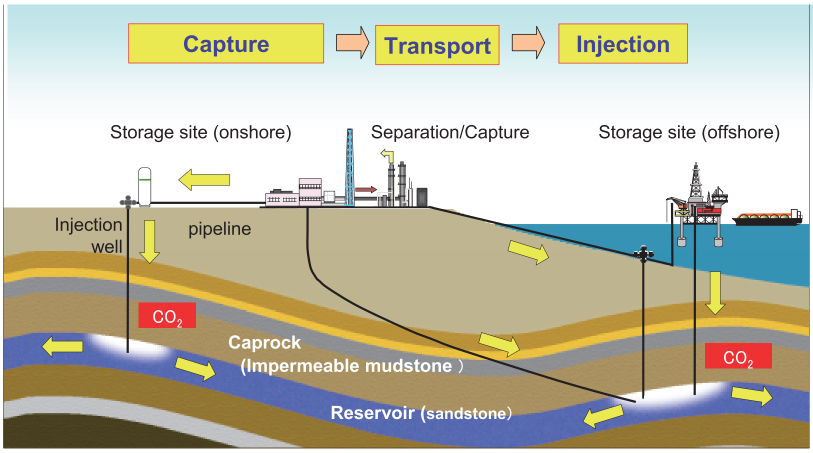


Fig. 1: Concept of geological storage of CO_2

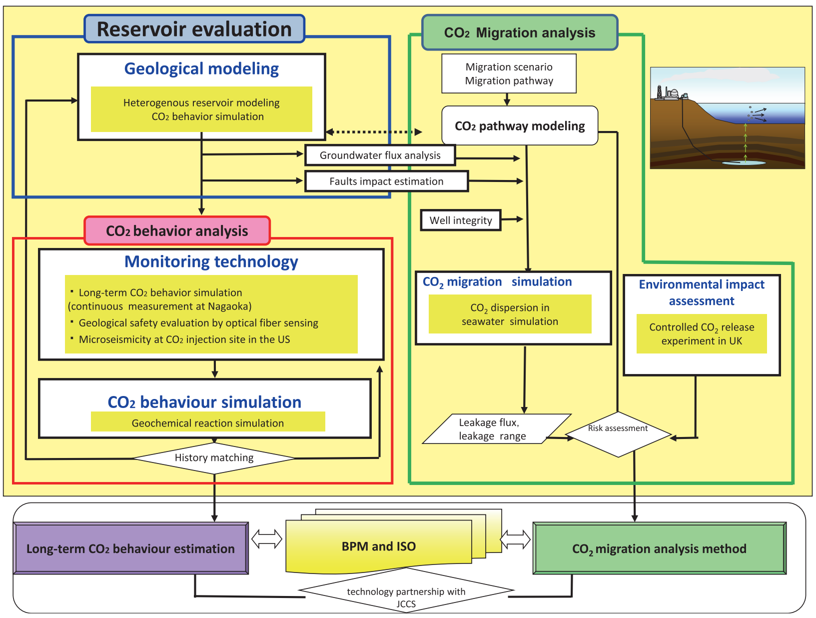


Fig. 2: R&D on CO_2 geological storage technologies

layer). Thus, once injected, CO_2 can be stably and safely stored for a long period of time.

Fig. 2 shows RITE's study works on geological storage of CO_2: evaluating storage performance (building geological models), analyzing CO_2 behavior in reservoir (monitoring and numerical simulation of CO_2 behavior), and analyzing CO_2 migration from reservoir (numerical simulation of CO_2 migration and developing methods for offshore environmental impact assessment). Furthermore, RITE is documenting best practice manuals based on our work and the lessons we have learned from the projects in and out of Japan.

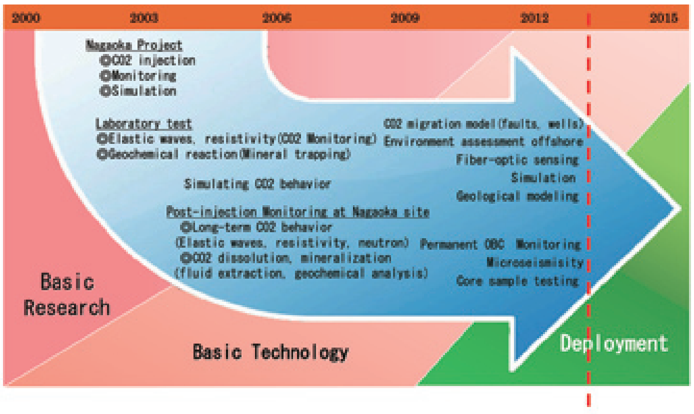


Fig. 3: History of RITE's R&D

2-1. Development of techniques of evaluating storage performance

RITE is developing methods of evaluating storage performance under two programs: "establishing a Japan-specific geological formation model" and "developing methods of analyzing a groundwater flow".

In order to establish a Japan-specific geological formations model, we are looking to the geological models and characterization often used in oil and gas fields, clarifying to what extent they can be applied to CCS, and establishing CCS-specific modeling to characterization. Compared to oil exploration, available data in CCS is insufficient from cost and leakage prevention perspectives. The number of wells and data from seismic surveys are limited in CCS. Accordingly, the uncertainty over geological characterization and reservoir models increases, greatly affecting on simulated results such as CO_2 injectivity and CO_2 distribution projection. RITE is developing methods of creating geological formation models by combining insufficient geological information with statistical analysis. Taking Nagaoka site's sand-mud alternate formations as an example, we examined geological characterization based on limited geological and geophysical data and has successfully built a reservoir model that is critical to analyzing the behavior of CO_2.

In order to develop methods of analyzing a groundwater flow, we presumed that CO_2 is geologically stored in the coastal areas of Japan, and collected

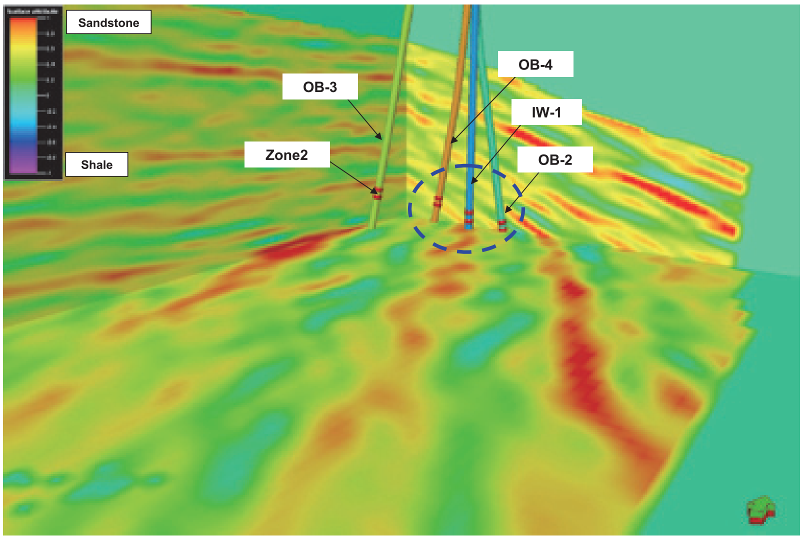


Fig. 4: Geological models based on 3D seismic survey

existing geological data to create a hydro-geological model. Using the model, the groundwater flow was simulated. It was found that: pre-injection salinity concentration distribution in the groundwater is a key factor to estimate the environmental impact of CO_2 injection on brine and its intrusion into shallow geological formations; and more precise estimation of the groundwater flow requires physical rock properties, such as porosity and permeability, on the basis of core samples from a storage site, instead of literature values.

2-2. Analyzing CO_2 behavior within reservoir

In order to enable massive deployment of geological storage of CO_2, it is important to monitor the injected CO_2 in a deep reservoir and demonstrate the effective and safe storage of CO_2. To this end, RITE is comprehensively analyzing the data from physical loggings at Nagaoka site to clarify the mechanisms of storing CO_2 and better simulate the long-term behavior of CO_2. Also, RITE is actively developing other technologies on geological storage of CO_2, including fiber-optic sensing for monitoring geological formations deformation.

