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RITE Today

2018 Vol.13

Annual Report

Research Institute of Innovative Technology for the Earth

RITE Today

2018 Vol.13

Contents

Mitigating Global Warming through the Power of Science

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In November 2016, the Paris Agreement entered into force as a new international framework to combat global climate change. In Japan, the Long-term Low-Carbon Vision was published in March 2017, and the Long-term Climate Change Policy Platform was presented in April of the same year.

We have to admit, however, that the future of the Paris Agreement is uncertain partly because the United States announced its withdrawal from the accord. In retrospect, since the issue of global warming was raised in the previous century, it seems we have yet to determine how humanity should deal with this issue.

It may sound extreme but humanity may never become serious about tackling global warming as long as we continue to treat this issue in a conventional way of thinking. It is thought that reducing CO_2 emissions will stifle economic growth and there are political or business leaders who try to take a “free-ride" on the efforts of other countries. Just upholding ideals is not enough in reality. In this respect, the most important thing is to make the reduction of CO_2 itself a highly profitable business to become industrialized, that is, to tackle global warming incorporating it into the system of human society. I believe that this goal can be achieved only by innovations through the power of science.

The mission of RITE is to address global warming using the power of science. Since I started working for RITE in July last year, I often have been impressed anew with the high quality of RITE's people and research. I am now convinced far more strongly than before that each and every one of RITE's research projects can bring innovations to global society in combating global warming

Among those research projects is one on geological CO_2 storage, a technology of injecting large amounts of CO_2 in geological formations deep underground. Although there are quite a few institutes working on this technology, RITE is highly evaluated internationally for its elaborate and untiring research activities, becoming on par with the United States and Norway, top-runners in this field. Recently, a Saudi Arabian state-owned oil company showed interest in RITE's storage technology, which is expected to be widely adopted in the future.

RITE has also been conducting research on technologies for separating and capturing carbon dioxide generated from industrial emission sources. In collaboration with Kawasaki Heavy Industries, RITE developed a CO_2 separation and capture system that boasts significantly lower energy consumption than conventional ones using a solid sorbent newly developed by RITE. In 2019 or later, we plan to conduct practical application tests at Maizuru Power Plant, Kansai Electric Power.

Another innovative technology is the RITE Bioprocess, a growth-arrested bioprocess that was established after many years of R&D at RITE on *Corynebacterium glutamicum.* By advanced metabolic engineering of the bacterium, biofuels and green chemicals can be efficiently produced. This high-yield production system enables cost-efficient processing of non-food biomass, such as rice straw and used paper, to green jet fuels, aromatic compounds, and other bio-based products.

Besides technology development, RITE has also been conducting research on the strategies to respond global warming. To help society make better decisions on issues related to global warming, it is necessary to present reasonable assessments that use various kinds of variables including demographics, industry, and technology. Scientific uncertainty is also taken into consideration in our analysis. RITE's analysis results have been provided for the policy recommendations and discussions of the Ministry of Economy, Trade and Industry and other governmental organizations. The researchers at RITE also actively exchange opinions with their counterparts around the world through collaboration with the International Institute for Applied Systems Analysis (IIASA), participation in international model inter-comparison projects, and other activities.

How we can achieve economic growth while protecting the environment is a challenge for our present day, not the future. RITE continues to play a leading role in the endeavor to achieve this goal by using the power of science.

Role of the Geological Carbon dioxide Storage Technology Research Association toward Deployment of CCS

The Research Institute of Innovative Technology for the Earth (RITE) established the Geological Carbon dioxide Storage Technology Research Association in April 2016 with four private companies and a national research institute to develop Carbon dioxide Capture and Storage (CCS) technology for the effective mitigation of global warming. This association is conducting research and development into areas that include effective geological CO_2 storage technology on a practical scale (one million tons of CO_2 per year) which will be suitable as a storage reservoir for Japan, technologies to improve the safety of CCS, and the development of conditions to spread the use of CCS. At board meetings, members of this association discussed the activities of the association and its future plans and goals.

Chairman of Research Promotion Advisory Committee:
Kozo Sato Professor, School of Engineering, The University of Tokyo.

President:
Kenji Yamaji Director-General, Research Institute of Innovative Technology for the Earth(RITE)

Board Members:
Shinichi Hiramatsu Senior Executive Officer, General Manager of Engineering Headquarters, OYO Corporation
Tetsuro Tochikawa Counselor, Technical Headquarters, INPEX CORPORATION
Yasuo Takehana Executive Officer, President, Environment and Innovative Technology Projects Division, Japan Petroleum Exploration Co., Ltd.
Yusaku Yano Director General, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST)
Satoshi Imamura Executive Officer, Chief of Nuclear Facilities Division, Taisei Corporation (written response)

Yamaji Now we are in the second half of the second year since the Geological Carbon dioxide Storage Technology Research Association was set up in April 2016. Today, board members of the association and Professor Kozo Sato, chairman of Research Promotion Advisory Committee will have a roundtable talk about the role of this association in developing CCS technologies. I am looking forward to frank and candid discussions.

Expected roles of the association

Yamaji First, I would like Chairman Sato to tell us what role he expects this association to play.

Sato Many people say that CCS has no economic

incentives, and we lack experience in this field. CCS is also associated with concerns such as high cost and the risk of CO_2 leakage. These opinions are based on a wrong perspective that believes that the current situation, which is not doing anything, is risk-free. Compared to doing nothing, CCS is more costly and risky. Since doing nothing would impede the achievement of the 2°C scenario and accelerate climate change, however, it will result in a situation that carries with it much higher cost and risks. Compared to the situation with higher costs and higher risks, proper operation of CCS to mitigate climate change means reduced risks, which consequently produces profits. There are two types of reducing the cost and risks. One is to reduce the cost and risks from an original situation that had higher cost and risks. A second type is to keep the cost and risks low when introducing new technologies in a risk-free situation. The goals to set for these two types will naturally differ. CCS research is the former one. It involves research to lower cost and risks from a situation that had higher cost and risks. I believe that we should be aware that the goals of CCS research will be different from the goals of the second type. We should also pay attention to this point when we release the outcomes of our research to gain public acceptance. For example, instead of describing how much we can reduce the cost, we should focus on how much profit will be generated as a result of reducing certain costs. And we should talk about CO_2 leakage in a way that gives people a heightened sense of safety rather than talking about specific technologies that can reduce the risk of leakage.

Yamaji Thank you very much. In the first place, the role of CCS, as Chairman Sato said, was to mitigate the significant risk of global warming. Yet, CCS also carries some risks. Chairman Sato was saying that we should describe them to the public in an effective way, based on the relationship between CCS and society. Next, I would like board members to say what made them join this association and what they expect from it.

Reasons to join the association and expectation to it

Takehana Since we are an exploration and production company, we have been conducting various kinds of technical R&D including microbubble technology, which is relevant to accelerating the dissolution of CO_2. We think that microbubble technology is extremely promising and we have a strong desire to complete it and put it to practical use. RITE has been conducting advanced research on microbubble technologies and has accumulated a wealth of experience in this field. Working on technological development while discussing and sharing the same goals with people from other companies gathered together in this association is extremely meaningful for us in achieving the goals and objectives of our company. This is why we joined this association.

Tochikawa INPEX published a position paper titled "Response to Climate Change" in 2015. The paper emphasizes the importance of CCS and the fact that we can and should contribute to its development. This recognition drove us to join this association. We also think there is a limit to the things we can achieve independently in all aspects of technological development, not just with CCS. Our expectation in joining this research association is to maximize synergies through stimulation within a collaborative framework and create a catalyst for development.

Hiramatsu People often think that our company only conducts geological investigations for public enterprises. Actually, we have been working on nuclear projects for a long time, and because of this, we have been interested in energy issues and global environmental problems which form the background to energy issues. We started studying global environmental issues to increase our knowledge base. We have worked on monitoring using elastic wave tomography at Nagaoka and assessed the amount of reserves in storage reservoirs around Japan with the Engineering Advancement Association. Through these projects, we started to think that logging the technologies and tomography that we learned through geological investigations for civil engineering projects as well as our knowledge of geology might be useful in the development of CCS technologies. That was when we were invited to participate in this association. Our company therefore decided to join this association to work on important future global environmental problems.

Yano The National Institute of Advanced Industrial Science and Technology (AIST) has been involved in research into geological storage since it was established in 2001. Rather, AIST was originally 15 research institutes, and one of the research institutes was the Geological Survey of Japan that had been working on CCS from when the concept first emerged. We have a long history in geological storage, because we have been participating in the Ministry of Economy, Trade and Industry's geological storage project since 2005. The technologies that we have accumulated through these projects include geophysical monitoring, geochemical, and geomechanics technologies. We have always believed that these technologies would be useful in the future for developing geological storage. AIST decided to participate in this association because it would be a great opportunity for all the related sectors to get together toward the deployment of CCS, so that private companies can take over their achievements.

Imamura Our company has been carried out many researches of groundwater flow and mass transport through the various projects such as our conventional construction works, soil and groundwater remediation, geological disposal of nuclear wastes and strategic underground storage of fossil fuels. We have also developed high performance computational tools on CO_2 migration for CCS to contribute global warming as a general contractor. We have been cooperated with RITE through the simulation technologies to apply demonstration experiments in Tomakomai etc. It is essential the existence of the partners who have underground exploration technique or CCS storage itself. We hope to continue our R&D in a position closer to the policymakers. We were invited to join the association just when we were considering the possibility of participating in a CCS storage design and construction project as a general contractor. That is why we decided to join the association to explore how general contractors can contribute to CCS and our new possibilities.

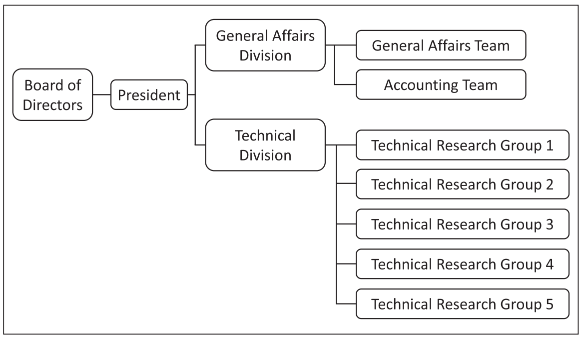
Yamaji RITE used to conduct R&D with AIST. And, companies such as Oyo Corporation have been cooperating with RITE by sending researchers and staff to it. RITE conducted a 10,000-ton CO_2 storage experiment in Nagaoka from 2003 to 2005 and Japan CCS Co., Ltd. (JCCS) is now conducting 100,000-ton/year class demonstrations in Tomakomai. The next step is to develop a practical storage level of one million tons per year, and for that we need a system to implement full-scale R&D with private companies. I understand that to be the main purpose of this association, and, this is the reason why RITE decided to participate.

Roles of members and research themes

Yamaji The mission of this association is to develop CCS. Now I would like you to describe your research themes, past achievements, and future goals.

Yano Our core technologies include monitoring technologies, technologies to assess long-term shielding performance, and technologies for the coupled analysis of hydraulics and dynamics. First, regarding monitoring technologies, long-term monitoring will surely be necessary for geological storage in the future. We are exploring how we can provide these technologies at low cost. One effective method to lower the cost is to monitor gravity. We are thus developing this technology by using superconducting gravimeters in Tomakomai. Second, the AIST has also been working on assessing the long-term shielding performance of cap rock since before the establishment of the association. Our research focus is on the effects of geochemical reactions. We are testing how geochemical reactions would affect the hydraulic and dynamic characteristics through experiments. When we were examining how geochemical reactions between supercritical CO_2 and water systems would affect the shielding performance, we found that the effects differed depending on the type of rock. Our core technologies also include geomechanical modeling technology. We would like to make these technologies useful for measuring distortion with fiber optics, a topic that RITE and other parties are researching.

Hiramatsu We belong in Technical Research Group 1. Our research theme is the construction of geological models. Specifically, we are evaluating geological characteristics by analyzing logging data from four wells at the experiment site in Tomakomai. The target layer is the bottom layer of the Moebetsu layer. We are comparing data with model curves while examining the correlation between natural radioactivity, specific resistance, porosity, and the speed of P-waves, as well as the correlation between physical properties. Some data variations are seen between wells, which is giving us a hard time to be honest. Still, we also have the data from the core tests on the wells. We are now working with RITE to examine them closely by finely classifying the lithofacies of the cores instead of the overall storage reservoir, taking the above findings into account.



Tochikawa　Our core technologies are closely associated to storage reservoirs. For example, underground imaging technology is a core technology that we have built up over the years. We are now experimenting with Vertical Seismic Profiling (VSP) using Distributed Acoustic Sensing (DAS) and fiber optics. The challenge is to provide reliable information at the lowest possible cost. We are conducting actual measurements in our oil fields this year. This is considered to be a new initiative even by global standards, and our geophysicists and personnel involved are taking the project on with great excitement, which is encouraging. I hope to be able to share some images from the project next year.

Yamaji　One big advantage of having an association is that we can actually perform experiments using actual fields.

Takehana　Our challenge is to increase CO_2 storage efficiency using microbubble technology. We believe that an important key to increasing the profitability of CCS is to use underground storage reservoirs effectively. Our mission is to develop new tools to generate microbubbles at depths of 1,000 to 2,000 meters and send the bubbles into storage reservoirs. The second mission is to discover the processes and mechanisms behind how CO_2 microbubbles permeate into storage reservoirs. Another mission is to clarify how storage efficiency can be improved by effectively combining core tests in the laboratory, field observation data, and simulations. We are developing prototype tools that we will use in a well this year. We are now checking whether they function properly and generate CO_2 microbubbles by actually injecting them into a well. We are planning to test the injection of CO_2 microbubbles into storage reservoirs in actual fields after next year.

Imamura　We are mainly responsible for topics related to simulating the underground migration of CO_2. The precision of underground investigations has certain limits which makes it difficult to forecast the cost of geological storage and assess its safety. We are anticipating whether we can estimate the realistic cost of Japanese future large scale storage or not as a business. The Ministry of Economy, Trade and Industry (METI) and Ministry of the Environment (MOE) are now jointly looking for and investigating proper sites. I think it is important to assess the realistic storage capacity including its uncertainties as quickly as possible and present them to stakeholders. Our tasks in the association is to develop a design method to decide the number of wells or appropriate storage site which considering uncertainties of investigation data of storage formation. Our high-performance simulation technologies can be effective to solve these problems. We are also developing estimation methods to quantitatively assess the safety of geological storage using probabilistic risk assessment techniques. We expect that our techniques which have built up in nuclear engineering field might be useful.

Yamaji　RITE is developing technologies with the main focus on (1) Development on Safety Management Technologies for Large-scale CO_2 Injection and Storage (2) Technologies for Efficient Pressure Management and Utilization of Large-scale Reservoirs, and (3) Environment Setting for CCS Deployment and Standard Development. There are concerns that the injection of CO_2 may increase the underground pressure and trigger seismicities, which is why seismicity monitoring and other types of monitoring are being conducted at the sites of CO_2 injection. Technical Research Group 1 is developing a CO_2 injection management system named the Advanced Traffic Light System (ATLS) based on observation data. Their research is to develop a system with more constructive functions that take into consideration the injections conditions while displaying monitoring information from CO_2 injection sites using the colors of traffic lights: green, yellow, and red. We are also developing monitoring technologies that can continuously measure the deformation (distortion) of geological formations in the depth direction using fiber optics. We gained important knowledge on the deformation characteristics of alternating layers of sand and rock as well as how to construct dynamics analysis models through on-site experiments in geological deformation observation using currently available wells. We are also developing methods to detect CO_2 bubbles using side-scan sonar as a technology to monitor CO_2 leakage just in case. We are going to apply these technologies to on-site operations to develop practical uses in the future. I believe doing so with the members of this research association is a shortcut to spreading CCS.

Yamaji Chairman Sato, do you have any comments on our talks?

Sato With regards to the unique goal-setting for CCS that I first talked about, I think it is reasonable to pursue the optimal locations for multiple wells. This is similar to oil companies taking as much oil as possible, for example, because it means more profit for them. In the case of CCS, however, the amount of CO_2 to be injected is pre-determined by the storage capacity required. In addition, since it involves the underground world, it is always accompanied by uncertainties. The goal for CCS should be to indicate areas that will cover the planned amount of storage no matter where the injection point is within the area, rather than finding a location that allows the maximum amount of storage. I also think there are suitable ways to construct geological models for CCS which should differ from the geological model used in oil development. I think this applies to all technical examinations in this association. I encourage all members to keep in mind the unique goals of CCS while conducting their research.

Evaluation of the activities of the association so far and future challenges

Yamaji In the end, since the association is going to wrap up the activities of the second year, I would like to hear how you evaluate the activities of the association, including good points, future challenges, and future plans and goals.

Takehana I find it meaningful that, as we are a gathering of so-called subsurface specialists who share the same sense of the problems, we are able to discuss and tackle problems with people from other industries in this association, because as Mr. Tochikawa said, there is a limit to what one company can achieve with regard to ideas and other aspects. I also greatly appreciate receiving candid opinions from independent standpoints on the direction of research from experts on the Research Promotion Advisory Committee of the association. This is also a point on which I feel the benefit of joining this association. In terms of challenges, we are still trying various ideas, because we are developing new technologies as I said earlier. I think we need to work really hard to complete the technology in the remaining three years from the perspective of developing the technologies required for CCS, as Chairman Sato mentioned.

Tochikawa It is more stimulating to work in a group than alone, and I earlier mentioned the expectation of creating a catalyst for development within this collaborative framework, but there is still some way to go. For example, in setting our challenge, there should be a discussion to determine the overall direction of CCS. I feel it may not be entirely appropriate if we focus solely on storage and disregard the other aspects. This association has five groups, and to fully unlock the potential of the research association, we should share and discuss our respective challenges and strengthen the relationships between the groups. I also feel that the E&P industry has made a rapid advancement in addressing the issue of climate change over the past year, and I think there are ways to work with various consortiums and groups overseas to enhance stimulation and catalysis. For example, we may be able to start by exchanging opinions with companies like Total, Shell, Statoil and Gassnova and eventually move on to doing something together.

Yamaji Recently we hear words such as green chemistry and ecosystems when we face R&D projects and startup businesses, and I believe that these are important inside this association as well.

Hiramatsu I have been in charge of interviewing new graduates for recruitment for many years. When I ask them why they apply to our company, many of them say that they are interested in global environmental problems and want to work on various projects such as geological surveys, CCS, and methane hydrate which are mentioned on the company website. I feel the advantage of this association because the activities of our company expanded from just being a geological survey firm to a company with a broader range of activities. I also find through interviews that young people in the field of natural science are very interested in CCS. Therefore, I think CCS should be more talked about in business journals, academic papers, and magazines so that it will be more well known among the public. With regard to future plans and goals, to strengthen the relationships among the groups, as Mr. Tochikawa said, I would like to use the various tools we have, including the seabed gravity meter and P-Cable (high-resolution three-dimensional reflection survey), plus the DAS-VSP seismic vibrator vehicle that was used in Mobara last year, to help activities at monitoring sites.

Yano The greatest advantage I feel from participating in this association is meeting with people like you. This may sound a bit abstract but, compared to when AIST was working independently on the issue of geological storage, I appreciate that our abilities are being improved by joining a group of people involved in national projects and receiving evaluations and opinions from the entire group. Speaking for AIST, we are pleased if we can work on future national projects as members of this association and strengthen cooperation among industry, academia, and government.

Imamura It has been nearly two years since this association was set up. Research by the individual groups is making steady progress. I also feel that national policy makers and members of this association are exchanging information and cooperating on a regular basis. Also, members of the Research Promotion Advisory Committees are suggesting accurately and appropriately. We appreciate to provide such an effective chance for our R&D. I can see the following challenges for the future. First is to gain proactive participation of electric power companies while offering them incentives from METI and MOE. The second is continuous activities to gain social acceptance which should be done by government agencies and businesses. The third is to establish methods to monitor environmental effects and leakage and their reliability. The fourth is to improve the accuracy estimating storage capacities. I hope we can quickly overcome these problems through the cooperation between the government and the private sector to move closer to the practical application of CCS.

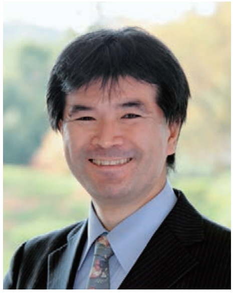
Yamaji Chairman Sato, what do you think of the discussions so far. Please give us your final comments.

Sato This may sound weird, the ideal storage safety goes against the function of this research association, meaning that there is no need to consider the safety of CCS if the safety of storage is assured. To move closer to such a situation, I think we should avoid ideas and approaches which pursue higher precision to excess. For example, the attitude of challenging the difficult task of constructing models because of the shortage in the number of wells may cause fear among some people who think that such an attitude is a bit of a high-wire act. Instead, we should notice that a geological model that can assess safety with a few wells is enough for CCS, and is good enough for ensuring low-risk and safe storage and estimating the movement of CO_2. Instead of aiming for the top, we can relax and settle for the second, third, or fourth best solutions. I want you to work on the activities of this association including public outreach feeling that these solutions are enough to reduce the risks and control CCS operations properly.

Wrap-up

Yamaji The purpose of this association is to conduct research into the practical application of large-scale CCS. Especially, the role as a bridge to practical application through the participation of the four private companies, I believe, has steadily progressed over the past two years. Still, from a wider perspective, among the issues that confront us, besides the development of technologies that will allow safe management, we have to face the issue of social acceptability, as Chairman Sato mentioned. This round table discussion has reminded me yet again of the importance of describing the need for CCS to people, rather than just explaining how to ensure the safety of micro vibration and leakage. I would like to use these findings in our future activities. Thank you very much for your participation.

Research & Coordination Group



Hideaki Tsuzuku
Group Leader

[Key Members]

Makoto Nomura, Deputy Group Leader, Chief Researcher
Satoshi Nakamura, Deputy Group Leader
Masato Takagi, Chief Researcher
Kunio Sakuyama, Manager
Yoshinori Aoki, Manager, Associate Chief Researcher
Tetsuya Deguchi, Associate Chief Researcher
Yoshito Izumi, Associate Chief Researcher
Haruo Kanaboshi, Planning Manager
Hiroyuki Azuma, Vice Manager
Jun-ichi Shimizu, Vice Manager
Yuji Misumi, Vice Manager
So Kuranaka, Vice Manager

Outline of Research Activity in Research & Coordination Group

1. Current status toward AR6 of IPCC

The Paris Agreement, an international framework on global warming countermeasure, entered into effect in November 2016. Intergovernmental Panel on Climate Change (IPCC), which takes a role of assessing the science related to climate change and providing a scientific basis, is currently in its Sixth Assessment cycle from 2015 to 2022. Writing and review process for Sixth Assessment Report (AR6) are accelerated after the Paris Agreement entered into effect.

RITE, commissioned by Ministry of Economy, Trade and Industry, METI, has been implementing information gathering and analysis through attending IPCC related meetings and dispatching experts, preparation of outreach activities, and research & reporting on IPCC plenary sessions and review. Current status toward The 6th Assessment Report (AR6) of IPCC is addressed as follows.

1.1. Outline of IPCC

The IPCC was established by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a comprehensive review on the state of anthropogenic climate change, impacts, adaptation measures and mitigation measures from the viewpoint of scientific, technical and socio-economic aspects. Experts who are recommended by governments from all over the world review and assess the most recent information on scientific analysis, socio-economic impact and countermeasure against climate change, including research papers, observed data and so on, and then the experts write and compile the Assessment Report (AR) in collaboration with each other.

AR has a strong influence on international negotiations because AR provides rigorous and balanced scientific basis for international countermeasures. To date, five Assessment Reports have been produced and published.

The IPCC is currently organized in 3 Working Groups and a Task Force. Figure 1 shows the structure of IPCC organization. WG1 assesses the physical scientific aspects of the climate system and climate change. WG2 assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it. WG3 assesses options for mitigating climate change through limiting or preventing greenhouse gas emissions and enhancing activities that remove them from the atmosphere. Major decisions are taken by the Panel during the Plenary Session. The Assessment Reports are produced by each WG and then the Synthesis Report is produced based on these Assessment Reports of the each WG.

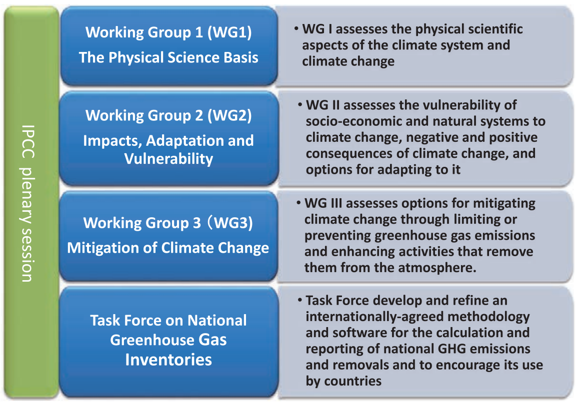


Figure 1 : The structure of IPCC organization

1.2. Organization of IPCC in the Sixth Assessment Cycle

Dr. Hoesung Lee (Korea) was elected as the Chair of IPCC, and Ms. Ko Barrett (USA), Dr. Thelma Krug (Brazil) and Dr. Youba Sokona (Mali) as the Vice-Chairs of IPCC in October 2015. Dr. Jim Skea (UK) and Dr. Priyadarshi R. Shukla (India) were elected as the Co-Chairs of IPCC WG3, and seven members out of seven nations including Hungary, Italy, New Zealand and so on were chosen as the Vice-chairs of IPCC WG3. AR6 cycle will proceed under the supervision of these members. Figure 2 shows the Organization of IPCC in AR6 cycle.

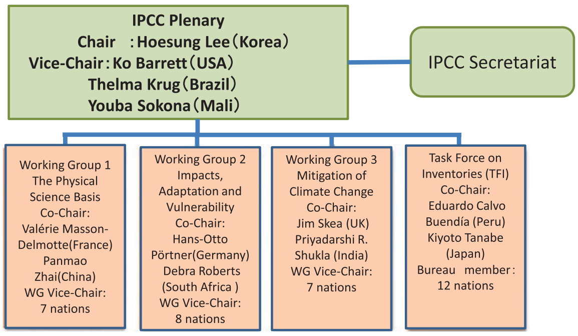
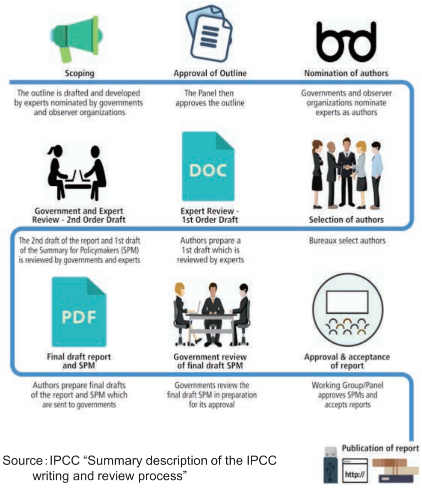


Figure 2 : Organization of IPCC in AR6 cycle

1.3. Writing and review process in AR6 cycle

Figure 3 shows Writing and review process in AR6 cycle. Each IPCC Report is preceded by a scoping meeting that develops its draft outline. Based on the result of the scoping meeting, the Panel decides whether to prepare a report and agrees on its scope, outline and work plan including schedule and budget. Authors are chosen from the lists recommended by the member governments, the observer organizations and so on. The Bureau of the Working Group or Task Force selects authors from these lists. The composition of authors may ensure appropriate representation of experts from developing and developed countries and countries with economies in transition; a mixture of experts with and without previous experience in the IPCC; and gender balance. A first draft of the report is prepared by the authors based on available scientific, technical and socio-economic information, and then the first order draft is reviewed by experts. Authors prepare a second order draft of the report and a first draft of its Summary for Policymakers (SPM). These are subject to simultaneous review by both governments and experts. Authors then prepare final drafts of the report and SPM. These are distributed to the governments who provide written comments on the revised draft of the SPM before meeting in plenary to approve the SPM and accept the report.



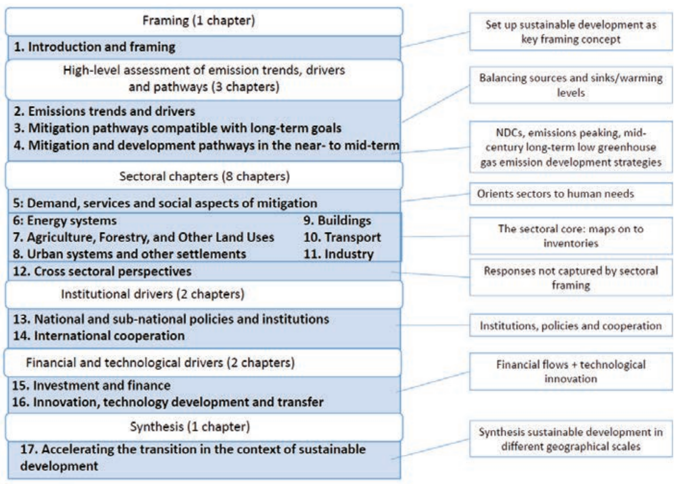
Source: IPCC "Summary description of the IPCC writing and review process"

Figure 3 : Writing and review process in AR6 cycle

1.4. Agreed outline of WG3 AR6

The experts, chosen by governments and organizations, discussed outlines of the Working Group at the scoping meeting held in May 2017. The Panel adopted the outlines of the Working Group at the 46th Session of the IPCC held in September 2017. Figure 4 shows Agreed outline of WG3 AR6 which is provided by Dr. Jim Skea, Co-chair of WG3, and summarizes Chapter outlines of the WG3.

