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RITE Today
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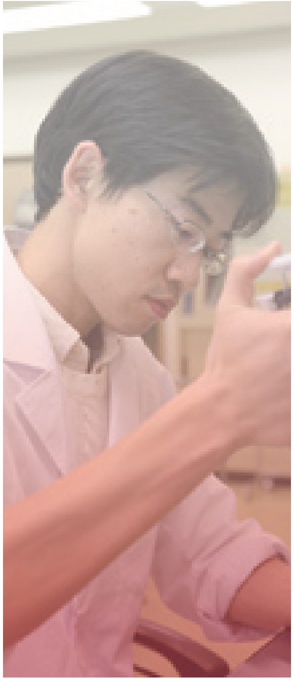
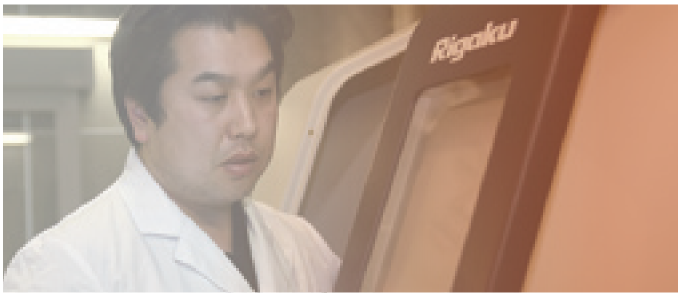
Annual Report

Research Institute of Inovative Tecnology for the Earth





RITE
Research Institute of Innovative Technology for the Earth

RITE Today 2015 Vol.10

Contents

Developing Long Term Measures for Mitigating Climate Change

Yoichi Kaya
President, Research Institute of Innovative Technology for the Earth

The basic role of our research institute is to investigate the long term strategy for resolving global warming issues and to develop related technologies. Here I describe two of the issues which we believe to be particularly important.

The first is to envisage decarbonization scenarios of Japan and the world. It has been widely discussed all over the world to limit the rise in global surface temperature to less than 2 degrees since the pre-industrial era. Whether this target is appropriate or not is still controversial, but the widely known idea for realizing this target is to halve the global emission of greenhouse gases by 2050. In fact our prime minister Abe, at the stage of his first cabinet seven years ago, made an announcement of achieving this target under the name “Cool Earth”. However taking into account the fact that developing countries are already responsible for 60% of the world greenhouse gas emissions and their emissions are still growing very rapidly, we have to confess that it is very hard to realize this target.

However recent IPCC reports published in 2013 and 2014 suggest that this target of limiting the temperature rise to 2 degrees should be reinvestigated in two aspects. One is that the new scenario analysis made in these reports shows the necessary reduction in greenhouse gas emission by 2050 can be 22% instead of 50%. The second is that a recent study shows the climate sensitivity (the rise in global surface temperature when CO_2 emission doubles) may be considerably lower than the values evaluated in the past. If the climate sensitivity of which the best estimate is now considered to be 3°C is lowered only by 0.5°C, according to the simulation by our institute’s model, the reduction in greenhouse gas emission by 2050 necessary for achieving the 2°C target is almost zero when compared with the present emission. In other words, the strategy leading up to the 2 degree target becomes much more achievable at least by 2050. More detailed analysis is therefore needed on the path connecting to the 2 degree target.

The second issue we believe to be important is realization of CO_2 capture and storage (CCS) technology. In order to stop climate change, eventually, according to IPCC and IEA, we have to realize a substantial reduction of CO_2 emission which almost inevitably requires development and implementation of CCS all over the world. Our institute already made an experiment of CO_2 storage in Niigata, and now supports the Tomakomai CO_2 storage experiment under the sponsorship of the government. In order to promote large scale introduction of CCS all over the world, we should make efforts for realizing much less costly and energy efficient capture technology, and safer storage technology.

In addition to these two issues, we see many other important research issues on climate change, and our institute make utmost efforts to resolve them.

On Synthesis Report of IPCC 5th Assessment Report

Mitsutsune Yamaguchi
Special Advisor

In this column, I will make comments on the IPCC Synthesis Report (SYR) that integrates three Working Groups' 5th Assessment Reports (AR5)[1]. The SYR consists of the Summary for Policymakers (SPM) and underlying texts, but I will focus on the SPM unless otherwise specified.

1. Main Contents of SYR

1.1 Observed Changes and their Causes

The SYR describes that temperature increases since 1950 are unprecedented and this is caused mainly by emissions of the Greenhouse Gases (GHGs) due to human activities. The report also points out that global average surface temperatures have increased by 0.85°C between 1880-2012 and sea level has risen by 19cm between 1901-2010, and that these changes are driven largely by economic and population growth.

1.2 Future Climate Changes, Risks and Impacts

Continued emissions increase will cause further temperature increase and adversely affect the climate system. To limit these to happen, a combination of substantial emissions reduction and adaptation is necessary, the report says. Remarkable findings of the report are that there exists an almost linear relationship between cumulative CO_2 emissions and temperature increase up to 2100, and to limit temperature increase below 2°C with a probability of >66%, the margin for future emissions will be around 1000Gt. In view of the fact that the annual CO_2 emissions in 2010 were 38Gt_CO_2 (WG3 report), this threshold would be hit in around 26 years.

It is noteworthy the report concludes that global economic damage due to climate change is difficult to estimate.

1.3 Future Pathways for Adaptation, Mitigation and Sustainable Development

On these items, please refer to the next article by Dr. Keigo Akimoto. Here the author would like to summarize the key messages as follows:

Decision making on to what extent we should cope with climate change should be based on the risks and benefit of response measures, taking account of various social aspects such as economics, uncertainty, ethics, equity, and value judgment etc. Sustainable development and equity are a basis for assessing climate policies. Also climate strategies that are consistent with sustainable development should consider co-benefits, and trade-offs and risks that may arise from response measures.

1) Each working group focusses on the Physical Science Basis (Working Group 1), Impacts, Adaptation and Vulnerability (Working Group 2), and Mitigation (Working Group 3) respectively.

2. Several concerns about the SYR and future considerations

2.1 Revision of Equilibrium Climate Sensitivity

In AR5, equilibrium climate sensitivity was revised to 1.5-4.5°C, (in AR4, it was 2.0-4.5°C), and no best estimate was shown due to lack of agreement. The importance of this change will be discussed in the next article. My question is why this crucially important information and its impact to response strategies were not touched upon in SPM, though there are some explanations in the SYR text.

2.2 Substantial Increase of Risks due to Climate Change

The attached figures (generally called Reasons for Concern) both show five categories of key risks from climate change, including loss of biodiversity, distribution of impacts, and large scale singular events. These figures are crucial for decision-making to cope with climate change. Figure A comes from Smith et al. (2009)[2)] and Figure B comes from AR5/WG2 (2014). It is very clear that risks have increased in Figure B. This is mainly because the authors of Figure B newly considered the limit of adaptation.

It is noteworthy, however, that “the levels of risk illustrated reflect the judgments of the authors of Chapter 19”[3)]. The basis for the value judgments of 7 authors of this Chapter is not shown and remains unclear.

2.3 Ways of describing Cost and Benefit

SYR explains that mitigation cost to limit below 2°C is very small if we compare it with annualized consumption growth. The cost here is calculated under idealized conditions. Although additional costs are shown, for example, in case of unavailability of technology or delayed participation, no calculation is shown when an unrealistic uniform carbon tax is not adopted. On the other hand, SYR shows no numerical figures for damages, and, as a result, avoided damages (benefit). This makes the comparison of mitigation cost and its benefit impossible. This is left for future consideration.

2.4 Priority of climate change among other globally urgent issues

“The choice of a stabilization level implies the balancing of the risks of climate change --- against the risk of response measures that may threaten economic sustainability” (AR4/WG3 /Chapter 1). Likewise, the balance between climate change and other globally urgent issues should be taken into account. SYR recognizes this point. It shows, though qualitatively, adverse side effects to sustainable development due to climate change. Adverse side effects of response measures such as risks of threat to food security or loss of biodiversity due to mitigation measures such as massive use of bioenergy or large scale afforestation, however, are not sufficiently addressed. This point is left for a future IPCC report.

2) Smith et al. (2009) “Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) ‘‘reasons for concern’’, Proceedings of the National Academy of Sciences of the United States of America, http://climatechange.pbworks.com/f/Assessing%20dangerous%20climate%20change%20reasons%20for%20concern%20PNAS%202009.pdf

3) Refer to the footnote to the Figure 19.4 of AR5/WG2/Chapter 19.

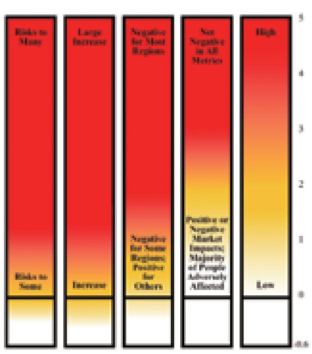


Figure A

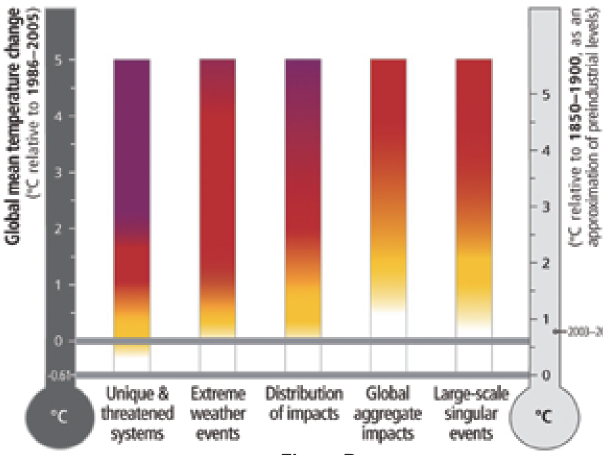


Figure B

Reasons for Concern (temperature increase and associated risks)

Figure A by Smith et al. (2009), Figure B from AR5 (AR5/WG2/SPM),

Undetectable risk (white), Moderate risk (yellow), High risk (red), Very high risk (purple),

The risk category order of Figure A is the same as that of Figure B.

0°C in Figure A corresponds to the temperature in1990. In Figure B, the scale of temperature on the left side almost corresponds to that in Figure A (the scale of temperature increase on the right side shows temperature increase since pre-industrialization).

Commentary on the Fifth Assessment Report of IPCC WG3

Keigo Akimoto
Group Leader, Systems Analysis Group

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) approved and provided the Fifth Assessment Report (AR5) of Working Group 3 (WG3; climate change mitigation)[1)] on April 2014. I contributed to Chapter 6 "Assessing Transformation Pathways" of the report as one of the lead authors. This commentary summarizes the WG3 report, particularly of Chapter 6, and discusses some key points.

2. Assessments of climate change mitigation

The AR5 approached better understanding of the gap between theories and realities, and conducted assessments considering the realities. I believe AR5 was greatly improved compared with the Fourth Assessment Report (AR4, 2007[2)]). IPCC WG3 treats socioeconomic issues which are very complex in the real world; however, the models assessing long-term emission scenarios are developed with very simplified assumptions. Chapter 6 of AR5 tried to understand the large gaps, and provided insights which help understand the gaps from state-of-the-art analyses. In addition, assessments of climate policies on emission reductions (mitigation) were conducted by using the basic theories of environmental economics in AR4, and also by using actual data since AR4. The descriptions of assessments in AR5 provided valuable insights, and also indicated the gaps between theories and realities.

The number of emission scenarios for assessing long-term emission pathways in AR5 was greatly increased compared with that in AR4. Such a large number of emission scenarios particularly of lower emission levels provided a wide range of possibilities of emission pathways meeting lower level targets of atmospheric GHG concentration and global mean temperature change. The wide range of the scenarios provided will help future policy decisions on climate change, widening policy alternatives for emission reductions.

The following chapters discuss some of the important points individually.

3. Assessing long-term emission scenarios in the Fourth Assessment Report, 2007

Before addressing AR5, I will address assessments of emission pathways provided in AR4[2)]. Figure 1 shows the summarized emission scenarios in AR4.

The number of scenarios was 177, but there were only six scenarios in the least level of emissions, Category I (445–490 ppm CO_2eq). Before AR4, emission scenarios for 550 ppm CO_2 stabilization (around 650 ppm CO_2eq as CO_2 equivalent concentration; Category IV) were used as a benchmark for assessments of emission reduction, and many of the scenarios, 118 scenarios, are classified in Category IV.

After the publication of AR4, international negotiations on climate change focused particularly on Category I, and widely shared the target of a global mean temperature below 2 °C relative to the preindustrial level with 450 ppm CO_2eq stabilization, and halving global emissions by 2050. However, IPCC did not recommend any specific targets such as the 2 °C target and 450 ppm CO_2eq stabilization target. These targets are only political (AR5 also does not recommend any specific targets). IPCC AR4 just summarized that about 450 ppm CO_2eq stabilization was required if the global mean temperature was to be kept below 2 °C relative to the preindustrial level assuming the equilibrium climate sensitivity (the equilibrium temperature increase level after stabilizing the CO_2 equivalent concentration at double the reference concentration) is 3.0 °C, and the temperature reduction approaches 2 °C after several hundred years from now. Then, the six scenarios that meet about 450 ppm CO_2eq stabilization just show that global emission reductions in 2050 are 50 to 85% reductions relative to 2000.

Thus the 2 °C target was widely recognized as an international political target after AR4, but the large gap between the deep emission reduction target and actual global emissions, and difficulties in emission reductions, made international negotiation on climate change difficult and led to stagnation.

Halving global emissions by 2050

About 450 ppm CO2-eq stabilization

2 °C target

Equilibrium temperature increase, which was calculated under the assumption of equilibrium climate sensitivity of 3.0 °C

Category	Radiative forcing (W/m^2)	CO_2 concentration[a] (ppm)	CO_2-eq concentration[c] (ppm)	Global mean temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity[b], [c] (°C)	Peaking year for CO_2 emissions[d]	Change in global CO_2 emissions in 2050 (% of 2000 emissions)[d]	No. of assessed scenarios
I	2.5-3.0	350-400	445-490	2.0-2.4	2000-2015	-85 to -50	6
II	3.0-3.5	400-440	490-535	2.4-2.8	2000-2020	-60 to -30	18
III	3.5-4.0	440-485	535-590	2.8-3.2	2010-2030	-30 to +5	21
IV	4.0-5.0	485-570	590-710	3.2-4.0	2020-2060	+10 to +60	118
V	5.0-6.0	570-660	710-855	4.0-4.9	2050-2080	+25 to +85	9
VI	6.0-7.5	660-790	855-1130	4.9-6.1	2060-2090	+90 to +140	5
						Total	177

Figure 1: Summary of emission scenarios in IPCC AR4[2)]

4. Assessing long-term emission scenarios in the Fifth Assessment Report

Table 1 shows a new summary of classified emission scenarios in AR5[1]. The number of emission scenarios in AR5 was increased compared to AR4, and there were over 1000 scenarios, including 114 scenarios for around 450 ppm (430 – 480 ppm) and 251 scenarios for around 500 ppm (480 – 530 ppm).

4.1 Emission reduction scenarios including "overshoot" scenarios

The scenarios in AR4 were basically GHG concentration "stabilization" scenarios (the concentration reaches a certain level and thereafter remains at that level). On the other hand, most of the scenarios in lower emission levels such as 450 and 500 ppm CO_2eq scenarios in AR5 are "overshoot" scenarios where the concentrations rise beyond a certain level (and also temperature) for a few decades, and thereafter decrease and reach the target level. These scenarios were developed inevitably reflecting the fact of recent faster increases in global GHG emissions. According to AR5, the increase in global GHG emissions between 1990 and 2000 were 2.2% per year, while those between 1990 and 2000 were 0.6% per year.

Please note that AR5 provided the temperature increase in 2100 (Table 1) instead of the equilibrium temperature increase which was provided in AR4 (Figure 1), because the scenarios included not only stabilization scenarios but also overshoot scenarios in AR5.

The 450 ppm CO_2eq stabilization and 2 °C reduction targets have been focused on in international negotiations since AR4, and then the modelers were required to analyze such targets. However, it is difficult to obtain the possible pathways to meet the targets without overshoots due to the actual large increase in global emissions after AR4. In overshoot scenarios, the emissions are required to be nearly zero or net negative emissions by 2100. Such emission pathways may be technologically feasible, but major deployments of carbon dioxide removal (CDR) technologies such as large scale afforestation/reforestation, and direct CO_2 removal and/or bioenergy with CCS (e.g., biomass power with CCS) are required. More detailed investigations and assessments for the achievability of such radical measures are needed to assess the practical realization of overshoot scenarios.

Table 1: Summary of emission scenarios in IPCC AR5[1]

CO_2 equivalent concentration in 2100 (ppm CO_2eq)	Subcategories	2050 global emission (relative to 2010)	2100 temperature (°C, relative to 1850-1900)	Probability of exceeding the targets (relative to 1850-1900)		
				1.5°C	2.0°C	3.0°C
<430	Only a limited number of individual model studies have explored levels below 430 ppm CO_2eq					
450 (430-480)	—	-72~-41%	1.5~1.7°C (1.0~2.8)	49-86%	12-37%	1-3%
500 (480-530)	Does not exceed 530 ppm CO_2eq	-57~-42%	1.7~1.9°C (1.2~2.9)	80-87%	32-40%	3-4%
	Exceeds 530 ppm CO_2eq	-55~-25%	1.8~2.0°C (1.2~3.3)	88-96%	39-61%	4-10%
550 (530-580)	Does not exceed 580 ppm CO_2eq	-47~-19%	2.0~2.2°C (1.4~3.6)	93-95%	54-70%	8-13%
	Exceeds 580 ppm CO_2eq	-16~+7%	2.1~2.3°C (1.4~3.6)	95-99%	66-84%	8-19%
(580-650)	—	-38~+24%	2.3~2.6°C (1.5~4.2)	96-100%	74-93%	14-35%
(650-720)	—	-11~+17%	2.6~2.9°C (1.8~4.5)	99-100%	88-95%	26-43%
(720-1000)	—	+18~+54%	3.1~3.7°C (2.1~5.8)	100-100%	97-100%	55-83%
>1000	—	+52~+95%	4.1~4.8°C (2.8~7.8)	100-100%	100-100%	92-98%

4.2 Uncertainty in climate sensitivity and temperature estimates

The assessment reports before AR4 concluded that the equilibrium climate sensitivity was likely to be 1.5–4.5 °C, and the best estimate was 2.5 °C. AR4 stated that climate sensitivity was likely to be 2.0–4.5 °C, and the best estimate was 3.0 °C. The equilibrium temperature increases for emission scenarios classified in AR4 (see Figure 1) were estimated with an equilibrium climate sensitivity of 3.0 °C. WG1 AR5 changed the climate sensitivity evaluation to 1.5–4.5 °C again reflecting the slow-down of temperature increase since the beginning of this century, which is called “hiatus”. However, WG1 was not able to reach any consensus on the best estimate[3)]. The equilibrium climate sensitivity used for estimating the temperature (see Table 1) is not clearly described in AR5, but the explanations including other literature referred to in AR5 implied that the parameters of a simple climate change model were assumed based on a climate sensitivity of 2.0–4.5 °C with the best estimate of 3.0 °C, which is not consistent with AR5 but with AR4. Thus, temperatures in 2100 and the probabilities exceeding target temperatures are lower than the temperatures and probabilities shown in AR5 (Table 1), if the climate sensitivity of AR5 (1.5–4.5 °C) is employed.

In addition, AR5 shows that the probability of not exceeding 2 °C of 450 ppm CO_2eq scenarios in 2100 is likely (>66%), but this is true when a climate sensitivity based not on AR5 but on AR4 is employed. However, the 500 ppm CO_2eq scenarios also meet the 2 °C target (the probability of not exceeding 2 °C is 39–68%), when the climate sensitivity of best estimate corresponding to 50% probability, which corresponds to AR4 estimates, is employed.

4.3 Required global GHG emission reductions in 2050

We should not simply think that global GHG emission reductions of 41–72% in 2050 relative to 2010 are required for not exceeding 2°C before 2100, which corresponds to 450 ppm CO_2eq scenarios. According to the findings of AR5, we should understand that reductions of 25–72% including 500 ppm scenarios are accepted for not exceeding 2 °C, if the basis of consideration is the same as AR4. In AR4, emission reduction ratios are shown relative to 2000, and the reduction of 25–72% relative to 2010 can be converted to 6–65% relative to 2000. The reduction ratios are much smaller than those of AR4 (50–85% reduction relative to 2000). In addition, as mentioned above, the estimates are made by employing the climate sensitivity of AR4. If the climate sensitivity of AR5 is employed, further smaller emission reductions are allowed for the 2 °C target (e.g., global emission in 2050 should return to around the current emission level).

5. Assessing emission reduction costs

5.1 Ideal emission reduction costs

Emission reduction costs are very important information for considering emission reduction levels and implementing emission reduction measures. According to AR5, global consumption losses for achieving a concentration below about 450 ppm CO_2eq in 2100 are 2–6% (median: 3.4%) and 3–11% (median: 4.8%) in 2050 and 2100, respectively. We should understand that these loss figures are large, recognizing that the GDP of the whole of Africa in 2011 is 2.4% of the global GDP. Meanwhile, emission reduction costs are about one third to two thirds for 550 ppm CO_2eq in 2100. We should also recognize that these emission reduction costs are estimated under the assumption of equal marginal abatement costs among all countries and with all emission reduction technologies available. This means that least cost measures are assumed to be employed in the world, which is too idealistic.

5.2 Assessment of emission reduction costs with and without key emission reduction technologies

One of the big messages of AR5 is that all of the key emission reduction measures play a large or certain role to meet deep emission reductions such as 450 and 550 ppm CO_2eq. However, the assumptions are very idealistic in the real world, and analyses of emission reduction costs were also summarized when some key measures are not available.

Particularly for meeting 450 ppm CO_2eq in 2100, emission reduction costs are estimated to greatly increase, to +138% and +64% when CCS and bioenergy are unavailable, respectively. Negative emissions are necessary in most of the 450 ppm scenarios. Negative emissions require large scales of CCS and bioenergy, but large scales of afforestation/reforestation are required if CCS and bioenergy are unavailable. Compared with the cost increases of unavailability of these technologies, the cost increases of nuclear power, and photovoltaics and wind power, are +7% and 6%, respectively. The cost increases are not small, and these technologies are also important.

6. Deployment of future climate change policies

AR5 of WG3 (aside from the Summary for Policymakers (SPM) which was drawn up by policymakers) collected and provided the latest scientific knowledge

References

1) IPCC WG3 (2014), Climate Change 2014–Mitigation of Climate Change, Cambridge University Press.

2) IPCC WG3 (2007), Climate Change 2007–Mitigation of Climate Change, Cambridge University Press.

3) IPCC WG1 (2013), Climate Change 2013– The Physical Science Basis, Cambridge University Press.