- Monitoring geological deformation with fiber-optic cables

In addition to temperatures and pressures, monitoring geological formations deformation, particularly the continuous monitoring in a depth direction, is critical in evaluating the integrity of geological storage of CO_2. RITE has been developing monitoring of geological formations deformation in fiber-optic sensing and established basic technologies of measuring the deformation using optic fiber cables. To aim for commercialization of the basic technologies, we tested fiber optic cables by installing them in a 300-meter-deep well in 2012 and successfully measured geological formations deformation accompanied by CO_2 injection. We will continue the field test until the end of 2013 to tackle other technical issues toward commercialization.

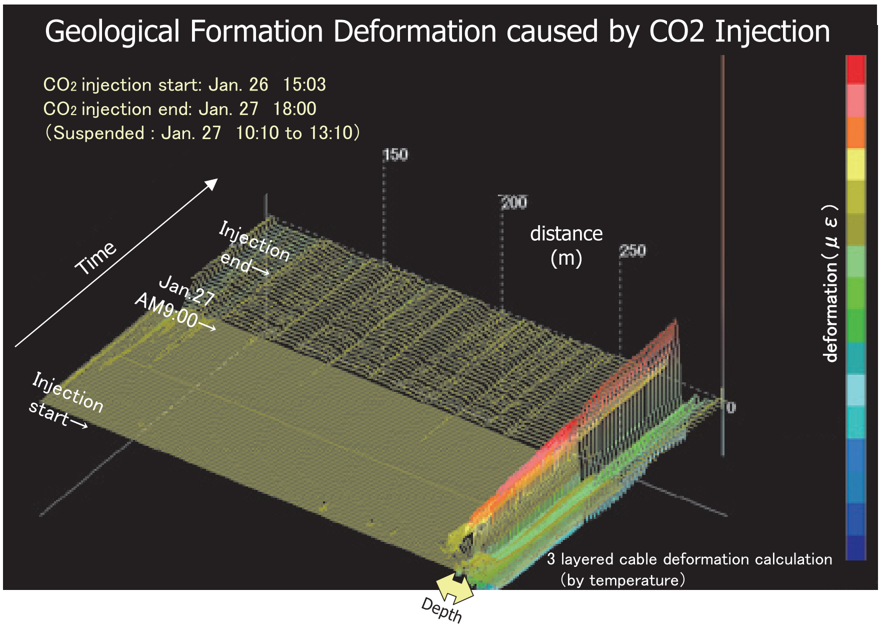


Fig. 5: Measurement Results Image using fiber-optic cables

Under commercial conditions, fiber optic cables fit in with geological storage of CO_2 are desirable. Thus, RITE is developing a fiber optic cable that is sufficiently robust and highly sensitive to temperature, pressure, and deformation when installed in the subsurface.

- Analysis with X-ray CT scanner

To evaluate long-term integrity of geological storage of CO_2 in deep reservoir, it is important to understand CO_2 behavior in heterogeneous reservoir and to reveal the replacement mechanism between formation brine and CO_2. Laboratory experimental studies about the effects of heterogeneity in saturated porous

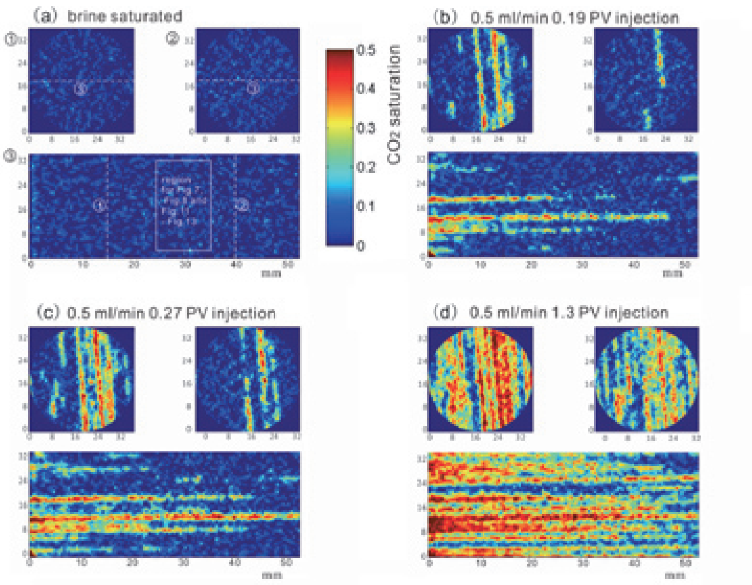


Fig. 6: Visualized CO_2 distribution in core samples

sandstone on CO_2 distribution provide important clues for developing tools that predict the behavior of multi-phased fluid flow in the up-scaled field storage site. X-ray CT imaging technique enables in-situ monitoring of the multi-phased fluid flow. On the basis of X-ray CT image analyses, RITE conducts technological development in evaluating petrophysical properties quantitatively from their relationships to rock porosity and degree of fluid saturation.

- Monitoring with Permanent OBC

Monitoring the behavior of CO_2 will be a key focus for research toward commercial deployment of CCS. One of the most promising monitoring methods is “Time-Lapse 3D seismic survey”. Its effective offshore application is a permanent ocean bottom cable (OBC) system. In the OBC system, sensor modules are deployed in the seabed of a target area, enabling efficient, cost-effective and high-quality measurement. RITE has so far conducted field tests of the system off the coast of Tomakomai (Hokkaido) and Hiratsuka (Kanagawa prefecture). In 2013, the OBC system was installed in the target seabed of the Tomakomai large-scale demonstration project. Preparations to simultaneously conduct time-lapse 3D seismic surveys and microseismic measurement are currently underway.

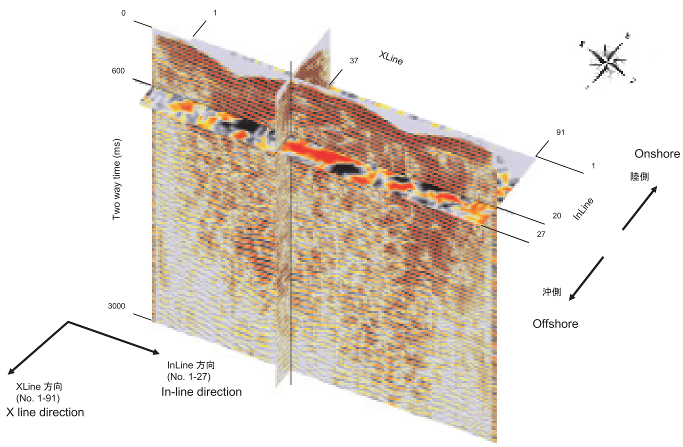


Fig. 7: Time-lapse 3D seismic images using Permanent OBC

- CO_2 behavior at Nagaoka site

RITE conducted CO_2 storage demonstration project in Nagaoka, Niigata from July 2003 to January 2005. In the project, 10,400 tons of CO_2 were injected into a deep saline aquifer at 1,100 meter depth and cross-well seismic tomography survey and physical loggings were carried out to understand the behavior of CO_2 in the subsurface. On the basis of obtained data, RITE has developed a long-term simulator for predicting the behavior of injected CO_2.

Changes in physical properties in the area of observation wells were measured by physical loggings. CO_2 distribution spreading in the depth direction of the aquifer and the state of injected CO_2 (whether in supercritical phase or dissolved in formation water) were estimated from the measurement results.

In 2013, RITE further conducted physical logging to check post-injection storage state of CO_2. History matching was carried out using the logging results to advance the numerical simulation of long-term CO_2 behavior. Although there have been many demonstration projects of geological storage of CO_2 in the world, Nagaoka is the only project that is continuously monitoring the CO_2 behavior even after the end of CO_2 injection. Thus, global attention has been put on our results.