Sustainable development is set up as a key framing concept in Chapter 1. Emissions trends and drivers, mitigation pathways are assessed in Chapter2 through Chapter4. These Chapters address balancing sources and sinks in the long-term pathway, NDCs emission peaking and low GHG emission development strategies in the mid-term pathway. Chapter5 through



Source: "Key findings from the WG III 5th Assessment Report and plans for AR6" Jim Skea 2017

Figure 4 : Agreed outline of WG3 AR6

Chapter11 address the sectoral assessment. Chapter12 addresses cross sectoral perspectives. Chapter13 addresses policies and institutions. Chapter14 addresses international cooperation. Chapter15 addresses investments and finances. Chapter16 addresses technology development and transfer. Chapter17 addresses sustainable development.

1.5. Planning schedule of WG3 AR6

Authors were selected in February 2018 out of the candidates who had been chosen and recommended by nations all over the world. Planning schedule of WG3 AR6 is addressed as follows.

The 1st Lead Author Meeting of WG3 will be held on 1st-5th April 2019 and then up to 4th meetings will be held. The first order draft (FOD) will be reviewed by experts from December 2019 to January 2020. The second order draft (SOD) of the report will be reviewed by both governments and experts from June to July 2020. The final drafts of the report (FGD) will be reviewed from February to March 2021, and then will be accepted, adopted and approved by the Plenary Session of IPCC in July 2021.

The reports of WG1 and WG2 will be approved by the Plenary Session of IPCC in April 2021and October 2021 respectively. The Synthesis Report will be approved by the Plenary Session of IPCC in 2020. Three Special Reports and Report on methodology of inventories will be produced from 2018 to 2019 in AR6 cycle.

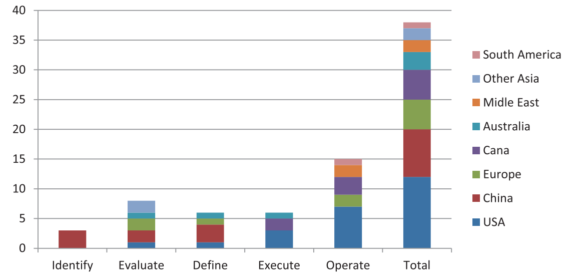
2. The current status of CCS deployment

2.1. The global status of large scale CCS projects

According to "The Global Status of CCS: 2017", there are 15 large scale integrated projects (LSIPs) listed in the Operate stage and 6 projects in the Execute stage. The number of total LSIPs including the planning stage of development amounts to 38 (Figure 5).

2.2. Transportation of CO_2 by ship

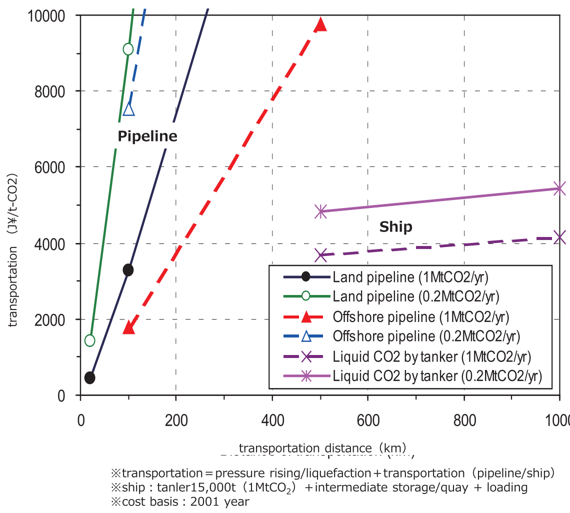
CO_2 is transported by pipelines in almost all large scale projects in operation. However, there would be an option to transport CO_2 by ship depending on the geological relation between a CO_2 emitter site and a CO_2 storage site. Many CO_2 storage sites are located at marine area in Japan. Large scale CO_2 emitters are located at coastal area. Therefore, Transportation of CO_2 by ship would be an option in Japan. Figure 6 shows the comparison of CO_2 transportation cost between by pipeline and by ship. The cost of transportation by pipeline increases in proportion to transportation distance, and is small in short distance. Transportation by ship is economical in the long transportation distance, but entails liquefaction facilities and demand of power, and then leads to high cost. The transportation cost is subject to public acceptance, limitation of land and pathway (city, river, depth of water, fishery, etc.) as well as transportation distance.



Nation/Area	Identify	Evaluate	Define	Execute	Operate	Total
USA	0	1	1	3	7	12
China	3	2	3	0	0	8
Europe	0	2	1	0	2	5
Cana	0	0	0	2	3	5
Australia	0	1	1	1	0	3
Midle East	0	0	0	0	2	2
Other Asia	0	2	0	0	0	2
South America	0	0	0	0	1	1
Total	3	8	6	6	15	38

Source : The global Status of CCS 2017 VOLUME 2

Figure 5 : The global status of large scale CCS projects



Source : CCS Workshop 2007 (RITE)

Figure 6 : Comparison of CO_2 transportation cost between by pipeline and by ship

The feasibility study has been implemented in Norway concerning to full scale CCS chain project where CO_2 emitted by cement factory, ammonia plant and waste-to-energy plant is captured, transported and stored. The CO_2 captured from these three plants is gathered to an intermediate storage facility and is transported by ship to the storage site. Figure 7 shows full-scale CCS chain project in Norway (CO_2 emitter and storage site). The reason why transportation system by ship is adopted in this project is that the distance between the CO_2 emitters and the storage site is almost 800km, which means it is too expensive to transport CO_2 by pipeline and that transportation system by ship is evaluated as a flexible solution in early stage. Three different types of transportation system by ship is assessed, that is, Low pressure type (6～8bar,-50℃), Medium pressure type (15 bar,-25℃) and High pressure type (45 bar,+10℃). Each type is feasible, but Medium pressure transportation system is technically matured. Although energy consumption for increasing pressure and temperature is necessary in Low pressure type and Medium pressure type, it is not necessary to increase temperature in High pressure type. The feasibility study has been implemented from 2016 to 2017, and then FEED (Front End Engineering and Design) will be implemented in 2018.

Source: Feasibility study for full-scale CCS in Norway

Figure 7 : Full-scale CCS chain project in Norway (CO_2 emitter and storage site)

3. International standardization for CCS

A technical Committee (ISO/TC265) was established within International Organization for Standardization (ISO) and the international standards for CCS have been developed under this ISO framework. 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. For participating in this international framework, Japan set up the mirror committee of ISO/TC265 for the domestic discussion.

Table1 shows the status of WG activities. Each WG is developing International Standards (IS), Technical Specification (TS) and Technical report (TR).

Technical Report (TR27912) on CO_2 capture was published in May 2016. WG1 started to develop International Standard (ISO27919-1) for performance evaluation methods for post combustion CO_2 capture integrated with a power plant. ISO27919-1 is in a stage of Final Draft of International Standard (FDIS). WG1 also started to develop International Standard (ISO27919-2) for evaluation procedure to assure and maintain stable performance of post-combustion CO_2 capture plant integrated with a power plant. WG1 is now developing Working Draft (WD) of ISO27919-2.

In WG2, IS for transportation by pipeline was published in November 2016. WG2 is now preparing TR on solution including flow assurance in transportation by pipeline. WG2 is starting the discussion for ship transportation.

International Standard (ISO27914) for CO_2 geological storage in onshore and offshore was published in October 2017 in WG3. WG3 will start to develop Technical Report on injection operations and infrastructure. Target date of the publication of this TR will be in 2020. Technical Report (TR27915) on quantification and verification was published in August 2017 in WG4. WG4 started to develop International Standard for quantification and verification based on TR27915 and is developing Working Draft(WD). WG4 aims to develop Committee Draft (CD) in 2018.

Final Draft of International Standard (ISO27917) for cross cutting terms was approved in November 2017 and ISO27917 was published in December 2017 in WG5. Technical Report (TR27918) on life-cycle risk management was approved in November 2016 and is ready to be published. WG5 started to develop Technical Report (TR27921) on composition of CO_2 stream and is developing WD.

WG6 is developing International Standard (ISO27916) for CO_2-EOR, and ISO27916 is at a stage of Draft of International Standard.

As mentioned above, International standardization for CCS has been progressing steadily.

WG	Work items	Target date	published
WG1 (Capture)	● ISO27919-1: preparing FDIS for vote ● ISO27919-2: developing WD ● Preparing for development of TR on CO2 Capture in cement industry	IS27919-1: 2018 IS27919-2: 2020	ISO/TR27912(capture): 2016
WG2 (Transportation)	● Preparing for TR on solution including flow assurance in transportation by pipeline ● Starting to discuss on transportation by ship	-	ISO 27913(pipeline transportation): 2016
WG3 (Storage)	● Preparing for development of TR on injection operations and infrastructure	-	ISO 27914(storage): 2017
WG4 (Q&V)	● ISO27920: developing WD on Q&V	IS:2019	ISO/TR 27915(Q&V): 2017
WG5 (Cross-Cutting Issues)	● TR27918: in the process of publication ● Preparing for development of TS on life-cycle risk management ● TR27921: developing WD	TR:2018 - TR:2019	ISO 27917(vocabulary): 2017
WG6 (CO2-EOR)	● ISO27916: closing of DIS voting	IS:2018	-

Table 1 : Summary of WGs activities

4. The status of countermeasures for CO_2 significant emission reduction from a long-term viewpoint

RITE had picked up the countermeasure technologies for CO_2 significant emission reduction from a long-term viewpoint and investigated the outline, CO_2 emission reduction potential and the challenges for deploying of the countermeasures. Figure 8 shows the menu of countermeasure technologies. The main technologies are addressed as follows.

CO_2 Capture & Storage(CCS)

CO_2 Capture & Storage(CCS) is the technology which captures CO_2 from large scale emitters, transports and stores it underground. Fossil-fueled power generations equipped with CCS are poised to play a critical role in IPCC AR5*7. They are also important as grid adjusting generator when renewable energies are largely deployed. The potential of CO_2 emission reductions, that is to say, the potential of CO_2 storage capacity over the world is estimated at 2 Tt which is equivalent to 100 times of total CO_2 emission in the world*1. The challenges of the deployment of CCS may include cost reduction, uncertainty of storage capacity, business risk, establishment of framework for CCS business, public acceptance and so on.

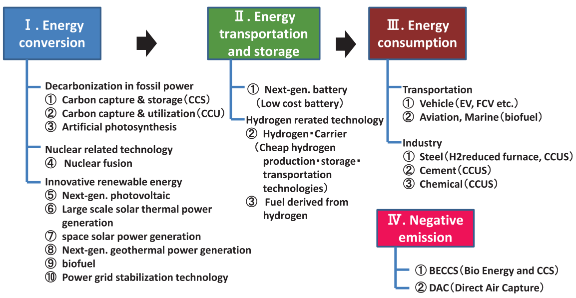


Figure 8 : Countermeasures for CO_2 significant emission reduction from a long-term viewpoint

CO_2 Capture and Utilization(CCU)

CO_2 Capture and Utilization(CCU) is the technology which captures CO_2 from large scale emitters and then utilizes CO_2. CO_2 is now utilized in urea production and EOR and so on. The potential of CO_2 emission reductions amounts to 300～3,600 Mt-CO_2 in aggregate production, 70～2,100 Mt-CO_2 in fuel production, 600～1,400 Mt-CO_2 in concrete production*2. The challenges of the deployment of CCU may include developing the innovative technology which can produce goods in large quantities and high-efficiently. Life cycle assessment is necessary because there is the possibility that CO_2 will be emitted into the air in the process of CO_2 utilization.

Nuclear Fusion

Nuclear Fusion is the technology to generate electricity extracting energy of fast neutron produced by nuclear fusion reaction with high temperature and high pressure fusion fuel. The 40% of the total electricity generation in the world in 2100 is evaluated to be supplied by nuclear fusion*3. Irradiation test of equipment constituting reactor and demonstration of prototype reactor are necessary to establish this technology. Irradiation test of material and test of blanket equipment are also important issues.

Space Solar Power System

Space Solar Power System (SSPS) is the technology which transforms the electricity, generated by huge photovoltaic in space, into microwave, transmits the microwave from power transmission antenna to power receiving antenna on the ground and then transforms the microwave into electricity. SSPS is expected to be a stable zero mission power system which can supply all day. The potential of CO_2 emission reductions amounts to considerable quantity which depends on how many SSPS satellites are on the stationary orbit. The challenges of the deployment of SSPS may include cost reduction of transmission to space, establishment of technology of long distance wireless energy transmission, securing microwave safety and installation sites of instrument of power transmission, and so on.

Biofuel

Biofuel is an energy made from plants. It is evaluated as CO_2 net zero emission energy (carbon neutral) because carbon in plants is fixed from the air. The potential of CO_2 emission reductions amounts to 35% of the total primary energy and 70% of total liquefied fuel in 2050*7. Biofuel is estimated to be able to cover only 3% of total energy supply in Japan*4. The challenges of the deployment of biofuel may include limitation of supply, competition in land use, securing water for plant cultivation and nitrogen monoxide generated by using fertilizer.

Next-generation Battery

Next-generation battery includes metal-air battery, lithium-ion battery and so on which are under development. The cost target for automobile is JY5,000/kWh*5. The cost reduction is a critical issue. The challenges of the deployment of next-generation battery may include developing innovative battery which can surpass performance limitation of lithium-ion battery

Hydrogen・Hydrogen Carrier

Hydrogen carries under consideration now are classified into three types, ①liquefied hydrogen, ②organic hydride, and ③ammonia. The cost target is JY60/m3 gasoline equivalent by 2020, JY40/m3 equivalent to LNG for thermal power by 2030*[6]. The challenges of the deployment of hydrogen carriers may include cost reduction, construction of hydrogen infrastructure, expansion of hydrogen usage, development of hydrogen instrument, establishment of regulation, and so on.

Fuel Derived from Hydrogen

The fuel derived from hydrogen includes methane, ammonia, alcohol and so on which are derived from hydrogen produced with renewable energy and used in conventional energy supply infrastructures. The production cost of the fuel is higher than that of hydrogen, but the transportation and supply cost of the fuel is lower than that of hydrogen because the fuel can be used in the conventional infrastructures. When CO_2 from biomass power station is used, the fuel contributes to CO_2 zero emission because biomass is what we call carbon neutral energy. Otherwise LCA assessment on CO_2 emission reduction is necessary.

BECCS

BECCS stands for Bio Energy with Carbon dioxide Capture & Storage and is technology combining biomass power with CO_2 Capture and Storage (CCS). BECCS is considered to contribute to net negative emission because biomass takes up CO_2 from the air. The net negative emission technologies like BECCS are deployed in the latter half of this century in many of the 2℃ scenarios of the IPCC report. The potential of CO_2 emission reductions is estimated to fall within 3 ～20 $GtCO_2$/year*[7]. The challenges of the deployment of BECCS may include securing land, competition from foods, environmental impact, demand for nutrition and limit by increasing use of water. They also include the same challenges as those of CO_2 storage, that is, technology, cost, institution, public acceptance and so on.

DAC

DAC stands for Direct Air Capture of CO_2 from ambient air and is the technology which captures CO_2 from the air with chemical reaction and stores it into the ground. DAC is like biomass in the sense of absorbing CO_2 in the air, but does not have limit of water unlike biomass which demands water for growth and is not applied to land with a little precipitation. The potential of CO_2 emission reductions is unknown. The cost of DAC is estimated very high, \$400/tCO_2～\$1,000/tCO_2, even though it excludes the cost of storage*[8]. The challenges of the deployment of DAC may include high cost and low productivity, securing land, necessity of considerable energy. They also include the same challenges as those of CO_2 storage.

5. Conclusion

AR6 cycle of IPCC had started. The Panel adopted the outlines of the Working Group. Authors were selected in February 2018. The Lead Author Meeting of WG3 will be held. The first order draft (FOD), the second order draft (SOD) of the report and the final drafts of the report (FGD) will be reviewed and then AR6 report will be approved in July 2021.

There would be an option to transport CO_2 by ship depending on the geological relation between a CO_2 emitter site and a CO_2 storage site.

The feasibility study has been implemented in Norway concerning to full scale CCS chain project where CO_2 captured from three plants is gathered to an intermediate storage facility and is transported by ship to the storage site.

International standardization for CCS, such as the development of international standards and technical reports, has been progressing steadily.

RITE had picked up the countermeasure technologies for CO_2 significant emission reduction from a long-term viewpoint and investigated the outline, CO_2 emission reduction potential and the challenges for deploying the countermeasures.

Reference

*1 IPCC Special Report on Carbon Dioxide Capture and Storage (2005)
*2 ICEF Roadmap 2016
*3 RITE Systems Analysis Group
*4 NEDO White paper of renewable energy technology chapter 4 (second edition) 2014
*5 NEDO secondary battery R&D roadmap 2013
*6 NEDO fuel cell and hydrogen technology R&D roadmap 2010
*7 IPCC the fifth assessment report
*8 National Research Council , The National Academies Press (2015)

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Research Activities in Systems Analysis Group

The Systems Analysis Group aims to provide valuable information about response measures to global warming and energy issues, both inside Japan and internationally through systemic approaches and analyses. We present here three research topics out of our recent research activities; 1) the analyses on decoupling between GDP and CO_2 emissions, 2) the evaluations of emission reduction efforts of Nationally Determined Contributions (NDCs) under the Paris Agreement, and 3) the economic evaluations of climate change adaptation measures. Our group has been contributing to the planning of better climate change policies and measures through such analyses and evaluations.

1. Decoupling between GDP and CO_2 emission increases

For recent several years, CO_2 emissions have decreased while GDP has increased in some developed countries, that is, decoupling between GDP growth and CO_2 emission increase. In addition, for a few years, global CO_2 emissions have been stable while global GDP has increased. Its potential factors were evaluated.

1.1. Global trends

The strong positive relationship between global GDP and CO_2 emissions has been continuing basically as seen in Figure 1. But global CO_2 emissions between 2013 and 2015 were almost constant. However, the emissions between 2009 and 2013 increase greatly above the historical trend, and the leveling between 2013 and 2015 can be regarded as an adjustment returning to the long term trend. However, the emission in 2015 was smaller by 1.1 $GtCO_2$ than that of a linear extrapolation by using the actual emissions between 2000 and 2015. The factors of this emission reduction of 1.1 $GtCO_2$ were analyzed.

According to the analyses by RITE, the estimated CO_2 emission reduction effects of the production adjustments of pig iron and cement were about 0.25 and 0.17 $GtCO_2$, respectively, and the most were in China. The productions in China will not increase again greatly in the future due to the sufficient stock levels of iron and cement in China. However, the productions in lower income countries such as India will increase in the future, and therefore the trends of global productions increases will also continue. On the other hand, the estimated emission reduction effect of the increase in

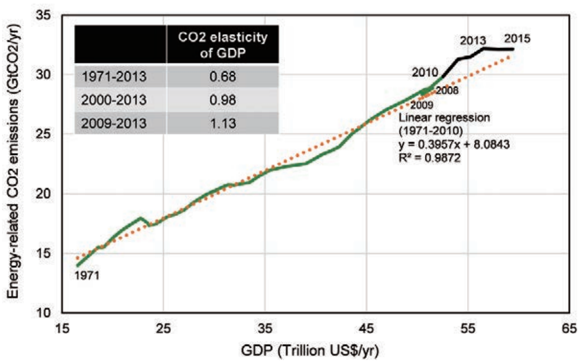

Figure 1 : The relationship between global GDP and energy-related CO_2 emissions

shale gas utilization in the U.S. was about 0.22 $GtCO_2$. The effect was not induced by climate constraints or climate policies but was induced by economic reasons that shale gas has been produced cheaply compared with coal by technology breakthrough. This is an important decoupling example. The emission reduction effect of increases in renewable energies was observed but only about 0.16 $GtCO_2$.

1.2. Trends of major developed countries

The trend of decreases in CO_2 emissions and energy consumptions can be observed in some European countries including the U.K. Figure 2 shows the production-based and consumption-based CO_2 emissions in the U.K. Production-based CO_2 emissions are the emissions that take place within the countries concerned, and are normally reported as the nation's official emissions. On the contrary, consumption-based CO_2 emissions are the embodied emissions of imported or exported products by adding or subtracting emissions at the time of manufacture. The production-based CO_2 decreased greatly during this period but the consumption-based emissions were almost constant. That means GDP increased due to industry structure changes from energy intensive manufacture industries to service industries, and CO_2 emissions within the countries decreased but global CO_2 emission reductions cannot be achieved because the CO_2 intensive industries move to and CO_2 are emitted outside the countries concerned. Actually, the U.K. successfully reduced the energy consumptions to some extent by substitution of fluorescent or LED lamps for incandescent lamps, and diffusions of high energy efficiency gas equipment, and achieved the decoupling. However, they contributed only a little to the emission reduction. As for the GDP growth in the U.K., one of its largest factors was high skilled immigrant labors according to a research study.

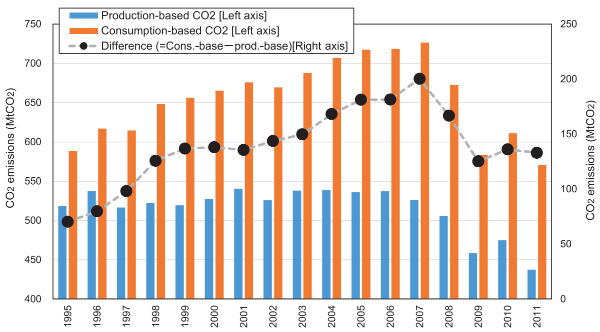

Figure 2 : Production-based CO_2 and consumption-based CO_2 emissions in the U.K. (based on OECD (2015))

1.3. Trends of Japan

Manufacturing industries in Japan have kept relatively a large share of GDP. A clear trend of the decoupling cannot be observed under relatively low GDP growth rate in Japan. On the other hand, the decrease in electricity consumption was observed in accordance with electricity price hike after the East Japan Great Earthquake. It will be important to analyze the factors carefully in the future, since there is a possibility of production decreases in manufacturing industries although behavior change, diffusions of high energy efficiency equipment etc. might have contributed to electricity savings. The industrial structure change to services under the EU umbrella was achieved in the U.K., but it will not necessarily be achieved also for Japan.

1.4. Summary on the decoupling

The decoupling between GDP and CO_2 emissions is a key for sustainable global warming mitigation measures. Shale revolution achieved large contributions to the decoupling by cheaper and lower-carbon energy supplies. LED also contributed to the decoupling. However, the largest factor of globally stable CO_2 emission trend during the past few years was the production adjustments of basic material industries in China, and it should be considered that the long-term trend of coupling between GDP and CO_2 emissions continues. In addition, the decoupling trend that was seen in some developed countries was not induced by consumption decreases but were induced by industry structure changes, and therefore CO_2 emissions were just transferred to other countries. The globally harmonized measures for emission reductions are crucial, and technology and social innovations are necessary for truly decoupling CO_2 emissions from GDP.

2. An analysis on the emission reduction costs for achieving the NDCs

2.1. Introduction

A new international framework for climate change responses beyond 2020, the Paris Agreement, was adopted at the 21st Conference of Parties (COP21) of the United Nations Framework Conventions on Climate Change in December 2015, and entered into force in November 2016. The participating countries including Japan pledged one's own emission reduction targets what is called Nationally Determined Contributions (NDCs).

Assessments of the collective progress towards achieving the long-term goals of the Paris Agreement will be carried out in the future. In the implementation process of the Paris Agreement, it will be important to conduct reviews on the emission reduction efforts and compare them across countries, which will help redress the balance of the emission reduction efforts among the countries.

In this study, the emission reduction costs are focused on as an important indicator of emission reduction efforts. The costs for achieving the NDCs were evaluated by using a global energy systems model DNE21+.

2.2. Evaluation of emission reduction costs of the NDCs

Figure 3 shows CO_2 marginal abatement costs of the NDCs. The CO_2 marginal abatement costs of Switzerland, Japan and EU are high, at over 200$/t$CO_2$. On the other hand, the CO_2 marginal abatement costs of China, India, and several countries are almost zero. The estimated CO_2 marginal abatement costs of the NDCs vary widely among countries. Under this situation of different MACs, the estimated global average of emission reduction costs per GDP are 0.38%. On the other hand, the CO_2 marginal abatement cost with the global least cost measures for the aggregated global emissions of the NDCs is only 6$/t$CO_2$, and the global average of emission reduction costs per unit of GDP is 0.06%.

In this way, the emission reduction costs per GDP of the NDCs (0.38%) are 6.5 times higher than that with the global least cost measures (0.06%), because larger emission reductions are needed in the developed countries including Japan which have little emission reduction potentials due to historical energy saving, and emission reductions are small in the developing countries which have large low-cost emission reduction potentials. The differences in the CO_2 marginal abatement costs as shown in Figure 3 may induce carbon leakage, thus the expected global emission reduction may be smaller than that predicted by aggregating the emission reductions of all the countries. However, realization of global CO_2 marginal abatement costs equalization in the real world is very difficult and unpractical, and the marginal abatement costs is not the sole indicator for measuring emission reduction efforts. It will be important to urge countries with low CO_2 marginal abatement costs for deeper emission reductions.

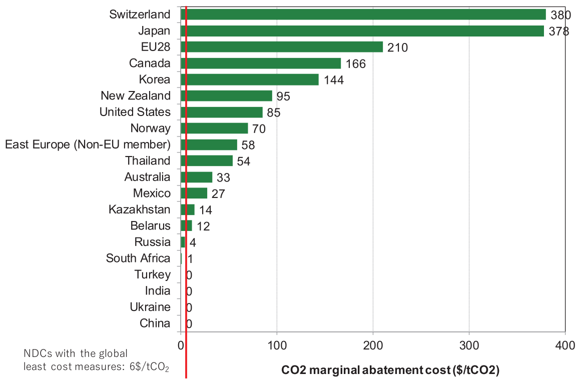

Figure 3 : CO_2 marginal abatement costs of the NDCs

2.3. Evaluation of emission reduction costs of the NDCs considering current policies and conditions of United States, EU, and Japan

Various policies will be adopted for achieving the NDCs. However, the measures to be taken may not be cost efficient. Not only climate change mitigation, but also other political and social objectives will be taken into account for decision making. In this study, several cases for policies and conditions (Table 1) were studied, and their impacts on emission reduction costs of the NDCs were analyzed.

For United States, the least cost cases and cases with constraints on emission reductions in power sector were analyzed. As shown in Figure 4, the CO_2 marginal abatement costs with the least cost measures are 76～94$/t$CO_2$. Emission reduction measures in power sector are widely adopted under the least cost measures. If emission reductions in power sector are limited according to the estimates for the Clean Power Plan by EPA, huge emission reductions in other sectors are required and the costs become higher.

Table 1 : Analyzed cases

		Assumptions
United States	I-a	26% reductions relative to 2005 with least cost measures
	I-b	28% reductions relative to 2005 with least cost measures
	I-c	26% reductions relative to 2005. The emission reductions in power sector are limited according to the estimates for the Clean Power Plan by EPA
	I-d	28% reductions relative to 2005. The emission reductions in power sector are limited according to the estimates for the Clean Power Plan by EPA
EU28	II-a	40% reductions relative to 1990 with least cost measures
	II-b	40% reductions relative to 1990 for both the UK and non-UK EU nations
	II-c	The emission reductions for EU-ETS sectors are determined by the planned emission allowances, and the non-ETS sectors fill the rest of reductions to meet the 40% reductions relative to 1990
Japan	III-a	26% reductions relative to 2013 with least cost measures. Maximum share of nuclear power in electricity generation is assumed to be 20%
	III-b	26% reductions relative to 2013 with least cost measures. Maximum share of nuclear power in electricity generation is assumed to be 15%
	III-c	26% reductions relative to 2013. Electricity share assumed to be same with the energy mix of Japanese governmental plan
	III-d	26% reductions relative to 2013. Electricity share assumed to be; nuclear: 15%, renewables: 29%, others: same with the energy mix of Japanese governmental plan

For EU, least cost cases, cases for Brexit, and burden sharing among ETS and non-ETS sectors were analyzed. The CO_2 marginal abatement cost with the least cost measures is 210$/t$CO_2$. Compared to this figure, the CO_2 marginal abatement cost for non-UK EU nations in scenario II-b is higher (230$/t$CO_2$). This means that the emission reductions ratio in UK under the least cost measures shall be larger than 40%, and the CO_2 marginal abatement costs for non-UK EU nations will rise if UK reduces the emission only by 40%. For the case where ETS and non-ETS sectors are separated, the CO_2 marginal abatement cost in ETS sectors is relatively low (70$/t$CO_2$), but the cost in non-ETS sectors is very high (480$/t$CO_2$). The emission allowances of EU-ETS are excessively large to promote economy-wide cost efficient emission reduction for achieving NDCs.