Note of the IPCC Fifth Assessment Report

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RITE's research results contributed to the IPCC's Fifth Assessment Report (AR5). Two lead authors from RITE joined the team who wrote the report. Over 20 academic papers written by scientists from RITE are referred to in the report. We also covered the IPCC meetings, in which the three WG reports and the SYR were approved, to give scientific advice to the policy maker.

The SYR integrates the findings from the three IPCC Working Group (WG) reports; WGI (The Physical Science Basis), WGII (Impacts, Adaptation and Vulnerability), and WGIII (Mitigation of Climate Change). The Synthesis Report (SYR) of the IPCC's AR5 was finally adopted at the 40th session of the IPCC in November 2014. This led to the end of the AR5 approval process, and the findings of the reports provides a scientific basis for negotiations on a new international agreement under the UNFCCC, which is expected to be adopted in Paris in 2015.

One of the most contentious issues in the approval process was the classification of countries. The UNFCC divides countries into two main groups, Annex I and Non-Annex I, according to differing commitments. Over the past decade, however, emissions from some Non-Annex I countries, such as China and India, have risen rapidly whereas emissions from Annex I countries have been more or less flat. This implies that global climate policy needs to update how it classifies countries.

The IPCC underlying report includes data on emissions based on a division of countries into four income-level groups based on the World Bank. Discussions centered on whether or not to include them in the SPM. Despite long and hard negotiation, participants were not able to agree on this issue because they are perceived to influence revision of groupings under the UNFCCC. Given concerns expressed by some countries over the grouping of countries based on income levels, the relevant figures and paragraph was removed from the SPM. This confrontation suggested tough negotiations will continue up to COP21 to form a new international climate regime.

by trying to include not only basic theories and ideal analyses, but also analyses considering real world activities and behaviors. AR5 is seen to make have made progress compared to AR4 and to have improved over AR4, and keeps a relatively good balance in description. Considerations of complex constraints and large uncertainties in the real society will help to make really effective emission reduction measures. In this context, it will be important to reconsider the targets of halving global emissions by 2050, and 80% reduction of Japanese emissions by 2050, for example, by reflecting the latest IPCC insights.

In addition, it is important to recognize that there are still large uncertainties in climate change issues. IPCC AR5 provided a broad range of possible emission reduction pathways and measures. Considering emission reduction targets with flexibilities, and not only mitigation but also adaptation measures, will support better and smarter decisions on responses to climate change.

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The Current Status and Issues on CCS

1. Introduction

A drastic reduction in CO_2 emissions is required for mitigation of global warming. According to "the Energy Technology Perspective 2014 (ETP2014)"[1)] issued by International Energy Agency (IEA) in 2014, global emissions of CO_2 in 2050 should be decreased to 15Gt CO_2/yr, which is almost half of those in 2009, in order to limit long-term global temperature increase to 2°C. This means that 40 Gt CO_2/yr should be cut from the baseline emissions in 2050, estimated as 55Gt CO_2/yr. Such a significant reduction cannot be achieved by only a sole technology, but combination of technologies with a great potential is required. In this context, "Carbon Dioxide Capture and Storage (CCS)" has been gaining attentions as an innovative mitigation option. This option is cost-competitive and more stable against power fluctuation comparing to photovoltaic or wind power.

This report provides comprehensive overviews of the latest progress and issues on CCS which is central focus in our laboratory.

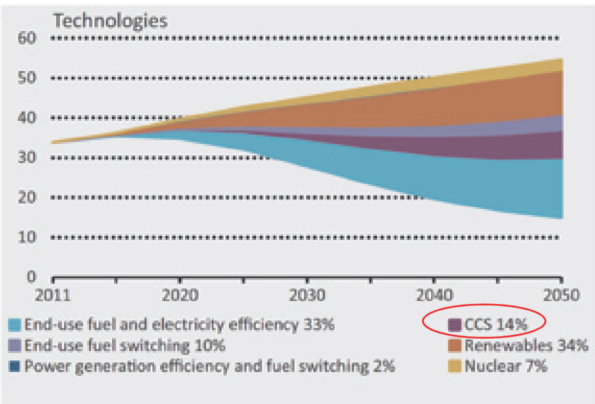


Figure 1: Contributions to annual emissions reductions between the 6DS and 2DS (source:IEA "Energy Technology Perspectives 2014"[1)])

2. Current status of CCS

2.1 Necessity and perspective of CCS

According to the 2°C Scenario (2DS) stated in the ETP2014, CCS plays an important role as a vital technology to contribute to 14% accumulatively through 2050, 17% in 2050, of the total global emissions reduction (Figure 1).

"Mitigation of Climate Change"[2)], Working Group III Contribution to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) was issued in March 2014. According to this report, at the global level, scenarios reach-

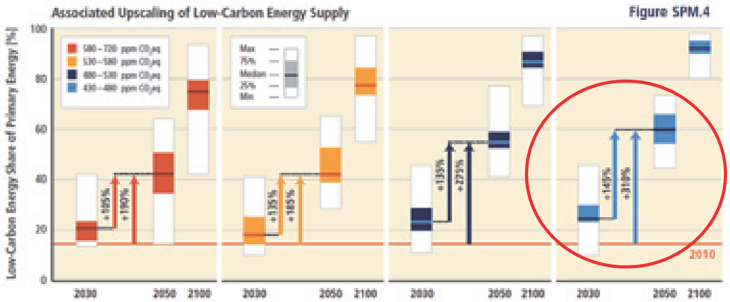


Figure 2: Low-Carbon Energy Share of Primary Energy [%]
(source:IPCC "Summary for Policymakers (SPM) the Working Group III report Fifth Assessment Report (AR5)"2))

	Increase in total discounted mitigation costs in scenarios with limited availability of technologies [% increase in total discounted mitigation costs (2015–2100) relative to default technology assumptions]				Increase in medium- and long-term mitigation costs due to delayed additional mitigation until 2030 [% increase in mitigation costs relative to immediate mitigation]			
					≤55 $GtCO_2eq$		>55 $GtCO_2eq$	
2100 Concentration (ppm CO_2eq)	No CCS	Nuclear phase out	Limited Solar/Wind	Limited Bioenergy	2030–2050	2050–2100	2030–2050	2050–2100
450 (430–480)	138 (29–297) [N: 4]	7 (4–18) [N: 8]	6 (2–29) [N: 8]	64 (44–78) [N: 8]	28 (14–50) [N: 34]	15 (5–59)	44 (2–78) [N: 29]	37 (16–82)
500 (480–530)								
550 (530–580)	39 (18–78) [N: 11]	13 (2–23) [N: 10]	8 (5–15) [N: 10]	18 (4–66) [N: 12]	3 (−5–16) [N: 14]	4 (−4–11)	15 (3–32) [N: 10]	16 (5–24)
580–650								

Figure 3: Global mitigation estimated cost increases due to assumed limited availability of specific technologies and delayed additional mitigation
(source:IPCC "Summary for Policymakers (SPM) the Working Group III report Fifth Asesssment Report (AR5)"2))

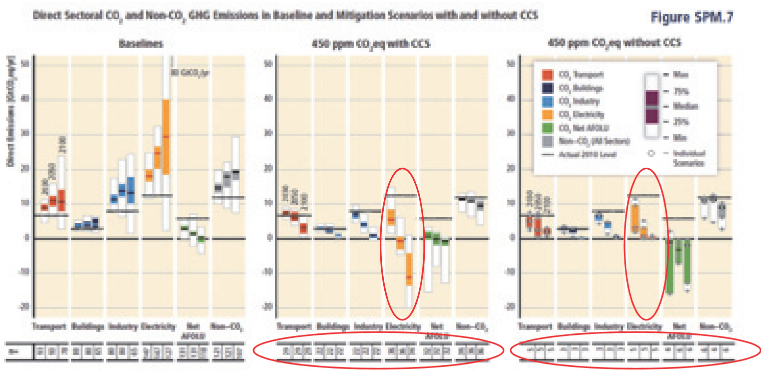


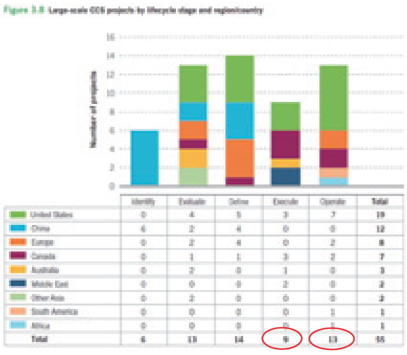
Figure 4: Direct emissions of CO_2 and total non-CO_2 GHGs across sectors in baseline and mitigation scenarios with CCS and without CCS
(source:IPCC, Summary for Policymakers (SPM) the Working Group III report Fifth Assessment Report (AR5)2))

ing about 450 ppm CO_2eq are also characterized by more rapid improvements in energy efficiency and a tripling to nearly a quadrupling of the share of zero- and low carbon energy supply from renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS) and so on by the year 2050 (Figure 2). This report also says that without CCS, mitigation costs can increase substantially depending on the considered technology (18-297 % increase in total discounted mitigation costs (2015-2100) relative to default technology assumptions) (Figure 3). This report furthermore says that many models cannot reach 450 ppm CO_2eq concentration level by 2100 under limited availability of CCS, and fossil fuel power generation without CCS is phased out almost entirely by 2100 (Figure 4).

In addition to the above, this report says that combining bioenergy with CCS (BECCS) offers the prospect of energy supply with large-scale net negative emissions which plays an important role in many low-stabilization scenarios, while it entails challenges and risks, and that CCS could contribute to significant GHG emission reductions in industry.

2.2 The status of CCS projects

The Global CCS Institute (GCCSI) published “The Global Status of CCS: 2014”[3)] which summarizes CCS projects activities in the world. According to the report, there are 13 large scale integrated projects (LSIPs) listed in the Operate stages and 9 projects in the Execute. The number of total LSIPs including the planning stages of development amounts to 55, decreasing by ten projects compared to those in last year (Figure 5). In addition to these LSIPs, the CCS demonstration project at the Tomakomai Area is conducted in Japan.



	Identify	Evaluate	Define	Execute	Operate	Total
United States	0	4	5	3	7	19
China	6	2	4	0	0	12
Europe	0	2	4	0	2	8
Canada	0	1	1	3	2	7
Australia	0	2	0	1	0	3
Middle East	0	0	0	2	0	2
Other Asia	0	2	0	0	0	2
South America	0	0	0	0	1	1
Africa	0	0	0	0	1	1
Total	6	13	14	9	13	55

【Definition of each stage】

Identify : a proponent carries out early studies and preliminary comparisons of alternatives

Evaluate : the range of options that could be employed is examined

Define : a positive final investment decision has been taken

Execute : A project is considered to have entered construction

Operate : the project is in operation

Closure : the project moves to the process of ceasing operations

【Definition of LSIP】

・ at least 800,000 tonnes of CO2 annually for a coal–based power plant, or at least 400,000 tonnes of CO2 annually for other emissions–intensive industrial facilities (including natural gas–based power generation).

Figure 5: Large-scale CCS projects by lifecycle stage and egion/country (source:GCCSI “The global Status of CCS 2014”[3)])

Figure 6 shows large-scale CCS projects classified by sectors and storage types. Most of LSIPs listed in the Operate stages are classified into Natural gas processing sector and EOR type. This result is considered to be turned out because Natural gas processing requires CO_2 capture with or without CCS, and EOR-typed CCS has feasibility by trade of captured CO_2.

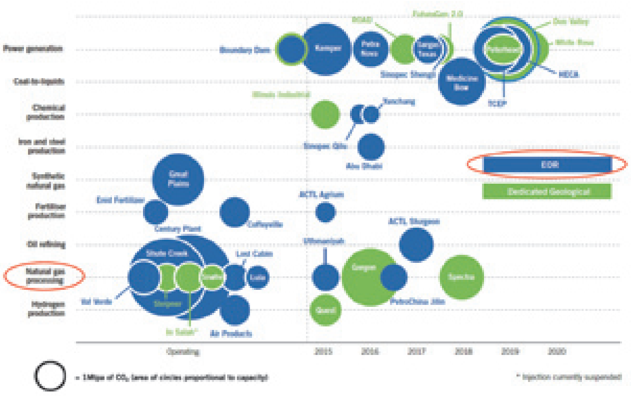


Figure 6: Actual and expected operation dates for large-scale CCS projects in the Operate, Execute and Define stages by industry and storage type (source:GCCSI “The global Status of CCS 2014”[3)])

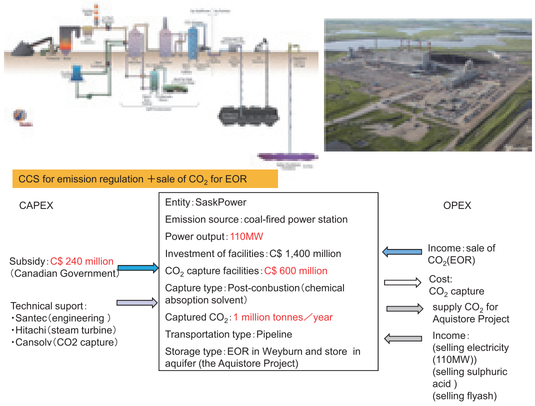


Figure 7: The outline of CCS project at Boundary Dam Power Station, Canada

The world's first large-scale project to capture the CO_2 from a coal-fired power plant opened at Boundary Dam Power Station, Canada in October 2013. Regulations for reduction in CO_2 emissions from coal-fired plants will come into effect in July 2015 in Canada. As Boundary Dam Power Station will be subject to these regulations, they decided to install CCS using an opportunity of replacing Unit #3 of Boundary Dam Power Station. One million tons of CO_2 will be captured every year from Unit #3 which generates 110MW of power. Canadian Government subsidized C$ 240 million for the expenses of C$ 6 million for CO_2 capture facilities. Subsidy rate is 40%. Most of captured CO_2 will be sold for EOR in an adjacent oil field and a part of captured CO_2 will be used for demonstration project of CO_2 storage in a deep saline aquifer. As described above, Boundary Dam CCS project is implemented under regulations on CO_2 emission reduction, with subsidy from the government and an income from the sale of CO_2 for EOR.

2.3 The issues on deployment of CCS (necessity of storage site characterization)

As mentioned at 2.2, most of large-scale CCS projects are implemented under the mechanism of regulations on CO_2 emissions, carbon tax, environmental regulations and so on. It is very difficult to deploy CCS by market mechanisms because CCS is a countermeasure only for global warming which has an external diseconomy. For deploying CCS it is necessary to build some mechanisms including incentive such as subsidy and tax reduction, emissions trading, and regulations. In addition, investigation of storage capacity through exploration and characterization of storage sites, maintenance of the legal systems, and increase in public understanding are also necessary for introduction and deployment of CCS.

This section explains that early-stage storage site characterization is one of the most important items to accelerate CCS deployment. The importance of early-stage storage site characterization is pointed out in "Technology Roadmap Carbon capture and storage 2013"[4)] published by IEA in July 2013. "The Global Status of CCS: 2014"[3)] published by GCCSI in November 2014 also pointed out as follows: "It can take a considerable period of time, possibly up to ten years, to fully appraise a greenfield site ready for a final investment decision", "In the early phases of project development, storage availability is also the most uncertain element, and may require a significant allocation of resources", "the importance of undertaking storage-related actions this decade to prepare for widespread CCS deployment post-2020 cannot be overstated", and "To lessen the risk of widespread CCS deployment being slowed by uncertainty over available storage, there is an urgent need for policies and funded programs that encourage the exploration and appraisal of significant CO_2 storage capacity".

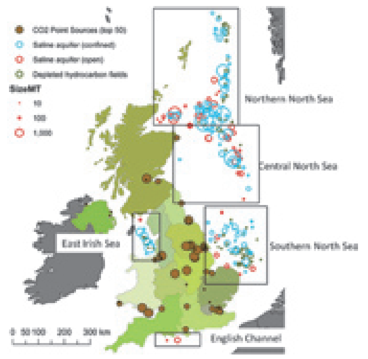
Table 1: Recomendations on early-stage storage site characterisation (souece:GCCSI "The global Status of CCS 2014"[3)])

Recomendations for Policy Makers (selection)
It can take a considerable period of time, possibly up to ten years, to fully appraise a greenfield site ready for a final investment decision.
In the early phases of project development, storage availability is also the most uncertain element, and may require a significant allocation of resources.
The characteristics of a particular storage site may have important influences on the design of the CO2 capture plant and transportation system.
Given the required scale of CCS deployment post-2020 to meet climate goals, the challenge of finding appropriate storage capacity may increase considerably.
Projects may need to investigate several storage targets to mitigate the exploration risk.
The importance of undertaking storage-related actions this decade to prepare for widespread CCS deployment post-2020 cannot be overstated.
To lessen the risk of widespread CCS deployment being slowed by uncertainty over available storage, there is an urgent need for policies and funded programs that encourage the exploration and appraisal of significant CO2 storage capacity.

Finally, this section introduces trends in the site characterization in the world. The British Geological Survey (BGS) and The Crown Estate built a data base on potential storage sites in the United Kingdom. This data base includes site characteristic data such as general characteristics, pore volume, static capacity, and injectivity, and risk assessment data such as seal, faults, lateral migration and risk profiles as well as economics data. The GIS-based database for CO_2 capture and storage including some tools for cost evaluation etc. is also available in the United States. This database includes information of stationary sources of CO_2, storage capacity of potential sites, and infrastructures. As explained above, the United States and the UK open information on potential storage sites and their storage capacities to public as databases. Such activities are very important to fully introduce CCS in Japan in future.

Database example in U.K.

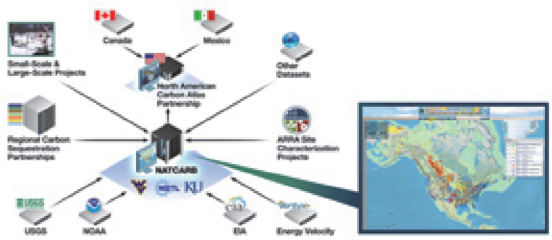
Publication of Database(CO_2 Stored):
the British Geological Survey (BGS) The Crown Estate



- ☐ Characteristics
  - General
  - Depositional Environment
  - Pore Volume
  - Static Capacity
  - Injectivity
  - Theoretical Capacity
- ☐ Risk
  - Seal
  - Faults
  - Lateral Migration
  - Wells
  - Formation Damage
  - Connectivity
  - Risk Profiles
- ☐ Economics
  - Economics
  - Oil & Gas Wells
- ☐ Results
  - Monte Carlo Summary

Figure 8: Storage sites databas (example in U.K.)
(source:The British Geological Survey (BGS) The Crown Estate)

Database NATCARB in USA



The National Carbon Sequestration Database and Geographic Information System (NATCARB) is GIS-based tool which indicats the potential of CO_2 capture and storage and includes following items which are required for introduction and deployment of CCS.

- Data : stationary sources of CO2, storage potential and infrastructure
- tool : Pipeline measurement, formation characterization and cost evaluation

Figure 9: Storage sites database (example in USA)
(source:The National Carbon Sequestration Database and Geographic information System (NATCARB))

2.4 Overseas trends in regulations on CCS

In September 2013, the Environmental Protection Agency (EPA), USA proposed New Source Performance Standards (NSPS). If the proposed standards will go into effect, newly constructed coal-fired power plants should be equipped with CCS facilities. This regulation is to limit emissions from individual power plant. On the other hand, the EPA, USA proposed “Clean Power Plan” (Emission Guidelines for existing fossil fuel-fired electric generating units). This proposes state-specific rate-based goals for CO_2 emissions from the power sector. The USA has a strategy to limit emissions both by regulation on individual power plant and state-specific rate-based goals. Nationwide, by 2030, this rule would achieve CO_2 emissions reductions from the power sector of approximately 30 percent of emissions levels in 2005.

In addition, CO_2 Emission Performance Standard (EPS) which requires limiting CO_2 emissions from coal-fired power plants will go into effect in 2015 in Canada. EPS has been already introduced in the UK.

CCS-ready regulation which requires feasibility studies for construction of new thermal power plants with CCS has been entered into effect in EU directive. Transposition of this EU directive to national law has been completed in some of EU member states, such as Spain, the Kingdom of Denmark and so on. The European Council endorsed a binding EU target of an at least 40% domestic reduction of greenhouse gas emissions in the ETS (Emission Trading Scheme) by 2030 compared to 1990.

In this way, mechanisms to introduce and deploy CCS are being formed steadily in the foreign countries.

Table 2: The outline of Overseas trends in regulations on CCS

Overseas trends in regulations on CCS（1）

nation	Outline of regulation about CCS
USA	【CO_2 emission regulation on individual power plant】 ○New Source Performance Standard proposed by EPA: ・New coal-fired power：500kg/MWh（12-operating month rolling average basis），480kg/MWh（84-operating month rolling average basis） ・New gas-fired power：450 or 500kg/MWh（applied depending on output scale） ○EPS regulation in individual State（California, Washington, Oregon） ・Base-load power：500kg/MWh 【State-specific rate-based goals】 ○Emission Guidelines for Existing Stationary Sources proposed by EPA ・Under the authority of Clean Air Act (CAA) section 111(d), the EPA would set out proposed state-specific emission rate-based CO_2 goals (the quantity of CO_2 per MWh of electricity generated). Each state must then develop, adopt, and submit its state plan under CAA section 111(d) period, through reasonable implementation of the BSER（Best System of Emission Reduction）adequately demonstrated. EPA will approve the plan. ・Nationwide, by 2030, this rule would achieve CO_2 emissions reductions from the power sector of approximately 30 percent from CO_2 emissions levels in 2005.
Canada	○EPS regulation：New coal-fired power ：420kg/MWh

Overseas trends in regulations on CCS（2）

Nation	Outline of regulation about CCS
UK	○EPS regulation：New thermal power：450kg/MWh（coal-fired power must be equiped with CCS） ○CCS-Ready regulation：New thermal power more than 300MW（50MW in Scotland）
EU	○EUCCS directive（CCS-Ready regulation）：New thermal power more than 300MW（EU member states which has completed transportation of EU directive into national law：Spain, Denmark, Netherlands, Italy, France, Lithuania, Malta, Slovenia, Portugal, Romania, Belgium, Bulgaria, Czech, Germany, Estonia, Greece, Latvia, Luxembourg, Finland, UK, Cyprus, Hungary, Ireland） ○EC Conclusions（decided in October 2014） ・The European Council endorsed a binding EU target of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990. "with the reductions in the ETS and non-ETS sectors amounting to 43% and 30% by 2030 compared to 2005, respectively" ・"An EU target of at least 27% is set for the share of renewable energy consumed in the EU in 2030." , "An indicative target at the EU level of at least 27% is set for improving energy efficiency in 2030" ・"the existing NER300 facility will be renewed, including for carbon capture and storage and renewables, with the scope extended to low carbon innovation in industrial sectors and the initial endowment increased to 400 million allowances (NER400)."

