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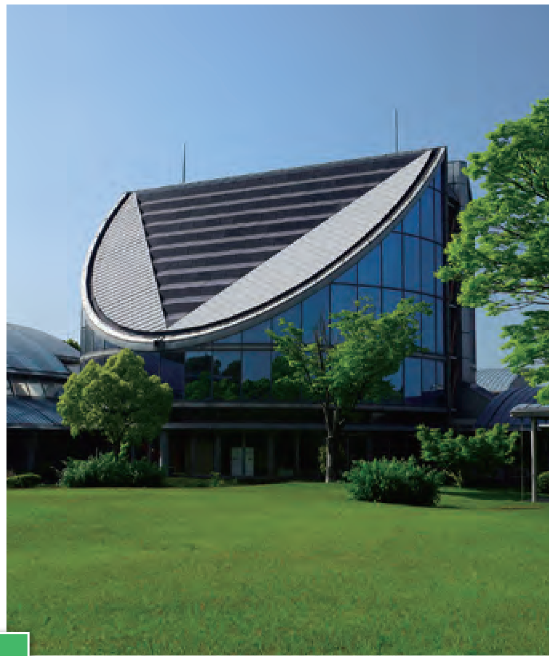
RITE Today
Annual Report

Research Institute of Inovative Tecnology for the Earth



Research Institute of Innovative Technology for the Earth

RITE Today 2017 Vol.12

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Social Acceptance of CCS

Toshifumi Matsuoka
Chairman, Fukada Geological Institute

In December 2016, it was reported as news that snow fell in the Sahara for the first time in 37 years. In Japan, the term "information on record-breaking heavy rain in a short period of time" was used many times. It appears that global climate change due to global warming has become obvious more than ever before. Climate change may lead to a variety of social risks, and a "climate security" concept has been discussed in many situations. The United States government stated that "Climate change is an underlying driver of natural disasters and extreme weather events, increases human migration, and contributes to conflicts around resources, such as food and water", and climate change is "a grave threat to the nation's security". Climate change has been considered to be a national security risk instead of a mere cause of a frequent localized torrential downpour, for example, and addressed from such a viewpoint. Needless to say, it is most important to mitigate global warming that produces such a risk.

CCS is considered to be an economical countermeasure against global warming since it is possible to directly reduce a large amount of CO_2 at a time. However, there are some concerns such as CO_2 leaks from the ground and the occurrence of an induced seismicity due to CO_2 injection. It is necessary to address these risks when implementing CCS. Long-term technology development by RITE has largely contributed to the reduction of these risks. When global risks due to global warming are compared with risks due to implementation of CCS, it is considered that it is better to proceed with CCS taking account of the future of the world. However, human society is very complex.

In 2016, events that overturned the prediction of many experts happened in the world. In the United Kingdom, it was decided by referendum to leave the European Union. In the United States, Donald Trump was surprisingly elected new President. In the Netherlands, a CCS project that was planned in 2010 was canceled due to opposition by local residents.

The Dutch government and Shell planned the Barendrecht project that collects CO_2 from a hydrogen production plant, transports the collected CO_2 to a depleted gas field situated about 17 km away from the plant through a pipeline, and stores 10,000,000 tons of CO_2 underground. However, it became difficult to continue the project due to strong opposition by local residents. Experts had estimated that the risks of CCS with respect to site workers and local residents would be an acceptable level, and the effects of noise and waste and an increase in traffic volume will be negligible. However, the project was canceled. It is considered that discussions and considerations with regard to social acceptance of CCS were insufficient. It may be considered that local residents decided to avoid unduly taking world risks. We would like to carefully observe the global warming policies of new President Trump who won the election campaign with an "America First" slogan. We should keep in mind that a decision that is made by human society often overturns the prediction of experts.

More than thirteen large-scale CCS projects are operating in the world, and a technical platform is now being established. However, it is another problem whether or not local residents at a construction site will accept a CCS project. RITE has been leading the development of CCS technology in Japan. I hope that RITE will also conduct more active research on the social acceptance of CCS.

Manufacturers, user companies, and RITE cooperate to implement early practical application and industrialization of inorganic membranes

Shin-ichi Nakao, Director, Inorganic Membranes Research Center

The Inorganic Membranes Research Center was established in April 2016 as a research department that aims to promote research and development of innovative environmental and energy technologies using inorganic membranes and to contribute to protection of the global environment by promoting practical application and industrialization of these technologies.