For Japan, several cases for electricity generation mix were analyzed. The CO_2 marginal abatement cost with the least cost measures (maximum share of nuclear power: 20%) is 165$/t$CO_2$. On the other hand, the cost of III-b (maximum share of nuclear power: 15%) is 230$/t$CO_2$. The impacts of the progress of nuclear power restart on emission reduction costs are large. For the cases following the energy mix of Japanese governmental plan, which was decided from the viewpoint of S+3E, the CO_2 marginal abatement cost is higher, at over 380$/t$CO_2$. CO_2 emission reduction is not the sole purpose, and balanced response to various purposes are important. Therefore, the emission reduction costs in the real world will be higher than the costs with the least cost measures which seek cost efficiency solely for the emission reduction.

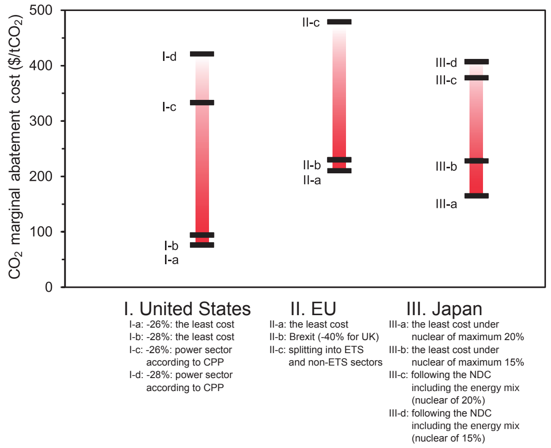

Figure 4 : CO_2 marginal abatement costs of the NDCs for United States, EU, and Japan

2.4. Summary

International comparison of the emission reduction costs for achieving the NDCs and analysis on the impacts of political and social barrier on emission reduction costs were carried out. The emission reduction costs will be higher than the costs with the least cost measures, because there are various purposes to be achieved in the real world. There are concerns about increased risk of the climate change issues related to economic downturn due to large emission reduction costs. It is important to promote internationally concordant emission reduction efforts and take flexible and continuous response to the climate change issues, while avoiding huge increase in climate change mitigation costs.

3. Economic impacts of climate change adaptation

3.1. Introduction

Risk management for climate change requires adequate understandings of climate change mitigation, adaptation and residual damages in terms of their costs as well as their natures. However, there were few studies on economic evaluations on climate change adaptation, because of large uncertainties on climate change damages. This study evaluates economic impacts of climate adaptation. We consider the benefits of climate change adaptation resulted directly from avoided climate change damages and also from spill-over effects of investments made for climate adaptation on the whole economy. It is important to analyze economic impacts of climate adaptation by sector and by region considering dynamic economic effects for multiple years, due to avoided losses of capital stocks caused by climate change.

Climate adaptations are mainly short-term and local measures, and they are usually considered economically reasonable, increasing the utility by adaptation investments.

In order to evaluate the economic effects of climate adaptation, we newly developed a multi-region and multi-sector economic model covering up to 2100. As a first step of the evaluation, this study focused on coastal sector. In the model, we considered damages separately; those from economic flows and those from capital stocks, based on input-output industrial structures, and then evaluated effectiveness of climate adaptation among climate change policies. Impacts of climate sensitivity uncertainty on climate adaptations were also evaluated. In addition, from the view of risk management, we evaluated climate change response strategies based on this study.

3.2. Outlines of analytical framework

A new economic model was developed as shown in Figure 5. The model is formulated as a dynamic non-linear optimization model with maximization of discounted global consumption utilities. The assumed discount rate is 3% per year. The world is divided into 12 regions with 10 economic sectors. The current version does not consider the economic impacts of climate mitigation.

In this study, climate impacts are assumed to be classified into coastal sector and the others. Firstly, climate damages and adaptation in coastal sector are set up based on Hinkel et al[1]. Coastal flood gives damages on capital stocks in coastal areas. Building/enhancing coastal dikes are considered as adaptation measures for coastal sector protection. Cost functions of the coastal dike building are formulated as quadratic functions on adaptation level. Secondly, climate damages in other sectors, corresponding to sectoral GDP damages, are formulated as the quadratic functions of global mean temperature. Adaptation in other sectors are not considered at present. By using this model framework, direct effects of adaptation investments and the relevant spill-over effects by region and by sector can be evaluated for multi-years.

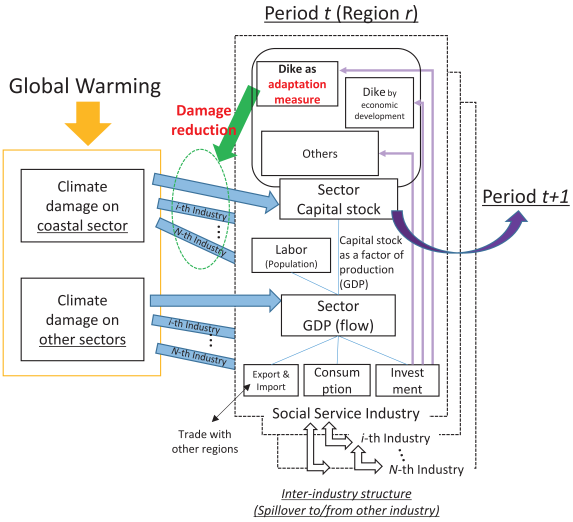

Figure 5 : Structure of developed model

3.3. Results

Figure 6 shows pathways of global GDP losses (negative changes in GDPs relative to the baseline (no climate scenario)) without and with climate adaptation in RCP*1) 8.5 (assumed global mean temperature rise of 4.2℃ in 2100) under the climate sensitivity of 3.0℃.

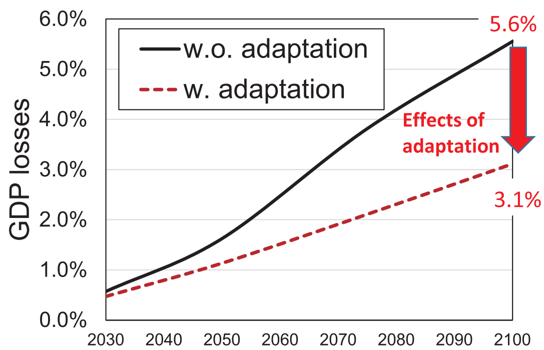

Figure 6 : Changes in global GDP losses

Note: Assumed climate sensitivity is 3.0°C. Adaptation only in coastal sector is assumed.

The global GDP losses without and with climate adaptation in 2100 are 5.6% and 3.1% (relative to the baseline), respectively. The global investment costs for cost effective dike building are very small compared to global GDP, and the relevant spill-over effects on the whole economy are also small. However, the effects of avoided damages due to dike building are large.

In order to thoroughly evaluate economic balances among climate mitigation, adaptation and residual damages, total costs of climate change are shown (Figure 7). The mitigation costs are based on datasets of IPCC-AR5-WGIII (mean of multiple models results). It is noted that these mitigation costs are basically evaluated under global cost minimizations (corresponding to the ideal uniform carbon price in all the regions).

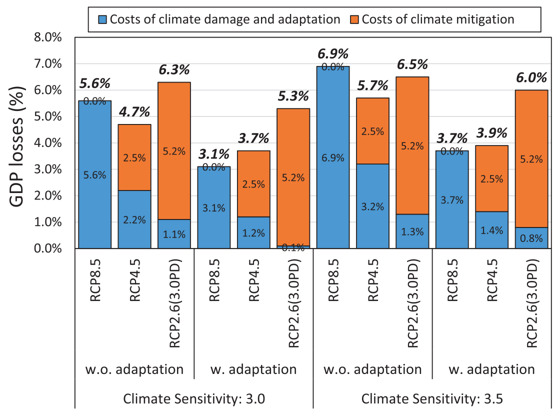

Figure 7 : Global costs of climate impacts, adaptation and mitigation(economic impacts of climate adaptations and climate sensitivities)

Note: PD:Peak and Decline

Under the climate sensitivity of 3.0℃, economically reasonable pathways are RCP8.5 and RCP4.5 among the three response scenarios (assumed global mean temperature rise of 2.3℃ in 2100) with and without climate adaptation, respectively. We should note evaluation accuracies of climate change damages and adaptation are poor as compared to that of mitigation. Considering the total costs, the most stringent pathways, RCP2.6 (assumed global mean temperature rise of 1.6℃ in 2100) is not considered economically effective. In addition, even in the high climate sensitivity of 3.5℃, effectiveness of climate adaptation are evaluated.

3.4. Summary

We newly developed an assessment model on climate change impacts and adaptations, and then by using the model, we evaluated effectiveness of adaptations and total costs of climate mitigation, adaptations and residual impacts under two cases of climate sensitivities.

Even in the RCP8.5 with the highest global mean temperature rise under the climate sensitivities of 3.0℃, with optimal adaptations, costs for the cost effective adaptations are small relative to GDP. This results indicate that climate adaptations largely decreases climate damages. Stringent GHG emission reduction cases like 2℃ target may seem to require large costs on climate mitigations and might not be economically reasonable in the view of total costs, although cost estimations of climate damages and adaptations have large uncertainties. This study limited evaluations up to 2100. However, we need to pay attention to climate impacts beyond 2100, where damages are expected to increase with time delay.

In addition, even in the case of the high climate sensitivities of 3.5℃, climate adaptations are useful measures for climate damages. For the higher climate sensitivity by 0.5℃, climate adaptations will be able to largely decrease climate change risks as well. Therefore, in terms of climate change risks management under the uncertainties of climate sensitivities, it may be wise to take mitigation actions for a broad temperature target in association with appropriate adaptation actions rather than trying to achieve the stringent temperature target.

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＊1) RCP: Representative Concentration Pathways

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Development of Biorefinery Technology toward a Low Carbon Society

1. Introduction

Biotechnology, which involves the use of biological processes, organisms, or systems, widely contributes to the fields of agriculture, industry, environment, medical treatment, etc. In recent years, a new concept of “Bioeconomy” was proposed. Bioeconomy refers to a market wherein industries using biotechnology are fused with resource-circulating societies (Fig. 1), and has been paid much attention as a global biotechnology strategy in Europe and America. Our group is advancing the research and development of biorefinery technologies to produce biofuels and green chemicals from renewable sources (biomass), which are core technologies of the “Bioeconomy.” In this section, we provide an overview of global biofuel and green chemical production.

Biofuels

Bioethanol, a major biofuel, is produced from corn (in the U.S.) or from sugarcane (in Brazil) as main raw materials, and mixed with 10-25% gasoline for use in automobiles. The highest production and consumption of bioethanol is in the U.S., where 15.0 billion gallons (57 million kL) of bioethanol, was produced in 2017, which slightly exceeded the volume of 2016, according to the good harvest. In Agricultural Outlook 2017-2026 by OECD-FAO, 120 million kL of bioethanol was produced worldwide in 2017, with the U.S accounting for about half of the production. Biodiesel is produced from rape seed (in Europe) or soybean (in the U.S.) as main raw materials, with 37 million kL of biodiesel being produced worldwide (Fig. 2). France and Germany, where about half of the automobiles have diesel engines, have the highest consumption.

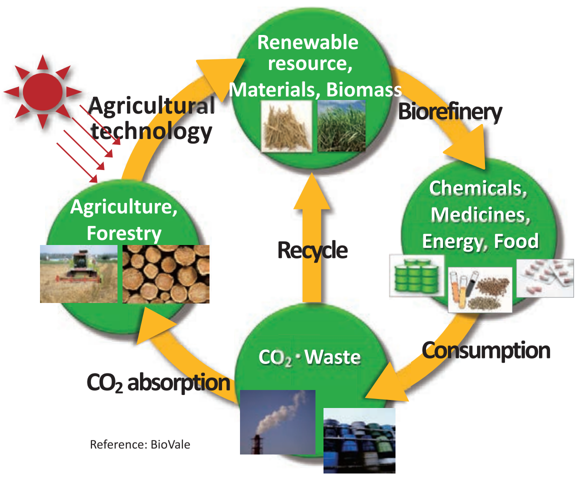

Fig. 1 : Concept of Bioeconomy

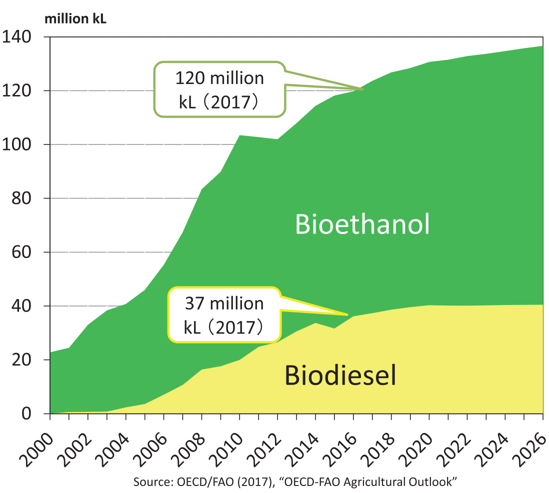

Fig. 2 : Biofuels outlook 2017-2026

In 2017, the news that French and British governments intended to ban fossil fuel-powered vehicle sales by 2040, left an impact. In Europe, the phasing out of petrol and diesel cars is due to a target of low carbon based on the Paris agreement, and the use of conventional internal combustion engines is predicted to decline in the future. On the other hand, dependency of aircrafts or large-sized ships on liquid fuels is considered to stay unchanged, because the shift toward electric power from liquid fuels is difficult for these machines. Therefore, the demand of biofuels is expected to rise to decrease CO_2 emission from the transportation sector (Fig. 2).

Since second generation cellulosic biofuels are produced from agricultural wastes such as corn stover, their production does not affect food supply, which is expected to reduce large CO_2 emission. However, it was reported that a large-scale commercial plant that could produce over 100,000 kL cellulosic ethanol per year was shut down in Europe in 2017. Now several large-scale commercial plants are in operation in the U.S. and Brazil. Biojet fuels, which are a trump card of CO_2 emission reduction from aircrafts, have become widely popular in global commercial flights through the use of material such as used-cooking oil as a raw material. In Japan, two projects on biojet fuel production from algae and woody biomass have also been adopted by New Energy and Industrial Technology Development Organization (NEDO). Plans are being set in place for consistent production processes (pilot scale) of these two projects in 2030 to produce biojet fuels.

Green chemicals

Owing to the shift of raw materials from fossil resources to renewable biomass, the production of green chemicals, such as biomaterials and biopolymers, is effective in reducing CO_2 emission. Moreover, these green products are expected as an important material to contribute to achieve a realization of circulating society and sustainable manufacturing. According to European Bioplastics, global bioplastics production reached 4.4 million tons in 2017 and is predicted to reach 6.1 million tons in 2021. Slower growth rate of the market than that of previous prediction may be due to recent economic performance such as production cost. However, as there is an increase in companies that use bioplastics and biofiber in smartphone cases, automobile parts, clothes, etc., the market for green chemicals is expected to expand worldwide.

In Japan, the consumption of biodegradable poly lactic acid (PLA) and drop-in biopolymers such as bio-polyethylene terephthalate (Bio-PET) and bio-polyethylene (Bio-PE) is increasing. Application of Smart cell technology, which is described later, is also expected to improve monomer productivity and production rate in the future.

2. Features of RITE Bioprocess

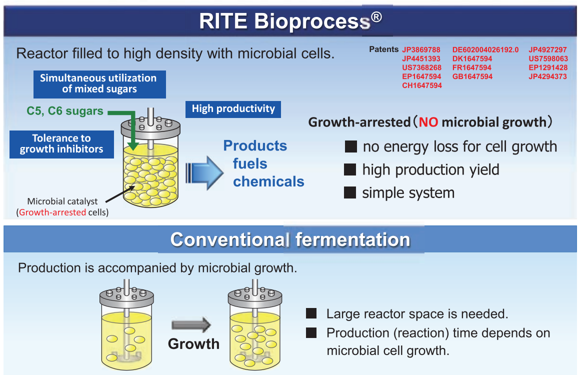

Fig. 3 : Features of RITE Bioprocess

In RITE Bioprocess, cells of a *Corynebacterium glutamicum* strain engineered to have an optimal metabolic pathway for a target chemical are grown on a large scale, packed to very high densities in a reactor, and allowed to produce the target metabolite (Fig. 3). The key to our process is the unique property of *C. glutamicum*. Bioconversion of feedstock to target products proceeds without microbial cell growth, achieving higher efficiency and productivity compared to conventional fermentative processes, in which formation of products and biomass inevitably occurs in parallel. Metabolic engineering enabled our microbial catalyst to utilize C6 & C5 sugars simultaneously, and we found that *C. glutamicum* is highly tolerant to fermentation inhibitors contained in cellulosic hydrolysates such as furans, demonstrating that the RITE Bioprocess is compatible with cellulosic non-food biomass (see RITE Today 2013-2017).

Through the RITE Bioprocess, we have been successful in production of ethanol, lactic acid, and various amino acids with remarkably high yield. We are currently applying the technology to microbial production of butanol, biojet fuels, and aromatic compounds such as phenol. In the following sections, we describe recent progress in our research on production of biofuels and green chemicals.

3. Research and development on production of biofuels

3.1. Biobutanol

Butanol is more suitable as a gasoline additive than ethanol due to its physicochemical properties, including higher energy content, lower vapor pressure, and lower water solubility. It can also be used as a starting material for biojet fuel production by conventional chemical reactions. Thus, biojet fuel synthesized from biobutanol can be used in airplanes. As this is recognized as key for reduction of CO_2 emission, airplane companies have paid great attention to biojet fuel. Biojet fuel synthesized from butanol is often referred to as “ATJ” fuel for “Alcohol to Jet.” ATJ fuel has been approved by American Society for Testing and Materials (ASTM) and is ready to use in commercial flights (http://www.gevo.com/).

We have developed a genetically engineered *C. glutamicum* that exhibits highly efficient production of butanol. We have been conducting a research project on cellulosic butanol production since 2015 (see Topics in RITE Today, 2016), which has been funded by the Ministry of Economy, Trade and Industry (METI). The advantages of our production process include the following (i) cellulosic biomass can be used as feedstock and (ii) production is fast with high yield (Fig. 4).

Since butanol is highly toxic, we have developed a genetically-engineered Corynebacterium strain that exhibits a very high productivity by the RITE Bioprocess. We accelerated R&D of biobutanol production from non-edible biomass by collaborating with the U.S. National Renewable Energy Laboratory (NREL).

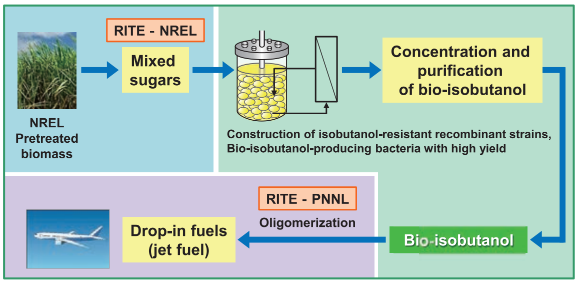

Fig. 4 : Production of biobutanol and biojet fuel by RITE Bioprocess

Moreover, we have been collaborating with U.S. Pacific Northwest National Laboratories (PNNL) from 2017 for R&D on production of jet fuels by chemical oligomerization of biobutanol.

We achieved the highest biobutanol productivity worldwide. We then carried out further attempts at fast and highly efficient production of biobutanol by improving biobutanol resistance, optimizing metabolic pathway, and by developing energy-saving biobutanol purification techniques.

3.2. Green jet fuel

Petroleum-based jet fuels are mixtures of hydrocarbons that consist mainly of linear-, cyclic-, and branched- saturated hydrocarbons and aromatic compounds with 10-15 carbon atoms. The jet fuel must meet strict physical properties such as freezing and flash points for safety reasons. Biojet fuels that have already been certified by ASTM lack essential components such as aromatic compounds, due to which they cannot be used singly as aviation fuel, but need to be mixed with petroleum-based jet fuels. The blending ratio of each biojet fuel is at the most 50%.

In order to reduce emissions from aviation, International Civil Aviation Organization (ICAO) sets a goal to carbon-neutral growth from 2020. On the other hand, International Air Transport Association (IATA) sets a goal for net reduction of carbon emissions by 50% of 2005 emissions by 2050. To meet both targets, more than 60% reduction of CO_2 emissions would be required in 2050, which suggests that present biojet fuels whose blending ratios are at 50% could not meet the targets. Therefore, we have started a new project to produce 100% green jet fuel consisting of various types of hydrocarbons including aromatic compounds.

Our core strategy is to create a novel hybrid-microbe equipped with an organo-catalyst in cells and to use the hybrid microbe as a biocatalyst facilitating reactions that have never been observed in microbial cells. The hybrid microbe makes it possible to produce C10-C15 branched and cyclic precursors of jet fuel from various non-food biomass. So far, we have successfully obtained a strain producing C10 jet fuel pre-

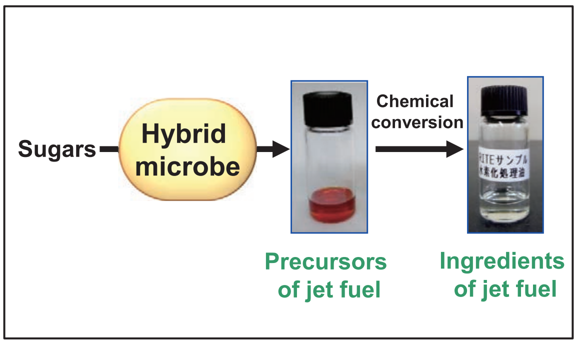

Fig. 5 : Production of jet fuel using hybrid microbe

cursors from glucose. We have also successfully converted the C10 precursors to C10 hydrocarbons satisfying the properties of jet fuel in cooperation with a petrochemical company. We are currently attempting to improve the productivity of our process to realize its industrialization (Fig. 5).

3.3. Biohydrogen

Hydrogen is considered the ultimate clean energy because its combustion generates only water. However, CO_2 emission during the existing hydrogen production processes is an important issue because fossil resources are used as feedstock. This issue should be addressed by a mid- or long-term R&D project on hydrogen production technologies using renewable and sustainable resources. In this context, METI has set the goal of establishing a CO_2-free hydrogen supply chain by 2040 in a long-term technology roadmap.

Although bioprocesses have significant potential for CO_2-free hydrogen production, an innovative improvement in technology is necessary to establish a cost-efficient bio-hydrogen process. Bio-hydrogen production from organic compounds, such as sugars derived from biomass, is divided into dark fermentative hydrogen production and photo-fermentative hydrogen production. The latter harnesses light energy unlike the former process. In collaboration with the SHARP Corporation, our group has developed a bio-hydrogen production process using formate-dependent dark fermentative hydrogen production pathway (Fig. 6). The hydrogen production rate achieved is two orders of magnitude higher than that of conventional fermentation processes. Based on the achievement, since 2015, our group has conducted an international collaborative research project supported by METI. This project has proceeded in collaboration with Kyoto University, NREL, and Center National de la Recherche Scientifique (CNRS) in France.

In this project, in order to improve the hydrogen yield from sugars derived from cellulosic biomass, we are now (i) introducing a new hydrogen production pathway in hydrogen-producing microorganisms, (ii) improving photosynthetic bacteria for photo-fermentative hydrogen production from acetate, a by-product of dark fermentation, and (iii) examining conditions for hydrogen production from corn stover (Fig. 6).

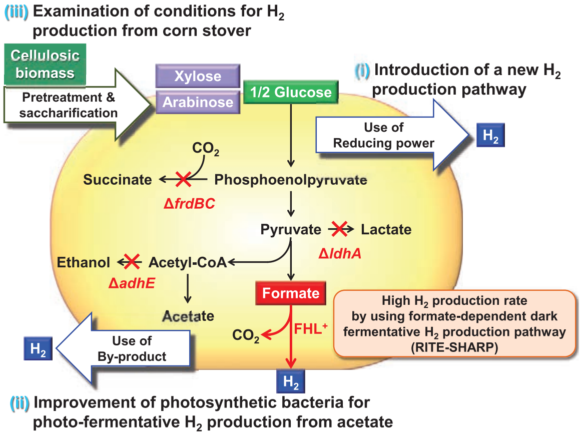

Fig. 6 : Research and development of highly efficient bio-hydrogen production from cellulosic biomass

4. Development of technologies for the production of bio-based chemicals

4.1. NEDO Smart cell project

Innovations in biotechnology have made it possible to expand the potential of biological functions. Considering the latest trends, METI defined "Smart-cell" as a finely-designed and expression-controlled cell, and presented a strategy to create a new industry ("Smart cell" industry) based on Smart cells.

To realize the creation of the industry, NEDO launched a project, "Development of Production Techniques for Highly Functional Biomaterials Using Smart Cells of Plants and Other Organisms" (Smart cell project). Our group participated in the project and started to develop an accurate metabolic model of Corynebacterium to maximize its productivity by prediction and design of metabolic pathway. We will validate the developed model by evaluating the productivity of target products of a strain (smart cell) engineered according to a metabolic design suggested by the model (Fig. 7).

During 2017, (the second year of the project), we obtained mutants highly resistant to our target prod-

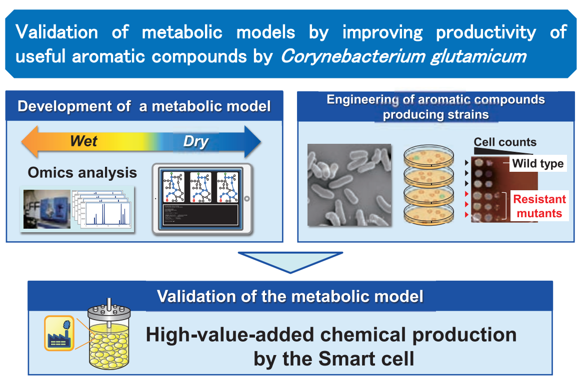

Fig. 7 : Overview of Smart cell project

ucts - aromatic compounds, analyzed their genomes, and screened for genes comprising metabolic pathways for the products. Besides, in collaboration with Kobe university and National Institute of Advanced Industrial Science and Technology (AIST), we are developing and tuning a metabolic model. We are also evaluating metabolic designs suggested by the model.

4.2. Expanding production technologies for various aromatic chemicals

Aromatic compounds represent important industrial chemicals used as polymer materials and are a group of diverse value-added chemicals, which find applications in pharmaceuticals, nutraceuticals, flavors, cosmetics, and food industries. While they are currently derived from petroleum or natural plant resources, their environmentally-friendly biotechnological production from renewable feedstocks is desired from the viewpoint of creating a sustainable society independent of petroleum resources and of production efficiency. In this context, we are undertaking the development of a highly efficient bioprocess to produce aromatic compounds from non-food ligno-cellulosic feedstock by employing our bioprocess using *C. glutamicum*. We have already succeeded in developing a highly efficient bioprocess to produce shikimate, which is a key building block in the chemical synthesis of Tamiflu, an anti-influenza drug, 4-aminobenzoate. It is used as a potential functional polymer material, and as several aromatic hydroxy acids with potential applications in polymers, pharmaceuticals, cosmetics, and foods industries. Now we are accelerating the research on their practical application by collaborating with chemical companies. Moreover, development of metabolically engineered *C. glutamicum* strains to produce other useful aromatic chemicals is also in progress (Fig. 8). We are also promoting research toward the development of high performance aromatics-overproducing strains with most appropriate metabolic designs by incorporating metabolic modeling and omics analysis technologies, which are also now being developed in the 'Smart cell project' described above.

5. Towards the industrialization of our technologies

5.1. Phenol

Commercial phenol is only derived from petroleum. We have been challenged to develop the world's first manufacturing bioprocess of biomass-derived phenol, which is considered to be difficult, for global environmental conservation and greenhouse gas reduction.

In May 2014, Sumitomo Bakelite Co., Ltd. and RITE established Green Phenol Development Co., Ltd. (GPD) to accelerate the industrialization of our biomass-derived phenol-producing technology named "two-stage bioprocess". According to the NEDO project of "Development of manufacturing process for biomass-based phenol (2015~2017)," additional purification and concentration processes were constructed near a bioprocess pilot plant in May 2016 at Shizuoka Plant at Sumitomo Bakelite Co., Ltd. This plant is ex-

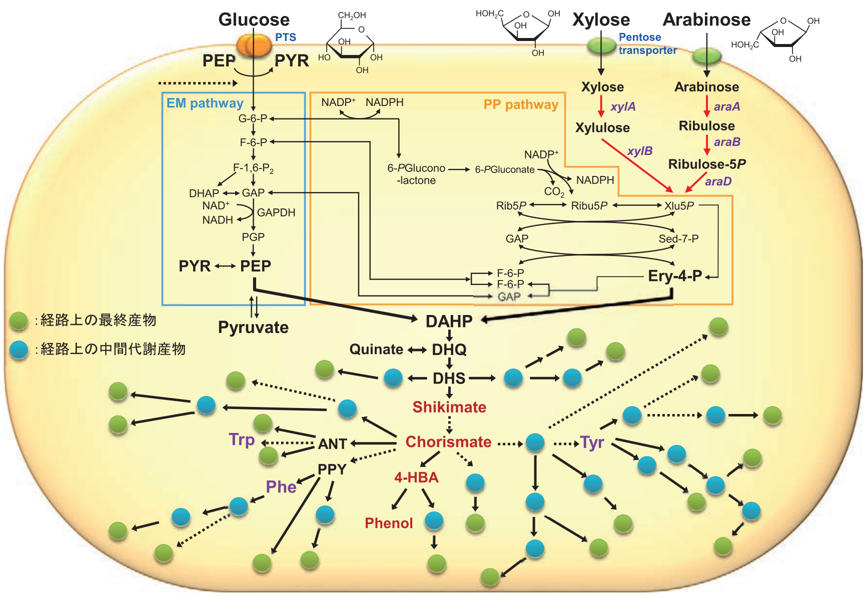

Fig. 8 : Development of manufacturing cells for various aromatic compounds

pected to enable integrated production of biomass-based phenol from non-food biomass-derived mixed sugars (Fig. 9). Next hurdles are as follows: supply of low-cost biomass-derived sugars, improvement of processes, such as the bioprocess as a whole, purification, concentration of phenol, recycling of waste water, etc. These processes are now in the process of industrialization.