2.5 International standardization for CCS

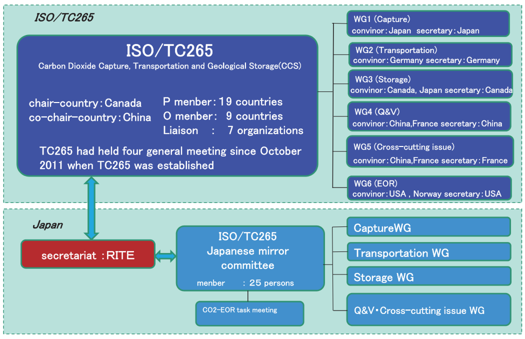


Figure 10: Organization chart of ISO/TC265

A technical Committee (ISO/TC265) was established within International Organization for Standardization (ISO) and the international standardization for CCS has been developed under this ISO framework. ISO/TC265 had held four general meetings since the establishment of TC in October 2011. 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. In response to involvement in this international framework, Japan set up the mirror committee of ISO/TC265 for internal discussions and decision-making. In addition, the third WG1 was held in October 2014 in Japan.

The activities of each WG are as follows.

Technical report (TR) on CO_2 capture has been developed under WG1. The target of the publication of TR is 2015. The International standard (IS) on power generation and post combustion capture technology is aimed to be published in 2018. The International standard (IS) on transportation by pipeline has been developed under WG2. The target of publication of the IS is 2016.

The International standard (IS) on onshore and offshore CO_2 storage has been developed under WG3. The target of publication of the IS is 2017. Technical report (TR) has been developed under WG4. The target of publication of the TR is 2015. The International standard (IS) on vocabulary has been developed under WG5. The target of publication of the IS is 2016. The International standard (IS) has been developed under WG6. The target of publication of the IS is 2017.

Table 3 shows the activities of each WG and Figure 11 shows the immediate schedules of each WG. A technical report is going to be published in 2015 and the first IS in 2016 at the earliest.

Table 3: activities of each ISO WG

WG	Activities	Publish (Target)	notes
WG1 (Capture)	●TR on the basis of Japanese draft is going to be balloted for the publication. ISO/TR 27912 ●NWIP for IS (power generation and post combustion capture) is going to be balloted.	TR:2015 IS:2017	TR 27912 is expected to be published in summer, 2015.
WG2 (Transport)	●IS for the transportation by pipeline. WG2 is preparing DIS according to the result of CD ballot. ISO 27913	IS:2016	DIS ballot is planed in April 2015. Transpotation by ship is possible future theme.
WG3 (Storage)	●IS on the basis of North American stanard, CSA-Z741, covers onshore and offshore storage. WD is on the editing process. ISO 27914	IS:2017	WD will be completed and CD ballot is planed in July 2015.
WG4 (Q & V)	●WG4 is gathering the information relating quantification and verification for TR.WD is on the editing process. ISO/TR 27915	TR:2015	WD will be completed and DTR ballot is planed in June 2015.
WG5 (Cross-cutting Issue)	●IS for vocabulary of CCS is continued to be enhanced as CD. Second CD ballot is expected at the end of 2015.The development track has been extended to 4 years. ISO 27917 ●TR for lifecycle risk management is started. ●Stakeholder engagement is started as PWI.	IS:2017 TR:2016	The development track of ISO 27917 has been extended to 4 years.
WG6 (CO2-EOR)	●IS for CO2-EOR will be developed by the initiated TP activities. ISO 27916	IS:2018	CD ballot is planed in October 2015.

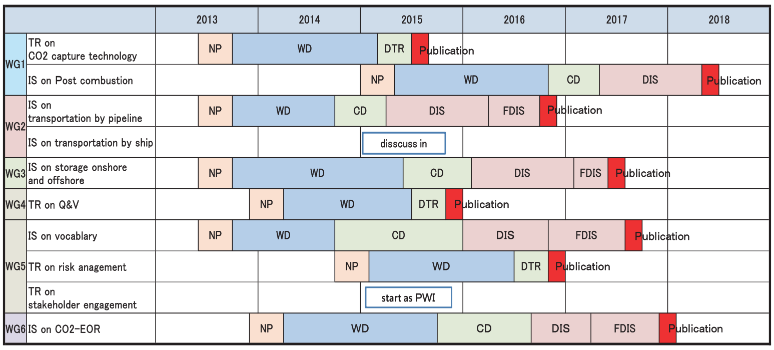


Figure 11: Schedule of ISO/TC265

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

More economical and safer CCS technology is required to increase the candidate sites for CO_2 storage. “SUCCESS” (Storage & Utilization of CO_2 for Coexistence of Economical & Safe System) is one of the more economical and safer CCS technologies. It can be called a next-generation CO_2 storage system which has three advantageous effects (geothermal heat-utilization, formation pressure-relaxation, and injection rate-increase) by extracting water from the aquifer (Figure 12).

The first advantage of this system is that utilizing of the geothermal energy improves the economic efficiency of CCS in its implementation. The second advantage is that the extraction of water brings in the relaxation of the formation pressure. It is expected to be a safety tool for the CO_2 injection. The third advantage is the increase of CO_2 injection rate per a well by the relaxation of the formation pressure. It brings in cost reduction since large amount of CO_2 injection using one well becomes available.

In 2014 F.Y, RITE has been focusing on the multi-well system, which is the system not involving geothermal utilization in the “SUCCESS”, and implementing ①investigation of the multiple-well system introduction sites and literature survey, and ②evaluation of efficacy of multiple wells system by numerical simulations for the Japanese formation.

As for ①investigation, RITE has been investigating the case of the Gorgon project in Australia, where they will adopt the multiple wells system for the first time in the world, and documents on multiple wells system. As for ②evaluation, RITE has been evaluating efficacy of multiple wells system by numerical simulation using simplified and detailed geological models for the Japanese formation.

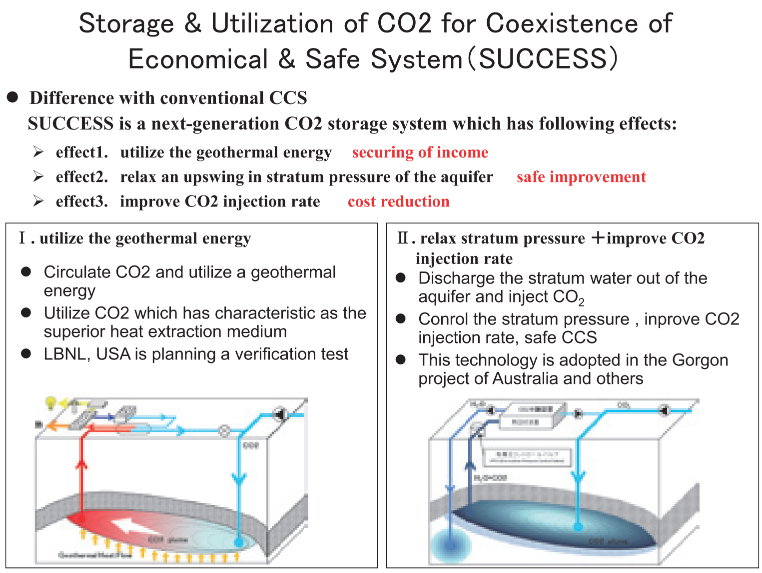


Figure 12: Outline of SUCCESS

4. Conclusion

Among limited technical options for the future, CCS is expected to play a critical role to substantially reduce CO_2 emissions. Working Group III Contribution to AR5 of IPCC and ETP2014, IEA, describe that CCS is a key technology to mitigate a global warming and contributes to a significant reduction in GHG emissions. It is very difficult to deploy CCS by market mechanism because CCS is a countermeasure only for global warming which has an external diseconomy. For deployment of CCS, it is necessary to build some mechanisms including incentive such as subsidy and tax reduction, emissions trading, and regulations. In addition, early-stage storage site characterization is necessary in particular for introduction and deployment of CCS. Mechanisms to introduce CCS, such as CCS-ready regulation and Emission Performance Standard (EPS), are being built steadily in the foreign countries. In the United States and the UK, they are investigating storage capacities of potential sites and open information on these to public as databases. In addition, International standardization for CCS has been in progress steadily.

The more economical and safer CCS technology is necessary to expand the potential CO_2 storage sites. RITE will continue to implement feasibility study on this approach in future.

References

1) IEA, "Energy Technology Perspectives 2014" (2014)

2) IPCC, "Summary for Policymakers (SPM), the Working Group III report, Fifth Assessment Report (AR5)"

3) GCCSI, "The Global Status of CCS: 2014" (2014)

4) IEA, "Technology Roadmap Carbon capture and storage 2013 edition" (2013)

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Research Activities in Systems Analysis Group

We are providing valuable information about measures for global warming and energy both in and outside Japan by conducting systems analysis. We introduce four research topics here out of our research activities.

1. An analysis on the option values of geoengineering under uncertainties in climate change

1.1 Introduction

According to IPCC AR5, “human influence on the climate system is clear”. Still, many uncertainties remain in the extent to which climate systems respond to accumulated GHG emissions (e.g., equilibrium climate sensitivity).

Solar radiation management (SRM) has been drawing much attention in recent years aside from mitigation of and adaptation to climate change. SRM is one of the methods of geoengineering (injecting sulphate aerosols into the stratosphere as a representative technology), which is meant to decrease the global average temperature by artificially reflecting solar radiation. SRM is generally considered affordable and quick option for cooling the earth, though it cannot prevent ocean acidification. However, injecting sulphate aerosols may not only cause environmental side effects (e.g., acid rain, ozone depletion) but also involve ethical and political concerns, and therefore there is room to discuss the plausibility of the strategy based on the premise of implementing SRM.

Hence, we quantitatively estimated the values of the strategy of holding SRM as options by letting SRM be implemented on a limited scale only in the incidence of high climate sensitivity. We show the summary below.

1.2 Assessment model and assumptions

We incorporated SRM options into a world energy model (DNE21), considering the two-stage decision-making process consisting of uncertain (pre-learning) and certain (post-learning) periods. For simplicity, we assumed that a deterministic value of climate sensitivity be uncovered after the year 2050. As Table 1 indicates, we defined a probability function of climate sensitivity based on the representative probability density function agreed in IPCC AR4, where three sensitivities from low to high are given specific discrete probabilities. SRM is assumed to be implemented only when Scenario 3 occurs and only after the year 2050 with maximum constraints on the mass of the sulphate aerosols injected (limited to cancel at most 0.5˚C in each time point) in consideration for ethical, political, and environmental concerns. Regarding SRM's costs per year, we assumed US$10/kg-S which is the higher-order of estimates in the existing literature. For comparison, we evaluated three cases of global mean temperature change below +2˚C, +2.5˚C and +3˚C relative to preindustrial levels in 2100.

Table 1: Three scenarios under uncertainty in climate sensitivity with SRM options

	Equilibrium climate sensitivity (T2x)	Occurrence probability	SRM implementation
Scenario 1	2°C (low)	10%	No (option)
Scenario 2	3°C (moderate)	71%	No (option)
Scenario 3	4°C (high)	19%	Yes

We estimated SRM's option values by comparing two systems costs (1990-2100) under Scenario 2 which were derived by two model-runs, one including SRM options and the other not including any. We also derived two energy-related CO_2 pathways.

1.3 Effects of SRM options on the energy-related CO_2 emission pathways and SRM's option values

For +2˚C target, the feasible solutions were not found because the high climate sensitivity scenario such as T2x=4˚C is included.

Figure 1 shows the results for +2.5˚C target case. Emission pathways will diverge into three branches after 2050. The higher climate sensitivities are the more stringent respective abatement pathways will be. In the uncertain period 2000-2040, stringent CO_2 emission abatement pathways are derived in the case not including SRM options (blue lines) because the scenario requiring stringent abatements (T2x=4˚C) is included. However, when SRM is implemented if Scenario 3 (T2x=4˚C) occurs after 2050 (red lines), it generates room for emission reduction requirements in 2000-2040 as well as 2050-2100. The shift of emission pathways (from the thick blue line to the red line) under the moderate climate sensitivity shows that it is desirable to select emission pathways closer to the deterministic pathway (the green line) where climate sensitivity is deterministically moderate (T2x=3˚C).

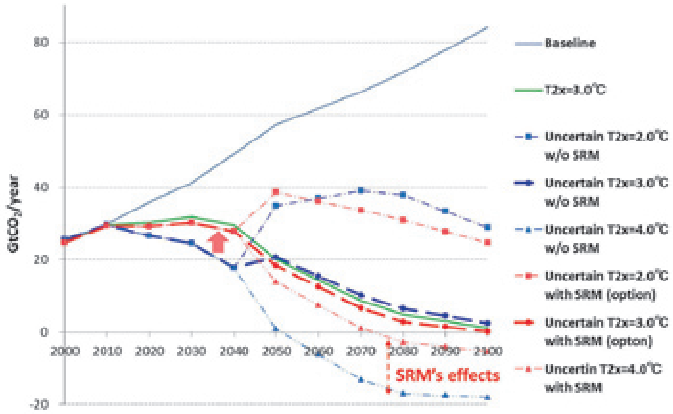

Figure 1: Effects of SRM options on CO_2 emission pathways under uncertainty [+2.5°C target]

We define the SRM's option value as the difference between two energy systems costs that correspond to two emission pathways (the thick blue and red lines) under the moderate climate sensitivity (Uncertain T2x=3 ˚C). SRM's option values rise with the stringency of mitigation targets: it is estimated to be US$201 billion for +3˚C target relative to preindustrial levels in 2100, US$456 billion for +2.5 ˚C target, and US$3,273 billion for +2.4˚C target.

1.4 Conclusion

This study showed that by merely holding SRM as an option, the short- to mid-term economic risks of mitigation policy would decrease even if a high climate sensitivity scenario is included as opposed to preceding studies[1], and that geoengineering could provide flexibility for the comprehensive risk management involving investments for R&D for the long-term mitigation and adaptation. Holding SRM options can also justify a strategy based on a moderate climate sensitivity.

References

1) Akimoto, K.; Decision analyses for energy strategies on global warming issues with an energy systems model of optimization type, Doctoral thesis, (1999).

2. Assessment of U.S. restrictions on public financing for new coal power plants overseas

2.1 Introduction

In 2013, U.S. President Obama announced to stop public financing for new coal power plants overseas, except for the most efficient coal technology in the least developed countries in cases where no other economically viable alternative exists, or plants with carbon capture and sequestration (CCS) technologies[1]. Later, the U.S. Department of the Treasury announced the financing conditions for coal power plants in developing countries. For example, regarding the financing conditions for International Bank for Reconstruction and Development (IBRD) and International Development Association (IDA) -blend equivalent borrowing countries, the plants should deploy CCS technology to reduce the carbon intensity to a level of $500gCO_2eq./kWh$[2].

While the objective of restriction on financing is to promote investment in clean energy by regulating coal power plants which emit more CO_2 than other energy sources, there is room to consider whether the restriction contributes to effective GHGs reductions. In short, there is a possibility that some developing countries construct inexpensive low-or middle-efficiency coal plants with own fund or by obtaining finance from other financial institutions. In such cases, the restriction on financing might result in limited or adverse effects in reducing emissions, which we call ‘loophole’ in the restriction on financing.

2.2 Objectives and methods

We develop four scenarios with different assumption on new construction of coal power plants, and estimate GHGs emissions and average reduction costs by using DNE21+ model. In all countries, all types of coal plants are allowed to construct in Scenario A (base case), only new high-efficiency ones (ultra supercritical, advanced USC, integrated coal gasification combined cycle, integrated coal gasification fuel cell combined cycle) are allowed in Scenario B, and only ones with CCS technologies are allowed in Scenario C. Furthermore, the following scenario (Scenario D) is considered to express the loophole precisely. It shows the situation in which the world is prone to Scenario D in reality, even though Scenario C is expected after the financing restrictions are imposed. In general, whether it is a qualified borrowing country for public financing depends on income levels of borrowing countries, we divide the world into four regions: High Income Countries (HICs), Upper Middle Income Countries (UMICs), Lower Middle Income Countries (LMICs) and Low Income Countries (LICs). As for the conditions of coal power plants construction, only new coal plants with CCS technologies are allowed for developed countries, considering domestic regulation in U.S. and expression of the support for U.S. financing policy by some developed countries. For developing countries, all types of coal power plants are allowed, considering that fact that some middle-income developing countries can construct the plants with own fund or by obtaining finance from other financial institutions, and strict financing conditions are exempted for low income countries.

Here, we show the results when there is no additional climate policy to examine the impacts of financing restrictions.

2.3 Results

Figure 2 shows global GHGs emissions and average reduction costs in 2030 across scenarios. If the regulation on new coal plants functions well (Scenario C), the emissions will be reduced by about 5Gt relative to Scenario A, and its average reduction cost will be +$32, which is the largest cost among scenarios. In this scenario, there will be small economic incentives for developing countries to construct coal plants with CCS technologies by paying high expenses unless stringent emission reduction targets are imposed, which will lead to the loophole.

Scenario D represents the loophole situation. In Scenario D, emissions in high income countries (HICs) will decrease, however, those in upper middle income countries (UMIC) and lower middle income countries (LMICs) will increase when compared with those in Scenario B in which high-efficiency coal plants are allowed. Also, the average reduction cost in Scenario D will be higher than the one in Scenario B. The results suggest that allowing new high-efficiency coal plants for all countries (Scenario B) is desirable in the context of both GHG emissions and average reduction costs when compared with the loophole situation (Scenario D).

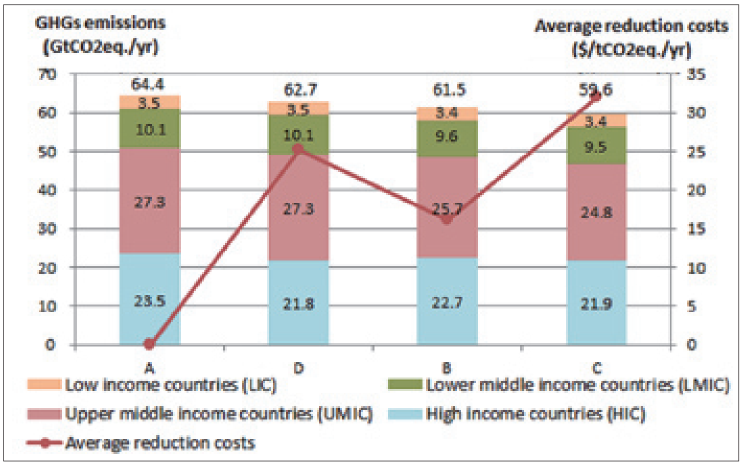

Figure 2: Global GHGs emissions and average reduction costs in 2030 (No additional climate policy)

2.4 Discussion

In case where strong reduction measures are not taken in the world (which is no additional climate policy scenario in this analysis), strict financing restrictions which require CCS technologies for developing countries might result in the loophole and increase CO_2 emissions worldwide. If so, minimizing the loophole by allowing new high-efficiency coal plants will lead to effective reduction and low reduction costs.

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3. Evaluations of Voluntary Action Plan for the Environment in Japan

3.1 Introduction

The first commitment period (2008–2012) of the Kyoto Protocol (KP), which has greenhouse gas emission reduction targets relative to 1990, has expired. Japan's target was a 6% relative to 1990; it achieved a 8.4% reduction. The Keidanren-centered VAP made an important contribution to the achievement of Japan's emission target. The study assessed CO_2 emission reduction efforts by the individual business associations that participated in the VAP.

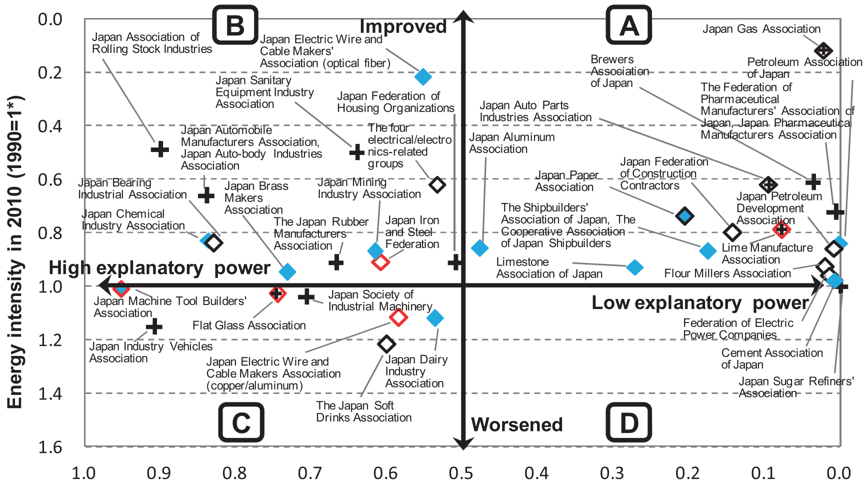
3.2 Overview and Evaluation of the Keidanren VAP

The Keidanren released the Keidanren Appeal on Environment in July 1996 and the Keidanren Voluntary Action Plan on the Environment in June 1997. While each business association had set their own targets, Keidanren, itself, has promoted global warming measures under its goal “to endeavor to reduce CO_2 emissions from the industrial and energy conversion sectors in fiscal 2010 to below the levels of fiscal 1990.” The Japanese government also decided to conduct the VAP follow-ups by the government councils including Industrial Structure Council in December 1997, and launched them in 1998. In that year, implementation of the VAP was specified by the Guidelines for Measures to Prevent Global Warming. Since 1997, the number of participating associations has increased: by 2012, a total of 114 associations had adopted the VAP including 61 associations under the Keidanren[1)].

The VAP is complex, with different types of targets voluntarily set by different associations having various activities. This study focused on 34 business associations in the industry and energy conversion sectors under the Keidanren, considering better comparability across associations in terms of their quantitative data, and evaluated through several indicators for measuring the effectiveness and efforts of emission reductions, using the data based on 1997-2010[2)].

3.3 Results

Energy intensity (energy consumption per economic activity) largely improved in most of the associations but worsened in some associations. Some associations increased also their energy consumptions. Energy intensity as well as energy consumption are affected by economic conditions. Figure 3 shows the energy intensity changes and the explanations of annual energy intensity changes by annual economic activity changes, in order to analyze that economic activities induced the worsening (or improvement) in energy intensity changes. The horizontal axis represents the explanations (R^2) for the energy intensity changes by economic activity changes in each association between 1997 and 2010. The vertical axis represents the energy intensity in 2010 relative to 1990. The pledged target types for the VAP are distinguished by different makers in the Figure. As can be seen on plots from zone A to C, the effectiveness of measures is no clear difference among the target attributes. The intensity changes of all the associations whose intensities worsened can be explained sufficiently well by the economic activity changes (for example, Japan Industry Vehicles Association; zone C). There is a possibility that economic conditions affected to worsen the intensity. Some associations may be considered to have unavoidable impacts on aspects of economy and not to neglect on effort to improve the intensity. In addition, the association in zone A are indicated that have made efforts of the intensity improvements without impacts of economic turndown.