—Please explain the aim of the Inorganic Membranes Research Center.

Japan is leading the world in research on inorganic membranes. However, only zeolite membranes used for alcohol dehydration have been put to practical use. Therefore, it has been desired to implement practical application and industrialization of inorganic membranes for use in a wide range of fields.

I have been involved in academic research on inorganic membranes for a long time, and feels there has been a tendency that academic research is only done to write papers. I am of the opinion that engineering research should be conducted taking account of industrial applications. When I was appointed as a group leader of the Chemical Research Group of RITE in 2012, I thought that RITE could make efforts toward practical application and industrialization of inorganic membranes instead of doing only research and development, and prepared to set up a new research department with the consent of RITE. The Inorganic Membranes Research Center was established with the support of many people.

—Please explain the anticipated role of inorganic membranes as global warming countermeasures.

The Inorganic Membranes Research Center aims to develop separation membranes made of inorganic materials. Membrane separation technology has an advantage that its energy consumption is small, and significant energy-saving can be achieved as compared with distillation technology and adsorption technology, so it is considered to be a promising technology that implements an innovative production process. In particular, inorganic membranes have attracted attention since they have excellent heat resistance and environmental resistance as compared with organic poly-

mer-based separation membranes, can be used for a wide range of applications, and have a separation performance that exceeds that of polymer membranes. Inorganic membranes have also been studied and developed as a hydrogen separation membrane that is considered to be indispensable for creating a hydrogen society. Inorganic membranes are thus expected to be a technology for preventing global warming.

—Research and development of inorganic membranes have also made progress in Europe, the United States, and China. Please outline the situation in Japan.

Research on inorganic membranes initially started in Europe. Japan then started advanced research, and has led the world in research of inorganic membranes. China has been rapidly catching up with Europe and Japan in recent years. In China, experiments using a demonstration plant are performed in the early stage of research and development, and identified problems are fed back to research. Demonstration involves high cost, but it is important for us to create a mechanism that facilitates early demonstration.

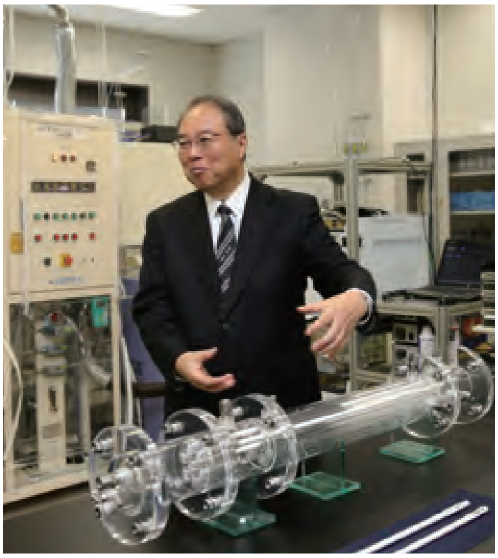
—The Inorganic Membranes Research Center has established an industry cooperation section, and makes efforts toward practical application and industrialization of innovative environmental and energy technologies using inorganic membranes. Please talk about the importance of RITE leading the establishment of an inorganic membrane industry.

It is meaningless for a research institute to conduct research and development of technology that is not used practically. I am of the opinion that RITE should help to establish an inorganic membrane industry while doing research and development. In order to establish an inorganic membrane industry, it is necessary for manufacturers and user companies to cooperate with each other in multiple ways from various viewpoints. Also the cooperation among the manufacturers and among the user companies are indispensable. Since RITE is a neutral research institute, RITE can play a coordinating role. RITE has done advanced research and development on inorganic membranes, and has a considerable knowledge of inorganic membranes. RITE has built a strong relationship of trust mainly with user companies. Therefore, RITE can contribute to the establishment of an inorganic membrane industry while cooperating with manufacturers and user companies.

—The members of the advisory board include leading experts in the field of inorganic membranes. The Inorganic Membranes Research Center also aims to transfer technology to medium-level and young researchers. Please give us your opinion on this.

It is important to transfer accumulated technology to the next generation. In universities, the research theme of a laboratory changes when the professor changes. Therefore, it is difficult to achieve technology transfer. On the other hand, research institutes such as RITE are free from such a problem.