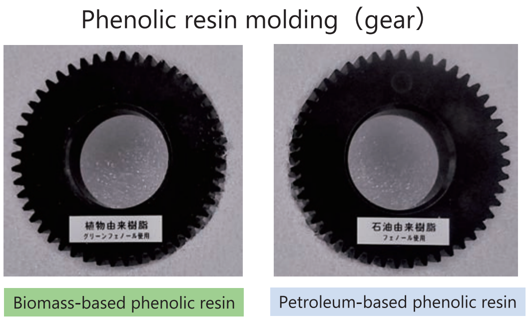

Fig. 9 : Molded samples using biomass-derived phenol in BioJapan 2017 (see topics)

5.2. Amino acids

Normally, amino acid fermentation is carried out under aerobic conditions and consequently, aeration and agitation should be properly controlled to attain high productivity, but it is often difficult in large-scale fermenters because the oxygen concentration is not homogeneous inside the fermenters. To overcome this problem, we have developed a new genetically modified Corynebacterium strain for amino acid production in the RITE Bioprocess, wherein the production of amino acid is carried out under anaerobic conditions. The technological hurdle for amino acid production under anaerobic conditions is to balance the redox reaction without oxygen as an electron acceptor. To this end, we introduced an artificial pathway for amino acid biosynthesis in microbial cells. Our group has solved the technological hurdle and published the research accomplishments in an international journal in 2010 (Appl. Microbiol. Biotechnol. 87: 159-165).

Green Earth Institute Co. Ltd. (GEI) was established in 2011 for industrialization of RITE Bioprocess. Since 2011, RITE and GEI started collaborative research for amino acid production using the RITE Bioprocess in which technologies for scaling up, development of efficient production strains, and cost reduction have been developed. Our first target for amino acid production was synthesized from a petrochemical product, but our goal was to produce the amino acid from renewable resources to reduce the life cycle carbon footprint. In 2016, we succeeded in demonstrating this production by using commercial-scale facilities of our partner company, which is an important milestone for industrialization. One of our group members also participated in the first operation and worked with local employees to lead the project to a successful conclusion. As a result of the evaluation by the Food Safety Committee in August 2017, the safety of L-alanine produced by our strain as a food additive was confirmed, and it became available as a food additive, besides its industrial application. The L-alanine production business was developed in cooperation with a domestic and foreign partner enterprise. In addition, we are working on a joint research project with GEI for valine production, and making sample production by improving the strain and scaling up.

6. Closing remarks

METI announced "Connected Industries Tokyo Initiative 2017" in October 2017. "Connected Industries" is a new concept framework which shows the future position of Japanese industries in the 4th industrial revolution, and is an action plan for a super-smart society after 2030 (Society 5.0). One of the fields of importance in the above concept is "New Biomaterial", wherein the biorefinery technology must play an important role as a core technology by using the Smart cell technology mentioned before (Fig. 10).

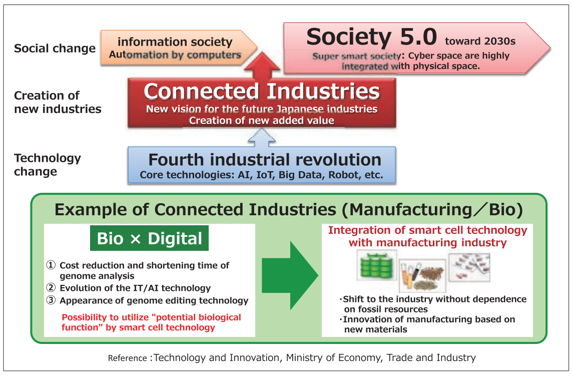

Fig. 10 : Fusion of biotechnology and digital technology

Our group continues to put effort into developing technologies to produce next generation biofuels including butanol, hydrogen, and green jet fuels by using the Smart cell technology. Through our research activities, we would like to contribute to environmental protection and establishment of a sustainable society.

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Challenges Associated with the Advanced Industrialization of CO_2 Capture Technologies

1. Technologies for CO_2 capture

CO_2 capture and storage (CCS) involves the trapping of CO_2 (a greenhouse gas) from the emissions generated during fossil fuel combustion from such sources as electric power plants and factories and includes the subsequent sequestration of the captured CO_2 in geological formations. At present, the costs associated with capturing CO_2 from emission sources account for approximately 60% of overall CCS expenditures. Therefore, it is important to reduce capture costs to allow the practical application of CCS.

The Chemical Research Group studies the different CO_2 capture technologies with a special focus on chemical absorption, adsorption, and membrane separation methods. This work involved the development of new materials and processing methods, as well as investigations of capture systems. The Group studies have thus far generated significant outcomes and assisted in the progress of research in this particular field.

Specifically, we developed high performance chemical absorbents, and one such chemical absorbent with particular promise was selected for application in a commercial CO_2 capture plant owned by a private Japanese company. This CO_2 capture plant has been in operation as the first commercial plant, and in 2018, a second commercial plant is scheduled to begin operations.

On solid sorbent technology, we have also been developing sorbents for CO_2 capture to efficiently reduce energy consumption. Currently, the low-temperature regenerable solid sorbent that we developed is being evaluated for practical use. In lab-scale cyclic tests, our novel solid sorbent is capable of achieving 1.5 GJ/t-CO_2 in regeneration energy. And, we have established a large-scale synthesis technology that can produce the solid sorbent at a scale of 10 m^3. Research on the practical application is now underway in collaboration with a private company. In the near future, we will install a test facility to capture 40 t-CO_2/day at the Maizuru power plant of Kansai Electric Power Company for practical application.

Membrane separation is expected as an effective means of separating CO_2 from high-pressure gas mixtures at low cost and with low energy. As a member of the Molecular Gate Membrane module Technology Research Association, RITE has been developing membranes and membrane elements using a novel dendrimer/polymer hybrid membrane, called the molecular gate membrane, to selectively capture CO_2 from pressurized gas mixtures containing H_2, such as those generated in the integrated coal gasification combined cycle (IGCC) at low cost and with low energy. We are also developing membranes with large membrane areas using the continuous membrane-forming method and developing membrane elements for the mass production of membranes and membrane elements in the future. In addition, we plan to evaluate the separation performance and process compatibility of our membranes and membrane elements using coal gasification gas both in Japan and overseas in order to identify and then solve the technical problems of membranes and membrane elements.

2. Development of CO_2 capture technology based on chemical absorption systems

CO_2 capture by chemical absorption is a prospective technology for the separation of CO_2 from gas mixtures. This technique consists of the thermal desorption of CO_2 following chemical absorption using an amine-based solution. From the Cost-saving CO_2 Capture System (COCS) project (funded by the Ministry of Economy, Trade and Industry (METI) between FY 2004 and 2008), RITE examined the capture and separation of CO_2 from steel industry blast furnace effluent gases (Fig. 1).

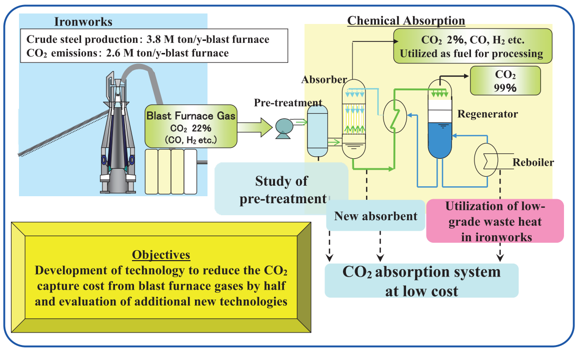

Fig. 1 : A cost-saving CO_2 capture system scheme

In the following project, the CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50 (Course 50 Phase 1 Step 1, 2008-2012: funded by the New Energy and Industrial Technology Development Organization (NEDO), RITE achieved the target CO_2 capture energy consumption value of 2.0 GJ/t-CO_2. In addition, significant new absorbents were developed for CO_2 desorption at less than 100℃. This result represents an improvement over the current desorption temperature of 120℃.

Beginning in FY 2013, the Course 50 Phase 1 Step 2 project funded by NEDO was initiated and intended to run until FY 2017. During this work, RITE and Nippon Steel & Sumitomo Metal Corporation continued to develop new absorbents that had the potential to deliver high performance and to allow more efficient CO_2 capture (Fig. 2).

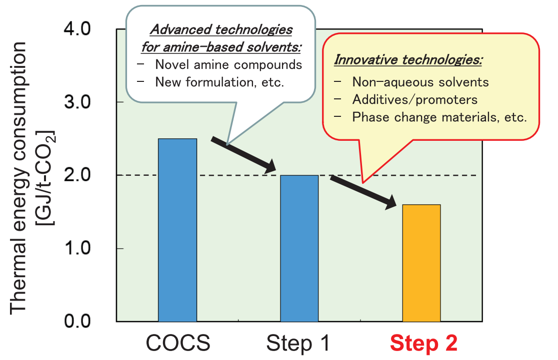

Fig. 2 : Continuous challenge of the high-performance liquid absorbent process

Regarding practical technology development, one of the outstanding new absorbents was adopted for use in commercial CCS plants operated by Nippon Steel & Sumikin Engineering Co., Ltd. The first such CCS plant began operation in the autumn of 2014 (Fig. 3); the second CCS plant is scheduled to start operation in 2018. The research results of RITE contribute to the practical application of CO_2 capture technology to different emission sources in the industry.

Fig. 3 : Snapshot of the first commercial plant for supplying CO_2 as industrial gas

*The construction site is Nippon Steel & Sumitomo Metal Corporation.

*The photo is provided by Nippon Steel & Sumikin Engineering Co., Ltd.

Additionally, we have advanced the development of chemical absorbents for high-pressure gas mixtures containing CO_2, obtaining excellent CO_2 absorption and desorption performance. The purpose of these studies has been the research of highly efficient absorbents that enable CO_2 desorption while maintaining the high CO_2 partial pressure of the initial gas mixture.

These are termed High-Pressure Regenerable absorbents. Using these novel absorbents, the energy consumption during the CO_2 compression process following capture is significantly reduced owing to the high pressure of the captured CO_2.

Several new solvent systems designed previously have demonstrated high CO_2 recovery levels in conjunction with superior CO_2 absorption and desorption rates. These capabilities are in addition to a relatively low heat of reaction under high-pressure conditions above 1 MPa (Fig. 4). 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 1.1 GJ/t-CO_2. (absorption: 1.6 MPa-CO_2, desorption: 4.0 MPa-CO_2).

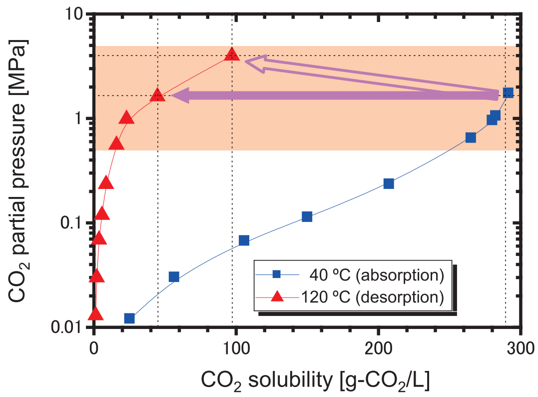

Fig. 4 : CO_2 pressure-solubility relationships for High-Pressure Regenerable absorbents

3. Solid Sorbent Technology

RITE has developed solid sorbents during a project aimed at the advancement of CO_2 capture technologies funded by METI from 2010 to 2014. Solid sorbents are composed of amine absorbents for chemical absorption and porous materials (Fig. 5). They have similar CO_2 adsorption characters with liquid amine absorbents. Furthermore, they make it possible to significantly reduce the energy consumed as sensible heat and evaporative latent heat in the regeneration process.

Novel amines synthesized by RITE have been employed for our developed solid sorbents (Fig. 6). Based on the established relationship between various amine structures and their CO_2 desorption capabilities, as determined by theoretical simulations, RITE successfully fabricated innovative, high-performance solid sorbents capable of low-temperature regeneration with high adsorption capacities.

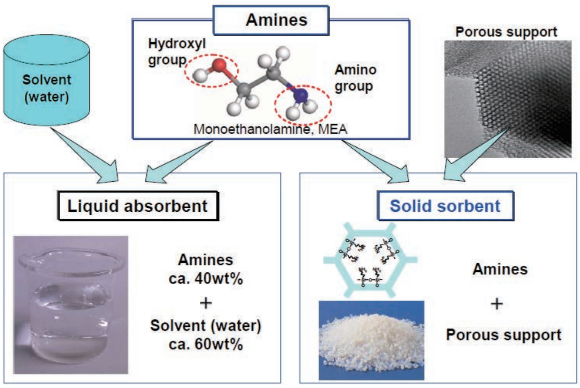

Fig. 5 : Liquid absorbent and solid sorbent

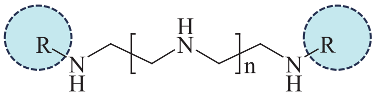

Fig. 6 : RITE Amine

The result of the process simulation based on the performance of our developed solid sorbents showed the potential of 1.5 GJ/t-CO_2 for the regeneration energy. When this CO_2 capture technology is applied to the coal-fired power generation, the reduction of power generation efficiency is expected to be improved by about 2% compared to conventional chemical absorption technology (2.5 GJ/t-CO_2).

Under a project aimed at the advancement of CO_2 capture technologies (R&D of Advanced Solid Sorbents for Commercialization) funded by METI since FY 2015, we are conducting the optimization of materials for practical use and working with Kawasaki Heavy Industries (KHI), Ltd., to develop bench scale test using moving-bed system for coal combustion exhaust gas and simulation technology of moving bed system.

So far, we have selected solid support with properties suitable to the moving-bed system. In addition, we have developed the synthesis method of materials on a larger scale. As a result, the midterm goal, which is the establishment of solid sorbents synthesis on a scale of 10 m^3, has been achieved.

The solid sorbents prepared by the established method (10 m^3 scale) were evaluated by using a lab-scale adsorption/regeneration test apparatus (Fig. 7).

These tests were conducted by using the steam-aided vacuum swing adsorption (SA-VSA) process, in which steam was supplied in a desorption process. After the cycle time was optimized, the result showed that RITE solid sorbents could capture high-purity (99%) CO_2 from a simulated flue gas (12% CO_2) in high yields (90%). In this case, the energy used for regeneration steam at 60℃ was extremely low (1.4 GJ/t-CO_2), demonstrating that RITE solid sorbents had superior performance in CO_2 capture.

Fig. 7 : Lab-scale apparatus for CO_2 capture test

Currently, the bench scale combustion exhaust gas test is underway by the moving bed system installed at KHI using RITE solid sorbents prepared by the established method: movement characteristic of the solid sorbent and CO_2 capture performance are being evaluated. We also are improving equipment for high CO_2 purity, selecting suitable measuring devices for water in the gas, and extracting problems for actual gas testing.

A 40 ton-CO_2/day capture plant will be installed at the Kansai Electric Power Co (KEPCO) coal-fired power station (Maizuru power station) and practical exhaust gas test will be carried out post 2019 (announced September 2017). We are working on the R&D roadmap to establish a solid sorbents system that has much higher performance to capture CO_2 from coal fired power generation (Fig. 8).

4. CO_2 and H_2 separation using polymeric membranes

The Japanese government announced the Cool Earth 50 project in May 2007 with the aim of reducing the country's CO_2 emissions to half the current amount by 2050. One promising means of lowering CO_2 emissions is the development of Integrated coal Gasification Combined Cycle with CO_2 Capture and Storage (IGCC-CCS) using CO_2 selective membranes (Fig. 9). For this reason, we are currently developing novel CO_2 selective membrane modules that effectively separate

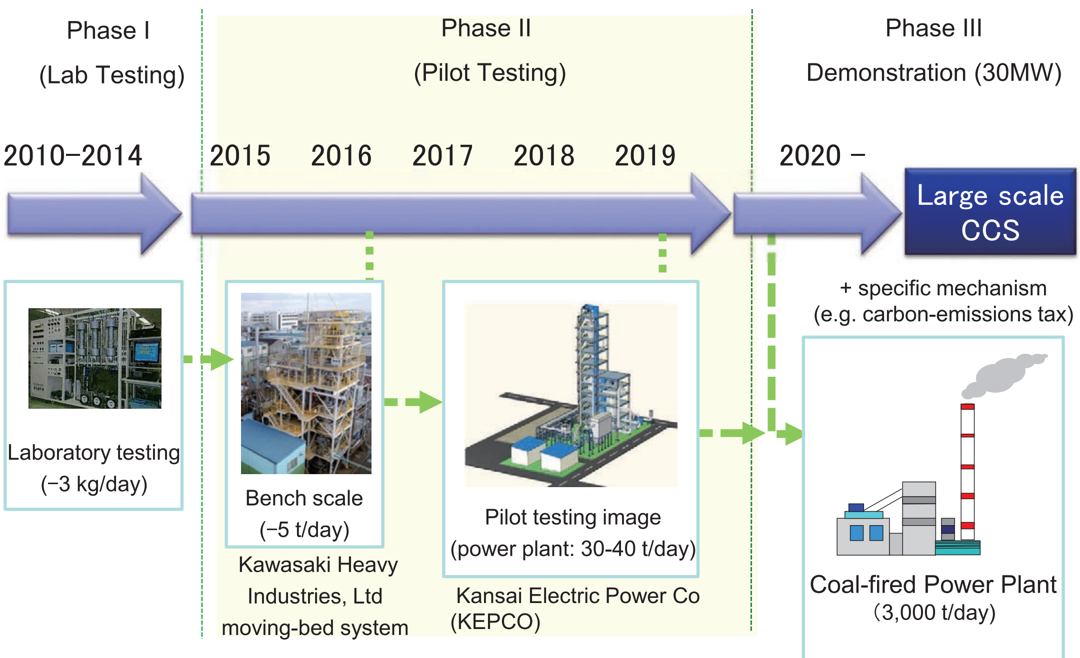

Fig. 8 : Project roadmap

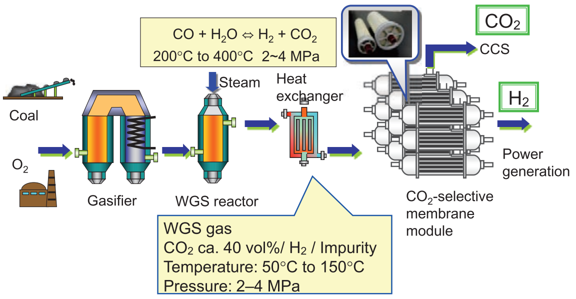

Fig. 9 : Schematic of the IGCC process with CO_2 capture by CO_2 selective membranes.

CO_2 during the IGCC process.

We found that novel polymeric membranes composed of dendrimer/polymer hybrid materials (termed molecular gate membranes) exhibit excellent CO_2/H_2 separation performance. Fig. 10 presents a schematic that summarizes the working principles of a molecular gate membrane. Under humidified conditions, CO_2 reacts with amino groups in the membrane to form either carbamate or bicarbonate, which then block the passage of H_2. Consequently, the amount of H_2 diffusing to the other side of the membrane is greatly reduced and high concentrations of CO_2 can be obtained.

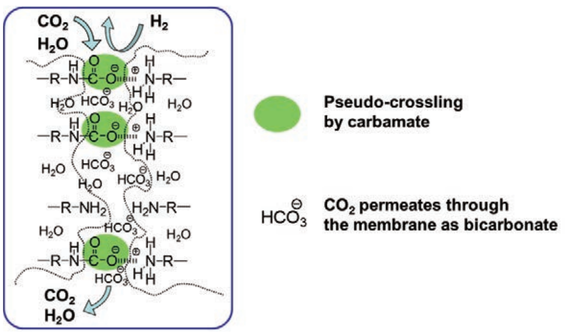

Fig. 10 : Schematic illustration of the working principles of the molecular gate membrane.

We developed new types of dendrimer/polymer hybrid membranes that provide superior separation of CO_2/H_2 gas mixtures.

Based on this work, the Molecular Gate Membrane module Technology Research Association (MGMTRA; consists of Research Institute of Innovative Technology for the Earth [RITE] and a private company) is researching new membranes, membrane elements (Fig. 11), and membrane separation systems.

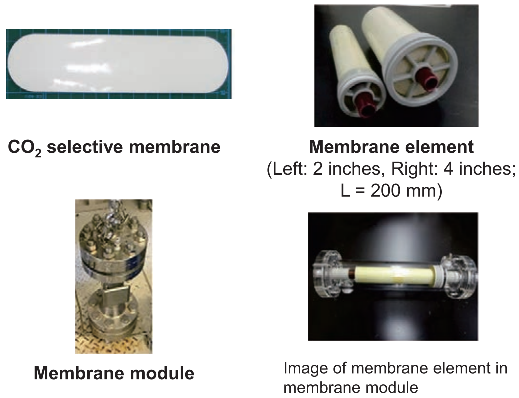

Fig. 11 : CO_2 selective membrane, membrane element, and membrane module.
Membrane element:
The structure with large membrane area composed of membrane, support and spacer etc.
Membrane module:
The structure in which membrane element is placed

In the project by the Ministry of Economy, Trade and Industry (METI), Japan, "CO_2 Separation Membrane Module Research and Development Project" (FY 2011-2014), we developed molecular gate membranes that show high CO_2 separation performance under high-pressure conditions of 2.4 MPa (IGCC conditions) using laboratory-scale membranes. In the current METI project, "CO_2 Separation Membrane Module Practical Research and Development Project" (FY 2015-), we are developing the membranes with large membrane areas by continuous membrane-forming method and also developing the membrane elements. We plan to conduct pre-combustion CO_2 capture tests using real gas from the coal gasifier to examine the separation performance and robustness of membranes and membrane elements.

The separation performance of the prepared membranes using the continuous membrane-forming method and membrane elements are shown in Table 1.

Comparing the separation performance of the membrane elements with that of the membrane itself, it is suggested that the membrane elements showed

Table 1. Separation performances of the membrane prepared by continuous membrane-forming method and the membrane element.

	Q_{CO2} [m³(STP)/m²/s/Pa]	Q_{He} [m³(STP)/m²/s/Pa]	α
Membrane	1.94E-11	1.18E-12	16.5
Membrane element	1.83E-11	1.54E-12	11.9

Membrane element: Diameter: 2 inches, Length: 220 mm
Operating conditions: Temperature: 85℃ , Feed gas composition: CO_2/He = 40/60%, Feed gas pressure: 2.4 MPa, Relative humidity in feed: 70% RH, Permeate gas pressure: atmospheric pressure.
He gas was used instead of H_2 gas, for safety reasons.

reasonable separation performance.

The real gas from the coal gasifier contains trace amounts of impurities, such as CO, CH_4, H_2S, and COS. Among them, the effect of H_2S exposure on the CO_2 separation performance was evaluated. The results are shown in Fig. 12. As shown in the Fig. 12, there was no significant effect of H_2S exposure on CO_2 separation performance. Therefore, it was confirmed that the prepared membrane is resistant to H_2S.

The CO_2 molecular gate membrane modules are being developed 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.

5. Conclusion

In December 2015, the Paris Agreement was adopted at COP 21.* To meet the conditions of the agreement, it is essential to promote innovative ways to dramatically reduce emissions on a worldwide basis. In April 2016, Japan released the National Energy and Environmental Strategy for Technological Innovation toward 2050. In addition, in September 2017, a technical roadmap for 2050 was formulated. The capture and effective usage of CO_2 were identified as promising technologies. Innovative CO_2 separation and recovery technologies contain medium- and long-term targets related to technological improvements that will reduce the energy used in separation and recovery by half (<1.5 GJ/t-CO_2) . In the technical roadmap, CO_2 separation and recovery technologies are planned to be demonstrated at the system level around 2030, and then become popular around 2050.

In general, it is crucial to promote the practical application of CCS by proposing optimized separation and recovery technologies for various CO_2 emission sources. It is also vital to establish new or improved technologies through scale-up studies and actual gas separation trials that closely mimic desired real-world applications. Furthermore, it is important to promote innovative technological development and to continually develop new energy-efficient, low-cost approaches to CCS.

*COP 21; The 2015 United Nations Climate Change Conference

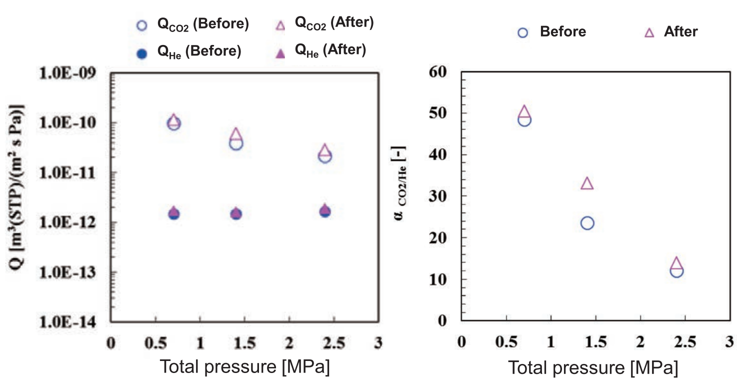

Fig. 12 : Separation performance of the membrane before and after the H_2S exposure test.

〈Conditions of H_2S exposure test〉

Pressure: 2.4 MPa; Temperature: 85℃ ± 3℃ ;

Gas composition: CO_2 (33%)+H_2S(500ppm)+N_2 balance (Relative humidity: ca. 80% RH)

Exposure period: 7 days

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Development of Geological CO_2 Storage Technology for Realizing Safe CCS at Scale

1. Introduction

Onshore CO_2 injection has been operational at scale in the Quest project in Alberta, followed by the Industrial CCS project in Illinois, USA. In Australia, the Gorgon project is coming on stream in 2018 and its injection rate will be 3.4-4 million tonnes per year. In Norway, a feasibility study is planned for an integrated full-scale project from CO_2 capture at multiple large emission sources to transport and offshore storage (Smeaheia). The US Department of Energy (DOE) selected two research projects for offshore storage in saline formations in the Gulf of Mexico in November 2017. They are probably aimed at leveraging a great amount of geological information acquired through the development of oil and gas fields and existing infrastructure such as pipelines there. Large-scale offshore CO_2 storage will draw more attention in near future.

The CO_2 Storage Research Group, as a member of the Geological Carbon Dioxide Storage Technology Research Association (GCS), works on the development of technologies for full-scale geological CO_2 storage suitable for Japan's geological features. Knowledge and understanding on marine environmental impact assessment for offshore formation storage is currently insufficient. In Europe, a research project called STEMM-CCS is being undertaken with the focus on the detection of leaked CO_2 and the assessment of impacts on marine organisms. The CO_2 Storage Research Group is aimed at establishing a methodology for detecting bubbles of leaked CO_2 physically with sonar technology. This could be alternative to a chemistry-based methodology based on measured amount of CO_2 dissolved in seawater sampled at designated offshore points at a storage site. In 2017, we demonstrated the feasibility of a methodology of detecting bubbles of leaked CO_2 with sonar through offshore testing.

In the development of microbubble technology, we attempt to improve storage efficiency and increase dissolution of CO_2 into formation water by injecting CO_2 via a special porous filter. We made a prototype of a borehole tool, which is the foundation for the realization of the concept, and test it at field.

The CO_2 Storage Research Group works on international collaboration and a survey of CCS development in the globe as well as the development of safety management technology for geological CO_2 storage. In addition, we work closely with the Tomakomai CCS demonstration project in pursuit of earlier CCS commercialization.

2. Major Research Themes and Outcomes

Under the framework of the Geological Carbon Dioxide Storage Technology Research Association (GCS), the CO_2 Storage Research Group works on "Development on Safety Management Technologies for Large-scale CO_2 Injection and Storage", "Technologies for Efficient Pressure Management and Utilization of Large-scale Reservoirs" and "Environment Setting for CCS Deployment and Standard Development" (Table 1) toward CCS commercialization. The major research activities and outcomes in the main research themes are outlined below.