2-3. Analyzing CO_2 migration from reservoir

RITE is developing simulation models for CO_2 leakage from reservoir as a part of our safety assessment technology development program.

Simulating CO_2 leakage from reservoir to seawater column requires two kinds of models, one of which simulates CO_2 migration within geological formations and the other simulates CO_2 dispersion in seawater. The model for geological formations simulates CO_2 migrating from the reservoir to the seabed, presuming that faults and abandoned wells serve as leaking pathway. Simulated results show that the model for geological formations needs to be site-specific to a target storage site and CO_2 distribution in the reservoir needs to be used as an initial value. A leakage rate derived from the geological model is in turn used as a default value in the model for dispersion in seawater.

To simulate CO_2 dispersion, RITE is developing models of simulating CO_2 behavior in gas state (bubbles) and in dissolved state. When CO_2 leaks from the seabed in the form of bubbles, it moves upwards due to buoyancy and gradually dissolves into seawater, while affected by seawater flow, temperature, and others. Therefore, the model was designed to calculate both the behavior of CO_2 bubbles

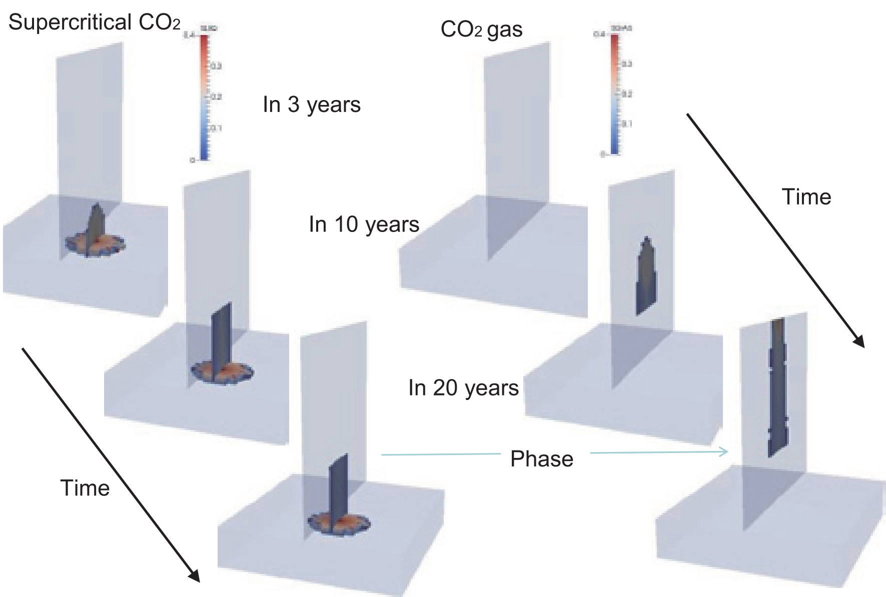


Fig. 8: Simulated CO_2 migration in geological formation (CO_2 saturation distribution in fault)

and its dissolution into seawater. Simulated results show that CO_2 dispersion is intricately affected by stratification, water temperature, background water flow, and bubble-driven rising flow.

To clarify the impact of increased CO_2 concentration caused by CO_2 leakage on marine organisms, RITE is updating the database of the impacts on marine organisms with the latest knowledge and continuing the analysis. Furthermore, the methods of distinguishing leaked CO_2 from natural fluctuations in CO_2 concentration have been developed for CO_2 monitoring in the ocean. It was found that abnormalities caused by CO_2 leakage can be detected by measuring water temperature, salinity, dissolved oxygen, and pH values using conventional equipment.

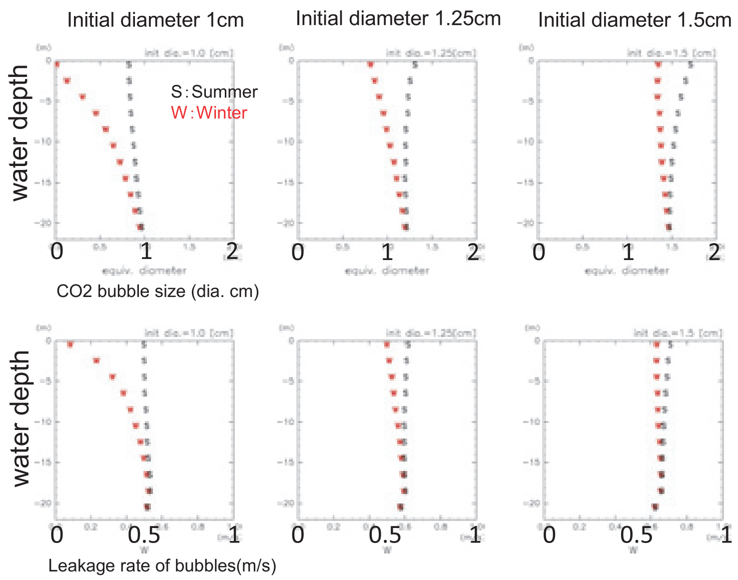


Fig. 9: Simulated CO_2 bubble size and leakage rate

2-4. Preparing CCS Best Practice Manuals

In 1996, the first-ever CO_2 storage project (in aquifer at 800m depth) started at Sleipner in Norway. Many CO_2 geological storage projects followed in Europe and the United States. The knowledge from the projects has been accumulated in the form of project reports. Best practice manuals started being published as a compilation of the comprehensive knowledge and site-specific experience some years later. Around this time, laws and regulations for CCS businesses were formulated. The US Environmental Protection Agency (EPA) incorporated regulations for geologic sequestration of carbon dioxide into the existing UIC Program regulatory framework, setting up a new class of wells, Class VI. In Europe, the European Commission issued the Directive on geological storage of CO_2 (a.k.a. “CCS Directive”) and released its guidance documents to promote a coherent implementation of the CCS Directive throughout the EU. In private sector, Norway-based DNV KEMA independently set up a certification framework and published guidelines to help CCS project get authorized in permitting procedures.

The Ministry of Economy, Trade and Industry (METI) of Japan released a guideline “For safe operation of a CCS demonstration project” for implementing a large-scale demonstration project in Japan in 2009. The guideline describes standards to be followed from the safety and environmental viewpoints in implementing the project. Meanwhile, RITE conducted basic researches, technological developments, Nagaoka CO_2 injection project (in July 2003 through January 2005), and ongoing post-injection CO_2 monitoring, thus accumulating a wealth of knowledge of CCS technologies.

On the basis of the knowledge, RITE is preparing “Japan’s best practice manuals of CCS” as technological reference for domestic developers who want to launch a CCS project at home or abroad. As shown in Fig. 10, our best practice manuals cover every CCS technology as a collection of global technological case studies for general purposes. In parallel, we are documenting Nagaoka project, Japan’s first CO_2 injection project as a separate case study. In future, we will incorporate knowledge from ongoing large-scale demonstration project at Tomakomai into the case study.