Notes.Types of the pledged target ◆: Energy intensity, ◇: Energy consumption, ◇: CO_2 intensity, ＋: CO_2 emissions. Two types of the pledged target represent a combination of two markers. Exceptions for base year for energy intensity as follows: Japan Aluminum Association, Japan Brass Makers Association (FY1995); The Japan Society of Industrial Machinery Manufacturers, Japan Bearing Industry Association, Japan Machine Tool Builders' Association (FY1997); Japan Dairy Industry Association (FY2000).

Figure 3: Energy intensity changes and the explanations (determination coefficient, R^2) for annual improvements in energy intensity by annual increases in economic activity between 1997 and 2010.

3.4 Conclusion

The industry sectors contributed greatly through the VAP to achieve the emission reduction target of Japan in the first commitment period of the KP. For measuring emission reduction efforts quantitatively, it is not appropriate to evaluate those only employing GHG emission reduction rates relative to base year. In addition, it is not so simple that the efforts can be evaluated by employing indicators of energy intensity levels and its changing rates. Emission reduction efforts should be as equitable under different conditions such as different levels of energy efficiency which has been already achieved and differences in expected economic growth and business conditions. Evaluating the equitable emission reduction efforts adequately will also induce enhancements of future mitigation measures, and this study will contribute to this inducement. Also, part of these analyses was employed in Report of the Committee for the Comprehensive Review of the Voluntary Action Plan on the Environment by the government in April 2014.

References

1) Comprehensive Review of the Voluntary Action Plan on the Environment (2014).

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4. Economic impacts of electricity price increases on manufacturing industries

4.1 Introduction

After the Great East Japan Earthquake, the environment around electricity has changed considerably. The situation of shut down of all the nuclear power plants caused increases in the dependency on fossil fuel power plants, and thus electricity prices have increased. The electricity price increases already made by the power companies include the assumptions on restarts on parts of the nuclear power plants. The delays on the expected nuclear plant restarts may cause additional price increases. In addition, surcharges on feed-in-tariff (FIT) are also expected to significantly increase electricity prices. Several reports explained a number of the private companies had considerably adverse impacts of those price increases on their business activities[1)].

The manufacturing industries suffer from the electricity price increases. Because the electricity consumptions and intensities in the production activities differ in region and industry, the high resolution in regions and industries are required for those evaluations. We analyzed impacts of the electricity price increases on manufacturing industry by prefecture and by respective industry.

4.2 Methodology

We use the Census of Manufactures (2010 edition[2)]). This analysis focused on about 540 industries (based on the 4-digit industrial classification) consisting of the establishments with more than four employees by prefecture and by respective industry. We estimate the electricity charges increases (relative to the pre-quake levels) owing to the assumed electricity price increases.

This study assumes four simulation cases. In Case 1, we assume the electricity price increases already made by the power companies until December in 2014. In Case 2 and 3, we assume the price increases based on low and high price projections, respectively when the complete future shutdowns of the nuclear powers are expected. In Case 1-3, the assumed price increases include both the price changes based on the fuel cost adjustments system and the FIT surcharge. The assumed FIT surcharge is 0.75 Yen/kWh which is uniformly applied in Japan. The surcharge is estimated by using the assumptions on currently operating facilities. In Case 4, we assume the FIT surcharge of 3.12 Yen/kWh in which all the currently approved facilities are operated. The other assumptions in Case 4 are same as those in Case 1. The price increases (relative to the pre-quake levels) in Case 1, 2, 3 and 4 are 15.6%-54.5%, 15.6%-57.9%, 15.6%-65.2%, and 35.4%-70.8%, respectively; the ranges represent the differences among ten power companies.

4.3 Results

Figure 4 shows the annual electricity charge increases per employee in the whole manufacturing industry for the whole country, and the Chiba prefecture which has the most significant adverse impacts. The figure also includes factor contributions to the charge increases per employee. In Case 1, the annual electricity charge increases per employee for the whole country is about 152 thousand Yen (relative to the pre-quake level). The charges increases per employee consist of about 55, 73, and 24 thousand Yen owing to shutdown of the nuclear power plants, price adjustments based fuel cost adjustments system and FIT surcharges (only for currently operating facilities), respectively. Assuming complete future shutdown of the nuclear power plants, the charge increases per employee are 183 and 201 thousand Yen in Case 2 and 3, respectively and thus result in much more adverse impacts on the manufacturing industry. When assuming FIT surcharges for all the approved facilities operating, the additional charge increase per employee in Case 4 is 77 thousand Yen relative to Case 1 and represent considerably severe impacts in the future. The results also indicate that the differences among the prefectures are large. Parts of the prefectures cumulating energy-intensive industries such as the Chiba prefecture have considerably adverse impacts. Figure 5 shows the annual electricity charge increases per employee by respective industry in Case 1. Parts of the industries such as the chemical, and iron and steel industries in the electricity-intensive industry have severer impacts than the whole manufacturing industry.

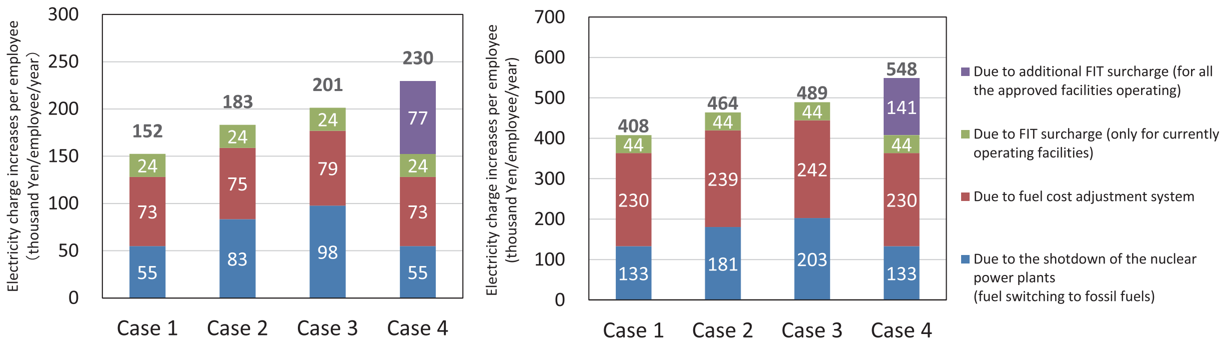
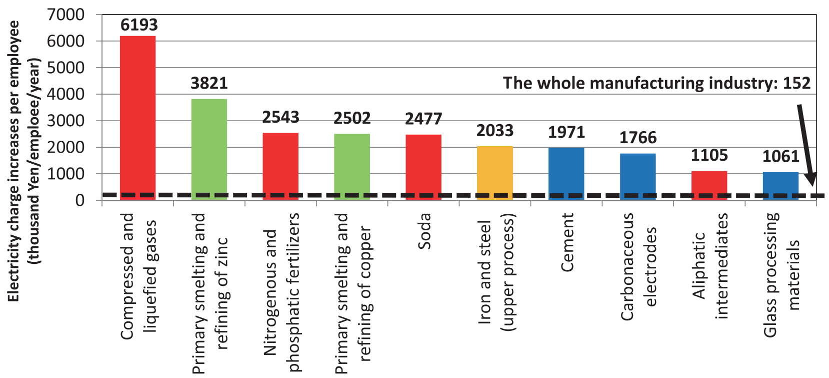


Figure 4: Annual electricity charge increases per employee (relative to the prequake level) on the whole manufacturing industry by price increase factor (left: the whole country, right: Chiba prefecture)



Note: Red, green, yellow and blue colors in the graph represent the industries belonging to chemical, non-ferrous, iron and steel, and non-metal industries based on the 2-digit industrial classification, respectively.

Figure 5: Annual electricity charge increases per employee (relative to the pre-quake level) for the whole country in Case 1: the top 10 industries based on the 4-digit industrial classification

4.4 Conclusion

Electricity is necessary for supporting production activities in almost all the industries. The companies facing severe cost competitiveness need electricity supplied stably and inexpensively. This analysis indicates that electricity price increases caused by shutdown of the nuclear power plants result in severe impacts on parts of the prefectures and the electricity-intensive industries. The electricity price estimates when assuming the complete future shutdown of the plants have much more severe impacts. In addition, the FIT surcharges assumed when all the approved facilities are operated have considerably adverse impacts on the manufacturing industries. This analysis indicates that before expanding severe economic impacts, the effective measures for alleviating the price increases are needed. (For the detailed results, refer to the RITE website[3).)

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

1. Introduction

The biggest topic last year in the global energy field was the sudden decline of crude oil price after October 2014. The price exceeded $100 per gallon in the summer of 2014 but broke $50 at the start of 2015 and it may fall more from the expectation. Since our group has advanced the research and development of biorefinery technologies which produce biofuel and green chemicals using biomass as raw materials, we pay close attention to influence this oil price decline has on the biorefinery industry. The competitiveness of the petrochemical-based industries such as gasoline, naphtha etc. has recovered due to the price decline. However it is apparent that more dependence on fossil resources exacerbates global warming and serious disturbs development of cleaner energy and green chemicals besides increasing CO_2 emissions.

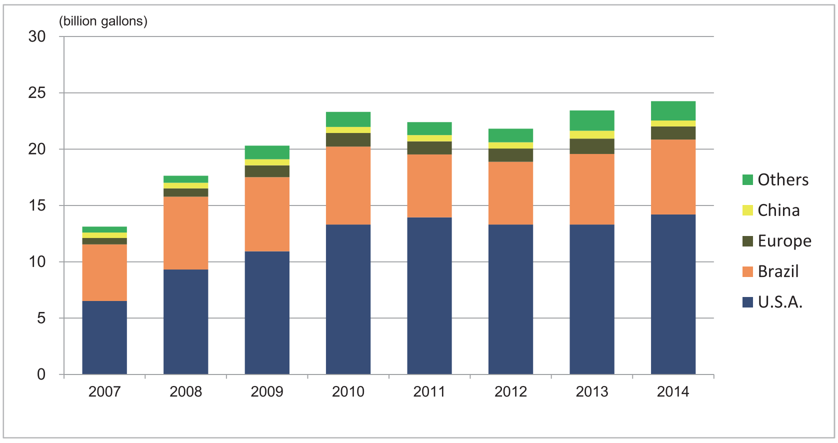
The second major topic was that large-scale commercial plants for cellulose ethanol with capacities in the range of 100,000 KL per year were opened in Europe and the U.S.. In the U.S., the government has been supported these plants for several years. Since cellulosic biofuels are more effective at reducing greenhouse gases (GHG) 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. In 2015, operationalization of a cellulosic ethanol plant is also scheduled in Brazil.

The third major topic was the substantial market expansion of green chemicals such as bio-based chemicals, bioplastics, etc. According to a U.S.-

based research company, the production of green chemicals is estimated to increase beyond 13 million tons by 2017, which is about double the present production level. In addition to conventional bio-based chemicals such as lactic acid, amber acid, amino acids, etc., further market growth is anticipated for biobased polyethylene terephthalate (Bio-PET) and biobased polyethylene (Bio-PE). Thus production expansion of biofuels and green chemicals is also expected in 2015, but the influence of the decline in oil prices on the production of green chemicals will draw attention as described above.

2. Current state of global production and expectation of next-generation biofuels

Global bioethanol production in 2014 was estimated to be over 23.8 billion gallons (F.O. Licht, etc.), which exceeds past levels (Fig. 1). According to the Renewable Fuels Association, bioethanol production in the U.S. was also somewhat increased and still accounted for ca. 60 % (14.2 billion gallons) of the global production.



source: F.O.Licht

Fig. 1: Global fuel ethanol production

2.1 Renewable Fuel Standard and starting up of commercial cellulosic ethanol production

To increase production and consumption of renewable fuels in the U.S., the government encouraged the spread of biofuels. The U.S. Environmental Protect Association (EPA) recommended the annual consumption of biofuels according to the Renewable Fuel Standard (RFS) established in 2005. But the EPA may look to lower this recommendation in fiscal year 2014 ~ 2015 due to the decline in gasoline consumption and a blend wall for several years (see RITE Today 2014). On the other hand, with respect to a feedstock change to non-food cellulosic materials to avoid undesirable competition with the food supply, large-scale cellulose ethanol plants became operational from last year, and a plant with the highest capacity to date is planned to open in Iowa in 2015. These plants use mixed sugars which are obtained by enzyme saccharification of agricultural residues such as corn stover as a raw material for ethanol fermentation. On the other hand, the production of corn ethanol in the U.S. also reached record levels toward the end of 2014. It is considered that this is due to a decline of corn prices (~$4/bushel) due to a plentiful harvest for several years, high prevailing ethanol prices and increase of U.S. ethanol export.

2.2 Current state of next generation biofuels

Biobutanol attracts attention as a next generation biofuel following ethanol. 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 (see RITE Today 2014 for biobutanol production technology). Isobutanol commercial plant using corn as a raw material became operational in the U.S. in 2014. In this facility, isobutanol is produced by a retrofitted ethanol plant modified in the processes of ethanol fermentation and distillation. At present, it is difficult to make sudden expansion of biobutanol production volume because U.S. bioethanol plants have a high profitability. However increased future of butanol development is expected because butanol is a hopeful raw material for C4 chemicals as well as biojet fuels.

3. Current state of global Green chemicals and their expectation

A market of bio-based chemicals (green chemicals) such as amber acid, lactic acid, Bio-PET, etc. is emerging, with an estimation that it will account for 10% in the world market of chemicals in 2015. For example, it was a topic of discussion last year when a major European chemical company succeeded in the production of a high water absorption resin from a bioacrylic acid. A material of this bioacrylic acid is 3-hydroxypropionic acid which is a fermentation product from glucose as raw material. In addition to the bioacrylic acid production, bioisoprene production by collaboration of a tire manufacturer and a biotechnology company, and a commercial production project of a polyamide material (dodecanedioic acid) by a biotechnology venture were also reported. In the green chemicals field, bioplastic production and consumption are expanding and Bio-PET and Bio-PE which are mentioned above are towing the market.

In Japan, it is predicted that the market for bioplastics will exceed 40,000 tons in 2015. Their major application is in the manufacture of drink bottles and plastic grocery bags. On the other hand, a new market is also advancing for conventional biological degradation resins such as polylactic acid which is used as a time-degradable material in shale gas mining and support ingredient to increase oil and gas recovery (called drilling chemical).

4. Technology development of RITE

4.1 Feature of 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. The process can produce them efficiently with high cost performance, therefore it receives recognition from home and abroad.

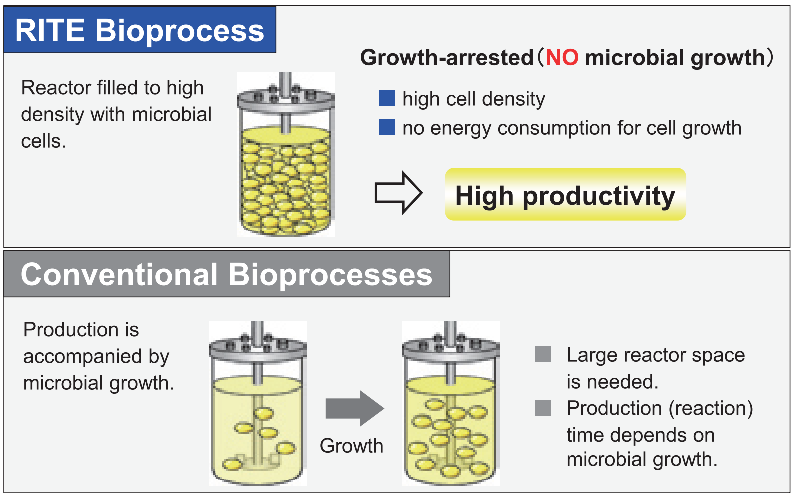


Fig. 2: Features of RITE Bioprocess (Growth-Arrested Bioprocess)

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. Sugars are subsequently added to initiate bioconversion as a substrate under oxygen deprivation (Fig. 2). 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 (see RITE Today 2013~2014 in detail).

We are constantly expanding the range of product options of the RITE Bioprocess. 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 such as butanol, aromatic compounds etc. In the next chapter, we introduce a challenge to high cell inhibitors manufacturing technology. These materials have been considered to be impossible to produce by fermentation due to its high inhibitory effect on microbial cells.

4.2 Challenge to high cell inhibitors manufacturing technology

High cell inhibitors are the materials which inhibit microbial fermentation. They inhibit microbial cell growth by their high toxicity to the cell and affect fermentation productivity. Specifically, phenol and higher alcohols are well known as the inhibitors. When such materials are produced by microbial fermentation, low productivity (declines of formation rate and product concentration, etc.) is seen due to their high toxicity to the cell, indicating that the practical production is difficult. But material production by our RITE Bioprocess is considered to be insensitive to the inhibitors due to its independence of cell growth compared to conventional bioprocess in which the production depends on cell growth. Moreover coryneform bacteria show higher tolerance to aromatic compounds and higher alcohols compared to other bacteria (Fig. 3). By using these excellent features of our process, we have developed a manufacturing technology with high tolerance to cell inhibitors. In the next chapter, we introduce phenol production by a two stage process originally developed by our group.

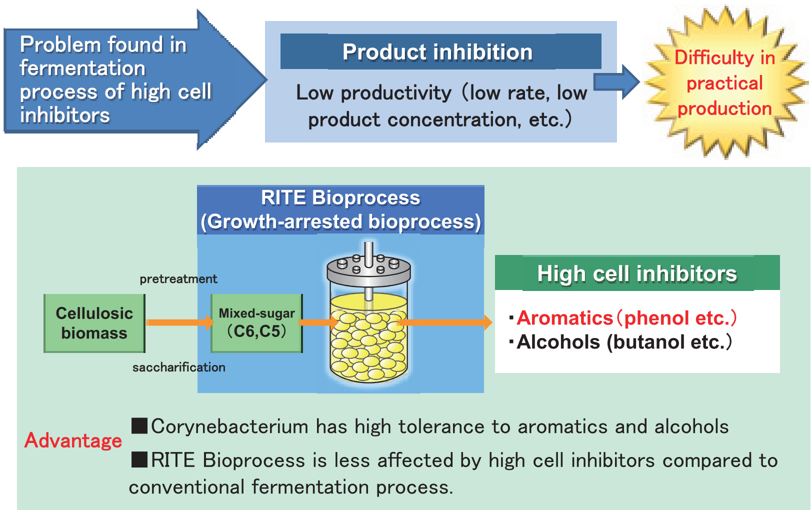


Fig. 3: Challenge to high cell inhibitors manufacturing technology

4.3 Phenol production by a two stage process

Phenol has been widely used as raw materials of phenol resin and a polycarbonate, etc. and its production from biomass by microbial fermentation has been expected, however green phenol was considered to be difficult due to its toxicity to microbial cells. On the other hand, the material production by RITE Bioprocess is independent of cell growth therefore it is expected to avoid cell inhibition by phenol during its production stage. Moreover, our coryneform bacteria show good growth in the presence of 0.2% phenol and they also can grow in the presence of 0.24% phenol, indicating high tolerance to phenol compared to other microbes such as *Escherichia coli.* In addition to these excellent features, we developed a two stage process for the practical production of green phenol (Fig.4).

In the two stage process, 4-hydroxybenzoate (4-HBA) is produced by

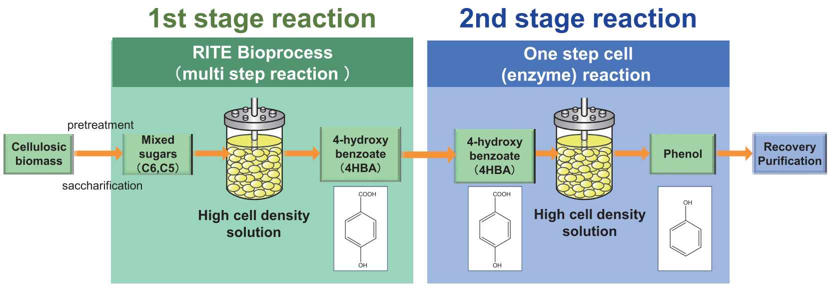


Fig. 4: Phenol production by a two stage process

RITE Bioprocess in the first stage. 4-HBA is an intermediate to phenol and has little inhibitory effect on the cell compared to phenol. And then the 4-HBA is converted to phenol. Since conversion of 4-HBA to phenol is one step reaction by a decarboxylase and low inhibitory effect on the cell is expected, the two stage process made high productivity of phenol possible compared with direct phenol production from glucose. This green phenol production process achieved final concentration of 22g/L, which is the best one in the experimental results reported so far. Thus the two stage process developed for green phenol production makes high efficiency and productivity possible, and realizes practical use of manufacturing technology to produce green phenol. We introduce our efforts of industrialization of this technology in Chapter 5.

4.4 Development of 100% green jet fuel production technology

According to an IEA report (IEA Energy Technology Perspective), 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). Current petroleum jet fuel is a mixture which consists of saturated branched or circular hydrocarbons with C10-C15 and aromatic compounds and its physical properties are standardized strictly. But, since a conventional biojet fuel derived from plant oil is composed of only saturated hydrocarbons, it is necessary to blend petroleum jet fuel to meet the requirement of the physical properties. Therefore we proposed the world's first 100% green jet fuel manufacturing technology which can produce both of various branched or circular saturated hydrocarbon and aromatics, and it can meet the standard of petroleum jet fuel (Fig. 6).

In this proposal, we modify microbes to produce the above-mentioned

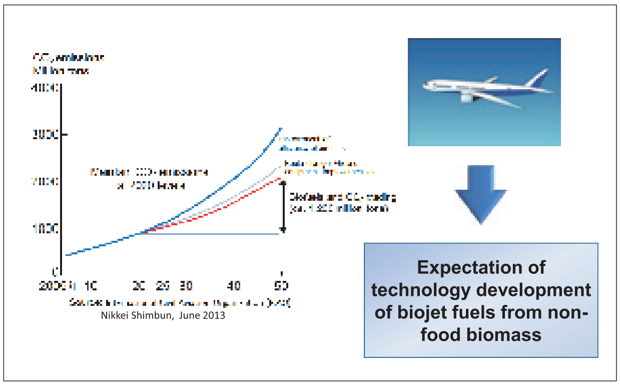


Fig. 5: Measure against CO_2 emission if international aviation

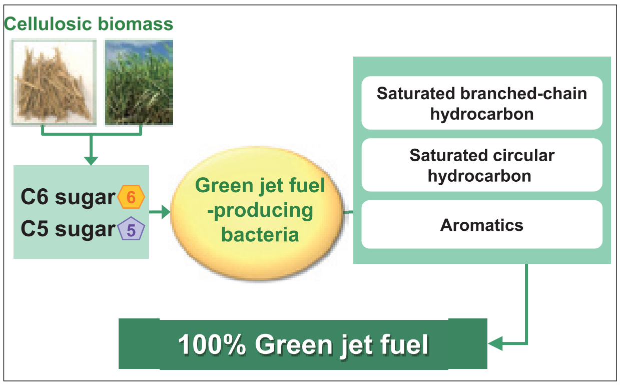


Fig. 6: Development of 100% green jet fuel production technology

compounds from mixed sugars of biomass and develop a 100% green jet fuel manufacturing technology which is difficult to achieve by a conventional fermentation technology.