Research Themes		Members Responsible
Development on Safety Management Technologies for Large-scale CO_2 Injection and Storage	Geological Modeling for Large-scale Reservoir, Evaluation of Reservoirs	RITE, JAPEX, Oyo
	The Development of Long-term CO_2 Monitoring Technologies	AIST
	The Development of Safety Management System for Injection	RITE, JAPEX, INPEX
	The Development of Methodologies for CO_2 Behavior Simulation and Long-term Prediction for Large-scale Reservoirs	RITE, AIST, Taisei, Oyo
	The Development of Fiber-optics-based Monitoring Systems for the Stability of Geological Formation and the Integrity of Abandoned Wells	RITE, AIST, JAPEX, INPEX
	The Development of a CO_2 Leakage Detection System and an Integrated System for Environmental Impact Assessment	RITE
Technologies for the Efficient Pressure Management and Utilization of Large-scale Reservoirs	The Development of Techniques to Optimizing a Layout of CO_2 Injection Wells and Pressure Management Wells	RITE, Taisei
	Improvement of Storage Efficiency by Applying Enhanced CO_2 Dissolution Technique	RITE, JAPEX
Environment Setting for CCS Deployment and Standard Development	The Development of CO_2 Storage Safety Management Protocol (IRP)	RITE
	Production of Best Practice Manuals by Incorporating Data from the Tomakomai Demonstration and Co-operation with Overseas Organizations	RITE
	The Improvement of Social Acceptance and Compatibility with International Standardization	RITE

Table 1 : Research Themes and the Roles of the Members in GCS

2.1. Development of Geological Modeling Techniques for Geological CO_2 Storage

Developing highly reliable geological models is fundamental but essential for geological CO_2 storage. Geological modeling has different objectives and requires different information at each CCS life cycle as shown in Figure 1. Modeling for CO_2 storage sites, in comparison with that for oil and gas production, usually have much few available data acquired at wells. Furthermore, data from cores, logging and seismic survey for the modeling have different special accuracy and coverage. It is, therefore, necessary to develop techniques for integrating these data to build a geological model. In this fiscal year, we worked on geological modeling techniques for a stage of site characterization. We examined a methodology to integrate data from different sources from the stratigraphycal viewpoint, aiming to extract as much as geological information from data acquired by, for example, logging from a limited number of wells.

FMI (Formation Micro-Imager) is a tool to measure fine scale resistivities with 192 image button electrodes. The shape of the histogram of the resistivities measured at each button has information about rock type and sedimentology in a resistivity domain. On the other hand, NMR (Nuclear Magnetic Resonance) tool is capable of measuring relaxation time distribution, which reflects the pore size distribution of the formation. The analyses of the distribution, therefore, provide

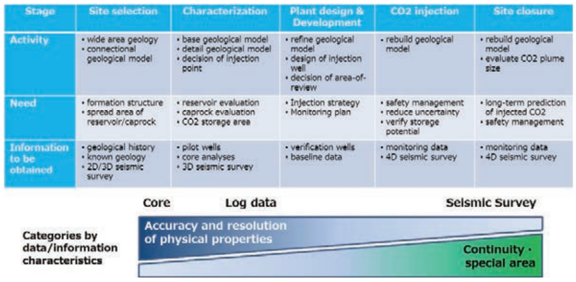


Figure 1 : Objectives of geological modeling for the different stages of the CCS life cycle

information regarding reservoir quality. We applied the two analyzing methods to the image logging data acquired at the Nagaoka site and interpreted the reservoir characteristics of the site. From the FMI data, we obtained a mean value and sorting of the resistivities at each depth. With the NMR data, we conducted a factor analysis of relaxation time distribution to examine the characteristics pore-size distribution in the reservoir, and concluded that it is the most reasonable to divide the reservoir into eight areas in terms of pore-size trends. Based on the results from the two approaches, we interpreted the Nagaoka reservoir. The green/yellow/red boxes in Figure 2 were interpreted as the facies with good/middle/poor reservoir quality in terms of, for example, pore space and permeability. The heterogeneity observed here are highly consistent with the injectivity shown in the most right part in Figure 2. We, therefore, concluded that the advanced log data analyses with appropriate resolution and coverage of log data provide useful information for the reservoir characterization for a geological CO_2 storage site.

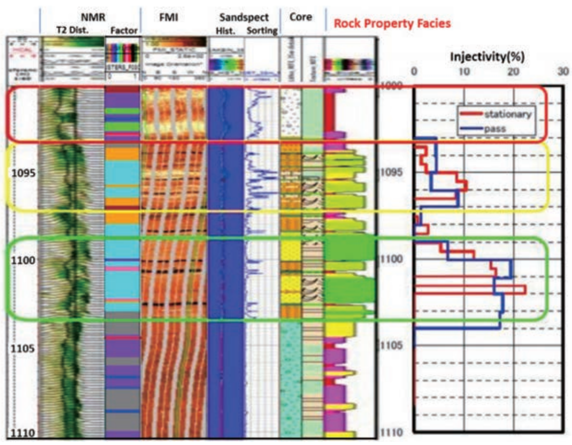


Figure 2 : Comparison between interpretation of the formation from the image data analyses and CO_2 injectivity

2.2. Development of Advanced Traffic Light System (ATLS) for the Safety Management of CO_2 Injection

There are concerns about earthquakes induced by formation pressure rise derived from CO_2 injection. This leads CO_2 injection sites to undertake various monitoring activities such as seismic monitoring. To leverage data acquired from these monitoring systems, the CO_2 Storage Research Group has been developing a management system for CO_2 injection, called the Advanced Traffic Light System (ATLS). For hot dry rock geothermal power or enhanced geothermal systems (EGS), a traffic light system (TLS) has been developed to label a level of safety with traffic light colors, i.e. green, yellow and red, judging by observed data of microseismicity. Our ATLS is a system equipped with advanced functions to utilize data from all monitoring systems such as seismic observation at a CO_2 injection site and also injection status there (Figure 3).

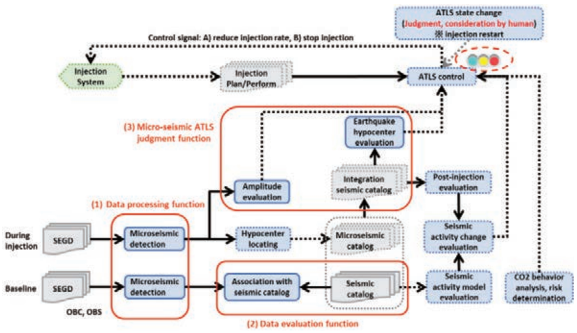


Figure 3 : ATLS Diagram

ATLS is designed to identify any irregularity as early as possible and feedback it to CO_2 injection operation. The system would enable the operator to control CO_2 injection rates in accordance with information from ATLS and to take countermeasures necessary against any identified irregularity. In Figure 3 that provides an overview of ATLS, the functions of which development have been completed are shown in the red boxes. The developments of the remaining functions are ongoing.

In order to utilize seismic monitoring data in ATLS, it is essential to detect all microseismicity (ultramicro earthquakes) and not to identify noise as an event in error. To identify microseismicity in observation data without errors, we have adopted not the conventionally-used Short Term Average/Long Term Average method (STA/LTA), but a new approach called the Sequentially Discounting AR model learning (SDAR). In this year, we have examined the applicability of the two methods, using observation data obtained by the Ocean Bottom Cable (OBC) in the Tomakomai CCS demonstration project. Figure 4 shows results of an analysis for earthquakes of which magnitude is less than M1 occurred within 100 km of OBC in a year. The results indicate that SDAR with parameters turned appropriately is capable of detecting seismic events more surely than STA/LTA. We plan to investigate its applicability to the analysis of other observation data acquired, for example, with borehole seismometers.

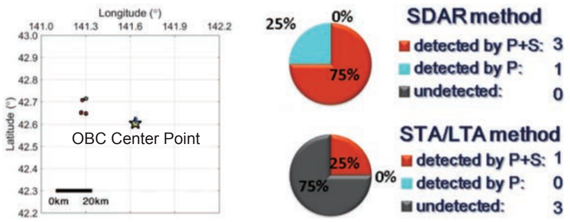


Figure 4 : Earthquake (< M1) detectability of the two methods and locations of observed earthquakes

2.3. Development of Technique for Monitoring Formation Stability during CO_2 Injection

From the viewpoint of geomechanical stability of formations at CO_2 injection sites, it is desirable to monitor not only the deformations of reservoir and cap rocks but also those of all formations from reservoir to the surface. As a technique for measuring all along the depth direction from the surface to deep subsurface, the Distributed Temperature Sensing (DTS) has been developed and commercialized in the oil and gas development sector. The CO_2 Storage Research Group has been developing a similar fiber-optics sensing technique but for measuring the deformations (strains) of formations all along a depth direction.

This year, we conducted a long-term observation test of this system to measure formation deformation all along the 300m-deep well which had optic fibers installed behind the casing. The strain measurements in every 20cm interval revealed deformation characteristics of sand-mud alternation and provided useful data for constructing geomechanical models.

During the long-term observation, we observed compressive strain changes several times which are attributable to groundwater pumping near the site. We then conducted a test to evaluate hydraulic properties of water-bearing formations by pumping groundwater from multiple wells around the site (Figure 5). Water pumping at a well 280m away from the fiber-installed well caused compressive strain changes at a depth of

200-230m in a water-bearing formation within a few hours after the beginning of the water extraction. Water pumping at another well 940 m apart in the same direction of the first test well caused compressive strains again, but their time delay and amplitudes were different from those in the first test. There were two note-worthy findings from the comparison of the results from the two tests: the depths of the maximum strains observed are different between two operations; and extensional strains were observed at the upper formation (80-140m deep) in the both tests. These observed results would be the first field data which are usable for coupling analyses between hydrology and geomechanics.

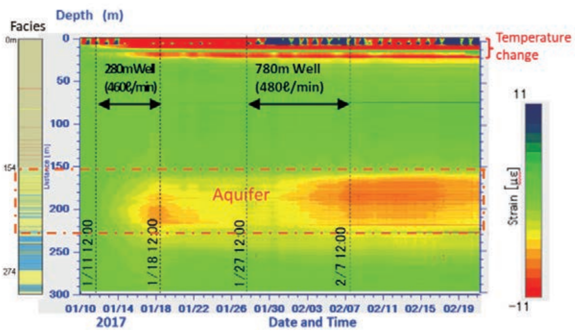


Figure 5 : Response of optical fiber during the water pumping tests

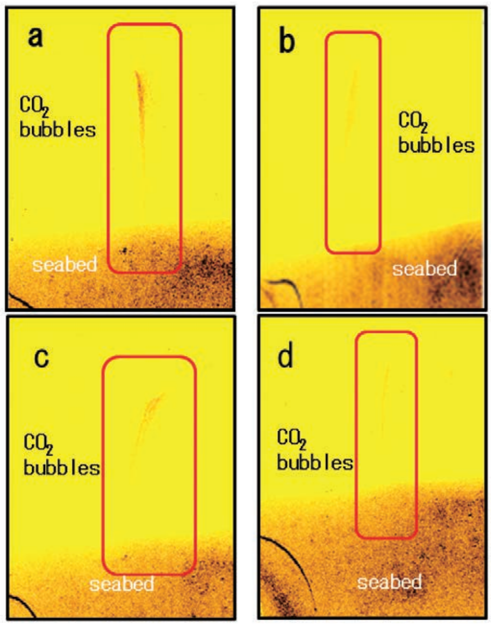
2.4. Development of Techniques for Detecting CO_2 Leaked into the Sea

Leaking of CO_2 stored in a deep geological formation under the seabed is deemed to be extremely improbable. Monitoring to verify that CO_2 is not leaking is, however, mandated to be ready just in case by the Act on Prevention of Marine Pollution and Maritime Disaster in Japan. Leaked CO_2 is to be in its gaseous phase under temperature and pressure conditions at the seabed of shallow sea so that CO_2 should go out as bubbles from the seabed if CO_2 leaks. Monitoring to confirm that there are no bubbles from the seabed can be, therefore, an option for leakage monitoring.

In order to detect bubbles in the sea, sonar is widely used and its applicability has been demonstrated to observe bubbles of gas such as methane. The CO_2 Storage Research Group has been developing a methodology to use side-scan sonar (SSS), which is applicable to wide area scanning, for detecting CO_2 bubbles. SSS is a tool to produce images of objects in the water column and topographic feature of the seabed by emitting sonic pulses from the both sides of SSS to the vertical section perpendicular to the direction of its travel, and receiving its reflection. In the preliminary experiment conducted in the previous year, we had shown that SSS towed under water by an observation ship (Fig. 1) is capable of detecting CO_2 bubbles in the sea.

We had also shown that knowledge on SSS detectability for bubbles of low-soluble gas such as air and methane is not applicable to that for CO_2 bubbles. It is much more difficult to detect CO_2 bubbles with SSS than air bubbles because CO_2 bubbles are far easier to dissolve into sea water. Therefore, to use SSS in monitoring at offshore CO_2 storage sites, it is necessary to clarify the detectability of SSS for CO_2 bubbles and its suitable operational conditions. The information we need includes detectable minimum rates of CO_2 leakage; maximum distances between SSS and detectable CO_2 bubbles; suitable speeds of the ship; and suitable depths of SSS towing.

In FY2017, we conducted a demonstration test for SSS to detect CO_2 bubbles released from the seabed at a depth of ~30m, equivalent to that of the offshore storage site in the ongoing Tomakomai CCS demonstration project. We observed the released CO_2 bubbles under various conditions in terms of bubble re-



a) CO_2 bubbles with a diameter of 10 mm released at 5000 ml/min, observed at 22.5 m above the seabed towed at a speed of 3.5 knots.
b) CO_2 bubbles with a diameter of 10 mm released at 1000 ml/min, observed at 26.9 m above the seabed towed at a speed of 6.3 knots.
c) CO_2 bubbles with a diameter of 10 mm released at 500 ml/min, observed at 24.8 m above the seabed towed at a speed of 3.5 knots.
d) CO_2 bubbles with a diameter of 5 mm released at 500 ml/min, observed at 22.9 m above the seabed towed at a speed of 3.3 knots.

Figure 6 : Images of CO_2 bubbles detected with SSS

lease (release rates and bubble sizes) and observation (depths of SSS operation, the speed of the ship and distances between the release point and SSS). Through the experiment, we concluded that SSS towed at 2.5-5.5 knots has the capability of detecting CO_2 bubbles released at a rate of 500-5000 ml/min (Fig. 6).

2.5. Enhanced CO_2 Dissolution Technique

The CO_2 Storage Research Group, in collaboration with Tokyo Gas Co., Ltd., has been developing a technology to store CO_2 in geological formations after turning CO_2 into microbubbles through a special filter. Figure 7 shows behavior of microbubble CO_2 injected in a 30cm-long porous sandstone sample visualized by an X-CT scanner. The warmer colors represent CO_2 distribution in pore space. Microbubble CO_2 injection is superior to the conventional injection in terms of storage efficiency because of higher CO_2 saturation rates.

In order to make the microbubble injection technique technically viable, we have been developing a borehole tool applicable to actual CO_2 injection sites in conjunction with JAPEX. In this fiscal year, we installed a prototype of the borehole injection tool in a 250m-deep well. Injecting N_2 and CO_2, we investigated microbubble CO_2 generated in a shallow formation. We plan to improve the injection tool to make it applicable to a higher temperature and higher pressure environment. We also plan to look into CO_2 storage mechanisms to make microbubble technology more viable.

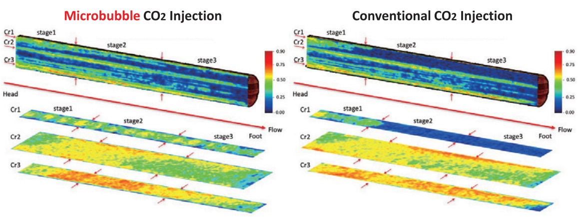


Figure 7 : Difference in CO_2 distributions due to injection methodologies

2.6. CCS Technical Best Practice Manual

CO_2 injection at a scale of one million tonnes per year was commenced in the Quest project in Canada, followed by the Industrial CCS project in the USA. In Japan, the injection of 100,000 tonnes per year was initiated in the Tomakomai CCS demonstration in 2016, aiming at injecting CO_2 of 300,000 tonnes in total.

Anticipating CCS deployment in Japan and global deployment of Japan's CCS technology, the CO_2 Storage Research Group has been compiling a CCS technical best practice manual as a technical reference for CCS developers to undertake a CCS project.

The best practice manual consists of eight chapters: project planning; site selection; site characterization; development planning; design and construction; operation and management; site closure; and post-closure management.

We completed a draft version of Chapter 1 (project planning) to Chapter 4 (development planning) in 2015 They were compiled, based on outcomes from Japan's first CO_2 injection test conducted in Nagaoka, Niigata from 2003 to 2005, and referring to CCS projects and technical reports in other countries such as USA and EU members. We are currently working on Chapter 5 (design and construction) to Chapter 8 (post-closure management). In this work, we are also referring to outcomes from the Tomakomai demonstration project and latest information on overseas CCS projects, for example, in Canada and USA.

We plan to cover CO_2 transport, CO_2 compression, design and construction of wells and equipment commissioning in Chapter 5; operation, maintenance and management of facilities for CO_2 injection operation, monitoring and incident response in Chapter 6; verification of well integrity, well plugging and abandonment, and planning for post-closure management in Chapter 7; and monitoring during the post-closure period, verification of safe storage, and status of post-closure management in CCS projects in other countries.

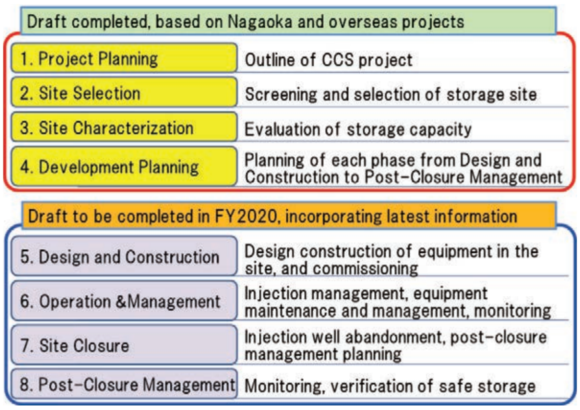


Figure 8 : Structure of CCS technical best practice manual

2.7. International Collaboration and Survey of CCS Development in the world

In addition to contribution to CCS deployment, the CO_2 Storage Research Group surveys CCS development in the world. The highlights in global CCS development in 2017 are summarized below, touching upon works done by international organizations.

In early 2017 in the USA, there were two large-scale CCS projects became fully commissioned: the Petra Nova project, where CCS was retrofitted to an existing coal-fired power plant; and the Illinois ICCS project, where biomass-derived CO_2 is injected into a deep saline formation. The year therefore started with the good news, but concerns about deaccelerating CCS deployment was gradually grown. The new US administration announced in March their intention to withdraw the CO_2 emission performance standards, which had a potential of driving CCS deployment in the power sector, and then proposed drastic cut in CCS R&D budget for the next fiscal year in May. In June, CO_2 capture from ignite gasification for power generation in the Kemper project was cancelled by a decision to convert the power plant into a gas combined cycle plant due to a problem in gasification. But the concerns were dispelled. The CCS budget cut was limited to 7% by the Congress. The DOE secretariat proposed new initiatives for CCS as well as nuclear in the Clean Energy Ministerial (CEM) meeting in Beijing in June. He also took the initiative to compile a communique to endorse supports to CCS in the ministerial meeting of the Carbon Sequestration Leadership Forum (CSLF) in Abu Dhabi in December.

In Europe, Norway has taken the strong leadership in the CCS community. This year, there were temporarily rising concerns that their efforts would be phased out. This was because the government announced 94% cut for the CCS project for three industrial sources in the government budget for the next financial year. But it was turned out that the continuation of the project will be decided by the parliament in mid-2018 and that when continuation is agreed the budget would be revised to a sufficient level by the parliament. On the premise of the project realization, they have a vision to receive CO_2 for offshore storage in their territory from their neighboring countries. Essential for this would be the implementation of the amendment of the London Protocol for enabling CO_2 export for the purpose of CO_2 storage under the seabed. In 2017, Finland became ratified the Protocol but the number of the ratified countries is still far below that required.

In the UK, the government presented their CCUS strategy for the first time after withdrawal of budgets for large-scale CCS demonstration projects in 2015 by releasing the Clean Growth Strategy in October. In the strategy, the deployment of CCUS is set out to be after 2030 on the assumption that CCS costs would be reduced to a proper level. Detailed pathways of CCS deployment will be presented by the end of 2018. The ROAD project in the Netherlands was cancelled by an announcement made by its proponents. It was a CCS project for coal-fired power and the only promising initiative for a large-scale CCS project in the EU region. On the other hand, the Dutch Government released ambitious climate goals for 2030 in October. The proposed measures to meet the goals include CO_2 emission reduction of 20 million tonnes per year by CCS in the industrial and waste incineration sectors. The government plan raised expectation for CCS realization in the Netherlands, but there have also been skeptical views for the implementation of the government plan. Europe has been inclined to promote CCS clusters with multiple industrial sources at a scale of 100,000 tonnes-CO_2 per year. There has also been also a trend to strengthen exploration of CO_2 utilization, aiming at giving added-values to captured CO_2. Technical study reports on CCS published by the IEA Greenhouse Gas R&D Programme (IEAGHG) in 2017 mostly looked into industrial sources such as refinery, hydrogen production and natural gas processing. Reports on CCS for power include a study on flexibility as an added value which is not evaluated monetarily.

Inputs to the above-mentioned CSLF ministerial meeting includes recommendations on reasonable and practical regulations for geological CO_2 storage. These were compiled, based on lessons learned from permitting process in seven projects, including Sleipner, ROAD, Peterhead, Quest, Decatur, Tomakomai and Otway, by the initiative of the CO_2 Storage Research Group. The original report is available on the CSLF web site.

Inorganic Membranes Research Center

Shin-ichi Nakao
Director,
Chief Researcher

[Key Members]

Ryoichi Nishida, Deputy Director, Chief Researcher
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Kunio Sakuyama, concurrently with the Research & Coordination Group

Research and Development of Innovative Environmental and Energy Technologies that Use Inorganic Membranes and Efforts toward Practical Use and Industrialization

1. Introduction

Inorganic membranes, such as silica membranes and zeolite membranes, have features, such as heat resistance and environmental resistance, in addition to their high separation performance, and are expected to be applicable to various applications. They have the potential to achieve significant energy savings compared to conventional separation and purification methods, such as the distillation or adsorption method, and they are also being developed for CO_2 capture applications or hydrogen separation and purification applications essential for hydrogen society construction. Therefore, they attract great attention as an environment and energy technology that contributes to conservation of the global environment. However, their practical application has been limited to some uses, such as dehydration of alcohol, and future efforts to promptly commercialize and industrialize the innovative environmental and energy technologies using inorganic membranes are required.

The Inorganic Membranes Research Center (IMeRC) established in April 2016 is promoting activities with research and development and industrial collaboration as the bilateral aim for the early commercialization and industrialization of innovative environmental and energy technologies using inorganic membranes. The organization is also composed of a research division and an industrial collaboration division. The research division is developing technologies for hydrogen separation and purification and CO_2/CH_4 separation; separation of organic compounds, such as hydrocarbons; and other research fields using silica membranes, zeolite membranes, palladium membranes with each having excellent features as core technologies. In the industrial collaboration division, we established the Industrialization Strategy Council with four inorganic separation membrane support manufacturers and twelve user companies to share the vision of manufacturers and user companies and to plan joint research. Members have meetings regularly and are promoting activities, such as working groups, for actively establishing national projects.

In fiscal 2017, we achieved successes, such as developing a silica membrane with the world's best hydrogen separation performance, in the development of a membrane reactor for methylcyclohexane (MCH) dehydrogenation as an efficient transportation and storage technology for hydrogen. Also, remarkable progress has been made for CCU (carbon capture and utilization) technologies, and our technology has been adopted for a new NEDO project. In addition, at the Industrialization Strategy Council, activities, such as working groups for establishing a national project, have been in full-scale operation. In this paper, we will introduce the main results and future prospects of the research department, such as the development of an MCH dehydrogenation membrane reactor and effective technology for the use of carbon dioxide, and activities of the industrialization strategy council.

2. Development of Silica Membrane Reactors for a Hydrogen-Based Society

The development of efficient hydrogen transportation and storage methods is essential for building a hydrogen-based society. As a promising method, the concept of an energy carrier is proposed, where hydrogen is converted into chemical hydrides that can be efficiently transported and stored, such as methylcyclohexane and ammonia. Then, the chemical hydride is transported and stored to take out hydrogen at a place and time where it is required. (Figure 1)

carrier and the development of a dehydrogenation system using inorganic hydrogen separation membranes for organic chemical hydrides in collaboration with Chiyoda Corporation. In this project, further improvements in hydrogen separation performance, development of the longer silica membranes, single tubular membrane reactor development for dehydrogenation and purification from methylcyclohexane, and bench-scale dehydrogenating apparatus development consisting of several membrane reactors have been carried out.

In the development of hydrogen separation performance, both the higher hydrogen permeation (hydrogen permeance) rate and higher blocking property for

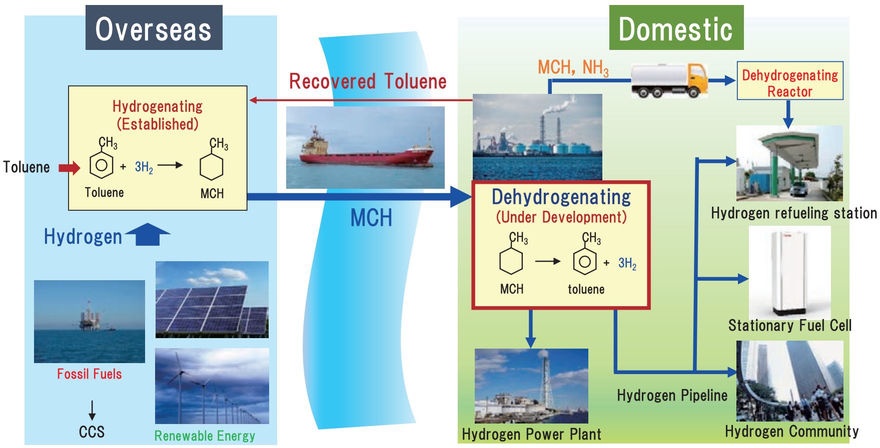


Figure 1 : Energy Carrier

The technology for the conversion of hydrogen to methylcyclohexane or ammonia has already been established as a mass production technology, but an extraction technology for hydrogen has not yet been developed as a definitive method. An excellent catalyst for dehydrogenation has recently been developed, but a technology for highly pure hydrogen to be supplied to a fuel cell has not yet been established.

IMeRC develops membrane reactors using a silica membrane, which is prepared by counter-diffusion chemical vapor deposition (CVD), for the purpose of the development and commercialization of the efficient and stable production of highly pure hydrogen from methylcyclohexane for small- to medium-sized customers, such as commercial establishments and office buildings.

This work is funded by the NEDO Advancement of Hydrogen Technologies and Utilization Project for the analysis and development of hydrogen as an energy

the other molecules (separation factor $\alpha = H_2$ permeance/SF_6 permeance) are required. It is well known that the compatibility of the high permeance and the high α is hard, and those are in trade-off relationships. To break the trade-off relationships, we tried to attribute the phenomena to individual factors to reach the highest performance of H_2 permeance > 3.5×10^{-6} mol/(m^2・sec・Pa) and separation factor α 63,000 (Figure 2).

In the development of the longer silica membrane, a 500 mm length of silica membrane was developed. As described above, in order to get good performance from a silica membrane, it is necessary to achieve both permeance and a separation factor at a high level. For that purpose, there needs to be a technique to make pores homogeneous with a molecular size of about 3-5 Å, without pinholes, over 500 mm. As a result of a multifaceted investigation assuming the correlation and mechanism of film formation and the formed film, we succeeded in forming a high performance silica film of

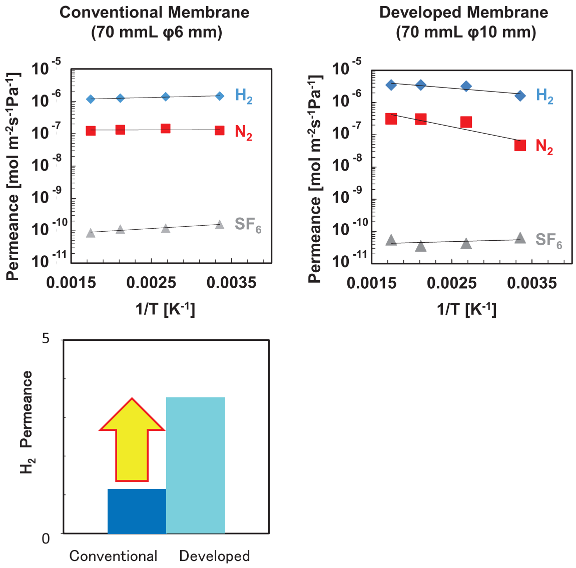


Figure 2 : High Performance of the Obtained Membrane

500 mmL equivalent to a 200 mmL silica membrane, and a further length improvement up to 500 mm, which would be applied to the industrial membrane reactor, was achieved by improving the CVD fabrication apparatus. In FY 2016, we also made certain achievements, such as further improvement of the hydrogen separation performance of silica membranes, compared with the previous one (Figure 3).

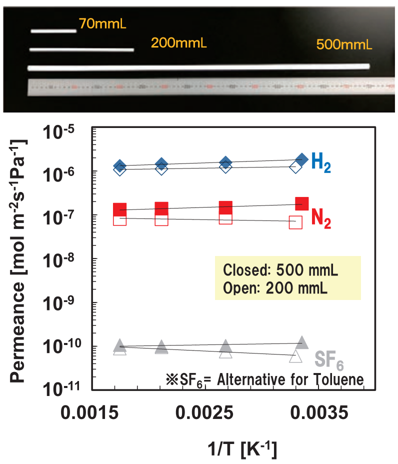


Figure 3 : Developments of the Longer Silica Membrane

The membrane reactor is a reactor in which the equilibrium shift effect can be obtained, and conversion can be improved by selectively removing the product from the reaction field using an inorganic separation membrane.