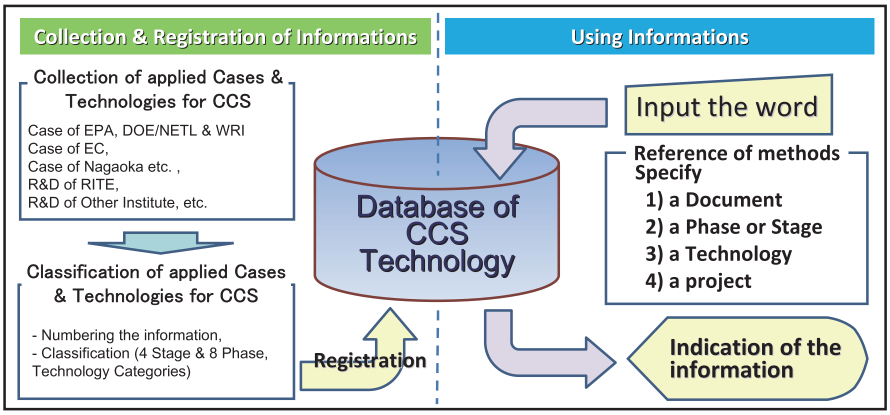


Fig. 10: Documents and case studies in CCS

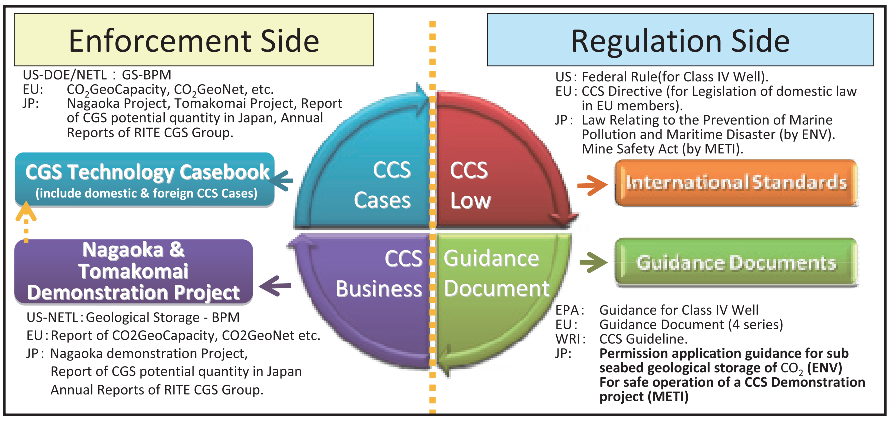


Fig. 11: Registration and how to use data base

Our best practice manuals of CCS discuss a wide range of CCS technologies, thus the information is expected to keep growing. To efficiently use and register the cumulative information in the manuals, we are now creating a database before the manuals are published in print. Fig. 11 shows a database system that facilitates registering and using information in the best practice manuals and case studies.

For better use of the best practice manuals and case studies, accessibility of users to the database is an important issue. Thus, we are proposing multiple ways of access according to the purpose of use (see Fig. 12). Indexing by CCS phase and by technology will be explained here.

In indexing by CCS phase, data is associated with each phase of a project, so that a user can refer to the case study corresponding to the phase where his/her project is in progress. In indexing by technology, data is associated with information specific to a certain technology, so that the user can refer to the case study and its relative information on specific technology. In addition, "CCS technological case study map" is going to be developed for visual aided search. Wordbook, abbreviation lists, comparative information, and history on CCS technology will be documented in future.

Collecting information was almost finished. The database is now in a

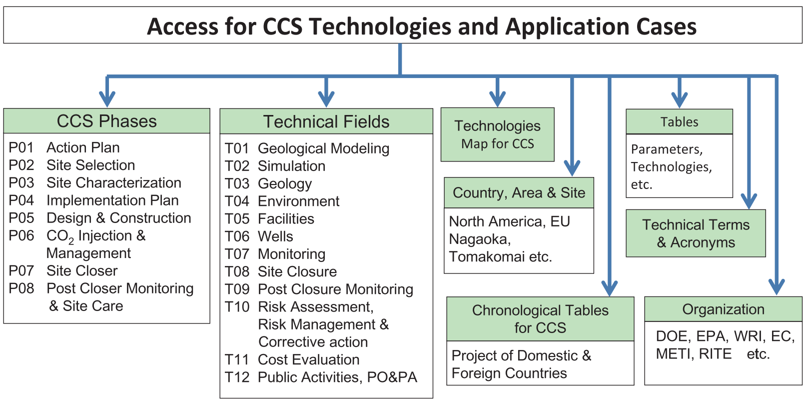


Fig. 12: Indexing structure of database for various use

process of designing and registering data. Draft database will be complete in the middle of FY 2014.

3. Japan-China CCS-EOR project

Carbon Capture and Storage (CCS) is a series of technologies that captures and geologically stores CO_2 emitted from fossil fuel combustion and will remain critically important to combat climate change. Among others, a CCS-EOR project involving CO_2-EOR is expected to be a driver of the early deployment of CCS technologies.

There are many potential CCS-EOR sites in China. The widespread use and implementation of CCS-EOR is highly expected and CCS-EOR has been experienced in some oilfields. However, expected enhancement in oil recovery was sometimes difficult to achieve and the efficiency has been a pressing challenge in the technological developments in CCS-EOR.

On November 8th, 2009, the 4th Japan-China Forum on Energy Saving and Environmental Protection was held in Beijing and the agreements on Japan-China Energy Saving and Environmental Protection projects were signed. At the time, RITE and China Oil Foreign Affairs Office signed the Japan-China CCS-EOR cooperation agreement.

This agreement led RITE to work in a partnership with China National Petroleum Corporation (CNPC) in developing CCS-EOR technologies. RITE co-organized with CNPC the CCS-EOR workshops (2009 and 2010), Energy Saving and Environment Protection, and Greenhouse Gas Reduction Workshop (2011). Members of RITE and CNPC visited CCS and CCS-EOR related facilities/sites in both countries under the partnership. RITE contributed greatly to CNPC advancing its technology and showed that improving monitoring technology that can closely monitor injected CO_2 behavior is critical to improving the efficiency of CCS-EOR.

In 2013, studies on oil field application of the monitoring technology have started. RITE and CNPC reached an important milestone of selecting prospective oilfields for demonstrating RITE's technology. Researchers visited a candidate site, exchanged information on the technology and identified technical challenges specific to CCS-EOR in China to demonstrate the effectiveness of RITE's monitoring technique.

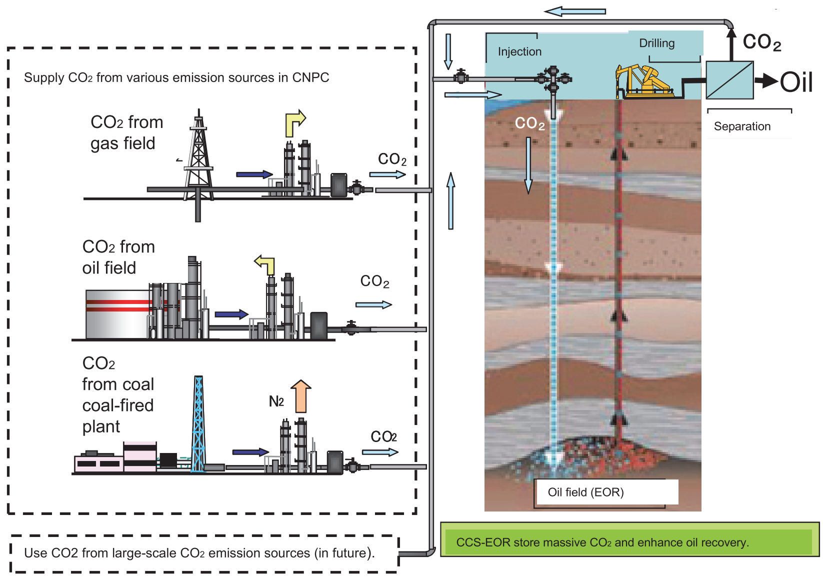


Fig. 13: Concept of CCS-EOR

RITE is going to propose a deployment plan of the monitoring technique in the candidate site and to clarify the effects of the deployment through a feasibility study. RITE is poised to proceed with the studies toward a new CCS-EOR monitoring demonstration project. Furthermore, under the support of plant engineering companies, we will come up with a business model for CCS-EOR in China.

4. Co-operation with International Organizations and Survey of Global CCS Activities

RITE contributes to accelerating CCS deployment through co-operation with international organizations and also monitors CCS activities in the world. It is essential to collaborate and share knowledge with other countries through such international organizations in order to address a number of challenges for CCS implementation, including economics, policies, regulations and public acceptance. The following are an outline and updates on the international bodies to which RITE contributes—the Carbon Sequestration Leadership Forum (CSLF), the IEA Greenhouse Gas R&D Programme (IEAGHG) and the London Convention—and the overview of CCS activities in the world.