5. RITE's effort for industrialization

5.1 Establishment of Green-phenol development Co., Ltd.

As described in a previous chapter, we established Green-phenol development Co., Ltd. by RITE and Sumitomo Bakelite Co., Ltd. for industrialization of green phenol by using the two stage process (see Topics in detail).

5.2 Research on Butanol

We have conducted 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. 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. We also started development of the production system to concentrate the butanol density (~several %) efficiently, by combining membranes with an efficient butanol recovering method (Fig. 7).

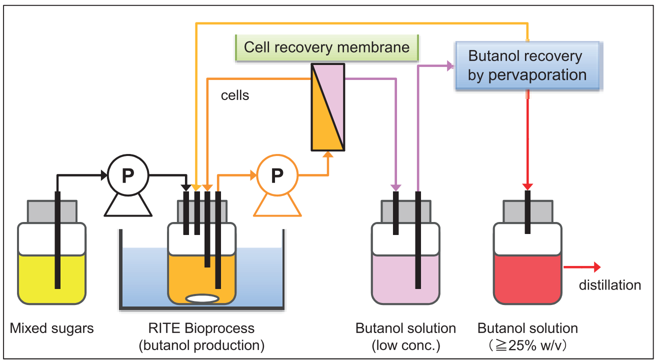


Fig. 7: Butanol production system combined a continuous reactor and membrane recovery method

We have worked with U.S. National Renewable Energy Laboratory (NREL) for the international collaboration study on a project aiming at use butanol as jet fuel material, introduced last year (see RITE Today 2014). In this project, we could obtain a corynebacterium strain with high tolerance to butanol by a gene mutation introduction method developed originally, and high butanol yield from sugars was achieved according to improvement by introduction of a high functionality enzyme into the strain. With respect to butanol manufacturing technology, practical strains for industrialization is developed smoothly. Since we launched a plan to develop a butanol production system including a recovery method, we expect a collaboration work with a company interested in the development.

5.3 Development of shikimic acid manufacturing technology

Global demand for shikimic acid is increasing as chemical intermediate in flu curative Tamiflu (oseltamivir) synthesis. Tamiflu is required to stockpile for flu pandemic, but a problem is lack of its raw material, shikimic acid. The shikimic acid belongs to hydroxy acid group with 3 asymmetric carbon atoms and is important as a raw material and synthetic chemical intermediate for medicinal products, cosmetics and agricultural chemicals, etc. in addition to Tamiflu. Since shikimic acid is usually extracted from dried fruit of Shikimi (Star Anise) and purified, it was low yield and high cost. Moreover, Shikimi production concentrated at China, and there was also a problem of overharvesting, therefore a production of microbial fermentation is expected by using renewable materials like biomass. In RITE, we have focused on shikimic acid as an important intermediate in the biosynthesis of aromatics such as aromatic amino acids in corynebacteria. As a result, we succeeded its high productivity compared to those previously reported, by the improvement of strain, for examples reinforcement of sugar import system and shikimate biosynthesis pathways, and a blocking of shikimate resolution process etc. This technology development received a lot of response from companies, and we expect to link it to collaborative research and development aiming at practical use.

6. Ending remarks

Production of new natural gas (shale gas) begins in earnest in North America, and the "shale gas revolution" is proceeding as a game changer in the energy market of the world, economy and industrial structure. A new petrochemical industry is predicted to lead to an expanded production of chemicals from shale gas as a raw material. Methane from shale gas and ethylene based chemicals are expected to have considerable cost competitiveness, whereas rise in the price of chemicals with 4 carbons or more and aromatics is predicted (Fig. 8). Such movement may be a fair wind in the future for biorefinery industry where chemicals with more 4 carbons can be easily produced by microbial fermentation from various sugars derived from biomass.

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.

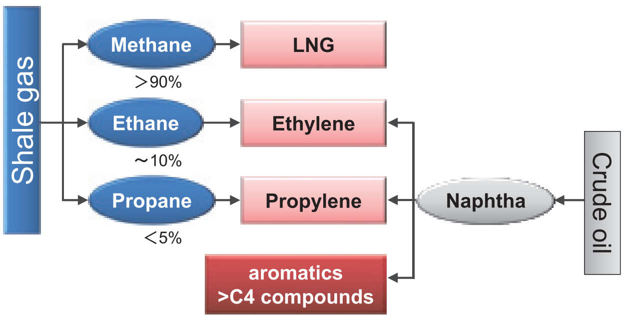


Fig. 8: Effect of shale gas revolution on chemical industry

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

1. Technologies for CO_2 capture and hydrogen energy

CO_2 capture and storage (CCS) consists of trapping CO_2 (a greenhouse gas) from the emissions generated during fossil fuel combustion by sources such as electric power plants and factories, and subsequently containing the captured CO_2 in geological formations. At present, the costs associated with capturing CO_2 from emission sources are estimated to account for approximately 60% of the overall CCS expenditures. Therefore, it is important to reduce CO_2 capture costs to allow the 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. This work has involved the development of new materials and processing methods as well as investigations of capture systems. These studies have thus far generated significant outcomes and assisted in the progress of research in this particular field.

In this regard, we have developed chemical absorbents that allow CO_2 capture at an energy consumption rate of 2.0 GJ/t-CO_2 and from which the CO_2 may be regenerated at temperatures below 100 °C. One such chemical absorbent with particular promise was selected for application in a commercial CO_2 capture plant owned by a private Japanese company that became operational in the fall of 2014.

Molecular gate membrane modules are also being developed to selectively capture CO_2 from H_2-containing pressurized gases such as those generated in the integrated coal gasification combined cycle (IGCC), with a CO_2 capture cost target of 1500 JPY/t-CO_2.

In addition, our investigations have demonstrated the exceptional performance of new types of dendrimer/polymer hybrid membranes designed to separate CO_2 from CO_2/H_2 gas mixtures. RITE, together with three private companies, has established a joint research association to develop these membranes along with membrane modules and separation systems for practical applications. Recently, our lab was successful in achieving the project's CO_2 separation performance goals using laboratory-scale membranes composed of modified materials.

Based on our technologies, including the development of proprietary solvents at RITE, we are also investigating solid sorbents for CO_2 capture with the aim of increasing the energy efficiency of the capture process. At present, the synthesis of novel solid sorbents that allow capture at an energy requirement of 1.5 GJ/t-CO_2 are being researched. As a result, we have successfully developed a RITE-solvent-based solid sorbent that can be regenerated at low temperatures, and this product is currently being evaluated with regard to its practical applicability.

Recently, there has been a significant emphasis of the use of CO_2-free, hydrogen-based energy, generated by either renewable sources or fossil fuels combined with CCS. To realize this, it is necessary to develop efficient processes for the dehydrogenation of chemical hydrides such as methylcyclohexane or ammonia to allow for the ready storage and transportation of hydrogen. In response to this requirement, our group is developing silica and zeolite membranes for the processing of methylcyclohexane as well as a palladium membrane for use with ammonia. Moreover, membrane reactors incorporating these membranes are also under development and steady gains are being made.

As noted above, our aim is to promote innovative CO_2 capture technologies as well as other new processes to reduce CO_2, thus laying the foundations for next generation technologies while developing practical processes that are acceptable to industry.

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 through the thermal dissociation of CO_2 that has been chemically absorbed in an amine-based solution. This technology is suitable for CO_2 separation from ambient pressure gases generated in industrial processes.

Over the last decade, we have developed highly efficient CO_2 absorbents capable of reducing the energy consumption associated with CO_2 separation, which is the primary concern associated with chemical absorption systems.

Between 2004 and 2008, the COCS project was implemented for the capture and separation of CO_2 from steel-making blast furnace gases. This technology was further assessed during a follow-up project (COURSE 50, Step 1) between 2008 and 2012, during which time the target CO_2 capture energy consumption rate of 2.0 GJ/t-CO_2 was achieved. Moreover, the development of breakthrough chemical absorbents enabled the associated CO_2 regeneration process to occur at temperatures of less than 100 °C. (Figs. 1, 2)

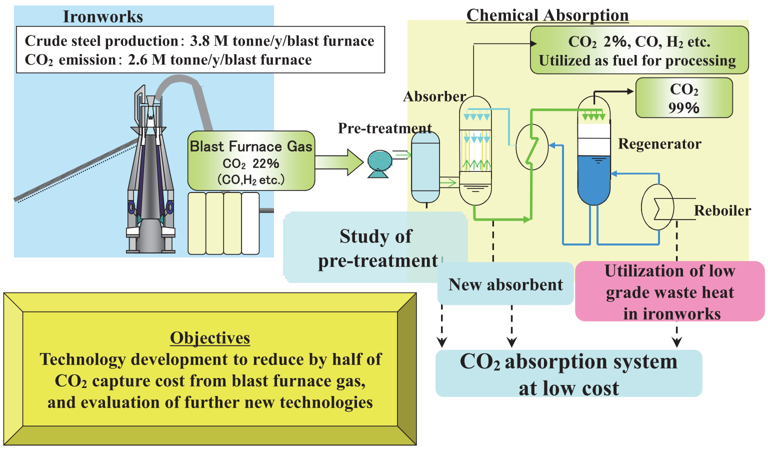

Fig. 1: A cost-saving CO_2 capture system scheme

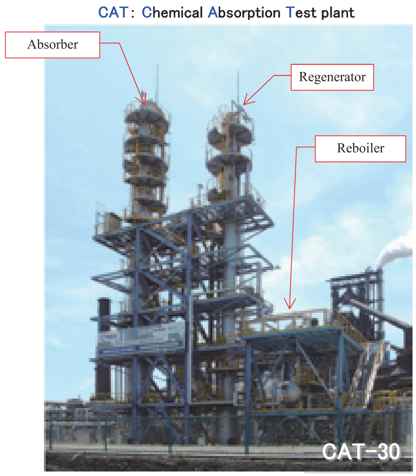

Fig. 2: Photographic images of a technology demonstration plant

As noted, one of the highest performing absorbents developed during this work was selected for application in a commercial CO_2 capture plant owned by a private Japanese company, which became operational in the fall of 2014.

Starting in 2013 with a projected end date in 2017, we are conducting the COURSE 50 Step 2 project, in which higher performance chemical absorbents will be developed, enabling a reduced CO_2 capture cost of 2000 JPN/t-CO_2 in the steel-making industry.

As additional outcomes of the research and development of highly energy-efficient absorbents, we have demonstrated chemical absorbents with excellent CO_2 absorption and dissociation performances that enable CO_2 regeneration under high pressures. We are also currently developing CO_2 sorption systems with improved performances.

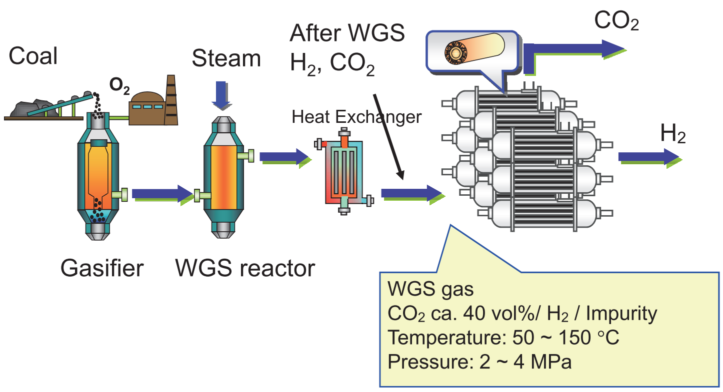

Fig. 3: Schematic of the IGCC-CO_2 capture system

In addition, a novel solvent has been synthesized that exhibits high CO_2 recovery and excellent CO_2 absorption and desorption rates, suggesting that it will allow the recovery of CO_2 with reduced energy consumption under high pressures. The total energy consumption rate for CO_2 separation and capture when using this process, including the energy required for compression, has been estimated to be less than 1.2 GJ/t-CO_2.

3. CO_2 and H_2 separation using polymeric membranes

Under the project "Cool Earth 50," the government of Japan has announced its intention to reduce the country's CO_2 emissions to half of the current emission levels by 2050. One promising means of reducing CO_2 emissions is the development of a joint integrated coal gasification combined cycle together with a CO_2 capture and storage system (IGCC–CCS, Fig. 3). As part of this project, our group is currently developing molecular gate membrane modules that effectively separate CO_2 during the IGCC–CCS process. The development of these CO_2 molecular gate membrane modules is being performed under a project recognized by the Carbon Sequestration Leadership Forum (CSLF), a ministerial-level international climate change initiative focused on the development of improved, cost-effective technologies for the separation and capture of CO_2 for transport and long-term safe storage.

Fig. 4 shows a schematic illustration of the working principles of a molecular gate membrane. In this device, the gas molecule pathways are occupied solely by CO_2, which acts as a gate to block the passage of other gases. Consequently, the amount of N2 or H_2 diffusing to the other side of the membrane is greatly reduced and high concentrations of CO_2 can be obtained.

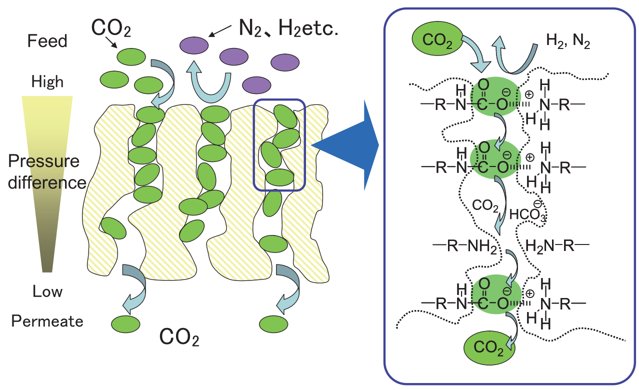

Fig. 4: Schematic diagram of a molecular gate membrane

RITE has also developed new types of dendrimer/polymer hybrid membranes showing excellent performance during the separation of CO_2 from CO_2/H_2 gas mixtures, enabling high CO_2 permeance and CO_2/H_2 selectivity.

Based on these materials, RITE, the Kuraray Co., Ltd., the Nitto Denko Corporation and the Nippon Steel & Sumikin Engineering Co., Ltd. have established the Molecular Gate Membrane Module Technology Research Association for the purpose of researching new membranes, membrane modules and separation systems (Fig. 5). As well, the Kuraray Co. and RITE are collaborating to develop membranes with a target CO_2 capture cost of 1500 JPY/t-CO_2. Recently, our group succeeded in improving the separation performance of such membranes through the modification of poly(vinyl alcohol) (PVA) materials, and the target CO_2 separation performance was obtained using laboratory-scale membranes (Fig. 6). In the future, we intend to investigate the effects of operating conditions on the performances of membrane modules during practical usage.

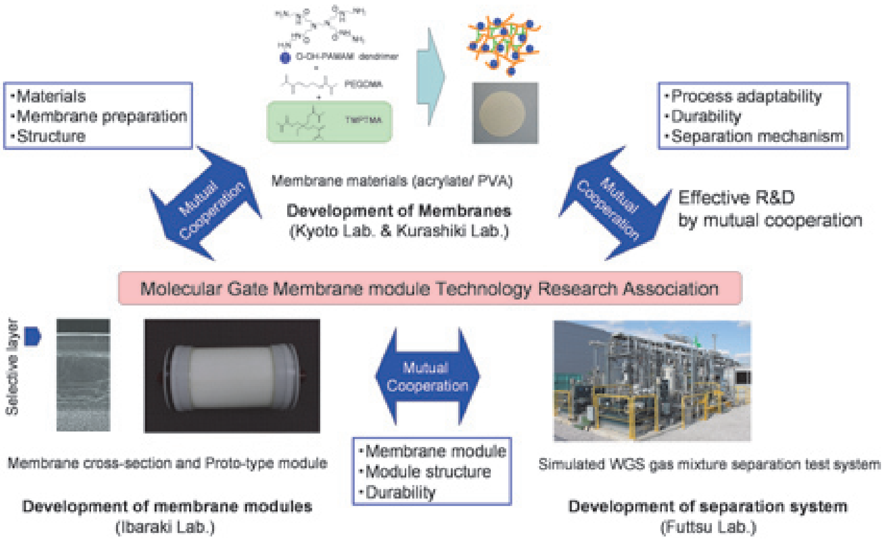

Fig. 5: Development of membrane modules in collaboration with private companies

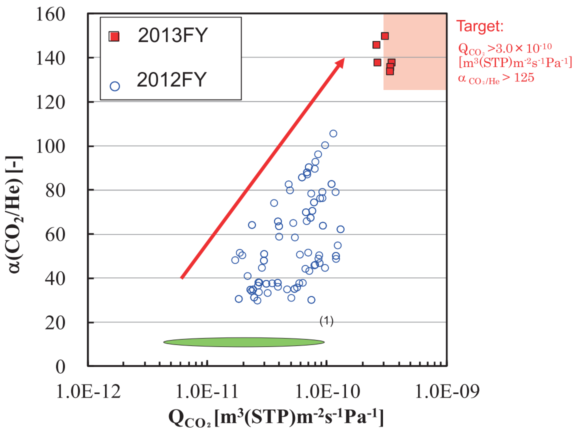

Fig. 6: Separation performance of PVA-based molecular gate membranes (QCO_2: CO_2 permeance; α: selectivity)

4. Advanced development of CO_2 capture by solid sorbents

Since 2010, RITE has been working on a project funded by the Ministry of Economy, Trade and Industry (METI) with the aim of developing solid sorbents for an energy-saving CCS process and establishing evaluation standards for such systems. We are endeavoring to fabricate novel solid sorbents that are applicable to CO_2 capture from coal-fired power plants, with a target energy requirement of 1.5 GJ/t-CO_2 (Fig. 7).

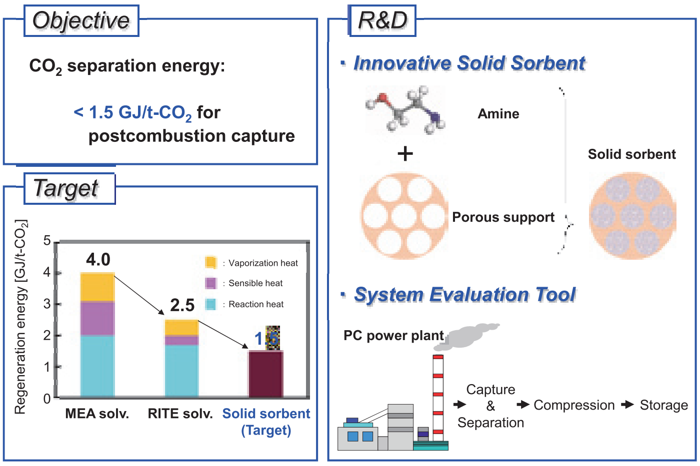

Fig. 7: Development of a CO_2 solid sorbent scheme

During this work it has been found that 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 anticipated heat input for regeneration. The relationship between amine structures and their CO_2 desorption performances was established by computational chemistry and these findings led to the fabrication of a more efficient solid sorbent in terms of desorption performance and sorption capacity (Fig. 8).

RITE also performed 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 CCS was estimated to improve by about 2% when a solid sorbent was used in place of 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 with regard to power generation. To date, the CO_2 capture en-

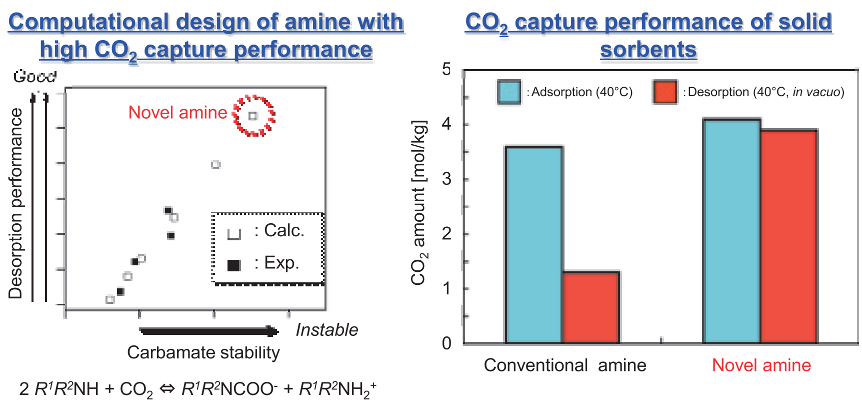

Fig. 8 Performance of a CO_2 solid sorbent system

ergy requirement using this system has been estimated to be less than 2.0 GJ/t-CO_2, and an examination of the practical use of the RITE-developed solid sorbent is underway.

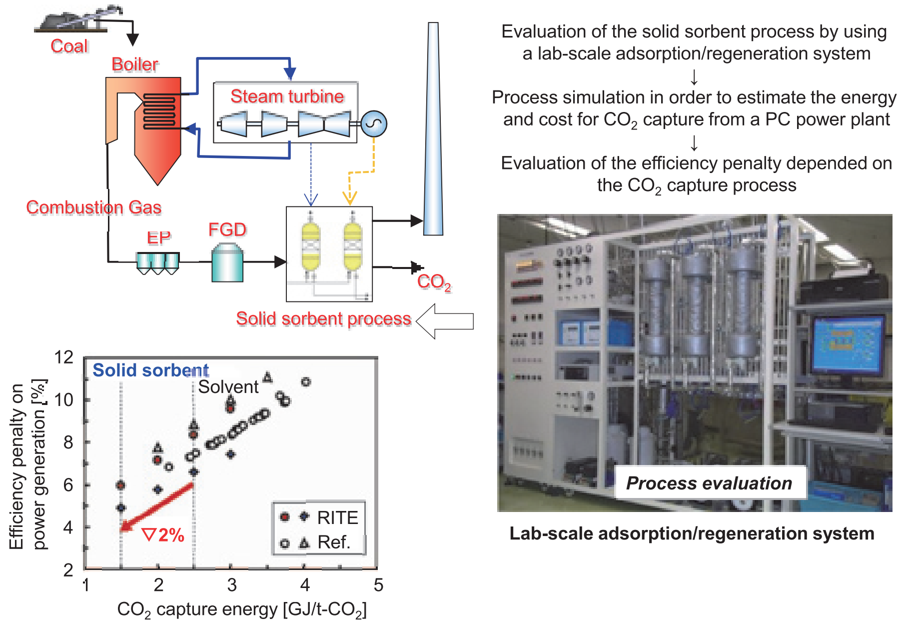

Fig. 9: Performance of a CO_2 capture solid sorbent system implemented in a power plant

5. Development of inorganic membranes for H_2 energy production

It is necessary to develop efficient means of dehydrogenating chemical hydrides such as methylcyclohexane or ammonia to establish new energy systems based on CO_2-free hydrogen. This topic was extensively addressed during the 4th Strategic Energy Plan endorsed by the Japanese Cabinet in April, 2014. As such, our group is developing inorganic membranes for hydrogen separation and designing membrane reactors incorporating such membranes.