We studied the MCH dehydrogenation reaction using a tubular single membrane reactor, which was experimentally confirmed a clear equilibrium shift effect, and demonstrated its effectiveness (Figures 4, 5).

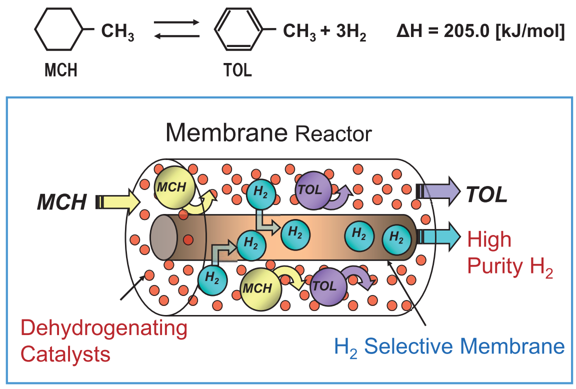


Figure 4 : Diagram of a tubular single membrane reactor

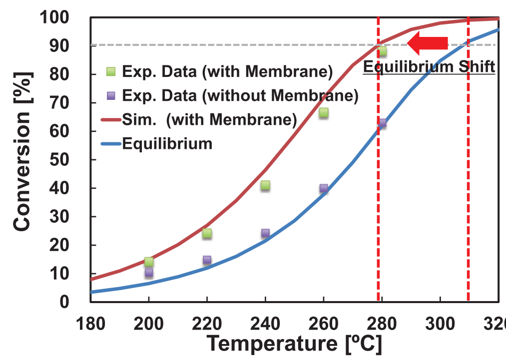


Figure 5 : Equilibrium shift in a membrane reactor

In FY 2017, we are studied the tubular single membrane reactor when the pressure on the reaction side increased. Up to now, because the supply side pressure was limited to 300 kPaA by the High Pressure Gas Safety Law, the pressure on the permeate side was reduced, but because of the deregulation in November 2016, it became possible to further increase the supply pressure. We started investigating whether it was possible to remove the pump and set the permeation side to normal pressure.

As a result of the simulation, even when the supply pressure is set to 500 kPaA / permeation pressure 105 kPaA, the same conversion would be obtained, as the standard condition with the supply pressure of 300 kPa A / permeation pressure 25 kPaA (Figure 6). This result indicates that there is a high possibility of reducing facility costs, such as depressurization pump removal. Currently, we collect basic data by experiment using a tubular single membrane reactor.

In the development to modularize the membrane reactor, we built a reactor consisting of seven silica membranes 200 mm in length and accumulated operating data. Based on the obtained data, improvement

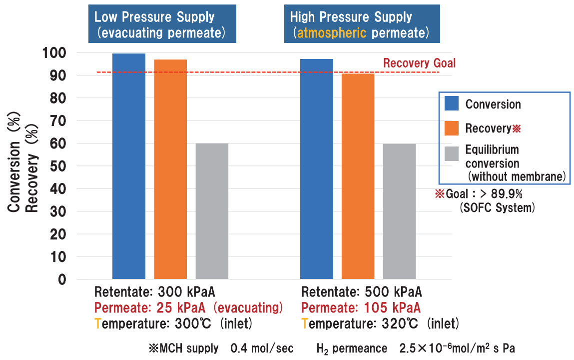


Figure 6 : Simulation Results at High Pressure Supply

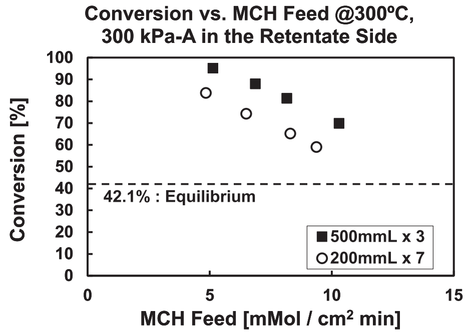


Figure 8 : Operation Result of the Bench-scale Membrane Reactor

of the reactor structure was promoted, and in FY 2017, we designed and fabricated a bench-scale apparatus composed of three 500 mm length silica membranes, which are estimated to be the practical sizes, and various engineering data were collected with this bench-scale apparatus (Figure 7).

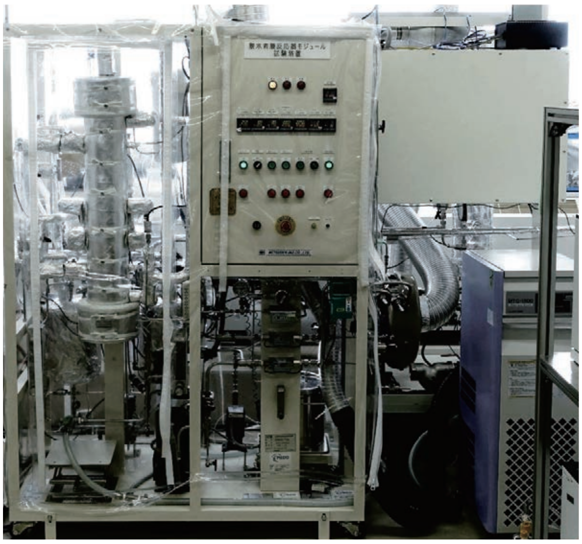


Figure 7 : Bench-scale Membrane Reactor

As a result, it was verified that a significant equilibrium shift was confirmed even with the 500 mm length silica membrane and that a conversion rate greatly exceeding the equilibrium conversion rate of 42.1% was obtained (Figure 8). In the future, we plan to further improve the equipment for scaling up, continue collecting engineering data, and achieve practical development.

3. Development of CCU Technology

In October 2017, RITE, JFE Steel Corporation, the Institute of Applied Energy (IAE), INPEX Corporation, and Hitachi Zosen Corporation collaborated in the technological development of next generation thermal power generation, next generation thermal power development of power generation infrastructure technology, and the development of technology for effective utilization of CO_2 as a project of the New Energy and Industrial Technology Development Organization (NEDO).

Thermal power generation using coal, which is a natural resource excellent in supply stability and economic efficiency, is positioned as an important power source that will contribute 26% of the domestic electricity supply amount in fiscal year 2030 in terms of long-term energy supply and demand forecast. However, coal-fired power plants emit comparatively large volumes of CO_2, and CO_2 utilization (CCU: carbon capture and utilization) is being studied after separation and recovery. Although large-scale processing of CO_2 is difficult at the present time, it is also possible to create profits and value by manufacturing valuable resources utilizing renewable energy. In the future, it is necessary to utilize the advantages of coal-fired power generation mutually by utilizing renewable energy in the attempt to ensure the stable supply of electricity and a reduction in CO_2 emissions in our country.

Therefore, in this project, we aim to establish future promising CCU technologies in anticipation of fiscal year 2030 and beyond and can further grant industrial competitiveness to Japan's excellent clean coal technology (CCT). We plan to establish a comprehensive evaluation of CCU technologies for the effective use of CO_2 in the product manufacturing process and system with the aim of establishing CCU technology. We plan to investigate CO_2 separation and recovery technology and effective utilization technology with the cooperation of the chemical research group and the planning research group.

4. Development of pure silica CHA type zeolite membrane

Thirty or more types of aluminosilicate zeolite membranes have been reported so far; however, pure silica zeolite membranes have only reported LTA membranes in addition to MFI and DDR. We succeeded in synthesizing two types of pure silica zeolite membranes, which were not reported in the past (Si-CHA membrane (RITE-1), and Si-STT membranes (RITE-2), patent pending). As a result of the investigations, we found that Si-CHA zeolite membranes having a ① three dimensional structure, ② high pore volume, and ③ oxygen 8 - membered ring pore can attain both water vapor resistance and high CO_2 permeance.

As shown in Figure 9, the CO_2/CH_4 separation performance of the Si-CHA membrane shows a CO_2 permeation rate of 4.0×10^{-6} mol/m²sPa or more and a CO_2/CH_4 permeation rate ratio of 100 or more. It shows better separation performance than the previously reported zeolite membranes. In addition, even when exposed to water vapor, there is no change in permeation performance, and since it has water vapor resistance, it is considered to be a membrane structure more suitable for practical use. To further increase the separation performance of Si-CHA membranes, it will be necessary to optimize the module structure and the method of introducing the supply gas to the module.

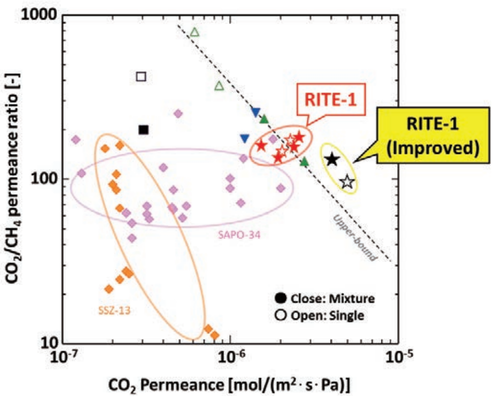


Fig. 9 : CO_2/CH_4 separation performance of Si-CHA membrane

This newly developed Si-CHA membrane has high potential and the capability for various separation applications besides CO_2 separation applications. We have confirmed the usefulness as a hydrogen separation membrane to date. Currently, we are studying long modularization aiming at commercialization and the separation process using these membranes.

5. Activities and efforts toward commercialization and industrialization

The Industry Collaboration Section of the IMeRC established the Industrialization Strategy Council together with manufacturers of separation membranes, support manufacturers, and user companies on April 15, 2016.

As of January 2018, sixteen selective membrane and support manufacturers and user companies participate in this Council. Our goal is to establish an inorganic membrane industry that contributes to innovative environmental and energy technologies by promoting a common vision for manufacturers and user companies, as well as a joint research plan involving national projects and other initiatives.

To realize this goal, we are promoting various activities, which include the following:

a) Conducting needs and seeds matching meetings toward the practical use of innovative environmental and energy technologies that use inorganic membranes, and the establishment and operation of a research group in which a future roadmap will be prepared

b) Planning joint implementation projects funded by the government and NEDO

c) Acceptance of researchers from council members to the Research Section of the IMeRC and Implementation of training workshops

d) Offering technical guidance from the IMeRC advisory board and Research Section

e) Hosting exclusive technology seminars for council members

f) Offering exclusive supply services (“Needs and Seeds Technology Information”) to council members

As for the Research Group activities, after careful examination and selection of the theme in the previous fiscal year, the following three Research Groups were set up in November 2016, and they started activities.

a) CO_2 Separation Research Group

b) Hydrogen Production Research Group

c) Common Base (Reliability Evaluation Method) Research Group

In fiscal 2017, we conduct surveys and studies through activities in both the Research Group meeting and its subsidiary research workshop (each Research Group had six to seven meetings, respectively, up-to the end of 2017), and they are creating a roadmap for practical use and preparing for projects funded at government expense. All three Research Groups are aiming for projects funded by government to start in FY 2019.

In addition, technology seminars for council members are held four times annually (three times as of the end of 2017), in which the latest R&D trends, needs, and seeds are introduced in a total of 10 lectures given by IMeRC advisory board members, member companies, and the IMeRC with active discussions among participants. The participants are pleased to take part in the seminars, not only because they can acquire knowledge of inorganic membranes, which is useful for promoting the practical use and industrialization of the membranes, but also because they have the opportunity to interact with other frontline researchers from member companies and organizations.

In October 2017, a two-day training workshop was held at the graduate school of Yamaguchi University. Lectures and experiments in membrane formation methods related to inorganic membranes and guidance on analytical and evaluation methods for prepared membranes were provided in the workshop. Ten young researchers from seven companies took part in the workshop. They were able to learn the actual inorganic membrane experiment method and to have valuable experiences (Figure 10).

Figure 10 : Exclusive training workshop for young and middle-class researchers at Yamaguchi University

We also conduct patent and literature surveys related to the seminar lecture content, and periodically provide council members with Needs and Seeds Technology Information, which has special comments from the IMeRC in the abstract.

In addition, we support the various activities of council members toward promoting the practical use and industrialization of inorganic membranes by providing a summary of the remarkable lectures with RITE comments on the 14th International Conference on Inorganic Membranes (ICIM 2016) and the 7th International Zeolite Membrane Meeting (IZMM 2016), which are international conferences related to inorganic membranes.

6. In conclusion

As mentioned above, in FY 2017, the second year of the establishment of the IMeRC, we are steadily achieving results from the research and development necessary for hydrogen production, transportation, and storage. In the CCU technology field, our technology has been adopted for a new NEDO project. Activities toward commercialization and industrialization of research and development results are also in full-fledged operation. We may be able to say that the foundation of our center is solidifying. We would like to continue working diligently to become a core organization leading the development and practical application of inorganic membranes in the world in the future.

Research & Coordination Group

IPCC Workshop and Symposium on Global Warming Countermeasures

As the Paris Agreement entered into force in November 2016, the writing and review process of the Special Report on the impacts of Global Warming of 1.5℃ (SR1.5) has been underway. With respect to the 6th Assessment Report (AR6) whose outline has been approved in September 2017, authors were selected in February 2018, and then the writing and review process will be started toward its completion in 2022. On this opportunity, the IPCC Workshop and Symposium, with the title "To Think about Measures for Mitigation of Global Warming -Activities and Perspectives in the IPCC's 6th Assessment Cycle-", were respectively held under the sponsorship by METI and the co-sponsorship by RITE in November 2017. Participants were about 290 in total.

(1) IPCC Workshop

Date : 24 November, 2017
Venue : Main Tower in Shinagawa Prince Hotel (Tokyo)
Program :

- Keynote lecture "Key findings from the WG III Fifth Assessment report and plans for AR6"
  Jim Skea (Co-chair of IPCC Working Group III)
- Lecture-1 "On CO_2 zero emission technology -A request to IPCC AR6 WG III-" Yoichi Kaya (RITE)
- Lecture-2 "New approach on carbon price comparison -Old but new indicator-" Junko Ogawa (IEEJ)
- Panel Discussion
  "Expectations, issues regarding IPCC and how to tackle global warming"
  Moderator, Mitsutsune Yamaguchi (RITE)
  Panelists,
  Jim Skea (IPCC), Ayumi Onuma (Keio University)
  Junko Ogawa (IEEJ), Taishi Sugiyama (CIGS)
  Tsutomu Kajino (TOYOTA Central R&D Labs., Inc.)

Following the keynote lecture of Professor Jim Skea on principal findings from AR5 and the aspirations and challenges to AR6, President Kaya and Ms. Ogawa presented key elements and important issues which should be contained in AR6. In addition, a panel discussion on expectations, issues regarding IPCC and how to tackle global warming was also held by Professor Jim Skea and some Japanese experts of various fields.

(2) IPCC Symposium

Date : 29 November, 2017
Venue : TKP Gardencity PREMIUM Kyobashi (Tokyo)
Support : Institute for Building Environment and Energy Conservation (IBEC)
Program :

- Keynote lecture "New elements of assessment in the IPCC's Sixth Assessment cycle with focus on the WGIII contribution" Diana Ürge-Vorsatz (Vice-chair of IPCC Working Group III)
- Lecture-1 "Deep decarbonization in buildings sector towards 2050" Shuzo Murakami(IBEC)
- Lecture-2 "Business sectors'efforts and expectation for IPCC" Hiroyuki Tezuka (Keidanren)
- Panel Discussion
  "Expectations, issues regarding IPCC and how to tackle global warming"
  Moderator, Mitsutsune Yamaguchi (RITE)
  Panelists,
  Diana Ürge-Vorsatz (IPCC), Keigo Akimoto (RITE)
  Jun Arima (The University of Tokyo)
  Yumiko Iwafune (The University of Tokyo)
  Hiroyuki Tezuka (Keidanren)
  Takashi Hongo (MITSUI & Co. Global Strategic Studies Institute)

The keynote lecture on mitigation strategies in an urban, the importance of AR6 affecting to policy makers, and new elements of assessment in AR6 cycle was presented by Professor Diana Ürge-Vorsatz. Then, President Murakami and Mr.Tezuka gave lectures respectively on the current status and future prospects of decarbonization in buildings sector, and efforts and expectation for IPCC in business sectors. In the latter panel discussion session, a meaningful discussion was implemented with many questions and comments from participants.

Research & Coordination Group

Signing Ceremony of Donation Sponsored by Aramco Asia Japan

RITE was selected as a recipient of the donation sponsored by Aramco Asia Japan K.K. (AAJ), the Japanese entity of Saudi Aramco, the world's largest state-owned oil company of the Kingdom of Saudi Arabia, and a signing ceremony for the agreement of the donation was held at the office of AAJ in Marunouchi, Tokyo, on Friday August 4th.

This donation is intended to contribute to the environmental protection and the research activities concerning environment, and this time it was awarded to support the research and development activities of innovative technologies to mitigate global warming such as CCS (Carbon dioxide Capture and Storage) that RITE conducts. At the signing ceremony, Mr. Anwar Hejazi, Representative Director of AAJ, stated his expectations toward further advancement of our research, and Mr. Yoichi Kaya, President of RITE, expressed words of gratitude in response describing RITE's willingness to promote its research by utilizing the donation, and both parties signed the agreement.

Saudi Aramco, the main body of the enterprise, also shows a great interest in our technologies for mitigating global warming including CCS, and several research engineers and experts came from Saudi Arabia to visit our research facilities a few years ago.

We would like to take this opportunity to promote further information exchange and strengthen cooperative relationship with Saudi Aramco and AAJ.

Research & Coordination Group

Innovative Environmental Technology Symposium 2017

~Development and Promotion of Innovative Technologies for Long-term Strategy to Mitigate Global Warming~

This symposium is an annual event that RITE hosts to present our research progress and achievements. This year we were honored to invite Mr. Kishimoto, Deputy Director-General for Environmental Affairs, METI, to deliver a speech on the outcomes of COP23 and the direction of Japan's long-term strategy for mitigating global warming. After that, Prof. Yamaji, Director-General of RITE, gave a keynote speech on the measures and the challenges to generate a drastic innovation of energy and global warming mitigation technologies toward zero emission of CO_2 in the future, followed by the presentations from each research group and center on the latest achievements and the future outlook of our R&D activities. In the poster session, which was held for three hours this year, the participants and the researchers of RITE had an active exchange of ideas.

Program

- Guest speech: Current status and future prospects of global warming issue
  Michihiro Kishimoto, Deputy Director-General for Environmental Affairs, METI
- Keynote speech: Role of innovation in long-term measures to mitigate global warming
  Kenji Yamaji, Director-General
- Actions toward practical application of CO_2 separation and capture technologies
  Shin-ichi Nakao, Group Leader, Chemical Research Group
- Research and Development toward deployment of large-scale CO_2 geological storage technologies
  Ziqiu Xue, Group Leader, CO_2 Storage Research Group
- Actions toward practical application of inorganic membranes as innovative environmental and energy technologies
  Shin-ichi Nakao, Director, Inorganic Membranes Research Center
- Development of biorefinery production technology toward realization of low-carbon society
  Masayuki Inui, Group Leader, Molecular Microbiology and Biotechnology Group
- Evaluation on emission reduction efforts of NDCs and policies by country under the Paris Agreement
  Keigo Akimoto, Group Leader, Systems Analysis Group
- Trend of technologies toward zero emission of CO_2
  Hideaki Tsuzuku, Director, Group Leader, Research & Coordination Group

Systems Analysis Group

FY2016 ALPS International Symposium Policies and Measures by Nations under the Paris Agreement, and the Challenges

The Paris Agreement entered into force in November 2016. Under a new framework of the Agreement, almost all nations would submit their emission reduction targets for mutual review, and issues are becoming elicited for each nation. In order to help obtain better perspectives of future response measures with better understanding on nations' state, ALPS International Symposium was held to disseminate the research achievements of the project and also to present lectures by eminent specialists. One of the key messages was the importance of working out better strategies toward climate change, in line with sustainable development with various uncertainties (scientific, economic, societal and political) taken into account.

Date 7 February 2017
Venue Toranomon Hills Forum (Tokyo)
Organization RITE
Co-organization Ministry of Economy, Trade and Industry
Number of participants 298
Program

- Grand transformation toward sustainable future for all
  Nebojsa Nakicenovic, Deputy Director General/ Deputy CEO, IIASA
- Principles of a response strategy to the climate risk
  Kenji Yamaji, Director-General, RITE
- How to reach the goals of the Paris Agreement - Experiences from Germany and Europe
  Georg Erdmann, Professor, Berlin University of Technology
- Frozen: UK climate change policy in the age of Brexit
  Pilita Clark, Environment Correspondent, Financial Times
- Preliminary assessment of potential policy options to meet Saudi Arabia's carbon mitigation goals under the Paris Accord
  Douglas Cooke, Director, KAPSARC
- The Trump administration and U.S. climate policy
  Takahiro Ueno, Senior Research Scientist, Central Research Institute of the Electric Power Industry
- Achieving long-term UK emissions reductions target in the light of short-term political and societal challenges
  Neil Strachan, Professor, University College London
- Evaluations on emission reduction efforts of nationally determined contributions under the Paris Agreement
  Keigo Akimoto, Group Leader, Systems Analysis Group, RITE

Systems Analysis Group

Winning of Best Paper Award and Kaya Award of Japan Society of Energy and Resources

Dr. Oda, Senior Researcher, and Dr. Gi, Researcher of the Systems Analysis Group, have been awarded 2017 Best Paper Award and Kaya Award of Japan Society of Energy and Resources respectively.

Best Paper Award is conferred on an author of the research paper, which was published in the Journal of Japan Society of Energy and Resources and made a significant contribution to a development of science of energy, resources and environment. Kaya Award is conferred on a young researcher who presented a paper at the conference of the Society and recognized its excellent accomplishment.

Dr. Oda was awarded Best Paper Award for his research paper "Study on Coal Power Plant and Carbon Capture and Storage Investments based on Real Options", in which he analyzed investment risks for business operators to invest in coal-fired plant (with CCS) and gas-fired plant (with CCS) under uncertainties of future LNG prices and carbon prices, utilizing Real Options method. It highlighted that predictable and stable carbon price is desired in order to promote investment to CCS under uncertainties.

Dr. Gi was awarded Kaya Award for his research paper "Cost-Effective Energy Systems in Consideration of Climate Change Mitigation and Ambient PM2.5 Concentration Reduction", which quantitatively estimates co-benefits derived from two different policies; climate change mitigation and air pollution reduction, by analyzing cost- effective energy systems. It indicated areas with greater co-benefits, measures that bring co-benefits, impacts on energy systems, trade-offs and cost-effective measures.

The Awarding ceremony was held after the Annual Meeting of the Society on 7th June of 2017, where testimonials were bestowed on Dr. Oda and Dr. Gi.


Dr. Oda


Dr. Gi

Systems Analysis Group

COP23 Side Event
Towards Sustainable Climate Change Response Measures under the Paris Agreement

The RITE side event at COP23 addressed the issue of sustainable climate change response measures, especially based on Nationally Determined Contributions (NDCs). After an introduction by Dr. Kopp of RFF, Dr. Akimoto presented RITE's work in assessing the targets in the Paris agreement: NDCs as well as long-term targets. As NDCs' ambitions are to be evaluated and raised through a Pledge and Review process that is under discussion, the study offers tools to measure and compare the level of effort of the NDCs. Regarding long-term targets, Dr. Akimoto insisted on the importance of social and technological innovation to achieve the 2 degrees target with more realistic measures than very high explicit carbon prices. Dr. Carraro presented a FEEM study on how NDCs would impact the implementation of the Sustainable Development Goals (SDGs). Dr. Navarra of CMCC talked about various models for climate policy. Mr. Tezuka introduced the KEIDANREN's Voluntary Action Plan and the NDCs submission process.

Date 14 November 2017
Venue COP23 Japan Pavilion (Bonn, Germany)
Organization RITE
Co-organization RFF, FEEM

RITE results were also presented at a RFF side event by Dr. Shoai-Tehrani in the Turkish Pavilion on November 15.

Chemical Research Group

Win the Japan Institute of Energy Award for Distinguished Paper 2017

The Japan Institute of Energy Award for Distinguished Paper 2017 was given to "Potential of Amine-based Solvents for Energy-saving CO_2 Capture from a Coal-fired Power Plant" presented by Dr. Goto, Dr. Chowdhury, Dr. Yamada and Mr. Higashii. The awards ceremony with a commemorative lecture was held at the annual conference in Nagoya in August.

In the paper, the potential of amine-based solvents was investigated by a thermodynamic analysis for low-energy CO_2 capture from the flue gas of a thermal power plant. The results showed that the solvent characteristics of high CO_2 cyclic capacity and low absorption heat had an important effect on reducing the thermal energy requirement for CO_2 capture. Also, the impact of amine-based solvent performance on the power generation efficiency of the power plant was quantitatively clarified. The award is given for those accomplishments that contribute to the advancement of CO_2 capture technology for CCS.

Although CO_2 capture by chemical absorption is on a practical level, further reduction of energy performance is strongly required. Because the paper shows the limitations of simple aqueous amine solvents, we need innovative technologies. The Chemical Research Group has been engaged in the research and development of CO_2 capture technologies through a variety of different approaches from the perspective of both materials and processes.

Dr. Goto

CO_2 Storage Research Group

Distributed Fiber Optics Sensing at the CaMI FRS Site

A test facility called CaMI / FRS in Calgary in Canada is available for the development and verification of monitoring technologies for geological CO_2 storage, operated by the Containment and Monitoring Institute (CaMI), which is part of CMC Research Institutions, Inc. and the University of Calgary. The goals of CaMI/FRS are to evaluate saturation of gaseous CO_2 in the ground and to develop and improve monitoring techniques for early detection of CO_2 migration in the ground. In the project, CMC, the University of Calgary and a number of other institutes - one from Canada, two from Norway, two from the USA and one from Germany - is conducting the verification of various monitoring technologies, including 3D seismic survey, Vertical Seismic Profile (VSP) survey, microseismic observation, electric survey, gravitational survey, s tiltmeters, temperature measurement, and monitoring for geochemical reaction, ground water and the surface environment. In October 2017, CO_2 was injected into a 300m-deep reservoir as phase 1 and monitoring is currently ongoing (Figure).

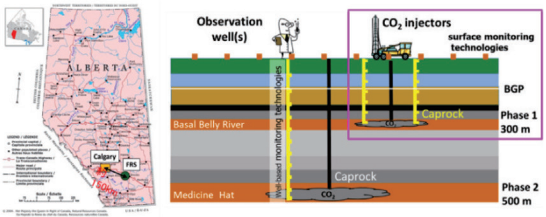


Figure CaMI site location and project overview

The CO_2 Storage Research Group is verifying a technique to measure strains of geological formations with distributed fiber-optics sensing (DFOS) at the CaMI /FRS site. In November 2017, we conducted the 1st measurement test, using optic fibers for distribute acoustic sensing (DAS) installed by the US Laurence Barkley National Laboratory (LBNL) at the site. The analysis of the test results revealed that responses vary depending on types and installment ways of optic fibers. We plan the 2nd field measurement in summer 2018. Comparative analyses between results from our measurement and those from other techniques are expected to contribute to deepening understanding of CO_2 migration in shallow formations and to demonstrate the applicability of fiber optics to early detection of CO_2 leakage.

Reference

Lawton et al. (2016) CaMI Field Research Station: Shallow CO_2 release monitoring. IEAGHG Monitoring and Modelling Workshop.

CO_2 Storage Research Group

CCS Technical Workshop

The CCS Technical Workshop was held to introduce outcomes from CCS projects in USA, and up-to-date expertise and methodologies, including risk management, applied to large-scale geological CO_2 storage demonstration such as Decatur in the USA and Smeaheia in Norway. The presentations there included the update of R&D being undertaken by the Geological Carbon Dioxide Storage Technology Research Association (GCS).