- CSLF and its Recent Activities

CSLF was established in 2003 as 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. CSLF is operated by the US Department of Energy as secretariat and is currently composed of 22 nations, including Japan, 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. A major activity of theirs is to hold a Ministerial Meeting every two years. RITE has been a member of the Technical Group since 2009.

Its fifth Ministerial Meeting was held in the USA in November 2013 where it was reaffirmed that the research and development, demonstration and global deployment of CCS must be accelerated. It was also agreed to adopt seven key actions needed for CCS deployment such as the development of incentive mechanisms and to set up a sub-committee under the Policy Group to have discussions on CSLF's future activities which could be unprecedented co-operation.

- IEAGHG and its Recent Activities

IEAGHG was established in 1991 as an implement agreement under the International Energy Agency (IEA) with the aims of evaluating greenhouse gas reduction technologies, promoting the deployment of these technologies, disseminating outcomes from evaluation studies and promoting international collaboration. It has put the focus on CCS among a number of GHG reduction technologies since its early days. The organization is funded by 20 contracting parties, including Japan, and 23 sponsors from the industrial and research sectors. Representing Japan, RITE has participated in its Executive Committee since 2009.

Its major activities include operating various CCS expert networks and organizing meetings for the networks as well as international conferences. In recent years, CO_2 storage related networks, i.e. those for monitoring, modelling, risk assessment and environmental research, have placed emphasis on knowledge sharing among a wider range of experts by organizing joint meetings for multiple networks. IEAGHG is proceeding with the preparations for the 12th International Conference on Greenhouse Gas Control Technologies (GHGT-12) to be held in Texas, USA, in October 2014.

- London Convention and its Recent Activities

CO_2 storage under the seabed has been allowed internationally since the amendment of the 1996 Protocol to the London Convention entered into force in 2007. RITE has participated in meetings for its contracting parties and related scientific meetings for science-based information sharing as a member of the Japanese delegation.

The Protocol was amended in 2009 to allow CO_2 trans-boundary movement but the amendment hasn't come into force yet due to shortage of the number of parties who has ratified. Since the amendment, activities have been carried out to clarify where responsibility lies in a case where exported CO_2 is injected and a case where CO_2 is injected in the same geological formation by more than one country or where injected CO_2 potentially moves across a national boundary. The locus of responsibility for the latter was incorporated in the existing offshore CO_2 storage guidelines in 2012 and that for the former was also settled with a guidance newly produced in 2013.

- CCS Activities Update

In 2012, IEA publicized an analysis result that CCS should contribute to 14% of CO_2 emission reduction required by 2050. They said that to achieve the target the annual amount of CO_2 stored by CCS needs to be 260 Mt in 2020, 2.5 Gt in 2030 and 8 Gt in 2050. We are, however, unlikely to achieve the targeted volume of CO_2 to be stored in 2020 so that IEA publicized an updated CCS technology roadmap in July 2013 with the focus on actions to be taken for a period of coming seven years by 2020. In the roadmap, the international organization pointed out the importance of, for example, introducing financial support mechanisms and promoting reservoir exploration.

According to GCCSI, there are currently only 12 large-scale CCS projects under operation, including Enhanced Oil Recovery (EOR) operations using anthropogenic CO_2. Furthermore all of them use CO_2 from industrial plants which need no or limited additional costs for CO_2 capture. As operating eight out of the 12 projects, North America is regarded as a leader in the global CCS scene. Their influence will become greater when they start operating two CCS projects, which are under construction to start running in 2014, in the power sector.

Europe has been enthusiastic in tackling global warming and has promoted CCS demonstration for coal-fired power plants but all of these projects have been cancelled or significantly delayed. In September 2013, the European Parliament publicized recommendations for policies to boost CCS in the region but it draws little attention. With the European Commission's schemes not working well, what drew great attention was a large-scale CCS project for a gas-fired power plant in a non-EU member—Norway, but its Government decided to cancel it in September 2013. In a few months, the UK made expectations for progress of CCS raised. Under a national scheme for CCS demonstrations in the power sector renewed in 2012, the Government decided to fund basic design (FEED) for two projects in late 2013 and early 2014. They have also been making progress in promoting the improvement of policies to facilitate CCS deployment.

On the other hand, in Asia, where drew less attention in terms of CCS, has shown significant progress on CCS—the Japanese Government has been preparing a full-chain demonstration in Tomakomai, Hokkaido; and according to GCCSI, China is the only country where the number of large-scale CCS projects planned has been increased over the past two years. In Southeast Asia, interest in CCS has rapidly been increased—with supports of developed nations, a fundamental survey was conducted toward future CCS deployment and a CO_2 storage pilot test has been under planning.

ALPS International Symposium

Systems Analysis Group

FY2012 ALPS International Symposium was held at Otemachi Sankei Plaza in Tokyo on February 27th, 2013. This symposium was hosted by Research Institute of Innovative Technology for the Earth (RITE) and co-hosted by Ministry of Economy, Trade and Industry, Japan (METI). The symposium was titled “Moving toward Sustainable Climate Change Actions.”

We are honored to have six leading experts from overseas, including Prof. Nabojsa Nakicenovic, Prof. Arnulf Grübler and Prof. Keywan Riahi from the International Institute Applied Systems Analysis, Mr. James L. Connaughton from Exelon, Prof. David Victor from the University of California, San Diego and Mr. Jun Arima from JETRO, London, and to have two Japanese experts, Dr. Hidetoshi Nakagami from the Jukankyo Research Institute Inc. and Prof. Yoichi Kaya from the President of RITE. Furthermore, Prof. Keigo Akimoto, from RITE introduced the up-to-date study results in the presentation on ALPS Project. We discussed sustainable development, 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.

FY2013 ALPS International Symposium is scheduled to take place in February 4, 2014 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.

Vital Spark Seminar

Systems Analysis Group

Vital Spark Seminar, subtitled Energy Innovation based New Climate Change Policy was held at International Conference Hall III, Kyoto University on October 10, 2013. (Hosted by RITE, co-hosted by The Institute of Energy Economics, Japan and supported by Iron and Steel Federation and many others).

‘THE VITAL SPARK’ was published in July 2013, coordinated by the London School of Economics and Political Science (LSE). LSE Emeritus Research Professor Gwythian Prins is a chief editor and twenty leading experts in energy and climate change issues co-authored the paper, including some researchers from Japan as well as from England, USA, Germany, Brazil, Canada and Sweden.

Overview of the paper is that only bottom-up approach based on the technology functions could be truly effective climate change mitigation and that policy for energy technology innovation in particular could be a key to the future.

LSE Emeritus Research Professor Gwythian Prins and Dr. Constable, Director of Renewable Energy Foundation were invited to the seminar and also 3 Japanese experts from the University of Tokyo, Keidanren, The Institute of Energy Economics, Japan delivered lectures, leading to vigorous discussions between the lecturers and audience.

We believe the seminar to be very meaningful providing an opportunity of broad exchanges for not only researchers involved in climate change issues but participants from industries and ministries.

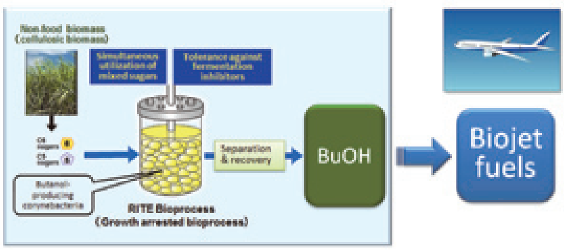
International joint research project with NREL on a production technology development of butanol as a biojet fuel

Molecular Microbiology and Biotechnology Group

Recently, CO_2 emissions from the aviation sector have become a global issue because CO_2 emissions from aircrafts continue increasing with an increase in the number of passengers from emerging countries and LCC (low cost carriers). Currently, worldwide flights by aircrafts contribute 20% of the CO_2 emissions of the global transportation sector, but it is not easy to reduce these CO_2 emissions from the aircrafts fundamentally. In order to reduce the CO_2 emissions, biojet fuels produced from biomass have attracted increasing attention (See text).