A project for manufacture and use of energy carriers initiated by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in 2013 restarted as a new project under the Cross-ministerial Strategic Innovation Promotion Program (SIP) in July, 2014. In this endeavor, RITE was tasked with developing inorganic hydrogen selective membranes and membrane reactors for hydrogen supply stations in collaboration with Hiroshima, Yamaguchi, Utsunomiya and Kogakuin Universities and the National Institute of Advanced Industrial Science and Technology (AIST).

This work focused in particular on silica membranes prepared using a counter-diffusion chemical vapor deposition (CVD) apparatus (Fig. 10) as well as other porous inorganic membranes for processing methylcyclohexane and pore-fill type Pd membranes (Fig. 11) for use with ammonia. Both processes can be expected to allow true high-efficiency, compact hydrogen generation. Our Pd membranes are anticipated to greatly improve the durability of the associated generation devices and also to reduce the cost, both of which are presently serious challenges with Pd membranes.

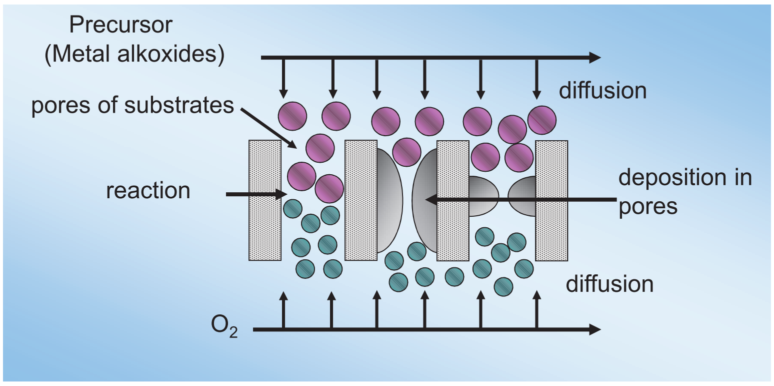

Fig.10: Preparation of methylcyclohexane using a counter-diffusion CVD apparatus

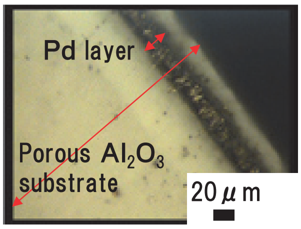

Fig.11: A pore-fill type Pd membrane

In 2013, RITE also began another project funded by NEDO. In this work, RITE is collaborating with the Chiyoda Corporation to develop membrane reactors for compact, lower-temperature H_2 generation systems using methylcyclohexane. The goal of this project is to fabricate a hydrogen generator with decentralized power for small-to-medium sized customers such as commercial establishments and office buildings. Thus our group is developing single-tube type membrane reactors and designing modular hydrogen generators for the dehydration of methylcyclohexane.

In dehydration tests using such single-tube type membrane reactors, it was confirmed that the membrane reactor operates at a reaction temperature lower than those of conventional dehydration reactions with post-separation (Fig. 12). We intend to continue to explore means of further lowering the reaction temperature and developing improved hydrogen generators incorporating dehydration membrane reactors.

Finally, in the COURSE 50 Step 2 project, CVD-based silica membranes will be developed as membrane reactors employing the water gas shift reaction and H_2 separation to allow H_2 generation from blast furnace gases.

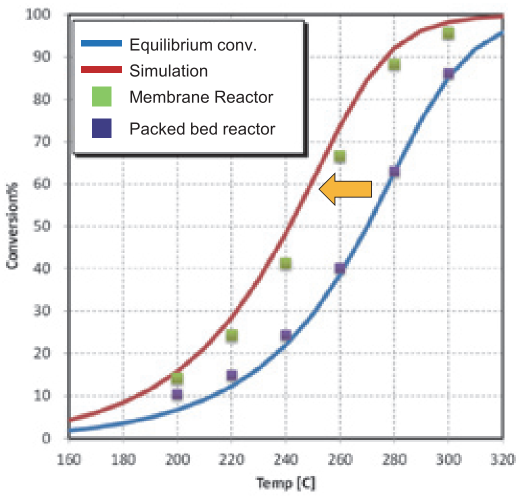

Fig.12: Decreased methylcyclohexane dehydrogenation reaction temperature using a single-tube type membrane reactor

CO_2 Storage Research Group

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Moving toward Commercialization of CO_2 Storage Technologies

1. Overview

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

The International Energy Agency (IEA) positions CCS as an important decarbonizing energy technology. Its “Energy Technology Perspectives 2014 (ETP 2014)” requires 17% contribution from CCS to CO_2 emission reductions in 2050 to achieve the internationally agreed target of limiting average global temperature rise to 2°C.

In this context, Japan launched a large-scale CCS demonstration project in Tomakomai, Hokkaido. Currently, Japan CCS Company advances drilling works and other preparations. In the demonstration project, more than 100 thousand tonnes of CO_2 will be captured from gas generated at a hydrogen production plant annually, injected into two geological formations (Moebetsu formation at a depth of 1,100 to 1,200 meters and Takinoue formation at a depth of 2,400 to 3,000 meters), and then monitored for watching its behavior.

RITE carries out a program of research and development on a wide range of safety assessment technologies for CO_2 geological storage, a Japan-China CCS-EOR project, collaboration with international organizations and a global CCS development survey. RITE aims to apply the outcomes from these projects to the large-scale CCS demonstration project and to facilitate the future implementation of CCS in Japan.

2. Research and Development of CO_2 geological storage

There are a number of types in CO_2 underground injections: injection into oil fields to enhance oil recovery (EOR); injection into coal seams to enhance methane recovery (ECBM); injection in depleted gas fields to sequestrate CO_2; and injection in deep saline aquifers to store CO_2. The injection into deep saline aquifer for storing CO_2 has, as shown in Fig. 1, an impermeable caprock formation (a mudstone layer) with high sealing properties above the aquifer (a sandstone layer). Thus, once injected, CO_2 can be stably and safely stored for a long period of time.

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

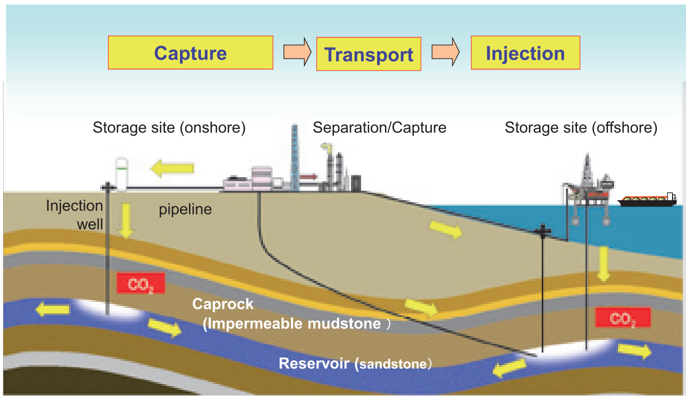


Fig. 1: Concept of CO_2 geological storage

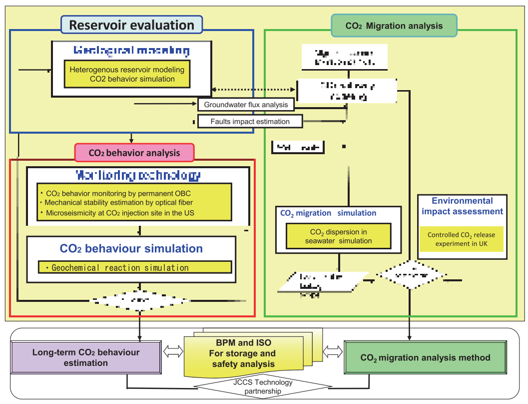


Fig. 2: R&D on CO_2 geological storage technologies

2.1 Development of techniques of evaluating storage performance

RITE is developing methodologies of evaluating storage performance under two programs: "establishing a methodology of modelling geological formations unique to Japan" and "developing a methodology of analyzing groundwater flow".

The Analysis of the behavior of CO_2 injected in a reservoir requires a precise geologic model that takes heterogeneity into account. On the other hand, not so many geological data such as those from core samples and physical logging are available because in CCS projects the number of exploration wells are limited from the viewpoint of avoiding leaks of stored CO_2 as much as possible. For the evaluation of reservoirs physical properties and geological modelling, therefore, the development of a methodology is desired to make the best use of data acquired under such restriction. Taking the Nagaoka CO_2 storage site as an example, RITE analyzed the geological properties of the site and clarified its depositional environment of stratums. We found out that geological

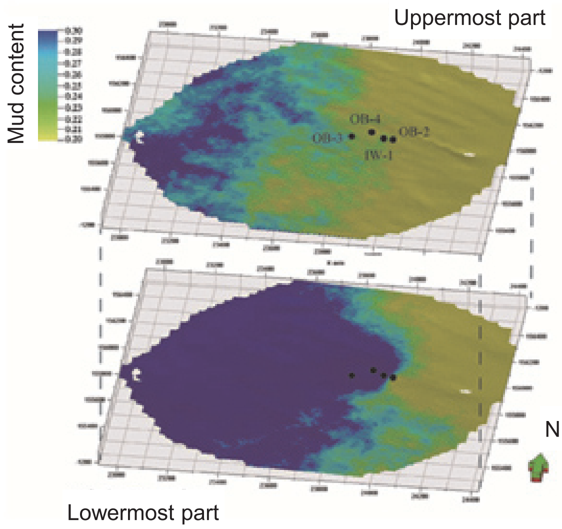


Fig. 3: 3-D distribution of mud content in the uppermost and lowermost parts of the reservoir

models can be refined by building a geological formation framework based on the depositional environment and then determining mud content rates, porosities and permeability of the formations.

In the development of a methodology of groundwater flow analysis, we assess the impacts of CO_2 injection on regional groundwater flow in a case where CO_2 is stored in a coastal area. The analysis of this kind requires us to develop a hydrogeological model that covers both the land and the sea by combining onshore and offshore geological data. In such a way, RITE has been building a model suitable for the Tomakomai demonstration site. It is critical in the precise evaluation of groundwater flow to utilize not only data in literatures and also data of hydrological constants such as porosities and permeability acquired by taking core samples on site and analyzing them and to understand the state of groundwater before CO_2 injection.

2.2 Analysis of CO_2 behavior in reservoir

For wider deployment of CO_2 geological storage, it is important to monitor CO_2 injected in a deep reservoir and demonstrate that the CO_2 is retained stably there. For this purpose, RITE is comprehensively analyzing data acquired at the Nagaoka site, including physical logging data, to clarify the mechanisms of storing CO_2 and to improve techniques to simulate long-term CO_2 behavior. In addition, RITE is actively developing other technologies for CO_2 geological storage, including a methodology to assess micro-seismicity induced by CO_2 injection and fiber-optic sensing for monitoring the deformation of geological formations.

— Development of a methodology of evaluating microseismicity induced by CO_2 injection

RITE, in co-operation with the US Lawrence Berkeley National Laboratory, continues monitoring of microseismicity induced by CO_2 injection with an observation system installed in shallow boreholes at a CO_2 injection site in the United State of America. We analyze the relationship between observed microseismicity and CO_2 injection by examining monitoring data acquired so far. We also consider a basic design of a Traffic Light System (TLS) for CO_2 injection management, based on microseismicity monitoring.

— Development of a technology to monitor the stability of geological formations during and after CO_2 injection

At a CO_2 geological storage site, it is essential to monitor the deformation of geological formations as well as temperatures and pressures continuously along a depth direction for the assessment of the integrity of CO_2 geological storage. RITE has been developing a technology for monitoring the deformation of geological formations and has completed to establish a basic technology to measure the deformation of formations with optic fibers. Aimed at making the technology commercially viable, we installed prototypes of long optic fiber cables in a deeper well in FY 2014, building on a field test in FY 2012, and examined technical challenges toward its practical application.

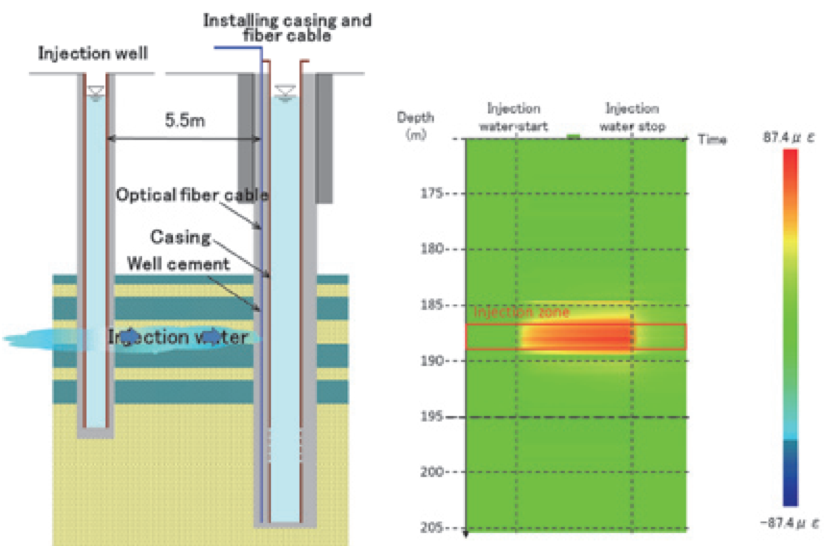


Fig. 4: Fiber-optic measurement of formation deformation due to water injection

Toward its commercialization in future, we need to develop fiber-optic cables applicable to CO_2 storage sites. RITE, therefore, is developing fiber-optic cables that are not only highly sensitive to temperature, pressure and strain but also strong enough to be embedded underground.

— Analysis of CO_2 behavior with a X-ray CT scanner and up-scaling

To evaluate long-term integrity of CO_2 geological storage in a deep reservoir, it is essential to understand CO_2 behavior in a heterogeneous reservoir and to reveal the mechanisms of replacement between formation brine and CO_2. RITE clarified the characteristics of CO_2-formation water replacement and CO_2 residual trapping mechanisms through visualizing CO_2 distribution in remarkably-heterogeneous core samples taken at the Nagaoka CO_2 storage site with a X-ray CT scanner. We revealed the correlations between the visualized CO_2 distributions and rock properties such as elastic wave velocity and resistivity and then applied them to interpretation of data of physical logging and seismic surveys obtained at the CO_2 injection site. We also made progress of up-scaling research, applying the expertise compiled through the study to storage performance assessment.

— CO_2 behavior at Nagaoka site

RITE conducted a CO_2 storage project in Nagaoka, Niigata from July 2003 to January 2005, injecting 10,400 tonnes of CO_2 into a deep saline aquifer at a depth of 1,100 meters. Building on the injection project, RITE has developed methodologies for monitoring the status of CO_2 underground and a simulator for predicting CO_2 behavior in a reservoir. There have been a number of overseas storage projects but it is only the Nagaoka site where the behavior of CO_2 has been monitored precisely for more than 10 years after the completion of injection.

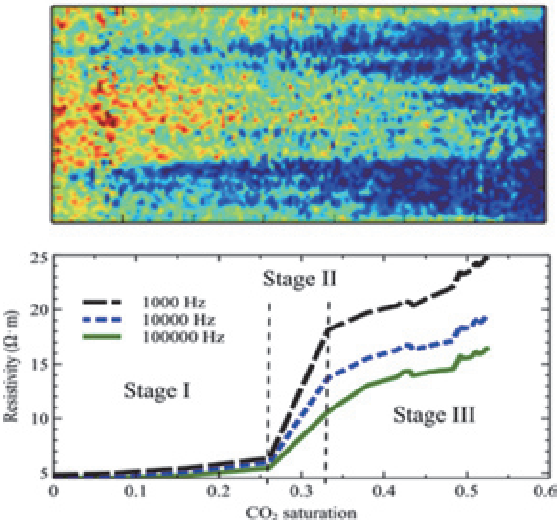


Fig. 5: Visualized CO_2 distribution in a core sample

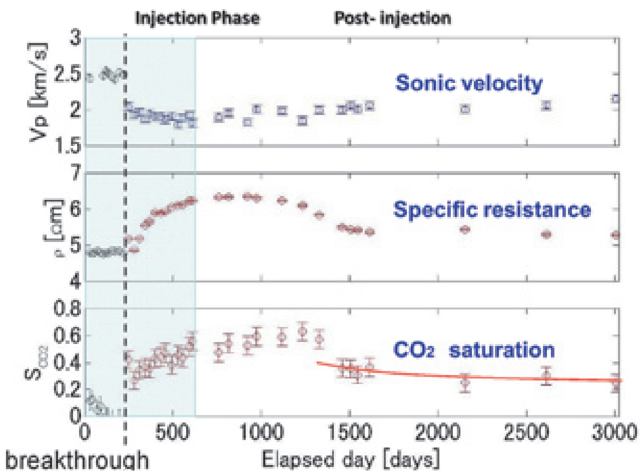


Fig. 6: Results of CO_2 behavior monitoring near an observation well at the Nagaoka site

Outcomes from the monitoring, therefore, attract close attention in the world.

In the development of monitoring methodologies, we repeatedly carried out physical logging, formation water sampling, and cross-well seismic tomography and evaluated CO_2 distribution and its state – whether to be in a supercritical phase or be dissolved in formation water. In FY 2014, we conducted borehole physical logging and made sure that CO_2 has been stored safely by verifying that CO_2 has stayed nearly at the same place after injection. We also made certain that dissolution of CO_2 has been in progress, shifting to safer trapping.

In the development of CO_2 behavior simulator, we have verified it precisely with monitoring data acquired at the Nagaoka site. We have been updating an initial geological model through history matching with observation data and have nearly completed a model necessary for a long-term behavior prediction of injected CO_2.

2.3 Analysis of CO_2 migration from reservoir

In order to keep the marine environment safe while storing CO_2 under the seabed, it is necessary to watch CO_2 not to seep from the reservoir into the sea. When leaked from the seabed, CO_2 is in a gaseous or dissolved state.

A way of monitoring CO_2 dissolved in seawater is to measure prime values that represent a carbonate system there, including pH, total carbonic acid and total alkalinity, and compare them with background data. Analyzing observational data in the public domain, RITE demonstrated that anomalous values caused by seepage are detectable when measuring the major components of the carbonate system together with dissolved oxygen. As a next step, RITE has been measuring these components of a carbonate system in a real sea to grasp natural fluctuation in a carbonate system and to examine the detectability of anomalous values in the natural fluctuation. Its preliminary results suggest that a carbonate system in a coastal area can be varied significantly under natural conditions in a short term but that the measurement of the variation of dissolved oxygen can make it possible to clarify a range of natural fluctuation in a carbonate system and to detect anomalous values with a high accuracy.

In a case where CO_2 is seeped as gas, monitoring with acoustic equipment may be effective because gas bubbles in seawater reflect and scatter sonic wave. For this purpose, we have been examining the capability of bubble detection of tools such as side-scan sonars and multibeam bathymetries by testing them with gas blowout at an offshore natural site and with man-made bubbles at laboratory. These devices are widely-used for seafloor exploration and bathymetric survey and capable of detecting bubbles. Outcomes so far demonstrate that they can detect relatively small-scale seepage. There are various kinds of instruments that have been developed for acoustic survey so that we may be able to apply them in various ways from two-dimensional

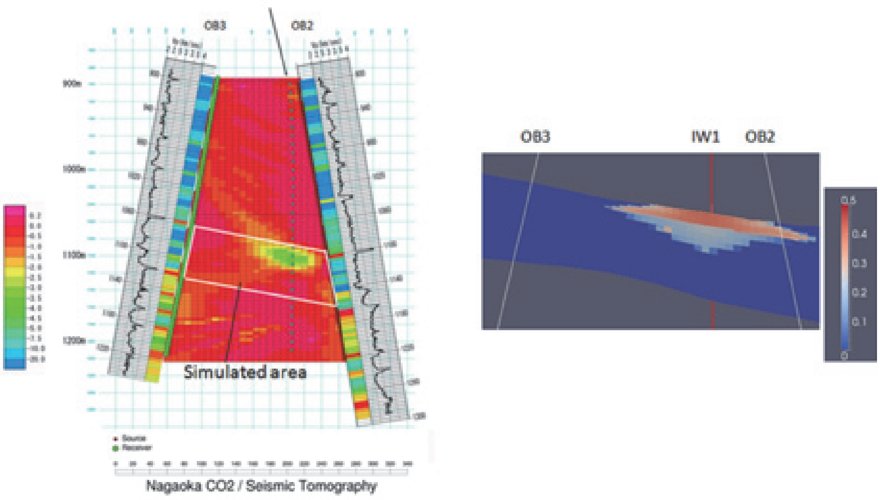


Fig. 7: CO_2 distribution immediately after the completion of injection - Results of cross-well seismic tomography and computational simulation

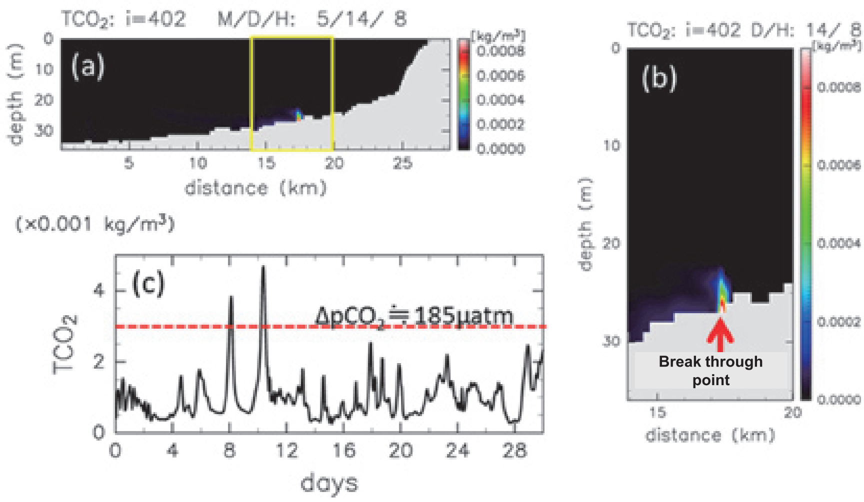


Fig. 8: Results of simulations with the narrow area model:
(a) Vertical distribution of concentration of seeped CO_2, (b) Enlarged view of the yellow box in Fig. a, and (c) Time series of seeped CO_2 at the seepage point

large area monitoring to spot monitoring with the limited number of survey points.

In addition, RITE is developing models to simulate in which area CO_2 seeped into seawater is spread at what concentration. Seawater flow, which is an essential element in the modelling, is generated not necessarily by wind blowing directly above around the flow and possibly by wind blowing at sea far from the flow. Aimed at making the models more accurate, RITE has, therefore, been developing them by combining two different numerical models: one is capable of simulating at a scale of hundreds km (a wide area model) and the other is capable of high-resolution calculation around a CO_2 seepage area (a narrow area model). We have confirmed so far that the wide area model is capable of simulating realistic flow. We have also improved the narrow area model in a way that can be given wind stresses on the seawater surface and water temperature and salinity on the side boundaries temporally and spatially. Shown in Fig.8 is a result of simulation with the narrow area model at a seepage rate of 250 tonnes per year.