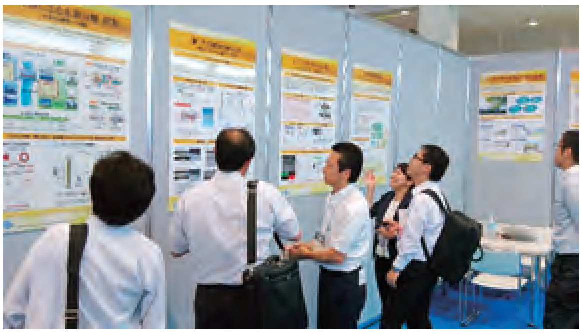
Agenda

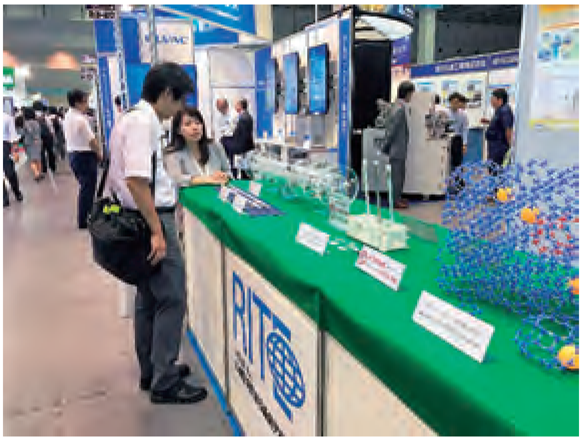
- Talk 1: Designing a commercial-scale storage site: Assessing the value of a pilot project
  Scott Frailey Illinois State Geological Survey, USA
- Talk 2: An overview of the US-Japan Collaboration on CCS Technologies and the NRAP Project
  Ziqiu Xue, Geological Carbon Dioxide Storage Technology Research Association (GCS), Japan
- Talk 3: Fiber-optic sensing technology for CCS monitoring
  Barry Freifeld LBNL, USA
- Talk 4: Progress of R&D in Geological Carbon Dioxide Storage Technology Research Association in Japan
  Ziqiu Xue, Geological Carbon Dioxide Storage Technology Research Association (GCS), Japan
- Talk 5: How Norway is building a full-scale CCS value chain
  Kari-Lise Rorvik GASSNOVA, Norway

Inorganic Membranes Research Center (IMeRC)

Highly Functional Ceramics Expo Osaka

The second Highly Functional Ceramics Expo Osaka, organized by Reed Exhibitions Japan Ltd., was held at INTEX Osaka on 20-22 September 2017. We introduced the R&D activities of RITE by showing samples and models of inorganic membranes (silica, palladium, and zeolite membranes) that are currently being studied by the IMeRC. We also introduced the Industrialization Strategy Council and our other efforts to put innovative environmental and energy technologies that use inorganic membranes into practical and industrial use. Over 220 people, including selective membrane manufacturers and potential user companies, came to the RITE booth and discussed the use and advantages of inorganic membranes. We will put the opinions of the attendees to good use in our future R&D activities and in strengthening industrial collaborations. Finally, we would like to thank all visitors for coming.





RITE booth

Inorganic Membranes Research Center (IMeRC)

Inorganic Membranes Research Center Symposium to Explore the Future

At this symposium, leading researchers in the field of inorganic membranes or energy technologies gave lectures on the latest trends in their research fields, and then the director reported the latest research and development results at our Inorganic Membranes Research Center. In the panel discussion, panelists from METI, corporate management, and the director of our center eagerly discussed the prospects for putting innovative environmental and energy technologies using inorganic membranes into practical use and industrialization. From the participants of the symposium, we earned a good reputation and that they understood the possibilities and problems of inorganic membranes.

Program

- Keynote Speech: The role of Innovation in Energy and Environment Policy
  Kenji Yamaji, Director General, RITE
- Special lecture ①: The latest trend in the inorganic membrane separation process and future prospects
  Masahiko Matsukata, Professor, Waseda University
- Special lecture ② : Trends and issues for building the hydrogen-based society- Role of carbon-free hydrogen and inorganic membranes
  Ken Okazaki, Institute Professor, Tokyo Institute of Technology
- Activity report: Research results of the Inorganic Membranes Research Center and future plans
  Shinichi Nakao, Director, Inorganic Membrane Research Center, RITE
- Panel Discussion
  “Toward industrialization of innovative environments and energy technologies using inorganic membranes - The role of the Industrialization Strategy Council, Inorganic Membranes Research Center, RITE - “
  Coordinator; Hirofumi Kyutoku, Advisor, Osaka Gas Co., Ltd. (Chairman of the Industrialization Strategy Council)
  Panelist; Takeru Numadate, METI
  Shinichi Nakao, RITE
  Toshiyuki Shiraki, Hitachi Zosen
  Yasuo Hosono, Chiyoda Corporation
  Takashi Yasuda, JGC Corporation

Molecular Microbiology and Biotechnology Group

BioJapan 2017

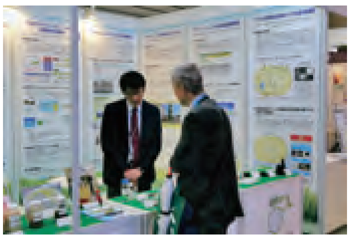
The World Business Forum ‘BioJapan 2017’ was held at PACIFICO Yokohama on October 11-13, 2017, and it was jointly conducted with Regenerative Medicine JAPAN 2017 for the second consecutive year.

The number of visitors was 14,153 in 2015; 15,133 in 2016; and 15,711 in 2017, which was the largest ever.

1. RITE put up a joint booth at the exhibition in collaboration with Green Phenol Development Co., Ltd (GPD). In the booth, we introduced our key technologies, and the current projects funded by METI and NEDO. We also explained the activities of Green Earth Institute Co., Ltd (GEI), as examples of the RITE Bioprocess’ commercial uses, and technologies of green phenol.

[Posters in the exhibition booth]

1) Introduction of RITE and research groups
2) RITE Bioprocess, a key technology for biorefinery from non-food biomass
3) R&D of bio-hydrogen production
4) R&D of bio-butanol production
5) R&D for production of 100% green jet fuel
6) Industrialization of RITE Bioprocess
7) Green Phenol Development Co., Ltd.
8) Development of bioprocess for production of green phenol



9) New trends for biotechnological production of green-aromatic compounds

We also had exhibits that included various samples and pictures, such as several non-food biomasses, the amino acid that is the first commercial product from GEI using the RITE Bioprocess, GEI’s ethanol for cosmetics, and green phenolic moldings from GPD.

2. In the NEDO booth located near our booth, RITE also exhibited a panel of our R&D funded by NEDO project ‘Smart cell’, ‘Validation of metabolic models by improving productivity of useful aromatic compounds by *Corynebacterium glutamicum*’.

3. RITE’s two associate chief researchers made presentations on the following projects funded by METI on the stage in the Exhibition Hall on October 12.
   # Kazumi Hiraga, ‘Production of biobutanol for biofuels from non-edible biomass’
   # Haruhiko Teramoto, ‘Highly efficient bio-hydrogen production from non-edible biomass’

We appreciate your attending this event and visiting our booth.

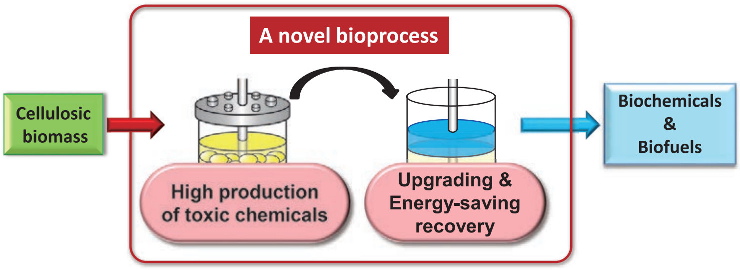
Molecular Microbiology and Biotechnology Group

Introduction of new METI project “A novel versatile bioprocess"

Alcohols, aldehydes, and phenols are important chemicals that are used for production of synthetic resins, plasticizer, pharmaceuticals, and flavors. They are also used as transportation fuels such as jet fuel through chemical conversion processes. At present, most of these useful chemicals are produced from petroleum by chemical processes, which are generally performed under energy-consuming conditions such as high temperature and high pressure and sometimes with expensive catalysts. On the other hand, bioprocess using microbial fermentation is performed under mild conditions such as room temperature and atmospheric pressure with regenerative and cheap microbial catalysts. For this reason, bioprocess is a promising technology for low-cost and low-carbon production of useful chemicals. However, there are some problems with the bioprocess. As many useful chemicals are toxic to microbes, it is very difficult to achieve high production of such toxic chemicals by conventional microbial fermentation. In addition, produced chemicals are often required to be extracted from fermentation broth by energy-consuming extraction methods such as distillation.

High-throughput screening of toxic-compound-resistant strains is widely performed for each toxic chemical to improve its productivity. However, such a strategy is unlikely to result in considerable improvements in productivity in a short period. Several extraction methods have been developed to be used instead of distillation, but are still energy-consuming. Furthermore, these extraction methods are dependent on physical properties of extracted compounds, and the condition needs to be considered for each chemical. For these reasons, it is difficult to achieve a rational and rapid improvement of productivity of toxic chemicals by conventional bioprocess.

Hence, we have started developing a novel bioprocess that makes it possible to realize high production of various toxic chemicals such as alcohols, aldehydes, and phenols, by a common process that is totally different from conventional bioprocess. Our new project, entitled “R&D of a novel versatile bioprocess for high-production of toxic biochemicals” has been adopted by METI in 2017, and is ongoing.



Overview of versatile bioprocess

In order to introduce the recent achievements of our research and development and also to promote the collaboration among industry, government and academia, RITE is providing the most advanced information for mitigating global warming through symposiums and various media.

In addition, we actively engage in environmental education activities on global warming issue targeting students from elementary school to high school mainly in the Keihanna district where RITE is located.

Symposiums

Date	Symposium Description	Related Dept.
19 Jan. 2017	**CCS Technical Workshop 2016** ・Venue: Toranomon Hills Forum, Main Hall ・Organizer: Geological Carbon Dioxide Storage Technology Research Association ・Number of participants: 365	CO_2 Storage Research Group
23 Jan. 2017	**6th Symposium for Innovative CO_2 Membrane Separation Technology** ・Venue: Ito Hall ・Organizer: Molecular Gate Membrane module Technology Research Association ・Number of participants: 201	Chemical Research Group
26 Jan. 2017	**Measures for tackling Global Warming** ・Venue: Hatsumeikaikan ・Organizer: Ministry of Economy, Trade and Industry ・Co-organizer: RITE ・Number of participants: 250	Research & Coordination Group
7 Feb. 2017	**FY2016 ALPS International Symposium** ・Venue: Toranomon Hills Forum ・Organizer: RITE ・Number of participants: 298	Systems Analysis Group
7 Nov. 2017	**Inorganic Membranes Research Center Symposium to Explore the Future** ・Venue: Ito Hall ・Organizer: RITE ・Number of participants: 199	Inorganic Membranes Research Center
14 Nov. 2017	**IPCC Workshop** ・Venue: Shinagawa Prince Hotel ・Organizer: Ministry of Economy, Trade and Industry ・Co-organizer: RITE ・Number of participants: 158	Research & Coordination Group
29 Nov. 2017	**IPCC Symposium** ・Venue: TKP Gardencity Premium Kyobashi ・Organizer: Ministry of Economy, Trade and Industry ・Co-organizer: RITE ・Number of participants: 126	Research & Coordination Group
6 Dec. 2017	**Innovative Environmental Technology Symposium 2017** ・Venue: Ito Hall ・Organizer: RITE ・Number of participants: 389	Research & Coordination Group
23 Jan. 2018	**CCS Technical Workshop** ・Venue: Iino Hall ・Organizer: Geological Carbon Dioxide Storage Technology Research Association ・Number of participants: 320	CO_2 Storage Research Group

Exhibitions

Dates	Event Description	Related Dept.
20-22 Sep. 2017	**2nd Highly Functional Ceramics Expo Osaka** ・Venue: INTEX Osaka ・Organizer: Reed Exhibitions Japan Ltd.,	Inorganic Membranes Research Center
11-13 Oct. 2017	**BioJapan 2017** ・Venue: Pacifico Yokohama ・Organizer: BioJapan Organizing Committee, JTB Communication Design, Inc.	Molecular Microbiology and Biotechnology Group

Press Releases

Date	Title
5 Jan. 2017	Announcement of ALPS International Symposium
19 Sep. 2017	Energy-saving CO_2 separation and capture system to be tested for practical use at Maizuru Power Plant, Kansai Electric Power
29 Sep. 2017	Announcement of Inorganic Membranes Research Center Symposium to Explore the Future
17 Oct. 2017	Announcement of Innovative Environmental Technology Symposium 2017
6 Nov. 2017	Announcement of IPCC Workshop
13 Nov. 2017	Announcement of IPCC Symposium
27 Nov. 2017	Announcement of CCS Technical Workshop
1 Dec. 2017	Announcement of 7th Symposium for Innovative CO_2 Membrane Separation Technology

Environmental Education

◇Facility Visit Program and Lecture

Date	Place	Participants	Number of participants
19 Jan.	RITE	Seikaminami Junior High School	5
25 Jan.	RITE	Kizugawadai Elementary School	31
20 Feb.	Seikaminami Junior High School	Seikaminami Junior High School	Approx. 60
8 May	RITE	Narakita High School	38
19 May	RITE	Seika Junior High School	10
2 Aug.	RITE	Nishimaizuru High School	8
28 Sep.	RITE	Naragakuen Tomigaoka Junior High School	12
13 Oct.	RITE	MASUDA Senior High School	22
11 Nov.	Suzaku Daiyon Elementary School	Suzaku Daiyon Elementary School	27
17 Nov.	RITE	Seikanishi Junior High School	12

◇Workshop and Exhibition

Date	Place	Title	Number of participants
4 Feb.	Keihanna-Plaza	Global Warming and CCS Study Workshop “Science Experiment"	22
Jul. - Aug.	RITE	Global Warming and CCS Study Workshop “Experiment and Game"	66
24 Aug.	RITE	Global Warming and CCS Study Workshop “Craft and Science Experiment"	54
4 Feb.	Keihanna-Plaza	KEIHANNA Science Festival 2017	

Research & Coordination Group

Original Paper

	Title	Researchers	Journal
1	Environmental impact of dispersed generation	T. Smolka, M. Katagiri, A.L. Mustafa, S. Hellweg, E. Mesquita, S. Martin, Y. Nakagami, E. Szechowicz, T. Dederichs, C. Capello, M. Haupt, L. Eymann.	ELECTRA, pp.49-55, No.291, April 2017
2	Distinguishing feature of Japanese climate policy planning process and the proposal for its improvement	M. Yamaguchi	The 22th Annual Meeting of Society for Environmental Economics and Policy Studies, Sep. 9, 2017
3	Climate Change: What Informs a Nation's policy?	M. Yamaguchi	The Japan Journal, pp.10-13, July/August, 2017

Systems Analysis Group

Original Paper

	Title	Researchers	Journal
1	Concept and Level of Carbon Price, and Ex-post Evaluation of Carbon Pricing Policy	J. Oda, K. Akimoto	Journal of Life Cycle Assessment, Japan, Vol.13, No.1, 2017
2	Analyses on Japan's GHG Emission Reduction Target for 2050 in Light of the 2℃ Target Stipulated in the Paris Agreement	K. Akimoto, F. Sano	Journal of Japan Society of Energy and Resources, Vol.38 No.1, 2017
3	Transdisciplinary co-design of scientific research agendas: 40 research questions for socially relevant climate engineering research	M. Sugiyama, S. Asayama, T. Kosugi, A. Ishii, S. Emori, J. Adachi, K. Akimoto, M. Fujiwara, T. Hasegawa, Y. Hibi, K. Hirata, T. Ishii, T. Kaburagi, Y. Kita, S. Kobayashi, A. Kurosawa, M. Kuwata, K. Masuda, M. Mitsui, T. Miyata, H. Mizutani, S. Nakayama, K. Oyamada, T. Sashida, M. Sekiguchi, K. Takahashi, Y. Takamura, J. Taki, T. Taniguchi, H. Tezuka, T. Ueno, S. Watanabe, N. Yamagishi, G. Yoshizawa	Sustainability Science, Vol. 12, Issue 1, pp 31-44, Jan. 2017
4	Comparing projections of industrial energy demand and greenhouse gas emissions in long-term energy models	O.Y. Edelenbosch, K.Kermeli, W.Crijns-Graus, E.Worrell, R.Bibas, B.Fais, S.Fujimori, P.Kyle, F. Sano, D.P.van Vuuren	Energy, Vol. 122, pp. 701-710, Mar. 1, 2017
5	Comparing emissions mitigation efforts across countries	J. Aldy, B. Pizer, K. Akimoto	Climate Policy, Vol. 17, Issue 4, pp. 501-515, 2017
6	Next step in geoengineering scenario research: Restrained deployment scenarios and beyond	M. Sugiyama, Y. Arino, T. Kosugi, A. Kurosawa, S. Watanabe	Climate Policy, Published online Jun. 8, 2017
7	The analyses on the economic costs for achieving the nationally determined contributions and the expected global emission pathways	K. Akimoto, F. Sano, B. Shoai-Tehrani	Evolutionary and Institutional Economics Review, Vol. 14, Issue 1, pp 193-206, Jun. 2017
8	Low-emission pathways in 11 major economies: comparison of cost-optimal pathways and Paris climate proposals	H. L. van Soest, L. A. Reis, L. Drouet, D. P. van Vuuren, M. G.J. den Elzen, M. Tavoni, K. Akimoto, K. V. Calvin, P. Fragkos, A. Kitous, G. Luderer, K. Riahi	Climatic Change, Vol. 142, Issue 3, pp 491-504, Jun. 2017
9	Preliminary Study on Policy Mix Effects on Economic Viability of Carbon Capture and Storage Project in Japanese Steel Industry	J. Oda, K. Akimoto	Energy Procedia, Volume 114, pp 7615-7624, July 2017
10	Prove Paris was more than paper promises	D. Victor, K. Akimoto, D. Cullenward, C. Hepburn, Y. Kaya, M. Yamaguchi	Nature 548, 25-27, 03 August 2017
11	GHG emission pathways until 2300 for the 1.5℃ temperature rise target and the mitigation costs achieving the pathways	K. Akimoto, F. Sano, T. Tomoda	Mitigation and Adaptation Strategies for Global Change, Published online: Sep. 5, 2017
12	Deregulation, market competition and innovation of utilities: Evidence from Japanese electric sector	N. Wang, G. Mogi	Energy Policy, Vol. 111, pp.403-413, December 2017
13	Future Fossil Fuel Price Impacts on NDC Achievement; Estimation of GHG Emissions and Mitigation Costs	Y. Arino, F. Sano, K. Akimoto	Eurasian Journal of Economics and Finance, Vol. 5, Issue 4, pp.16-35, 2017

Systems Analysis Group

Other Paper

	Title	Researchers	Magazine, Newspaper, etc.
1	Global warming mitigation in consideration of the Paris Agreement and energy mix	K. Akimoto	Enelog, Vol.24, 2017
2	Societal and economic implication of the Paris Agreement goals	K. Wada	Environmental Information Science 46-3, 2017

Oral Presentation (International Academic Society)

	Title	Researchers	Forum
1	Economic Impacts of Climate Change Adaptation Considering Spill-over Effects of Stock Investment as Adaptation Measures: Coastal Sector	T. Homma, Y. Arino, A. Hayashi, M. Nagashima, T. Tomoda, K. Akimoto	ICEESD 2017 : 19th International Conference on Ecosystems, Environment and Sustainable Development, Feb. 16-17, 2017, UK
2	Towards co-producing environmental scenario research: A case of climate engineering	M. Sugiyama, Y. Arino, S. Asayama, A. Ishii, T. Kosugi, A. Kurosawa, S. Watanabe	JpGU-AGU Joint Meeting 2017, May 20, 2017, Japan
3	An analysis of long-term reduction scenario of CO_2 and position for CCS	Y. Nakagami, K. Akimoto	JpGU-AGU Joint Meeting 2017, May 20, 2017, Japan
4	Combined effects of electricity market liberalization and climate policy: Lessons from Europe	B. Shoai-Tehrani, P. Da Costa, K. Akimoto, Y. Nakagami	40th IAEE International Conference, Jun. 19, 2017
5	Deregulation and Utility Innovation: The Case of Japanese Electric Sector	N. Wang, G. Mogi	40th IAEE International Conference, Jun. 20, 2017
6	An Economic Evaluation of the Nationally Determined Contributions of the Paris Agreement under Multiple Scenarios on Fossil Fuel Prices	Y. Arino, F. Sano, K. Akimoto	23rd Annual Conference of the European Association of Environmental and Resource Economists (EAERE) , Jun. 30, 2017
7	Estimation of Japanese Steel Product Trade Elasticity of Substitution	J. Oda, T. Homma, K. Akimoto	15th IAEE European Conference 2017, Sep. 6, 2017, Austria
8	An assessment of global land-use change required for achieving the 2 ℃ and 1.5 ℃ targets	A. Hayashi, F. Sano, K. Akimoto	12th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), Oct. 8, 2017, Croatia
9	An analysis of cost-efficient energy systems in consideration of climate change and ambient PM2.5 concentration mitigation by using a global energy systems model	K. Gi, F. Sano, A. Hayashi, K. Akimoto	12th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), Oct. 8, 2017, Croatia

Oral Presentation (Domestic Academic Society)

	Title	Researchers	Forum
1	Japan's mid- and long-term mitigation pathways and associated challenges: A model intercomparison pilot project	M. Sugiyama, S. Fujimori, K. Wada, S. Endo, Y. Fujii, R. Komiyama, E. Kato, A. Kurosawa, Y. Matsuo, K. Oshiro, F. Sano	The 33rd Conference on Energy, Economy, and Environment, Feb. 2, 2017
2	Evaluations on Carbon Pricing Based on Quantitative Analyses	K. Akimoto, F. Sano, J. Oda, B. Shoai-Tehrani	The 33rd Conference on Energy, Economy, and Environment, Feb. 2, 2017
3	Factor Analysis of Carbon Intensity Trend in Japanese Steel Industry	J. Oda, K. Akimoto	The 33rd Conference on Energy, Economy, and Environment, Feb. 2, 2017
4	An Evaluation of the Nationally Determined Contributions of the Paris Agreement under Multiple Scenarios on Fossil Fuel Prices	Y. Arino, F. Sano, K. Akimoto	The 33rd Conference on Energy, Economy, and Environment, Feb. 2, 2017
5	An Analysis on Long-term Climate Change Mitigation and Costs Under the Socioeconomic Scenarios Harmonizing SSP Storylines	F. Sano, K. Akimoto, T. Homma, J. Oda, A. Hayashi, B. Shoai-Tehrani, Y. Arino, K. Gi	The 33rd Conference on Energy, Economy, and Environment, Feb. 2, 2017
6	Feasibility of limiting warming to below 1.5℃	K. Wada	The 33rd Conference on Energy, Economy, and Environment, Feb. 2, 2017
7	Estimation on Agricultural Land-use and Water Resources for Different levels of Climate Change Mitigation under the SSP Scenarios	A. Hayashi, F. Sano, K. Akimoto, Y. Nakagami	The 33rd Conference on Energy, Economy, and Environment, Feb. 3, 2017
8	Cost-Effective Energy Systems in Consideration of Climate Change Mitigation and Ambient PM2.5 Concentration Reduction	K. Gi, F. Sano, A. Hayashi, K. Akimoto	The 33rd Conference on Energy, Economy, and Environment, Feb. 3, 2017
9	Analysis on Economic Impacts of Climate Adaptation in Coastal Sector	T. Homma, Y. Arino, A. Hayashi, M. Nagashima, T. Tomoda, K. Akimoto	The 33rd Conference on Energy, Economy, and Environment, Feb. 3, 2017

Systems Analysis Group

	Title	Researchers	Forum
10	Policy issues for EU electricity market liberalization and climate policy	B. Shoai-Tehrani, K. Akimoto, Y. Nakagami, P. Da Costa	The 33rd Conference on Energy, Economy, and Environment, Feb. 3, 2017
11	Response Strategies to Climate Change Risks from the Perspective of Climate Change Damages and Adaptation Costs	T. Homma, Y. Arino, A. Hayashi, M. Nagashima, T. Tomoda, K. Akimoto	The 36th Annual Meeting of Japan Society of Energy and Resources, Jun. 7, 2017
12	Climate Risk Management Strategy from the Perspective of Climate Change	F. Sano, K. Akimoto	The 36th Annual Meeting of Japan Society of Energy and Resources, Jun. 7, 2017
13	Expert Questionnaire Survey on Climate Change Risk Management and Implication of Risk Management Strategy	J. Oda, K. Akimoto, A. Hayashi	The 36th Annual Meeting of Japan Society of Energy and Resources, Jun. 7, 2017
14	Response Strategies to Climate Change Risks Holding Solar Radiation Management as a Risk Hedge Option	Y. Arino, K. Akimoto, F. Sano, T. Homma, J. Oda, T. Tomoda, A. Hayashi	The 36th Annual Meeting of Japan Society of Energy and Resources, Jun. 7, 2017
15	A Proposal for response strategies to climate change risks and the related quantitative analyses	K. Akimoto, F. Sano, T. Homma, J. Oda, Y. Arino, A. Hayashi, K. Gi	The 36th Annual Meeting of Japan Society of Energy and Resources, Jun. 7, 2017
16	Analysis of Long-term Trend of Energy Intensity in Japanese Steel Industry	J. Oda, K. Akimoto	The 36th Annual Meeting of Japan Society of Energy and Resources, Jun. 8, 2017
17	An Analysis on Global Impacts of the Nationally Determined Contributions in Consideration of Current Climate and Energy Policies in Major Economies	K. Gi, F. Sano, T. Homma, J. Oda, A. Hayashi, K. Akimoto	The 26th Annual Meeting of Japan Institute of Energy, Aug. 2, 2017
18	A trend of nuclear fusion development	K. Gi	Japan Society of Energy and Resources Summer workshop, Aug. 21, 2017
19	Assessment of Fusion Development Targets under Global Energy Scenarios	K. Gi, F. Sano, K. Akimoto	A Session of Fusion Engineering Division, Atomic Energy Society of Japan 2017 Fall Meeting, Sep. 14, 2017
20	A study on the volatility of energy prices	J. Oda	National Conference of The Japan Association of Real Options and Strategy 2017, Nov. 25, 2017

Other Oral Presentation and Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Energy strategies and their issues in consideration of global warming mitigation	K. Akimoto	Regular Meeting of Japan Atomic Energy Commission, Jan. 10, 2017
2	Evaluations of climate change response measures considering several constraints and multi objectives in the real world	K. Akimoto	Symposium on Measures for tackling Global Warming - IPCC Activities and Perspectives in AR6 Cycle-, Jan. 26, 2017
3	ALternative Pathways toward Sustainable development and climate stabilization (ALPS)	J. Oda	Expert workshop towards further collaboration between Japanese research community and IIASA, Jan. 30, 2017, Japan
4	RITE ALPSII Project and IIASA-RITE Collaboration	K. Akimoto	IIASA-IGES Symposium on the future perspective with a core of “The World in 2050” project, Jan. 31, 2017
5	Chapter 10 Industry & living environment (Editor)	K. Gi, K. Akimoto	Chronological Environmental Tables 2017-2018, Maruzen Publishing, January 2017
6	Evaluations on Emission Reduction Efforts of Nationally Determined Contributions under the Paris Agreement	K. Akimoto	ALPS International Symposium, Feb. 7, 2017
7	Energy issues to be known	K. Akimoto	Lecture on Nuclear (Ikata Nuclear Information Center), Feb. 18, 2017
8	Energy Mix under the Deregulation of the Electricity Market in Japan	K. Akimoto	A Lecture on Future Energy Vision of Japan as a Resourceless Nation in Tokyo, Feb. 21, 2017
9	Future perspective viewed from energy	K. Akimoto	Smart Energy Promotion Group of METI Kansai, Feb. 22, 2017
10	Global Warming and Energy	K. Akimoto	Seminar on “Mental and Environmental Issues”, Feb. 23, 2017
11	Feasibility assessment of the introduction of nuclear fusion in low-carbon scenario using world energy system model	K. Gi	Practical Usage Strategy Cluster meeting, Fusion Energy Forum of Japan, Feb. 24, 2017

Systems Analysis Group

	Title	Researchers	Magazine, Newspaper, etc.
12	Challenges for Land-use and Water Management Under the 2°C Target	A. Hayashi, F. Sano, K. Akimoto, T. Homma, Y. Nakagami	Global Carbon Project/Managing Global Negative Emission Technologies Workshop, Pre-conference, Mar. 1, 2017, Austria
13	Considering the future of energy in Japan in accord with the Paris Agreement	K. Akimoto	Lecture at Energy Technology Committee, Osaka Science & Technology Center, Mar. 9, 2017
14	Emission reduction and estimates of economic effect achieved by energy conservation, low-carbon technologies and products and their overseas expansion	K. Akimoto	The Task Force meeting for Overseas Expansion Strategies, the Long-term Global Warming Countermeasures Platform, Ministry of Economy, Trade and Industry, Mar. 31, 2017
15	Projection of TEC14 meeting and technology negotiation	K. Wada	The 62nd TECUSE Study Meeting, Apr. 19, 2017
16	DNE21+ team paper (Assessments of long-term climate change mitigation scenarios from the perspectives of bioenergy contribution and middle-term climate policy)	F. Sano, K. Akimoto, A. Hayashi, T. Homma, K. Gi, K. Wada	Project meeting of EMF-33 bioenergy study, Apr. 25, 2017, France
17	The analyses on the economic costs, co-benefits and risks for the Paris Agreement goals	K. Akimoto	IEA Noon Talk, June 12, 2017
18	A perspective of energy supply and demand	K. Akimoto	The 28th CEE Symposium "Challenges in analyses of ultra long-term energy supply and demand - a significance and challenges in quantitative analyses and their solutions-", Aug. 30, 2017
19	An impact of emission reduction towards 2030 in Japan and its challenge	K. Akimoto	Kansai Economic Federation / Asia Pacific Institute of Research seminar "A global trend of warming mitigation and challenges in Japan", Sep. 8, 2017
20	Deep emission reduction from a global perspective	K. Akimoto	Open Symposium of Science Council of Japan "A Long-term Strategy for GHG emission reduction under the Paris Agreement", Sep. 27, 2017
21	Transforming to a long-term zero emission with taking into account uncertainty of a projection	S. Emori, K. Akimoto	Nikkei Ecology, October 2017
22	Energy mix issues to be known	K. Akimoto	Hokugenkon "Environment & Energy Lecture Meeting", Oct. 3, 2017
23	Challenges and opportunities for net zero CO_2 emission harmonized with sustainable development	K. Akimoto	ICEF 4th Annual Meeting, Oct. 5, 2017
24	Outcomes of CTCN and TEC, and prospect for technology negotiation at COP23	K. Wada	The 67th TECUSE Study Meeting, Oct. 18, 2017
25	Toward Strong Weak Target	Y. Kaya, M. Yamaguchi, K. Akimoto	Energy Forum, October 2017
26	A strategy for decarbonization - Seeking the solution for reconciliatory achivement of economy and environment	J. Arima, T. Ohno, K. Akimoto	Monthly Energy Forum, No. 755, November 2017
27	Sustainable Climate Change Response Measures under the Paris Agreement	K. Akimoto	COP23 side event (Japan Pavilion), Nov. 14, 2017, Germany
28	Sustainable Climate Change Response Measures under the Paris Agreement	B. Shoai-Tehrani, K. Akimoto	COP23 side event (Turkish Pavilion), Nov. 15, 2017, Germany
29	Toward better understandings of uncertainties in climate change countermeasures and development of risk management strategies	K. Akimoto	Let's Consider Measures for Climate Change Mitigation: IPCC Activities during the Sixth Assessment Cycle and Future Efforts (2), Nov. 29, 2017
30	Impacts of climate change and adaptation - focusing on coastal area-	T. Homma	2017 special lecture on energy, Japan Society of Energy and Resources, Dec. 4, 2017
31	Mitigation costs of climate change and their economic risk, trade-offs and co-benefits with the countermeasures of air-pollution	F. Sano	2017 special lecture on energy, Japan Society of Energy and Resources, Dec. 4, 2017
32	A role of geoengineering method in the light of risk countermeasure for climate change	Y. Arino	2017 special lecture on energy, Japan Society of Energy and Resources, Dec. 4, 2017
33	A summary of responces to climate change risk	K. Akimoto	2017 special lecture on energy, Japan Society of Energy and Resources, Dec. 4, 2017