In this project, we set out the technology development to produce butanol, which is one of expected materials for biojet fuels, from non-food cellulosic biomass. If we can put this material into practical use for biojet fuels production, we will contribute to the reduction of the CO_2 emissions by the aviation sector and mitigate adverse global climate change.

The project is conducted by an international joint working group involving RITE (Research Institute of Innovative Technology for the Earth), GEI (Green Earth Institute) and NREL (National Renewable Energy Laboratory). RITE contributes technologies to improve coryneform bacteria by metabolic engineering and innovative RITE Bioprocess; GEI is a venture company established to industrialize the RITE Bioprocess; NREL has accumulated the most research data on sugar preparation from cellulosic biomass in the world. This project brings together these three institutions and is supported by the Ministry of Economy, Trade and Industry of Japan.

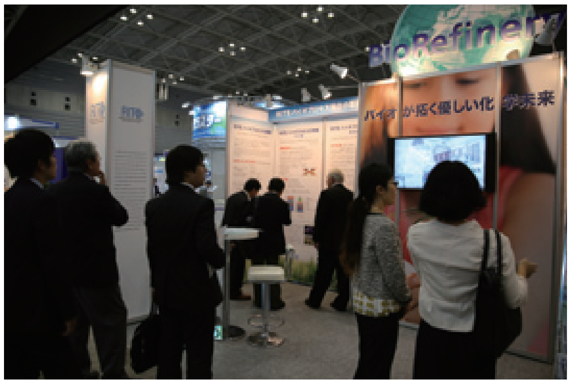


Outline of the international joint research of RITE/GEI/NREL

Many visitors attended our seminar and exhibition booth at BioJapan 2013 World Business Forum

Molecular Microbiology and Biotechnology Group

BioJapan 2013 World Business Forum was held at Pacifico Yokohama from 9th to 11th October 2013. RITE has hosted the forum as a sponsor organization since 2011, and our group exhibited and presented a seminar. In our exhibition booth, RITE and GEI jointly exhibited the innovative bio-conversion RITE-Bioprocess and its strategy for industrialization. RITE Director, Dr. Hideaki Yukawa moderated the seminar on “Green Innovation Summit”, this time in its fifth year, where many participants attended. In the seminar, executives of prominent companies gave lectures on their environmental management and the CEO of GEI also introduced the state of U.S. biorefinery and GEI’s strategy for industrialization of the RITE Bioprocess. We thank all those who visited of our booth very much.



RITE/GEI joint exhibition booth

Seminar on “Green Innovation Summit”

Research on CO_2 capture technologies

Chemical Research Group

Herein, information on the CO_2 capture technologies in the United States, Norway, and the Netherlands is discussed.

In July 2013, we attended the CO_2 Capture Technology Meeting organized by the National Energy Technology Laboratory (NETL) in Pittsburgh. This annual meeting presents research findings of R&D projects of the US Department of Energy (DOE), whereby information relating to the research agenda of the DOE can be gathered. Fundings are accordingly assigned to research themes that suit the strategy of DOE.

In that year, 209 people attended the meeting, and 61 oral presentations and 11 poster presentations were given. In the post-combustion research area, 13, 10, and 8 presentations relating to absorption, adsorption, and membrane technologies were presented. In contrast, in the pre-combustion research area, only 4, 1, and 1 presentations relating to membrane, absorption, and adsorption technologies were presented. DOE awards funding grants to the proposals based on the novelty of the concept rather than on a well-developed technology. Hence, in general, the basic research findings of the proposals were presented, including in the absorption research area. For example, in the absorption-related post-combustion field, R&D on processes that involve the recovery of CO_2-absorbed amine as a slurry by precipitation, use of enzyme, and whereby the absorber and desorber are contacted using a membrane were reported. In the pre-combustion field, several presentations involving membrane technologies were given, and projects on membrane separation were selected as new projects.

In August 2013, we attended a workshop on membrane separation in Norway and also visited Energy research Centre of the Netherlands (ECN) and the University of Twente in the Netherlands to gather recent trends in gas separation membranes such as those employed in Europe.

In the workshop, presentations on CO_2 separation membranes, H_2 separation membranes, and solvent separation membranes were given by Norwegian University of Science and Technology (NTNU), Stiftelsen for Industriell og Teknisk Forskning (SINTEF, Norway), the University of Oslo (Norway), Yamaguchi University (Japan), and RITE (Japan). In the area of CO_2 separation membranes, interesting results pertaining to enhanced transport properties of membranes for CO_2/CH_4 separation were reported by researchers from NTNU.

ECN is the largest research institute involving 500 staffs for energy in the Netherlands. We visited Dr. Jaap Vente who has been working on development of separation membranes. His research group is collaborating with the University of Twente and SINTEF for the development of membrane modules. We visited bench-scale facilities for H_2 separation membranes (palladium membranes) and long-term testing facilities for water/alcohol separation membranes. They are conducting R&D for the practical application of their membranes that involves scale-up and long-term testing.

We also visited Prof. Dr. Arian Nijmeijer at the University of Twente. His research group extensively investigates the fabrication of silica membranes, surface-modified ceramic membranes, porous ceramic or metallic hollow fiber membranes, and palladium membranes, and their application in IGCC processes.

In Europe, universities are conducting fundamental studies. Research institutes, such as SINTEF and ECN, play an important role, just as RITE, to integrate seeds technologies developed by universities into companies.

CCS Technical Workshop

The latest development in safety evaluation technology for CCS large-scale demonstration projects

CO_2 Storage Research Group

Japan has been proceeding with the CCS demonstration project at Tomakomai, Hokkaido. Its CO_2 injection is expected to start in 2016. Under the circumstances, much attention has been given to technological development to ensure a safe and reliable CO_2 storage. On 23 January 2014, RITE co-organized with the Ministry of Economy, Trade and Industry (METI) the CCS technical workshop on "the latest development in safety evaluation technology for CCS large-scale demonstration projects" at Dai-ichi Hotel Tokyo (Minato ward, Tokyo). We had as many as 295 participants from governments, businesses, universities, research institutions and others. Prof. Dr. Toshifumi Matsuoka, graduate school of engineering, Kyoto University moderated the workshop. The presentations by invited five speakers (three from overseas and two at home) provided a good opportunity for the participants to discuss the safety evaluation technologies in CCS.

First, Dr. Iain W. Wright, program manager of In Salah JIP (retired) talked about the "Upscaling CCS: How In Salah can inform Tomakomai", followed by Mr. Daiji Tanase, general manager, operation department, Japan CCS Co. Ltd. outlining the "progress on Tomakomai CCS demonstration project", and Dr. Don White, senior research scientist, geological survey of Canada talking about "the Aquistore project: commercial-scale CO_2 storage in a Saline Aquifer in Saskatchewan, Canada". Then, Dr. Tom Daley, research scientist, LBNL, U.S and Dr. Ziqiu Xue, chief researcher, RITE each gave presentations on the recent development in monitoring technology in fiber-optic sensing.

Prof. Dr. Matsuoka wrapped up the workshop, underscoring the importance of monitoring technology in the context of a long-term CCS project, for reducing the uncertainty of numerical simulations with better understanding of CO_2 distribution and thus making CCS economically viable.

Innovative Environmental Technology Symposium 2013

- Creation of low-carbon society based on new energy and environmental policies -

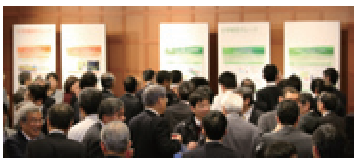
Research & Coordination Group

On December 4th of 2013, we held the conference of "Innovative Environmental Technology Symposium 2013" at ITO Hall (The University of Tokyo).

This meeting was 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, and the Japan Institute of Energy.