2.4 Compilation of CCS Best Practice Manuals toward CCS commercialization

The world-first commercial operation of CO_2 saline aquifer storage was started in a North Sea oil field Sleipner in Norway in 1996. Since then, the practical application of CCS technologies has been increased with a number of CO_2 storage projects launched in various countries such as Australia, the United State of America and Japan. In parallel, laws and regulations necessary for CCS deployment have been made.

Foreseeing domestic and global CCS deployment in future, RITE has been compiling CCS Best Practice Manuals as a technical reference for Japanese companies to carry out CCS projects. Best practices have been collected and sorted out from Japan's experiences, including the Nagaoka CO_2 storage project and the CCS demonstration project in Tomakomai, and overseas experiences mainly in American and European projects.

We have been making progress in the compilation work of the manual, receiving consultation from a working group of experts from the CCS related areas for the manual formed in FY 2014. The current schedule is to complete Chapter 1 "basic planning" to Chapter 4 "implementation planning" by the end of FY 2015 and to complete Chapter 5 "designing and construction" to Chapter 8 "post-closure management" by FY 2020.

Fig. 9: Structure of CCS Best Practice Manual

3. Japan-China CCS-EOR project

Carbon Capture and Storage (CCS), a series of technologies of capturing CO_2 from fossil fuel combustion and storing it geologically, will be a critically important technology among countermeasures against global warming. Among others, CCS-EOR, a combination of CCS and enhanced oil recovery (EOR), draws attention as a driver of the early deployment of CCS technologies since the scheme generates commercial profits.

A broad use of CCS-EOR is highly anticipated in China. There are a number of potential sites and several oil fields have already experienced CCS-EOR operations. On the other hand, there are some cases where oil production increase is far less than expected and improvement in the effect of CCS-EOR is a challenge to be addressed.

To tackle the problem, RITE and the international department of the China National Petroleum Corporation (CNPC) concluded a co-operative agreement on CCS-EOR at the 4th Japan-China Energy Conservation and Environment Forum in Beijing in November 2009.

Based on the agreement, RITE and CNPC have been collaborating on CCS-EOR, promoting technical exchange by co-hosting CCS-EOR workshops in 2009 and 2010, a workshop on energy conservation, environment preservation and GHG reduction in 2011 and paying reciprocal visits to CCS or CCS-EOR related facilities and sites.

Through these co-operative activities, CNPC got recognized that RITE has technologies effective to improve the efficiency of CCS-EOR, including CO_2 behavior monitoring and a CO_2 microbubble technology that increases the penetration of CO_2 in oil layers. In order to demonstrate these technologies, several candidate sites were selected in FY 2013.

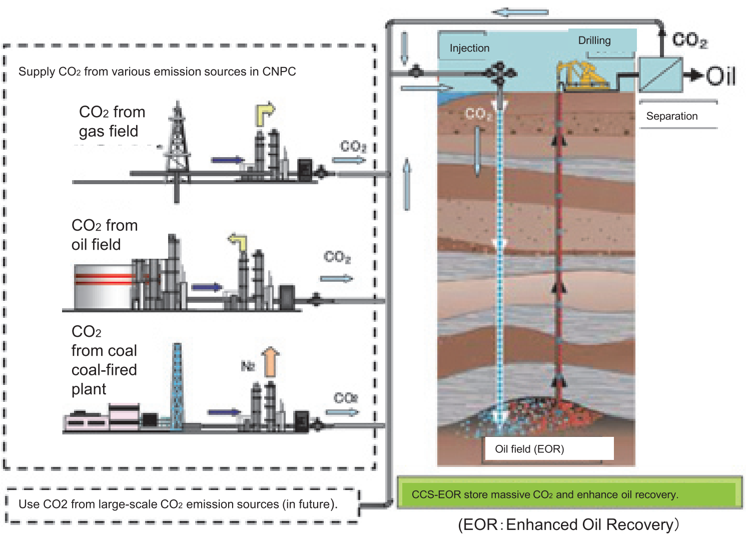


Fig. 10: Concept of CCS-EOR

Fig. 11: Japan-China CCS-EOR workshop in 2014

To review outcomes from the collaboration, another Japan-China CCS-EOR workshop was held in Beijing in September 2014, which received the great number of participants from major oil companies, power companies and policy-making organizations as well as stakeholders in CNPC. The event included the status of CCS-EOR presented by China, the introduction of RITE's technologies and Japan's proposal of business models for CCS-EOR operation. The workshop revealed accomplishment and challenges in CCS-EOR in China and reconfirmed the effectiveness of RITE's technologies to improve the efficiency of EOR.

When presenting a

CCS-EOR demonstration project in a specific oil field, CNPC requested RITE to join the project. After the workshop, core members in Japan and China visited counterparts mutually and shared details of RITE-owned technologies, which led to an agreement that RITE contributes to the demonstration.

As a next step, it is planned to discuss details of the collaboration and examine a business model for CCS-EOR in conjunction with plant engineering companies and trading houses.

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

RITE monitors CCS-related activities in the world and also contributes to accelerating CCS deployment through co-operation with international organizations. 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. Summarized below are key topics related CCS in the world in the fiscal year, starting in April 2014, and major activities in an international body to which RITE contributes—the Carbon Sequestration Leadership Forum (CSLF).

4.1 Key CCS Topics in FY 2014

The year of 2014 was a memorial year for the CCS community. In October, the world first large-scale CCS project in the power sector became operational at the Unit 3 of Boundary Dam Power Station in Canada. The power plant is relatively small with a rated output of 110 MW, but it is significantly meaningful to gain practical experience of CCS operation in the CO_2 intensive sector. In July, prior to this historic event, the US Petra Nova project became the third CCS project that entered a construction phase in the power sector. This project became a hot topic particularly in Japan because of the involvement of two Japanese companies: JX Nippon as a project owner and Mitsubishi Heavy Industries as a capture technology vendor. It also drew attention from the perspective that it has a business model different from that in earlier projects. Its business model is the same as others in a sense that captured CO_2 is utilized to enhance oil recovery (EOR), but different in that the captured CO_2 is not sold to any EOR operators but is used in their own EOR operation. This can be regarded as a more profitable business model.

Contrary to vigorous activities in North America, it is hard not to feel that it has still been inactive in Europe. Having said that, the United Kingdom is exceptional: preparation toward delivering large-scale projects and improving the political environment is making progress steadily. For large-scale CCS projects, basic engineering design – Front-End Engineering Design (FEED) – for two projects have been proceeded with funding from the UK Government. It was announced in July 2014 that one of the projects, White Rose Project, where an oxyfuel combustion coal-fired power plant is to be built equipped with CCS technology, was to be awarded up to 300 million Euro from an EU funding program NER 300. In the following month, the Government published a policy document to call the public for input for 23 challenges in 11 categories for their future policy-making toward wider CCS deployment in future. The Government also made announcement in December that they would co-fund two and half million sterling pound for industries to identify suitable CO_2 storage sites under the North Sea and opened a call for proposals. The fate of the project should draw interest from Japanese stakeholders, too. This is because the UK project likely shares a goal with Japan's project to look for appropriate offshore storage sites jointly launched by the Ministry of Economy, Trade and Industry and the Ministry of the Environment in 2014.

From the viewpoint of CCS legal and regulatory issues, two movements in the United State of America drew attention—one is regulations on CO_2 emissions from power plants and the other is the first issuance of permit to CO_2 injection wells, so-called Class VI wells. Both of the regulations are managed by the Environment Protection Agency (EPA). Stakeholders paid close attention to a final version of an EPA proposed CO_2 emissions standards which was due to come into force by January 2015 and would virtually oblige all new coal-fuelled power plants to be equipped with CCS. EPA, however, deferred its finalization and implementation to summer, claiming that it is reasonable to introduce it together with the final Clean Power Plan, which is virtually a regulation for emissions from existing power plants and has been controversial since the publication of its draft in June 2014. The Class VI well permits were issued to six wells in total in the latter half of 2014: those in FutureGen 2.0, which is a CCS project with repowered oxyfuel combustion coal-fired power plant, and an industrial CCS project with a bioethanol plant as the CO_2 source. Operation of FutureGen CCS is not for sure at this moment but anyway all of the wells are for CO_2 storage in saline aquifer formations. Expertise and data to be acquired through these projects will be meaningful for Japan as well since she puts the focus on aquifer storage.

In the area of international co-operation, an agreement between the leaders of the USA and China was spotlighted. In the agreement, which is basically for climate change countermeasures, they reached a consensus that the role of innovation is critical and agreed on collaboration on advanced coal technology development, a large-scale CO_2 storage project and enhanced recovery of fresh water (EWR). The collaboration on large-scale storage is due to be carried out with the involvement of third countries, which is consistent with the after-mentioned US-China led activity regarding global co-operation on large-scale CCS projects under CSLF. EWR is aimed at producing fresh water in parallel with CO_2 injection and the two countries plan its pilot-scale test. It is worthy of monitoring progress the co-operation between the USA, a world leader in large-scale CCS operations, and China, an outstanding owner of a number of CCS project plans.

4.2 CSLF Update in FY 2014

The Carbon Sequestration Leadership Forum (CSLF) was established in 2003 as an international initiative to promote research, development, 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 currently composed of 22 countries, including Japan, and the European Commission. Its activities are conducted by two groups – the Policy Group the Technical Group – and RITE has been a member of the Technical Group since 2009.

In response to outcomes from the CSLF ministerial meeting in Autumn 2013, most time in a fiscal year of 2014 was spent for lively discussions in the Policy Group to determine themes for CSLF to work on and activity plans of the selected themes. These discussions led to agreement for CSLF to start three new activities. Above all, an activity led by the USA and China regarding international collaboration on large-scale CCS projects is ambitious in a sense that CSLF is aimed at conducting global co-operation in actual projects with CO_2 storage in saline aquifers, the number of which in the world is currently very limited. CSLF is attempting to determine a project for the collaboration at the same timing of the next ministerial meeting to be held in autumn 2015. In an activity on the second and third generation capture technologies, which will be jointly conducted with the Technical Group, deliverables will include summaries of existing funding schemes and various relevant technologies, exploration of the best use of existing large-scale testing facilities, and policy recommendations toward accelerating the development and commercialization of the technologies. Participants in this activity include researchers in the Chemical Group in RITE. A taskforce named Communications will determine CSLF's unified messages to promote CCS and then disseminate it at various events. Among important opportunities to send the message out, the 21st Conference of Parties (COP21) under UNFCCC is regarded as the most critical one. In addition, it was agreed that an existing taskforce will be continued for financing large-scale CCS projects from the financial sector. Its activity will be in the same manner as before with roundtable-type discussions.

The Technical Group, as described above, will contribute to the activity on the second and third capture technologies. In addition, the group launched a couple of new taskforces in 2014. Among others, a taskforce that researchers in the CO_2 Storage Research Group in RITE participate actively in is on offshore storage. The task-force team plans to compile a report in mid-2015 and the report is to summarize the current status of offshore CO_2 storage and EOR projects; storage potential; transport; risk analysis; wellbore management; monitoring, verification and assessment; and related regulations.

Research & Coordination Group

Prof. Yoichi Kaya Received the Order of the Sacred Treasure, Gold and Silver Star

Prof. Yoichi Kaya, the President of RITE, was awarded the Order of the Sacred Treasure, Gold and Silver Star in the Biannual Decoration Ceremony in 2014 Spring. This was in recognition of his service in educational and research field as a professor of Tokyo University over the years and also of his contribution to the governmental affairs serving in several key positions such as the former chairman of the Advisory Committee for Natural Resources and Energy.

He is acknowledged as a foremost expert of the research of global warming issues in Japan because of his work as an advisor and a chairperson in the IPCC related internal conferences. Not only that, he has been acting as a pioneer in this field worldwide by developing “the Kaya Identity”, which is widely referred by researchers around the world and remains a significant impact on the IPCC reports. Furthermore, he contributed to establishing the basis of energy and environment strategies of Japan while playing presidential roles in the governmental councils and demonstrated his strong leadership in delivering the Kyoto Protocol target plan, which brought Japan to an accomplishment of its international commitment. Through these achievements, he made a considerable contribution to the national benefits.

A celebration party was held at the RITE headquarters on June 20th, and around 140 staff members participated in the party. The room was decorated with the pictures and flowers associated with Switzerland and Austria that Prof. Kaya is fond of, and we celebrated his award with violin performance by Prof. Yamaguchi, the Special Advisor of RITE, and two songs from Prof. Kaya’s favorite musical by a voluntary choral group. Some memorable pictures and comments were introduced, and a congratulatory video letter from Prof. Nebojsa Nakicenovic, the Deputy Director General of IIASA, was also presented. The room was filled with enjoyable atmosphere throughout the party.

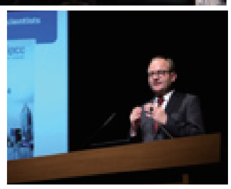
Symposium on the IPCC Fifth Assessment Report

“Symposium on Global Warming Countermeasures-To Learn the Latest Knowledge in the IPCC Fifth Assessment Report concerning Measures for Mitigating Climate Change – was held by Ministry of Economic, Trade and Industry, Japan (METI) and RITE in Tokyo on 8th of September 2014.

This symposium was to introduce the latest finding of the Working Group III contribution to the IPCC’s Fifth Assessment Report (AR5) adopted in Berlin in April 2014 and to enhance understanding on mitigation of climate change. The report describes the Working Group's assessment concerning policies and measures for curbing and reducing greenhouse gases or mitigating climate change, and also assesses the choices for a variety of administrative-level entities and economy sectors, as well as evaluating various types of mitigation measures to see if they would make any impact on society.

Dr. Ottmar Edenhofer (PIK), co-chair of Working Group III of IPCC, presented his keynote speech, then other lead authors of WGⅢ, Dr. Keywan Riahi (IIASA), Mr. Taishi Sugiyama(CRIEPI), and Dr. Keigo Akimoto (Group leader, Systems Analysis Group)clarified key points of IPCC AR5. In the latter half of the symposium, Ms. Masayo Hasegawa (Keidanren/Toyota) was added to the speakers above, and under the coordination of Prof. Mitsumine Yamaguchi (Tokyo Univ.), a panel discussion about mitigation strategies was actively held.

More than 350 audiences with various back grounds participated in the symposium and we believe that the symposium was rich in significance for understanding of mitigation strategies.



Research & Coordination Group

GHGT-12 Participation Report

GHGT-12 (12th International Conference on Greenhouse Gas Control Technologies) was held in October 6-9th in Austin, the United States, hosted by University of Texas at Austin and IEAGHG which is an international collaborative research programme as an Implementing Agreement under the International Energy Agency (IEA). This is the largest international conference that focuses on mitigation technologies especially CCS (Carbon dioxide capture and storage) and are held every two years between North America, Europe and Asia. The former conference in 2012 was held by RITE and IEAGHG in Kyoto, Japan.

Participants were about 1,160 from 35 countries and discussed on 14 themes in 77 technical sessions: geological storage has 24 sessions (including other storage options) and capture has 22. These two themes were major, about 60% of all sessions.RITE gave five oral and ten poster presentations in technical sessions on geological storage, capture, and others. This conference had several panel discussions, one of which was on international standardization on CCS. In this session, activities of technical committee of ISO/TC265 (ISO: International Standard Organization) was overviewed and Takayuki Higashii, senior researcher of Chemical Research Group, RITE explained activities of Working Group 1 (capture) as a convener.

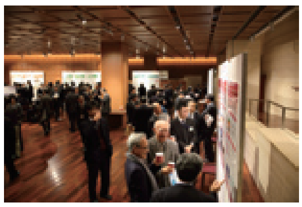
At the end of five-days conference, the next GHGT-13 was announced to be held in Lausanne, Switzerland in November, 2016.

Innovative Environmental Technology Symposium 2014
- Toward clean and economical low-carbon society -

The Innovative Environmental Technology Symposium 2014 was held at ITO Hall (the University of Tokyo) on December 17th, 2014.

This symposium is an annual event that RITE hosts to present our research progress and outcomes to all the parties concerned. This year we were honored to invite Mr. Mitsumata (Deputy Director-General for Technology and Environment, METI) to deliver a speech on the main points of COP20 and the current standpoint of Japan for the reduction target commitment. Also, Prof. Yamaguchi, the Special Advisor of RITE, who is one of the lead authors of IPCC reports, gave a keynote speech on the interpretation of he IPCC Fifth Assessment Report and how to approach the controversial issue of “limiting temperature change to 2 °C relative to pre-industrial levels”. After those speeches, the latest achievements and the future outlook of our research and development activities were presented from each research group concerning the assessment of global warming mitigations, biorefinery technology and CCS technology. We had an attendance of 394 people in total from ministries, industries and universities and could receive meaningful inputs from the audience through active discussion.

The poster session, being organized the second time after last year, had a large number of visitors and offered an opportunity to exchange opinions directly between the



Research & Coordination Group

Environmental Education Program on Global Warming with Experiments and Games

- Our outreach activity based on "CarbonKids" -

It is important for next generation to have the opportunity to think about the worldwide issue of global warming. For us, RITE, as the research institute which deals with this issue, it is necessary to provide easy-to-understand explanation about carbon dioxide reduction measures, such as CCS, in order to increase the public awareness of the technologies. RITE has been continually conducting an environmental education activity targeting students from elementary school to high school, and this fiscal year in particular, we are working on the planning and implementation of the Japanese version of "CarbonKids", an environmental educational program developed in Australia. Here we would like to introduce our outreach activity based on this CarbonKids program.

We have been specifically focusing on the following two areas in our educational programs this year; first we brought in environment-related educational games, and secondly we adopted various kinds of science experiments related to CO_2 and CCS.

Regarding the first one, we adopted "Snakes and Ladders", a board game which is well-known in the Western countries, and "Carbon Cards Challenge", a card game which helps children to understand the key words about the global warming issue and CCS through playing the game. These games were tried in our facility tour programs for school students or in the external exhibitions held at Keihanna, and were well-received by the participants of all ages as they could be helpful to learn about the global environmental issues more easily.

As for the science experiments, we are trying to include more variety of experiment items to introduce CO_2 reduction technologies, especially CCS, one of the major research areas of RITE. One example is a simple experiment using 'chocolate' to explain the geographical structure of CCS. We tried the demonstration of this "chocolate CCS" in our summer educational program and received many favorable comments that it was helpful to understand how to store CO_2 in the ground. Furthermore, we have been trying to enhance the program by bringing in the experiments which deals with deeper scientific themes, such as generating, liquefying or storing CO_2. We would like to do our best to make our science experiment program more comprehensive in cooperation with the experts of science education and teachers in the field.

We are planning to proactively deploy our education program more widely. We will work on expanding our outreach activity to enhance the public awareness and the exact understanding of CCS.

Chocolate CCS

Science Experiment

Children playing games

Systems Analysis Group

ALPS International Symposium

FY2013 ALPS International Symposium was held at Tokyo International Forum in Tokyo on February 4th, 2014. 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 were honored to have five leading experts from overseas, including Prof. Nabojsa Nakicenovic from the International Institute Applied Systems Analysis, Prof. Robert N. Stavins from the Harvard University, Prof. Scott Barrett from the Columbia University, Dr. Niklas Höhne from Ecofys and Dr. Raymond J. Kopp from the Resources for the Future, and to have two Japanese experts, Dr. Seita Emori from NIES and Prof. Yoichi Kaya, 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 240 people from industries, ministries and universities. Their active discussion motivated us to dedicate further efforts to our research and development.

FY2014 ALPS International Symposium is scheduled to take place in February 27, 2015 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 effective frameworks and measures for climate change towards COP21.

COP20 Side Event

The Side Event, titled “New Methods for Comparing Levels of Effort,” was held at COP20 in Lima (Peru) on December 9th, 2014. The Event was hosted by RITE and Resources for the Future (RFF).

RITE and RFF are undertaking research to better refine the analytics underlying ex-ante/ex-post evaluations of nationally determined contributions (NDCs) proposals and performance. Such a review system is one of the key roles within a Plan-Do-Check-Act-(PDCA) cycle. Rather than using a single metric, it makes sense to decide on a set of principle that metric should follow, evaluate metrics against those principles, and examine NDCs on the basis of multiple metrics.

After the above presentation, we had a fruitful discussion with the audience and had questions from the floor regarding how to evaluate the effort of development of innovative technologies and consumption-based CO_2 emissions, etc.

Molecular Microbiology and Biotechnology Group

Establishment of Green-phenol development Co., Ltd.

RITE and Sumitomo Bakelite Co., Ltd. established Green-phenol development Co., Ltd. (GPD) in May 2014 to realize world's first industrialization of green phenol by using our two stage process developed originally (see text). The organization of GPD was converted from Greenphenol Technology Research Association established by RITE and Sumitomo Bakelite Co., Ltd. in February 2010. GPD takes over intellectual assets of the research association and continues technology development for the efficient green phenol production. Our technology has the possibility to achieve a low cost production of green phenol comparable to or lower than that of petrochemical phenol if we can get inexpensive mixed sugars derived from cellulosic biomass. Since our technology of green phenol production shows less environmental load such as CO_2 emission, it possesses a high market competition power (Fig). Now we are operating a pilot plant (500L) constructed in the Kazusa Academia Park in Kisarazu-shi, Chiba and aspire to realize early practical production.

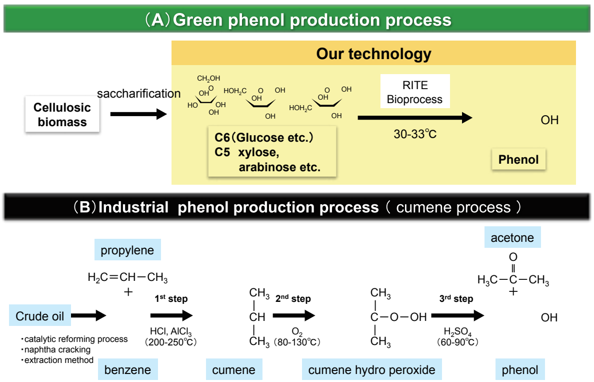
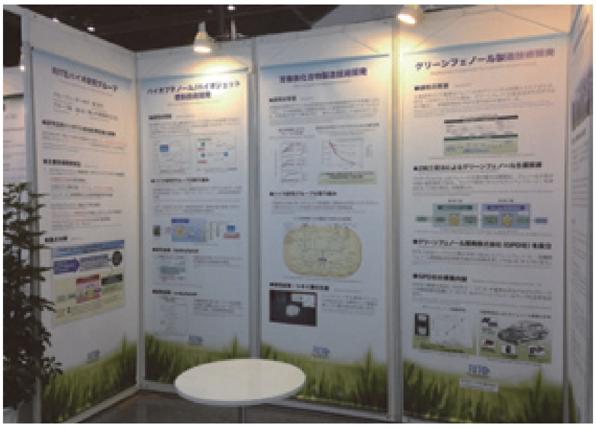


Fig. Comparison of green phenol production process and industrial phenol production process

Many visitors attended our exhibition booth at BioJapan 2014 World Business Forum

BioJapan 2014 World Business Forum was held at Pacifico Yokohama from 15th to 17th October 2014. RITE has hosted the forum as a sponsor organization since 2011, and our group jointly exhibited it with Green Earth Institute (GEI). GEI is the business company of our "RITE Bioprocess (Growth-arrested Bioprocess)" which is our core technology (see RITE Today 2012). In our booth, in addition to biofuel (butanol) production technology, we introduced a new research target of high cell inhibitor manufacturing technology in a panel presentation. The high cell inhibitors are the materials which inhibit microbial fermentation. They inhibit microbial cell growth by their high toxicity to the cell and affect fermentation productivity. Specifically, phenol and higher alcohols are well known inhibitors. We also introduced the Green-phenol development Co., Ltd. established by RITE and Sumitomo Bakelite Co., Ltd. in May 2014 and its developmental status, and exhibited a green phenol molded sample in our booth.