Systems Analysis Group

	Title	Researchers	Magazine, Newspaper, etc.
34	An assessment of emission reduction efforts and its policies in the NDCs under the Paris Agreement	K. Akimoto	Innovative Environmental Technology Symposium 2017, Dec. 6, 2017
35	Technology negotiation at COP23	K. Wada	The 68th TECUSE Study Meeting, Dec. 13, 2017
36	IPCC/UNFCCC updates	K. Wada	The First International Workshop of Japan Model Intercomparison Project (JMIP), Dec. 14, 2017
37	Energy Intensity in the Japanese Steel Industry: Trend, Determinants, and Decarbonization Challenge	J. Oda	The First International Workshop of Japan Model Intercomparison Project (JMIP), Dec. 15, 2017

Molecular Microbiology and Biotechnology Group

Original Paper

	Title	Researchers	Journal
1	Enhanced glucose consumption and organic acid production by engineered *Corynebacterium glutamicum* based on analysis of a *pfkB1* deletion mutant	S. Hasegawa, Y. Tanaka, M. Suda, T. Jojima, M. Inui	Appl. Environ. Microbiol., Vol.83, e02638-16, 2017
2	Polynucleotide phosphorylase, RNase E/G, and YbeY are involved in the maturation of 4.5S RNA in *Corynebacterium glutamicum*	T. Maeda, Y. Tanaka, M. Wachi, M. Inui	J. Bacteriol., Vol.199, e00798-16, 2017
3	Development of the bio-production technology of green aromatic compounds	T. Kogure, M. Inui	CHEMICAL ENGINEERING, Vol.62, pp.54-61, 2017
4	Functional analysis of arabinofuranosidases and a xylanase of *Corynebacterium alkanolyticum* for arabinoxylan utilization in *Corynebacterium glutamicum*	T. Kuge, A. Watanabe, S. Hasegawa, H. Teramoto, M. Inui	Appl. Microbiol. Biotechnol., Vol.101, pp.5019-5032, 2017
5	Biorefinery by a growth arrested bioprocess	M. Shimizu, M. Inui	Enzyme engineering news, Vol.78, pp.19-22, 2017
6	Trehalose acts as a uridine 5'-diphosphoglucose-competitive inhibitor of trehalose 6-phosphate synthase in *Corynebacterium glutamicum*	S. Oide, M. Inui	FEBS J., Vol.284, pp.4298-4313, 2017
7	Increasing diversity of the bio-based chemicals produced by *Corynebacterium glutamicum*	T. Kubota, M. Inui	Kagaku to Seibutsu, Vol.55, pp.690-698, 2017
8	Extracytoplasmic function sigma factor σ^D confers resistance to environmental stress by enhancing mycolate synthesis and modifying peptidoglycan structures in *Corynebacterium glutamicum*	K. Toyoda, M. Inui	Mol. Microbiol., Vol.107, pp.312-329, 2018
9	Production of 4-hydroxybenzoic acid by an aerobic growth-arrested bioprocess using metabolically engineered *Corynebacterium glutamicum*	Y. Kitade, R. Hashimoto, M. Suda, K. Hiraga, M. Inui	Appl. Environ. Microbiol. (in press)

Other Paper

	Title	Researchers	Magazine, Publication
1	TOPICS 6 Current status of R&D on effective utilization of biomass in RITE / Production of biofuels and green chemicals by smart cells for the realization of a low-carbon society	M. Inui	Keihanna View, Vol.36, pp.24, Dec., 2017

Oral Presentation (Domestic Academic Society)

	Title	Researchers	Forum
1	Production of *para*-amino benzoic acid by *Corynebacterium glutamicum* and identification of a byproduct during the fermentation	Takeshi Kubota, Akira Watanabe, Masako Suda, Takahisa Kogure, Kazumi Hiraga, Masayuki Inui	The 12th Conference on Biomass Science, Jan. 18-19, 2017
2	Metabolic engineering of *Corynebacterium glutamicum* for overproduction of shikimate as a starting material for the anti-influenza drug	Takahisa Kogure, Takeshi Kubota, Masako Suda, Kazumi Hiraga, Masayuki Inui	The 12th Conference on Biomass Science, Jan. 18-19, 2017
3	RNase E/G and Rho cooperatively suppress pervasive transcripts in *Corynebacterium glutamicum*	Norihiko Takemoto, Yuya Tanaka, Tohru Akiyama, Tomoya Maeda, Nagisa Hamamoto, Masayuki Inui	The 11th Annual Meeting of Society of Genome Microbiology, Japan, Mar. 2-4, 2017
4	Regulation of expression of the transcription termination factor Rho in *Corynebacterium glutamicum*	Yuya Tanaka, Norihiko Takemoto, Yuji Yamamoto, Masayuki Inui	The 2017 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 20, 2017

Molecular Microbiology and Biotechnology Group

	Title	Researchers	Forum
5	Engineering of *Corynebacterium glutamicum* for arabinoxylan utilization	Takayuki Kuge, Akira Watanabe, Satoshi Hasegawa, Haruhiko Teramoto, Masayuki Inui	The 2017 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 20, 2017
6	Functional analysis of glucokinase genes in *Corynebacterium glutamicum*	Yuta Tsukada, Takahisa Kogure, Masayuki Inui	The 2017 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 20, 2017
7	Analysis of tolerance mechanism under aromatic compounds-induced stress in *Corynebacterium glutamicum*	Ryoji Ogura, Takeshi Kubota, Masayuki Inui	The 2017 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 20, 2017
8	Functional analysis and gene expression analysis of the aspartic acid biosynthetic enzymes in *Corynebacterium glutamicum*	Akihiro Domon, Ikumi Fukui, Masako Suda, Taku Nishimura, Kazumi Hiraga, Masayuki Inui	The 2017 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 20, 2017
9	Research and development for the production of aromatic compounds	Takeshi Kubota, Masayuki Inui	NEDO Smart Cell Project Meeting, Mar. 30, 2017
10	Research and development of technology for highly efficient bio-hydrogen production from cellulosic biomass using genetically engineered *Escherichia coli*	Haruhiko Teramoto, Masako Suda, Masayuki Inui	The 69th Annual Meeting of the Society for Biotechnology, Japan, Sep. 12-14, 2017
11	Research and development of highly efficient bio-hydrogen production from acetate by genecially engineered purple non-sulfur bacteria	Tetsu Shimizu, Haruhiko Teramoto, Masayuki Inui	The 69th Annual Meeting of the Society for Biotechnology, Japan, Sep. 12-14, 2017
12	Thermotolerance of *Corynebacterium glutamicum* on production of lactate and succinate under oxygen deprivation	Hikaru Mizuno, Yota Tsuge, Kazuaki Ninomiya, Masayuki Inui, Akihiko Kondo, Kenji Takahashi	The 69th Annual Meeting of the Society for Biotechnology, Japan, Sep. 12-14, 2017
13	Development of methods to efficiently construct DNA libraries by circumventing restriction-mocification systems in *Corynebacterium glutamicum* as a host	Satoshi Hasegawa, Toru Jojima, Masayuki Inui	The 2017 joint meeting of the Kansai, Western Japan, Chugoku and Shikoku branches of the Japan Society for Bioscience, Biotechnology, and Agrochemistry in Osaka, Sep. 22, 2017
14	Validation of metabolic models by improving productivity of useful aromatic compounds by *Corynebacterium glutamicum*	Masayuki Inui, Kazumi Hiraga, Masako Suda, Koichi Toyoda, Takeshi Kubota	BioJapan 2017, Oct. 11-13, 2017
15	Production of biobutanol for biofuels from non-edible biomass	Kazumi Hiraga, Masayuki Inui	BioJapan 2017, Oct. 12, 2017
16	Highly efficient bio-hydrogen production from non-edible biomass	Haruhiko Teramoto, Masayuki Inui	BioJapan 2017, Oct. 12, 2017

Other Oral Presentation and Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Development of phenol-manufacturing technology from plants	Hiroyuki Miyauchi, Masayuki Inui, Kazumi Hiraga	16-3 Research Group of Ecological Materials, Mar. 3, 2017
2	Development of biofuel production technology for the realization of a biorefinery society	Masayuki Inui	Energy environmental education / Kansai workshop, Apr. 22, 2017
3	Safety assessment of recombinant L-alanine developed by Musashino Chemical Laboratory, Ltd. and RITE / Assessment documents compiled by the research committee on genetically modified foods in Food Safety Commission of Japan	—	Nikkei Biotechnology & Business ONLINE, Apr. 27, 2017
4	Production of 100% green jet fuel from unutilized biomass	Masayuki Inui	The 4th GOJO University, Jun. 4, 2017
5	Development of biofuel and green chemical productions technology for the realization of low carbon society	Masayuki Inui	Society of Biomass Utilization, Jul. 14, 2017
6	Development and commercialization of production technologies for green chemicals and biofuels	Masayuki Inui	Industry-academia-government collaboration social gathering, Sep. 8, 2017
7	Emerging Technologies for Biojet Fuel Production in Japan	Masayuki Inui	ICEF 4th Annual Meeting, Oct. 5, 2017
8	Development of biorefinery production technology for the realization of low carbon society	Masayuki Inui	17-2 Research Group of Ecological Materials, Oct. 6, 2017
9	Development of phenol-manufacturing technology from biomass	Hiroyuki Miyauchi, Kazumi Hiraga, Masayuki Inui	7th CSJ Chemistry Festa, Oct. 19, 2017
10	Development of biorefinery production technology for the realization of low carbon society	Masayuki Inui	Innovative Environmental Technology Symposium 2017, Dec. 6, 2017

Chemical Research Group

Original Paper

	Title	Researchers	Journal
1	Carbon Dioxide Absorption using Solid Sorbents Incorporating Purified Components of Tetraethylenepentamine	Ryohei Numaguchi, Firoz A. Chowdhury, Hidetaka Yamada, Katsunori Yogo*	Energy Technology Vol. 5 issure 8 pp.1186-1190 August 2017
2	Effect of pore size, aminosilane density and aminosilane molecular length on CO_2 adsorption performance in aminosilane modified mesoporous silica	Keisuke Hori, Tatsuhiro Higuchi, Yu Aoki, Manabu Miyamoto*, Yasunori Oumi, Katsunori Yogo, Shigeyuki Uemiya	Microporous and Mesoporous Materials 246 (2017) pp.158-165
3	Development of CO_2 Molecular Gate Membranes for IGCC Process with CO_2 Capture	Teruhiko Kai*, Shuhong Duan, Fuminori Ito, Satoshi Mikami, Yoshinobu Sato, Shin-ichi Nakao	Energy Procedia Vol.114 (July 2017) pp.613-620
4	Results of RITE's Advanced Liquid Absorbents Develop for Low Temperature CO_2 Capture	Firoz Alam Chowdhury*, Kazuya Goto, Hidetaka Yamada, Yoichi Matsuzaki, Shin Yamamoto, Takayuki Higashii, Masami Onoda	Energy Procedia Vol.114 (Juy 2017) pp.1716-1720
5	Development of Post-combustion CO_2 Capture System Using Amine-impregnated Solid Sorbent	Ryohei Numaguchi, Junpei Fujiki, Hidetaka Yamada, Firoz Alam Chowdhury, Koji Kida, Kazuya Goto, Takeshi Okumura, Katsuhiro Yoshizawa, KatsunoriYogo*	Energy Procedia Vol.114 (July 2017) pp.2304-2312
6	Development of Chemical CO_2 Solvent for High-pressure CO_2 Capture (3): Analyses on Absorbed Forms of CO_2	Shin Yamamoto*, Hidetaka Yamada, Mitsuhiro Kanakubo, Tsuguhiro Kato	Energy Procedia Vol.114 (July 2017) pp.2728-2735
7	Effect of isopropyl-substituent introduction into tetraethylenepentamine-based solid sorbents for CO_2 capture	Hidetaka Yamada, Junpei Fujiki, Firoz A. Chowdhury, Katsunori Yogo*	Fuel Vol.214 (15 February 2018) pp.14-19
8	Effect of addition of Proline, ionic Liquid [Choline][Pro] on CO_2 separation properties of poly(amidoamine) dendrimer / poly(ethylene glycol) hybrid membranes	S H Duan*, T Kai, F A Chowdhury, I Taniguchi, S Kazama	IOP Conference Series: Materials Science and Engineering, vol. 292 (2017)012040
9	Role of silanol groups on silica gel on adsorption of benzothiophene and naphthalene	Junpei Fujiki*, Katsunori Yogo, Eiji Furuya	Fuel Vol.215 (1 March 2018) pp.463-467

Oral Presentation

	Title	Researchers	Forum
1	Chemically Tunable Ionic Liquid-Amine Solutions for CO_2 Capture	Firoz Alam Chowdhury, Tsuguhiro Kato	ILSEPT2017, Renaissance Kuala Lumpur Hotel, Malaysia, Jan. 8-11 2017
2	(Invited) A study of the chemical reactions involved in amine-based CO_2 capture	Hidetaka Yamada	I2CNER INTERNATIONAL WORKSHOP 2017, Kyushu University, Fukuoka, Japan, Feb. 3 2017
3	Post-combustion CO_2 capture using N-(isopropyl)-tetraethylenepentamine-based solid sorbent	Hidetaka Yamada, Junpei Fujiki, Ryohei Numaguchi, Firoz Alam Chowdhury, Koji Kida, Kazuya Goto, Katsunori Yogo	IEA Clean Coal Centre's 8th international conference on clean coal technologies, Cagliari, Italy, May 10 2017
4	(Keynote, Invited) RITE's Advanced CO_2 Capture Technologies	Hidetaka Yamada	9th Trondheim Conference on CO_2 Capture, Transport and Storage, Trondheim, Norway, Jun. 12-14 2017
5	Post-combustion CO_2 capture by low-temperature steam-aided vacuum swing adsorption using a novel polyamine-based solid sorbent	Junpei Fujiki, Hidetaka Yamada, Firoz Alam Chowdhury, Ryohei Numaguchi, Katsunori Yogo	10th World Congress of Chemical Engineering, Barcelona, Spain, Oct 2-5 2017
6	(Keynote, Invited) The Chemistry of Amine-Based CO_2 Capture	Hidetaka Yamada	The International Conference on Chemical Science and Technology for Sustainable Development, Hanoi, Vietnam, Nov 8-9 2017
7	(Plenary Lecture, Invited) Research and Development of CO_2 Capture Technlogy for CCS	Kazuya Goto	The 11th International Conference on Separation Science and Technology, Busan, South Korea, Nov 9-11 2017
8	Impregnation of Tetraethylenepentamine and Imidazoles Binary Amine in Mesoporous Cellular Foam Silica for CO_2 Capture	Quyen Thi Vu, Hidetaka Yamada, Katsunori Yogo	The 11th International Conference on Separation Science and Technology, Busan, South Korea, Nov 9-11 2017

CO_2 Storage Research Group

Original Paper

	Title	Researchers	Journal
1	Geophysical monitoring at the Nagaoka pilot-scale CO_2 injection site in Japan	Takahiro Nakajima, Ziqiu Xue	Active Geophysical Monitoring, Second Edition, submitted
2	XRF Analysis of Sediment Cores from the Nagaoka CO_2 Injection Site using the Pressed Powder Pellet Method Combined with Fundamental Parameter Method	Kazuhiko Nakano, Takuma Ito, Atsushi Ohbuchi, Ziqiu Xue	Advances in X-Ray Chemical Analysis in Japan, 48,417-428
3	Experimental assessment of well integrity for CO_2 geological storage: A numerical study of the geochemical interactions between a CO_2-brine mixture and a sandstone-cement-steel sample	Joachim Tremosa, Saeko Mito, Pascal Audigane, Ziqiu Xue	Applied Geochemistry, 78, 61-73, 2017
4	Application of marine engineering to offshore CO_2 storage: A method to detect CO_2 leakage using pCO_2	Keisuke Uchimoto,(Makoto Nishimura, Ziqiu Xue	Bulletin of the Society of Sea Water Science, Japan, in print
5	Evaluation of accessible mineral surface areas for improved prediction of mineral reaction rates in porous media	Beckingham, Lauren E., Carl I. Steefel, Alexander M. Swift, Marco Voltolini, Li Yang, Lawrence Anovitz, Julie M. Sheets, David R. Cole, Timothy J. Kneafsey, Elizabeth H. Mitnick, Shuo Zhang, Gautier Landrot, Jonathan Ajo-Franklin, Donald DePaolo, Saeko Mito, Ziqiu Xue	Geochimica et Cosmochimica Acta, 205, 31-49, 2017
6	Migration mode of brine and supercritical CO_2 during steady-state relative permeability measurements at very slow fluid flow velocity	Tetsuya Kogure, Yi Zhang,Osamu Nishizawa, Ziqiu Xue	Geophysical Journal International, 211, 2, 1259-1275, 2017
7	Effects of fluid displacement pattern on complex electrical impedance in Berea sandstone over frequency range 10^4-10^6 Hz	Yi Zhang, Hyuck Park, Osamu Nishizawa, Tamotsu Kiyama, Yu Liu, Kwangseok Chae, Ziqiu Xue	Geophysical Prospecting, DOI: 10.1111/1365-2478.12451, , 65, 4, 1053-1070, 2017
8	Long term CO_2 plume behavior calibrated by 10 years monitoring data at the Nagaoka site	Takahiro Nakajima, Takuma Ito, Ziqiu Xue	Greenhouse Gases: Science and Technology, submitted
9	CO_2 leakage detection using partial pressure of CO_2 and dissolved oxygen at offshore CO_2 storage sites	Keisuke Uchimoto, Takamichi Nakamura, Makoto Nishimura, Jun Kita, Ziqiu Xue	International Journal of Greenhouse Gas Control, , accepted
10	Different flow behavior between 1-to-1 displacement and co-injection of CO_2 and brine in Berea sandstone: Insights from laboratory experiments with X-ray CT imaging	Yi Zhang, Tetsuya Kogure, Osamu Nishizawa, Ziqiu Xue	International Journal of Greenhouse Gas Control, 66, 76-84, 2017
11	Detecting CO_2 leakage at offshore storage sites using the covariance between the partial pressure of CO_2 and the saturation of dissolved oxygen in seawater	Keisuke Uchimoto, Makoto Nishimura, Jun Kita, Ziqiu Xue	International Journal of Greenhouse Gas Control, accepted
12	Different flow behavior between 1-to-1 displacement and co-injection of CO_2 and brine in Berea sandstone: insights from laboratory experiments with X-ray CT imaging	Yi Zhang, Tetsuya Kogure, Osamu Nishizawa, Ziqiu Xue	International Journal of Greenhouse Gas Control, submitted
13	Mass transfer coefficient measurement during brine flush in a CO_2-filled packed bed by X-ray CT scanning	Lanlan Jiang, Bohao Wu, Yongchen Song, Mingjun Yang, Dayong Wang,Yu Liu, Ziqiu Xue	International journal of heat and mass transfer, 115, 615-624, 2017
14	Numerical simulation study of pressure build-up in the formation during injection of CO_2	Claudia Fujita, Hajime Yamamoto, Takahiro Nakajima, Ziqiu Xue	Journal of Groundwater Hydrology, submitted
15	Identifying the source of natural gamma-rays in shallow-marine siliciclastic strata and their significance for shale evaluation: A case study of the CO_2 storage aquifer at the Nagaoka site, Japan	Takuma Ito, Atsushi Ohbuchi, Takahiro Nakajima, Ziqiu Xue	Journal of Natural Gas Science and Engineering, 46, 782-792, 2017
16	Challenges for social impact assessment in coastal regions: a case study of the Tomakomai CCS project	Leslie Mabon, Jun Kita, Ziqiu Xue	Marine policy, Volume 83, 2017, Pages 243-251
17	The Pathway - Flow Relative Permeability of CO_2: Measurement by Lowered Pressure Drops	Yi Zhang, Osamu Nishizawa, Hyuck Park, Ziqiu Xue	Water Resources Research, 53, 10, 8626-8638, 2017

Non-Journal Publication

	Title	Researchers	Journal
1	Develop optimum tool for well location in Carbon dioxide Capture and Storage	Mitsuhiro Miyagi, Hajime Yamamoto, Ziqiu Xue	Report of Taisei Technology Center

CO_2 Storage Research Group

Oral Presentation (International Academic Society)

	Title	Researchers	Forum
1	Micro-bubble Injection Enhanced dissolution during CO_2 Sequestration in saline	Lanlan Jiang, Ziqiu Xue, Hyuck Park,	Carbon Capture, Utilization and Storage Conference,2017/1/21
2	Leak detection	Keisuke Uchimoto	2nd International Workshop on Offshore CO_2 Geologic Storage, Texas, USA, Jun 19, 2017
4	2nd International Workshop on Offshore Geologic CO_2 Storage	Tim Dixon, Susan Hovorka, Tip Meckel, Katherine Romanak, Owain Tucker, Nick Hoffman, Kim Swords5, Lars Ingolf Eide, Niels Peter Christensen, Keisuke Uchimoto, Noel Kamrajh	Mastering the Subsurface through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, Pennsylvania, Aug 01, 2017

Oral Presentation (Domestic Academic Society)

	Title	Researchers	Forum
1	Flow behavior of supercritical CO_2 at the formation boundary visualized by X-ray CT and threshold pressur	Tamotsu Kiyama, Hyuck Park, Yi Zhang, Xue Ziqiu, Lanlan Jiang	MMIJ Annual Meeting 2017, Mar 27, 2017
2	Effect of micro-bubble CO_2 injection on CO_2-EOR	Ryo Ueda, Masanori Nakano, Xue Ziqiu	JAPT Spring Meeting (Technical conference and symposium), Jun 14, 2017
3	Monitoring technology development by distributed strain measurement using optical fiber	Xue Ziqiu	Proceedings of 59th Meeting on Lightwave Sensing Technology, Jun 06, 2017
4	Trapping mechanisms in field scale observed by time-lapse well logging at the Nagaoka site	Takahiro Nakajima, Xue Ziqiu	JpGU-AGU Joint Meeting 2017, May 20, 2017
5	An option for marine monitoring at offshore CO_2 storage sites: observing pCO_2 in the sea	Keisuke Uchimoto, Takamichi Nakamura, Makoto Nishimura, Ziqiu Xue	JpGU-AGU Joint Meeting 2017, May 20, 2017
6	Acoustic sonar detectability of gas bubbles from seafloor for environmental monitoring at offshore CO_2 storage sites	Takamichi Nakamura, Keisuke Uchimoto, Makoto Nishimura	JpGU-AGU Joint Meeting 2017, May 20, 2017
7	Visualization and measurement of CO_2 microbubble flooding in heterogeneous sedimentary rock	Hyuck Park, Lanlan Jiang, Tamotsu Kiyama, Ziqiu Xue	JpGU-AGU Joint Meeting 2017, May 20, 2017
8	valuation of shale volume using a combination of the gamma-ray logs and core analysis in terms of sedimentology and geochemistry: a case study of the Nagaoka site, Japan	Takuma Ito, Atsushi Ohbuchi, Takahiro Nakajima, Ziqiu Xue	JpGU-AGU Joint Meeting 2017, May 20, 2017
9	Micro-bubble Injection enhance dissolution during CO_2 Sequestration in saline	Lanlan Jiang, Ziqiu Xue, Hyuck Park,Tamotsu Kiyama	JpGU-AGU Joint Meeting 2017, May 20, 2017
10	Adopting optimum methods for Carbon dioxides Capture and storage	Mitsuhiro Miyagi, Hajime Yamamoto, Ziqiu Xue	JpGU-AGU Joint Meeting 2017, May 20, 2017
11	Numerical simulation study on mitigation of the pressure build-up in the geological formation during injection of CO_2	Claudia Fujita, Yusuke Hiratsuka, Hajime Yamamoto, Takahiro Nakajima, Ziqiu Xue	JpGU-AGU Joint Meeting 2017, May 20, 2017
12	Numerical simulation study of pressure build-up in the formation during injection of CO_2	Claudia Fujita, Hajime Yamamoto, Takahiro Nakajima, Ziqiu Xue	Japan Society of Civil Engineers 72nd Annual Conference, Sep 11, 2017
13	Effect of micro-bubble CO_2 injection on CO_2-EOR	Ryo Ueda, Masanori Nakano, Xue Ziqiu	The 23rd Formation Evaluation Symposium of Japan (JFES), Oct 11, 2017
14	Geological modeling for an aquifer as a case study of the CO_2 storage site	Takuma Ito,Takahiro Nakajima, Ziqiu Xue	The 124th Annual Meeting of the Geological Society of Japan: 2017 Ehime, Sep 17, 2017
15	Automatic optimization of well placement for mitigating pressure build-up during Geologic CO_2 Storage	Mitsuhiro Miyagi, Hajime Yamamoto, Yohei Akimoto, Ziqiu Xue	rock mechanics symposium, Jan 15, 2017
16	Effect of microbubble injection for CO_2 dissolution in long core experiment	Hyuck Park, Lanlan Jiang, Tamotsu Kiyama, Ziqiu Xue	Annual Fall Meeting of the Mining and Materials Processing Institute of Japan (2017) & The 14th International Symposium on East Asian Resources Recycling Technology (EARTH 2017), Sep 26, 2017
17	Visualization of flow behavior by X-ray CT and strain measurement by optical fiber in supercritical CO_2 injection experiment using formation boundary core	Tamotsu Kiyama, Hyuck Park, Yi Zhang, Lanlan Jiang, Ziqiu Xue	Annual Fall Meeting of the Mining and Materials Processing Institute of Japan (2017) & The 14th International Symposium on East Asian Resources Recycling Technology (EARTH 2017), Sep 26, 2017

CO_2 Storage Research Group

	Title	Researchers	Forum
18	Detecting anomalously high values of pCO_2 using both pCO_2 and DO	Keisuke Uchimoto, Makoto Nishimura, Ziqiu Xue	The Oceanographic Society of Japan, Fall meeting in 2017, Oct 15, 2017

Other Oral Presentation and Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Report from CSLF Regulation Task Force	Ryozo Tanaka	Carbon Sequestration Leadership Forum (CSLF) Policy Group Meeting, Dec, 2017
2	Practical Regulations and Permitting Process for Geological CO_2 Storage	Ryozo Tanaka	Carbon Sequestration Leadership Forum (CSLF), Nov, 2017
3	Caprock and wellbore integrity monitoring using fiber opctic cable: our recent outcomes and what we want to do in the CaMI project	Nobuo Takasu	The annual technical update workshop of CaMI

Inorganic Membranes Research Center

Original Paper

	Title	Researchers	Journal
1	Synthesis of pure silica STT-type zeolite membrane	Koji Kida, Yasushi Maeta, Katsunori Yogo*	Materials Letters Vol. 209, 15 December 2017, pp.36-38
2	Hydrogen Purification from Chemical Hydride Using Pure Silica Zeolite Membranes	Koji Kida, Yasushi Maeta, Taichi Kuno, Katsunori Yogo*	Chemistry Letters Vol.46 No.12, 2017, pp1724-1727.
3	Pure silica CHA-type zeolite membranes for dry and humidified CO_2/CH_4 mixtures separation	Koji Kida, Yasushi Maeta, Katsunori Yogo*	Separation and Purification Technology, Vol.197, 2018, pp116-121.

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