In addition to research presentations, we were honored to invite Mr. Mita (Deputy Director-General for Technology and Environment, METI) for the lecture of "Latest countermeasures against global warming from COP19 and trends". From RITE, Dr. Yamaji, Director-General, made his keynote lecture of "New visions and challenges for new energy and environmental policy", where he mentioned about the latest trends for rebuilding environmental policies after the disaster of March 11th in 2011. Also he talked on technical subjects that RITE is working for under the innovative plans to environmental energy and technology set by the Japanese government. After then, the presentations from experts followed related to the scenario for global-warming countermeasures, biorefinery technology and CCS technology. Besides, the chemical research group made a speech on the latest development and future views for inorganic membranes for H_2 energy production, and this project has been under development at RITE since last year.

Totally, we invited 357 attendees to the conference. The discussions were very active so that we were glad to receive so many inquiries. In this time, we also held poster sessions during the conference, which could make a great opportunity for information exchange between attendees and RITE researchers.

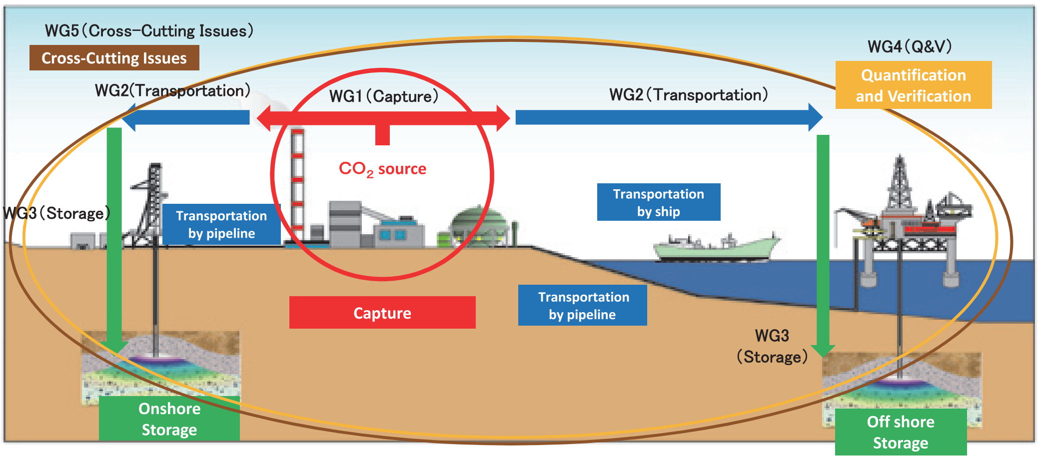


International Standardization for CO_2 Capture and Storage (CCS)

Research & Coordination Group

Regarding International Standardization for CCS which is already introduced in the other chapter, here the detailed activities are reported by each of Working Group separately. Six working groups, WG1 to WG6, are set up currently and the covering areas of each working group (except WG6) are indicated in Fig 1.

New Work Item Proposals (NWIP) from "Capture WG", "Transportation WG", "Storage WG" and "Cross-Cutting Issues WG" were approved in September, 2013, and the development of International Standards has practically started. In addition, NWIP of "Quantification and Verification WG" and "CO2-EOR (Enhanced Oil Recovery) WG" are on ballot by participating countries as of December, 2013 and they are preparing for the next step. The main activities in 2013 and future schedule of each WG as of January, 2014 are listed below.



- WG1 (Capture) — Capture from CO_2 source (heat power plant, steel plant, chemical plant(cement/ petroleum processing etc.)
- WG2 (Transportation) — Transport CO2 from CO2 source to permanent storage facilities
- WG3 (Storage) — Geological storage of CO2
- WG4 (Q&V) — Quantification and Verification for reduction of CO2 emission by CCS
- WG5 (Cross-Cutting Issues) — Cross-cutting issues across WGs
- WG6(CO2-EOR) — CCS for EOR(Enhanced Oil Recovery)

Fig. 1: Areas of standardization on CCS

•WG1 (Capture)

The 1st WG1 meeting was held in Beijing (China) in September, 2013. Participating experts from each country agreed to develop TR (Technical Report) prior to IS (International Standard) at the meeting and to use a document submitted by Japan as a seed document. Section editors were assigned to each section to proceed editing respectively.

For future schedule, WG1 aims at completing Working Draft of TR at early fall, ensuring the progress of each section at the teleconference in February, 2014 and discussing it at the 2nd WG1 meeting in March. Japan positively leads discussion as Convenor and Secretariat of WG1.

•WG2 (Transportation)

The 1st WG2 meeting was held in Bonn (Germany) in June, 2013. Germany proposed to develop IS of pipeline system prior to various kinds of other transportation systems and it was approved at the meeting. To be more precise, DNV-RP-J201 from NNV (Norway) is used as a seed document, divided into each section, and was assigned leaders to each section. Experts are reviewing it in detail for the 2nd WG2 meeting in February, 2014. Japan is participating discussion in an effort to develop IS in 2016.

The 1st WG1 meeting

The 1st WG2 meeting

•WG3 (Storage)

The 1st WG3 meeting was held in Toronto (Canada) in September, 2013. WG3 experts reached a consensus to use CSA-Z741 which is a standard in North America as a seed document in order to develop IS of geological and offshore storage. TPs (Technical Panel) were set up for each chapter to promote editing. Aiming to publication of IS in 2017, WG3 advances discussion. Japan actively leads discussion as Convenor toward practical application of offshore storage and CCS in earthquake countries.

•WG4 (Quantification &Verification)

The 1st WG4 meeting was held in Beijing (China) in September, 2013. TR (Technical Report) was proposed to be developed prior to IS (International Standard). The NWIP is on ballot until March and each participating country is discussing the NWIP. The Japanese internal committee will cast a vote in cooperation with experts and relevant parties.

•WG5 (Cross-Cutting Issues)

The 1st WG5 meeting was held in Beijing (China) in September, 2013. Experts from participating countries have reached an agreement to establish IS of CCS vocabulary aiming publication in 2016. Discussion on system integration starts along with development of vocabulary IS.

•WG6 (CO2-EOR)

WG6 addressing CO2-EOR was established by joint proposal from the United Stated and Norway at the 3rd Plenary TC meeting in September, 2013. NWIP from WG6 was submitted in December, 2013 and participating countries are reviewing it to cast a vote. Although WG6 relates to a whole CCS, overlap discussion with other WGs should be avoided. The NWIP should be discussed with the related parties to cast a vote and also a structure for WG6 should be established in Japan.

RITE continues to be involved actively in developing International standards for CCS in order to reflect technologies and expertise which Japan has cultivated so far.

Systems Analysis Group

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11. E. Kriegler, N. Petermann, V. Krey, J. Schwanitz, G. Luderer, S. Ashina, V. Bosetti, J. Eom, A. Kitous, A. Méjean,L. Paroussos, F. Sano, H. Turton, C. Wilson, D. van Vuuren, Diagnosing integrated assessment model of climate policy, Technological Forecasting & Social Change, in press

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2. K. Akimoto, Analysis of Energy and Environmental Council's options and proposal of alternatives using RITE Model, 29th Conference on Energy, Economy and Environment, Jan. 30, 2013

3. J. Oda, K. Akimoto, F. Sano, K. Wada, T. Tomoda, International comparison of energy efficiency and CO_2 reduction potential in steel sector, 29th Conference on Energy, Economy and Environment, Jan. 30, 2013

4. F. Sano, K. Akimoto, K. Wada, An evaluation of electric appliances for CO_2 emission reduction, 29th Conference on Energy, Economy and Environment, Jan. 30, 2013

5. T. Homma, K. Akimoto, F. Sano, Economic analysis on power supply and CO_2 emission reductions, 29th Conference on Energy, Economy and Environment, Jan. 30, 2013

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7. K. Tokushige, K. Akimoto, J. Oda, T. Homma, A. Hayashi, F. Sano, K. Wada, M. Nagashima, T. Tomoda, Comprehensive achievement of indices relating to climate change response measures and sustainable development, 29th Conference on Energy, Economy and Environment, Jan. 30, 2013

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Systems Analysis Group

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Molecular Microbiology and Biotechnology Group

◆ Original Paper

1. K. Watanabe, H. Teramoto, N. Suzuki, M. Inui and H. Yukawa, Influence of *SigB* inactivation on *Corynebacterium glutamicum* protein secretion, Applied Microbiology and Biotechnology, Vol. 97, pp.4917-4926, 2013

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6. H. Teramoto, M. Inui and H. Yukawa, OxyR acts as a transcriptional repressor of hydrogen peroxide-inducible antioxidant genes in *Corynebacterium glutamicum* R, FEBS Journal, Vol. 280, pp.3298-3312. 2013

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◆ Oral Presentation

1. K. Toyoda, H. Teramoto, M. Inui, H. Yukawa, Transcriptional regulation of the global regulator RamA in *Corynebacterium glutamicum*, The 2013 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 25, 2013

2. T. Kuge, H. Teramoto, M. Inui, H. Yukawa, Transcriptional regulation of arabinose utilization genes in *Corynebacterium glutamicum*, The 2013 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 25, 2013

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14. M. Inui, Highly efficient production of biofuels by metabolically engineered corynebacteria, The 2013 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 27, 2013.