RITE / GEI joint exhibition booth



RITE exhibition panels

Molecular Microbiology and Biotechnology Group

New Project Starts: Development of the Production Technologies for 100% Green Jet Fuel by Hybrid Microorganism

We interviewed Dr. Shinmyo, a professor in Nara Institute of Science and Technology, who is a project committee chairman of the new research project entitled “Development of the production technologies for 100% green jet fuel by hybrid microorganism” that will be started in Molecular microbiology and biotechnology group in this year.

Research objective of the new project

We are going to develop a novel bioprocess for production of 100% green jet fuel that is derived from non-food-based biomass and it is not required for mixing fossil jet fuel. It is worth noting that a kind of reaction that has never been used in biological process is employed to develop a microbial catalyst in our project, which enables to efficiently produce chemicals that cannot be produced by microorganisms. I think this research is technically unique and novel.

Based on more than 10-years research in RITE, they have had cost-competitive technologies for production of ketones and aldehydes. Technological hurdle in this new project is to synthesize jet fuel from these precursors in microbial cells. Catalytic reactions proposed in this project will make a breakthrough in biorefinery research if we can accomplish this task. In the view point of a project manager, it is important to clarify priority of candidates of the catalyst, otherwise we will waste time and research budget.

Jet fuel is consisted of not only saturated hydrocarbons, but also aromatic compounds. New biocatalyst that RITE’s scientists are proposing can produce both compounds, which is great concept. Airplane can be flown by the green jet fuel without mixing fossil jet fuel if they will succeed this research project. Although our task is not easy, I am sure scientists in RITE will done successfully.

A near-term target is to replace 10 to 15% of fossil jet fuel to the green jet fuel derived from cellulosic biomass, but theoretically, all jet fuel consumed in the world can be replaced to the green jet fuel. Market of green jet fuel is huge, which gives us big dream.

What is attractive of research

When I encounter difficulties in research, I encourage myself by thinking that I will have fruits if I can solve the difficulties. That is why research has attracted me for a long time. After one year goes, investor of research project will ask us what we make progress, but I think budget and time is not always certified research progress unlike in the case of simple task. In research, big progress suddenly comes to our hands. I think RITE’s new project has the essential element of research.

Next step; national project

No need to accomplish all research tasks only by RITE. When RITE’s scientists will face technological difficulties that are apparently impossible to solve by themselves, collaboration to scientists outside RITE who are specialists in different research fields will help combat with the technological difficulties. Since global warming is major issue for everyone around the world, I think collaborators are also chosen in the world. To advance to national project, one important my role is transmission of information about our research, which may bring people who will help us.

Future challenge

Scientist should select own research subject by considering the future direction of humankind. To do so, we need to be susceptible to current issues which beset the world. This new research project on green jet fuel fits with this viewpoint and I really make this project successful.

CO_2 Storage Research Group

CCS Technical Workshop 2014

- Effort for environmental impact assessment of CO_2 storage –

The CCS Technical Workshop entitled "Effort for Environmental Impact Assessment of CO_2 Storage" was co-organized by RITE and the Ministry of Economy, Trade and Industry (METI) at Dai-ichi Hotel Tokyo on January 30, 2015. The workshop was attended by 186 participants mainly from governments, businesses, universities, research institutes.

CCS (Carbon dioxide Capture and storage) is a promising technology to reduce global CO_2 emissions and consequently to mitigate global warming. There are currently more than 10 large-scale CCS projects under operation around the world. For full deployment of CCS, it is essential to demonstrate the safety of CCS for building public confidence in commercialization of CCS. Hence, technological development for ensuring safe and reliable CO_2 storage draws much attention.

The workshop was moderated by Prof. Toru Sato (The University of Tokyo). Following four presentations by international experts we had a fruitful discussion on tackling safety evaluation in CCS.

Firstly in this workshop, Dr. Jun Kita (Senior Researcher) introduced "the Current status of R&D on potential CO_2 leakage from a reservoir". Then, Prof. Lee Spangler (Director, Energy Research Institute, Montana State University, USA) gave clear details of a US project in his presentation titled "The ZERT on-shore controlled release, lessons learned about monitoring methods, impacts and detection limits". Mr. Jeremy Blackford (Project Leader, QICS project, Plymouth Marine Laboratory, UK) gave a talk entitled UK project "The QICS Project, outcomes and implications for the development of CCS". Finally, Dr. Keisuke Uchimoto (Senior Researcher) gave a presentation on "Development of numerical models for the dispersion of CO_2 in the sea corresponding to some leakage scenarios".

Prof. Sato wrapped the workshop up with his statement that "Carbon dioxide capture and storage is one of the most effective options for the reduction of CO_2 emissions. The presentations today gave us an overall picture and a direction of the technological development of environmental impact assessment toward the commercialization of CCS. If developed in the direction, Japan's CCS technologies will have an additional value with a higher safety of CO_2 storage and be accepted world-wide more easily."

World-first Experiment on an Offshore CO_2 Storage Leak

- First step to building mutual understanding and trust of CCS technology -

In order to understand the potential risks of carbon dioxide (CO_2) leakage in a project to store CO_2 in subseabed geological formations, an international team of scientists, including RITE's researchers, carried out the first-ever experiment of an on-site controlled CO_2 release under the UK QICS (Quantifying and Monitoring Potential Ecosystem Impacts of Geological Carbon Storage) project [1]. The results of the experiment was published in Nature Climate Change [2], presenting how marine environment might react to a real-life leakage. This study is expected to contribute not only to the development of monitoring technologies and the biological assessment of CO_2 leak but also to improvement of the reliability of offshore CO_2 storage.

One of the concerns over CCS technology raised by the public is potential CO_2 leaks from a reservoir. Hence, we carried out a small-scale on-site experiment of controlled CO_2 release to assess the validity of technologies for detecting and monitoring CO_2 leakage and to investigate physical, chemical and biological impacts on the marine environment in detail.

It was demonstrated that a combination of chemical sensors and bubble acoustic techniques is the optimal monitoring technique to detect leakage or prove no leakage. It was also shown that the impacts of the released CO_2 on that scale was limited and its chemical and biological impacts were restored to background levels in a short term after the cease of the CO_2 release. These findings contribute to the growth of a knowledge base necessary for the appropriate deployment of CCS as a climate change mitigation measure, in particular for regulatory requirement for monitoring. Although the results show that small-scale leakage would not be catastrophic, we would say that if a larger amount of CO_2 is released its impacts are likely to be significant. We also believe that in site selection water movement around a site is a key factor. This is because when seawater is mixed intensively CO_2 is supposed to disperse more rapidly so that the impacts of the CO_2 is to be insignificant and restored quickly.

[1] http://www.bgs.ac.uk/qics/
[2] J. Blackford, et al., "Detection and impacts of leakage from sub-seafloor deep geological carbon dioxide storage," Nat. Clim. Chang., vol. 4, no. 11, pp. 1011–1016, Sep. 2014.

Chemical Research Group

Symposium for Innovative CO_2 Membrane Separation Technology

- Recent trends of membrane separation technology contributing to the prevention of global warming –

On February 2nd, 2015, the Fourth Symposium for Innovative CO_2 Membrane Separation Technology, "Recent trends of membrane separation technology contributing to the prevention of global warming", was held at the Dai-ichi Hotel Tokyo. The event was sponsored by the Molecular Gate Membrane module Technology Research Association (The Association*) and co-sponsored by the Japanese Ministry of Economy, Trade and Industry (METI). The event attracted 194 attendants from companies, universities, research institutes and government agencies.

The purpose of this symposium was threefold. First, to report recent research trends in CO_2 separation membrane technologies that The Association has been developing. Second, to gain an overview of overseas research and development in this technology area. Third, to provide interested parties with the background to understand the required public and private R&D activities for CO_2 emission reductions.

In this Fourth Symposium, the keynote speeches were given by Mr. Tony Wu from Southern Company in a presentation titled "CO_2 Capture at the National Carbon Capture Center," and then by Prof. May-Britt Hägg of NTNU in a presentation titled "Latest trends in membrane technologies in Norway and Europe". Following these keynote speeches, membrane technology keynote speech was given by Prof. Shigetoshi Kita of Yamaguchi University, who presented on the "Current status and future perspective of membrane separation technology."

From The Association, Mr. Akio Fujita gave the speech "Report of investigation on overseas membrane technologies." The presentations were concluded by Senior Managing Director Shin-ichi Nakao who spoke of the research progress being made at The Association in a speech titled "Next-Generation membrane module".

* The Molecular Gate Membrane Module Technology Research Association was established in February 17th, 2011. The Association's members are RITE, Kuraray Co., Ltd., Nitto Denko Co., Ltd., and Nippon Steel & Sumikin Engineering Co., Ltd.

Directors

◆Books

1. Kenji Yamaji (Commissioners) , The Fukushima Daiichi Nuclear Power Station Disaster,Investigating the Myth and Reality, Routledge, 2014

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◆Original Paper

1. K. Akimoto, T. Homma, F. Sano, M. Nagashima, K. Tokushige, T. Tomoda, Assessment of the emission reduction target of halving CO_2 emissions by 2050: Macro-factors analysis and model analysis under newly developed socio-economic scenarios, Energy Strategy Reviews, Vol.2, Issue 3-4, pp.246-256, February 2014
2. M. Kii, K. Akimoto, K. Doi, A land-use transport model to assess the impact of urban policies on Carbon dioxide reduction and sustainability, Journal of Eastern Asia for Transport Studies, Vol.10, pp.1112-1128, 2013
3. M. Kii, K. Akimoto, K. Doi, Measuring the impact of urban policies on transportation energy saving using a land use-transport model, IATSS Research, Volume 37, Issue 2, pp.98–109, March 2014
4. M. Kii, K. Akimoto, K. Doi, A land-use transport model to assess the impact of urban policies on Carbon dioxide reduction and sustainability, Journal of Eastern Asia for Transport Studies, Vol.10 pp.1112-1128, 2014
5. M. Sugiyama, O. Akashi, K. Wada, A. Kanudia, J. Li, J. Weyant, Energy-efficiency potentials for global climate change mitigation, Climatic Change, Vol.123, Nos.3-4, pp.397-411, April 2014
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7. F. Sano, K. Akimoto, K. Wada, Impacts of different diffusion scenarios for mitigation technology options and of model representations regarding renewables intermittency on evaluations of CO_2 emission reductions, Climatic Change, Vol.123, Nos.3-4, pp.665-676, April 2014
8. S. H. Kim, K. Wada, A. Kurosawa, M. Roberts, Nuclear energy response in the EMF27 study, Climatic Change, Vol.123, Nos.3-4, pp.443-460, April 2014
9. K. Akimoto, F. Sano, A. Hayashi, T. Homma, J. Oda, M. Nagashima, K. Tokushige, T. Tomoda, Trade-offs and synergies of sustainable development and climate stabilization in Asian regions, Edited Volume of Environment Policy in Asia, National University of Singapore (NUS), Chapter 10, pp.203-225, July 2014
10. A. Hayashi, K. Akimoto, T. Homma, K. Wada, T. Tomoda, Change in the annual water withdrawal-to-be-availability ratio and its major causes: An evaluation for Asian river basins under socioeconomic development and climate change scenarios, Energy and Environment Research, Vol.4, No.2, pp.34-46, 2014
11. A. Hayashi, K. Akimoto, T. Tomoda, Analyses on change in global water stress and its major factors, Energy and Resources, Vol.35, No.4, pp.40-49, July 2014
12. N. Bauer, V. Bosetti, K. Calvin, M. Hamdi-Cherif, A. Kitous, D. L..McCollum, A. Mejean, S. Rao, H. Turton, L. Paroussos, S. Ashima, K. Wada, CO_2 emission mitigation and fossil fuel markets: Dynamic and international aspects of climate policies, Technological Forecasting & Social Change, in press
13. K. Riahi, E. Kriegler, N. Johnson, C. Bertram, M. den Elzen, J. Eom, M. Schaeffer, J. Edmonds, M. Isaac, V. Krey, T. Longdon, G. Luderer, A. Mejean, D. L. McCollum, S. Mima, H. Turton, D. P. van Vuuren, K. Wada, V. Bosetti, P. Capros, P. Criqui, M. Kainuma, Looked into Compenhagen Pledges - Implications of short-term emissions targets for the cost and feasibility of long-term climate goals, Technological Forecasting & Social Change, in press
14. E. Kriegler, K. Riahi, N. Bauer, J. Schwanitz, N. Petermann, V. Bosetti, A. Marcucci, S. Otto, L. Paroussos, S. Rao, T. Arroyo-Curras, S. Ashina, J. Bollen, J. Eom, M. Hamdi-Cherif, A. Kitous, A. Mejean, F. Sano, M. Schaeffer, K. Wada, P. Capros, D. van Vuuren, O. Edenhofer, Making or breaking climate targets: The AMPERE study on staged accession scenarios for climate policy, Technological Forecasting & Social Change, in press
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17. K. Tokushige, K. Akimoto, J. Oda, T. Homma, Analysis on emission reduction efforts of GHG emissions in Japan for the first commitment period of the Kyoto Protocol, Journal of Japan Society of Energy and Resources, in press

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3. K. Akimoto, H. Kudo, T. Sugiyama, J. Fujino, A. Kurosawa, Evaluation on voluntary action plan for greenhouse gas emission reductions –The Special Session in the 33rd Meeting of JSER-, Energy and Resources, Vol.35, No.5, pp.339-342, September 2014
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3. T. Homma, J. Oda, K. Akimoto, Development of socio-economic

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scenarios based on SSP storylines, 30th Conference on Energy, Economy and Environment, Jan. 24, 2014

4. M. Nagashima, T. Homma, F. Sano, K. Wada, K. Akimoto, T. Tomoda, A study on sharing the burden of financing options for climate change, 30th Conference on Energy, Economy and Environment, Jan. 24, 2014
5. F. Sano, K. Akimoto, K. Wada, J. Oda, An analysis of hydrogen systems by using a world energy systems model, 30th Conference on Energy, Economy and Environment, Jan. 24, 2014
6. K. Tokushige, K. Akimoto, J. Oda, T. Homma, Analysis and study on factors of change in GHG emissions in major countries, 30th Conference on Energy, Economy and Environment, Jan. 24, 2014
7. J. Oda, K. Oshima, K. Akimoto, T. Tomoda, International comparison or electricity price: Cost structure, subsidy, and tax, 30th Conference on Energy, Economy and Environment, Jan. 24, 2014
8. M. Sugiyama, O. Akashi, K. Wada, Amit Kanudia, Jun Li, John Weyant, Energy efficiency potentials for mitigating climate change, 30th Conference on Energy, Economy and Environment, Jan. 24, 2014
9. K. Wada, K. Akimoto, A. Hayashi, F. Sano, T. Homma, The Water-Food-Economy-Climate nexus of ALPS scenario, CESM Societal Dimensions Working Group Meeting Boulder Colorado, USA, Feb. 27, 2014
10. K. Akimoto, Updated trends in international analyses of scenarios reducing greenhouse gas emissions, Japan Geoscience Union Meeting 2014 (JpGU2014), May 2, 2014
11. K. Akimoto, K. Tokushige, J. Oda, F. Sano, T. Homma, K. Wada, Quantitative analysis and evaluation of accomplished emission reductions under the Voluntary-Action-Plan, The 33rd Annual Meeting of Japan Society of Energy and Resources (Special Session), Jun. 10, 2014
12. J. Oda, K. Akimoto, Energy supply and demand in South Asian countries based on hearing survey: Pakistan, The 33rd Annual Meeting of Japan Society of Energy and Resources, Jun. 11, 2014
13. K. Wada, K. Akimoto, T. Homma, Quantitative risk assessment of rising electricity prices in Japan, The 37th IAEE International Conference, N.Y., USA, Jun. 18, 2014
14. B. Shoai Tehrani, T. Tomoda, J.C. Bouquet, Electricity Investment and Nuclear Development: Invest Choice Modeling based on Value Creation, Dependence and Structure Modeling Conference, Ecole Centrale, Paris, France, Jul. 2, 2014
15. F. Sano, K. Akimoto, K. Wada, Evaluation of contribution of renewable energy to climate change mitigation, Grand Renewable Energy 2014, Tokyo, Japan, Jul. 29, 2014
16. J. Oda, K. Akimoto, K. Oshima, Renewable energy and its observed effect on electricity price, Grand Renewable Energy 2014, Tokyo, Japan, Jul. 29, 2014
17. A. Hayashi, K. Akimoto, F. Sano, T. Tomoda, Evaluation of global energy crop production potential up to 2100 under socioeconomic development and climate change scenarios, Grand Renewable Energy 2014, Tokyo, Japan, Jul. 30, 2014
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19. K. Akimoto, Greenhouse gas mitigation strategy, 46th Autumn Meeting of the Society of Chemical Engineers, Japan (IPCC Session), Sep. 17, 2014
20. J. Oda, T. Homma, K. Akimoto, Future electricity demand of industrial sector in Japan, The 4th IAEE Asian Conference, Beijing, China, Sep. 19, 2014
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23. F. Sano, K. Akimoto, K. Wada, Evaluation of diffusion and deployment of climate mitigation technologies considering heterogeneity of technology adoption in IAM, 7th Annual Meeting of the Integrated Assessment Modeling Consortium, Maryland, USA, Nov. 18, 2014
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2. K. Akimoto, Chapter 3 Quantitative analyses for climate change measures, Climate Change and Energy, Energy Forum Pub., Jan. 31, 2014
3. K. Akimoto, Perspective on energy and environmental policies, Committee on Environmental Issues, Toyama Association of Corporate Executives, Feb. 6, 2014
4. K. Akimoto, Quantitative analysis on evaluation of the Voluntary-Action-Plan, Review Meeting for the Comprehensive Evaluation of the Second Voluntary-Action-Plan, Feb. 6, 2014
5. K. Akimoto, Chapter 3 Model analysis for climate change mitigation strategy, Climate Change and Energy -Japanese Perspective on Climate Change Mitigation Strategy, World Scientific Publishing, in press
6. K. Akimoto, The new strategic energy plan, Comprehensive Energy Workshop, Aomori Prefecture, Feb. 21, 2014
7. K. Akimoto, The future energy in Japan -From the environmental and economic viewpoint, Energy Technology Committee, Osaka Science & Technology Center, Feb. 28, 2014
8. K. Akimoto, Towards the optimum energy mix -Quantitative analyses and evaluation, Symposium: the Desired Energy Mix and Climate Change Measures hosted by Keidanren / Environmental Measures Promotion Foundation, March 26, 2014
9. K. Akimoto, The strategic energy plan and the establishment of future energy mix, Energy Policy Meeting, Japan Society of Energy and Resources, May 14, 2014

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10. K. Akimoto, Evaluation of scenario, technology and policy of IPCC WG3 Fifth Assessment Report, Green Forum 2014, Nikkan Kogyo Shimbun, Jun. 17, 2014

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13. K .Akimoto, The strategic energy plan and the future energy mix prospect, Workshop for the Next-generation Electric Network, Institute of Applied Energy, Jul. 17, 2014

14. K. Akimoto, IPCC Fifth Assessment Report and strategic response to the international situation of climate change, 2014 CIGS Symposium on Climate Change, Canon Institute for Global Studies, Jul. 24, 2014

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17. K. Akimoto, Global warming and sustainable development scenario - Based on the strategic energy plan and the IPCC report, Committee for Promoting Global Environment Technology, Osaka Science Technology Center, Aug. 11, 2014

18. K. Akimoto, The points of IPCC Fifth Assessment Report and the future energy and environmental policy, Energy and Environmental Education Seminars for Teachers (for high school teachers), Aug. 26, 2014

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21. K. Akimoto, Prospect of the energy mix and nuclear power under electricity liberalization, Academic Study Group, The Japan Society of Public Utility Economics, Sep. 18, 2014

22. K. Akimoto, THE ACEEE 2014 INTERNATIONAL ENERGY EFFICIENCY SCORECARD: 'Myth that Japan is superior in energy efficiency' is no longer true? Is China superior to Japan?, On the web page of International Environmental Economic Institute (IEEI), Sep. 22, 2014

23. K. Akimoto, ALPS Project-studies on policies and measures for climate change and sustainable development toward green growth, IIASA Seminar: Exploring Future Collaboration with the Japanese Research Community, Oct. 13, 2014

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26. K. Akimoto, Scientists challenges to global warming –Study on system analyses for strategies in response to global warming, SSH Science Festival, Nov. 8, 2014

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29. K. Akimoto, Nuclear power corresponding to increased climate change risks, The Second Central Meeting, Global Energy Policy Research, Nov. 17, 2014

30. K. Akimoto, Reading long-term emission scenarios in IPCC Fifth Assessment Report, Joint Expert Meeting of Global Environment Committee of MOE Central Environment Council and the Global Environmental Subcommittee of METI Industrial Structure Council for Intended Nationally Determined Contributions, Nov. 25, 2014

31. K. Akimoto, Proposal of review methods for comparability efforts of pledged targets and their example assessments, COP20 Side Event (Japan Pavilion), Peru, Dec. 9, 2014

32. K. Akimoto, Evaluation of intended nationally determined contributions for the post-2020 period based on equity sharing emission reduction efforts, RITE Innovative Environmental Technology Symposium 2014, The University of Tokyo, Dec. 17, 2014

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◆Original Paper

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2. N. Takemoto, Y. Tanaka, M. Inui and H. Yukawa, The physiological role of riboflavin transporter and involvement of FMN-riboswitch in its gene expression in Corynebacterium glutamicum, Applied Microbiology and Biotechnology, Vol. 98, pp.4159-4168, 2014
3. T. Kubota, Y. Tanaka, N. Takemoto, A. Watanabe, K. Hiraga, M. Inui and H. Yukawa, Chorismate-dependent transcriptional regulation of quinate/shikimate utilization genes by LysR-type transcriptional regulator QsuR in *Corynebacterium glutamicum*: carbon flow control at metabolic branch point, Molecular Microbiology, Vol. 92, pp.356-368, 2014
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5. Y. Tanaka, N. Takemoto, T. Ito, H. Teramoto, H. Yukawa and M. Inui, Genome-wide analysis of the role of global transcriptional regulator GntR1 in *Corynebacterium glutamicum*, Journal of Bacteriology, Vol. 196, pp.3249-3258, 2014
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