Chemical Research Group

◆ Original Paper

1. F.A. Chowdhury, H. Yamada, T. Higashii, K. Goto, M. Onoda, CO_2 Capture by Tertiary Amine Absorbents: A Performance Comparison Study, Industrial & Engineering Chemistry Research, Vol.52, Issue 24, pp.8323-8331, 2013
2. S. Duan, T. Kai, I. Taniguchi, S. Kazama, Development of Poly(amidoamine) Dendrimer/Poly(vinyl alcohol) Hybrid Membranes for CO_2 Separation, Desalination and Water Treatment Journal, Vol. 51, Issue 25-27, pp.5337-5342, 2013
3. T. Kai, I. Taniguchi, S. Duan, F.A. Chowdhury, T. Saito, K. Yamazaki, K. Ikeda, T. Ohara, S. Asano, S. Kazama, Molecular Gate Membrane: Poly(amidoamine) Dendrimer/polymer Hybrid Membrane Modules for CO_2 Capture, Energy Procedia, Vol.37, pp.961-968, 2013
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19. K. Yogo, H. Takeyama, K. Nagata, Pore-fill-type Palladium-Porous Alumina Composite Membrane for Hydrogen Separation, Energy Procedia, Vol. 37, pp.1104-1108, 2013
20. T. Watabe, Y. Nishizaka, S. Kazama, K. Yogo, Development of Amine-Modified Solid Sorbents for Postcombustion CO_2 Capture, Energy Procedia, Vol. 37, pp.199-204, 2013
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24. S. Kazama, K. Haraya, Optimization of CO_2 concentration captured by membrane technology - Possibility of reduction in CO_2 capture energy and cost -, Energy Procedia, Vol. 37, pp.969-975, 2013

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3. T. Kai, Molecular Gate Membrane:Poly(amidoamine) Dendrimer/polymer Hybrid Membrane Modules for CO_2 Capture, Japanese-Norwegian Workshop Membranes for Sustainable Energy Technology, Aug. 27-28, 2013

Chemical Research Group

4. T. Saito, S. Nakao, M. Seshimo, K. Akamatsu, K. Miyajima, Effect of physically adsorbed water molecules on the H_2-selective performance of a silica membrane, Japanese-Norwegian Workshop Membranes for Sustainable Energy Technology, Aug. 27-28, 2013

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7. K. Goto, H. Yamada, T. Higashii, Prediction of Reaction Rate constant of Carbon Dioxide Absorption into Aqueous Amine Solution, 2013 AIChE Annual Meeting, Nov. 7, 2013

8. J. Fujiki, K. Yogo, Synthesis and characteristics of amine functionalized biopolymers for CO_2 capture, 2013 AIChE Annual Meeting, Nov. 6, 2013

9. T. Saito, T. Kai, S. Duan, K. Yamazaki, I. Taniguchi, K. Ikeda, The Effect of Water Vapor on Separation Performance of PAMAM dendrimer/cross-linked PEG hybrid Membrane, IMSTEC2013, Nov. 28, 2013

CO_2 Storage Research Group

◆ Original Paper

1. H. Ishida, L.G. Golmen, J. West, M. Kuger, P. Coombs, J.A. Berge, T. Fukuhara, M. Magi, J. Kita, Effects of CO_2 on benthic biota: An in situ benthic chamber experiment in Storfjorden (Norway)., Mallin Pollition Bulletin, Vol.73, pp.443-451, 2013
2. J. Kita, T. Kikkawa, T. Asai, A. Ishimatsu, Effects of elevated pCO_2 on reproductive properties of the benthic copepod Tigriopus japonicus and gastropod Babylonia japonica, Marine Pollution Bulletin, Vol. 73, pp.402-408, 2013
3. T. Kogure, T. Kiyama, O. Nishizawa, Z. Xue, Fiber optic strain measurements using distributed sensor system under static pressure conditions, Exploration Geophysicists of Japan, submitted

◆ Other Paper

1. J. Kita, Enviromental impact assessment of carbon dioxide storage in sub-seabed geological formations, The earth monthly, 2013

◆ Oral Presentation

1. K. Uchimoto, Development of an assessment methodology for CO_2 leakage from off-shore reservoir, CCS Technical Workshop, Jan. 24, 2013
2. J. Kita, Site selection and environmental impacts assessment - regulations and case studies, CCS Technical Workshop, Jan. 24, 2013
3. T. Kogure, Z. Xue, Development of an monitoring methodology for stability of formation in the vicinity of well using optical fiber, Spring Meeting of Japanese Association for Petroleum Technology, Jun. 28, 2013
4. T. Nakajima, O. Nishizawa, Z. Xue, A relationship between Vp/Vs and lithology in the reservoir at the Nagaoka site, Japan Geoscience Union meeting 2013, May 19, 2013
5. T. Kogure, Z. Xue, Distributed fiber optic temperature and strain sensing in a cement specimen, Japan Geoscience Union meeting 2013, May 19, 2013
6. T. Kiyama, O. Nishizawa, Z. Xue, Swelling deformation behavior of mudstone injected with supercritical CO_2 for threshold pressure measurement, Spring meeting of the Mining and Materials Processing Institute of Japan, Mar. 29, 2013
7. R. Tanaka, CCS RD&D and Strategy in Japan, The 5th Symposium on CCS in Gungih Area, Central Java, Indonesia, Mar. 16, 2013
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10. H. Azuma, Z. Xue, Partial saturation and seismic attenuation in CO_2 geological storage, 128th Society of Exploration Geophysicists of Japan Conference, Jun. 3, 2013
11. T. Nakajima, O. Nishizawa, Z. Xue, A relationship between Vp/Vs and rock properties in the reservoir at Nagaoka CCS site, AGOS 10th Annual meeting, Jun. 24, 2013
12. S. Chiyonobu, T. Nakajima, Z. Xue, A three-dimensional static reservoir model of the Nagaoka CCS Site and to simulate a carbon dioxide plume migration, JPGU Meeting, May 22, 2013
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14. H. Ishida, T. Makino, J. Ishizaka, K. Yoshizawa, Y. Watanabe, Y. Watanabe, J. Kita, Potential effect of typhoon on the phytoplankton community in the subtropical western North Pacific, Fall meeting of Oceanographic society of Japan 2013, Sep. 17, 2013
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17. Ziqiu Xue,Zhang Yi, Osamu Nishizawa, Tamotsu Kiyama, Visualization of two-phase flow in porous sandstone using X-CT and simultaneous measurement of wave velocity changes, Fall meeting of the Mining and Materials Processing Institute of Japan, 2013, Sep. 4, 2013
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21. M. Takagishi, T. Hashimoto, S. Horikawa, K. Kusunose, Z. Xue, Microseismic monitoring at the CO_2 geological storage site and estimation of detectable minimum magnitudes, Seismological Society of Japan 2013 Fall Meeting, Oct. 7, 2013
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