Fortunately, leading experts in the fields of inorganic membranes, hydrogen, and fuel cells have agreed to the aim of the Inorganic Membranes Research Center, and accepted to work as advisors. I hope that the Inorganic Membranes Research Center contributes to technology transfer to medium-level and young researchers of RITE, and also to corporate researchers.



—About 1 year has elapsed from the establishment of the Inorganic Membranes Research Center, and it appears that various activities have started. Please give us an idea of future schedule and developments.

The research section has steadily produced good results. The research section has advanced research and development that will lead to early industrialization of inorganic membranes, such as a dehydrogenation membrane reactor for an energy carrier (i.e., technology that efficiently transports and stores hydrogen) using a silica membrane. We have also proposed a new research and development plan to the Japanese government and private companies.

The industry cooperation section established the Industrialization Strategy Council that consists of manufacturers and user companies. The Council is led by Mr. Kyutoku (Osaka Gas) who acts as Chairman, and sixteen companies participate in the Council. It has formed study groups that implement a need-seed matching process and draw up a roadmap on a theme basis, and has provided seminars exclusive to members, for example.

The research section and the industry cooperation section will work closely with each other, and start up research together with the manufacturers, the user companies, and RITE so that early practical application and industrialization of inorganic membranes can be implemented.

Member companies aiming to implement "industrialization of inorganic membranes" hold earnest discussions

Hirofumi Kyutoku, Chairman, Industrialization Strategy Council

The Inorganic Membranes Research Center has established an industry cooperation section in addition to the research section. The Industrialization Strategy Council formed in the industry cooperation section with manufactures and user companies as members is making various efforts to promote practical application and the industrialization of inorganic membranes.

—What did you think when you first heard about the Inorganic Membranes Research Center and the Industrialization Strategy Council, and was invited to act as Chairman?

I had only known about inorganic membrane technology as one of the research themes while I was the CTO of a private company, but when I was contacted by RITE, I realized that inorganic membranes are a valuable technology that protects the global environment and strengthens Japan's industrial competitiveness, and we need to make efforts toward practical application and industrialization of inorganic membranes. I thought that my experiences of technology development in a gas company that is a potential user of inorganic membranes would contribute to the activities of the Industrialization Strategy Council that aims to implement practical application and industrialization of inorganic membranes, and so I decided to accept the appointment of Chairman.

Joined Osaka Gas Co., Ltd. in 1978, appointed as Associate Director in 2005, Head of Energy Technology Laboratories in 2008, Executive Officer and Managing Director of the Japan Gas Association in 2009, Senior Executive Officer in 2010, Executive Vice President in April 2013, and Advisor in June 2016.

—What is necessary for industrialization of inorganic membranes?

I think that it is necessary for separation membrane/support manufacturers and user companies to share a vision toward practical application and industrialization of inorganic membranes. It is very important for manufacturers and user companies to share their wisdom and draw up a roadmap for industrialization of inorganic membranes. We would like to initially address these priority issues.

In order to draw up a roadmap and implement a need-seed matching process, RITE can play an optimum role since it is well versed in inorganic membrane technology and has a neutral standpoint.

—The Industrialization Strategy Council was established with the aim of implementing practical application and industrialization of innovative environmental and energy technologies using inorganic membranes. Please explain the activities of the council.

The Industrialization Strategy Council has established study groups that draw up a roadmap and implement a need-seed matching process on a theme basis. The members of the Industrialization Strategy Council have led discussions with regard to the study groups for 6 months since the council was established in April, 2016, and a CO_2 separation study group, a hydrogen production study group, and a common infrastructure technology study group were established in November. I was rather anxious before the discussions started. However, the members participated in positive and constructive discussions, and are building a relationship of trust. I think that the study groups were established in a very good way.

—Please talk about the key activities of the Industrialization Strategy Council.

Manufacturers and user companies have participated in such councils, and similar study groups have been established in various fields. However, the most characteristic aspect of the Industrialization Strategy Council is that the members of the Council share the aim of implementing "industrialization of inorganic membranes" and have earnest discussions. I think that such an atmosphere is important for an activity to bear fruit. I would like to manage the Council so that all the members enhance that atmosphere.

—It appears that the members of the Industrialization Strategy Council include companies that are rivals with each other. Are there any difficulties in managing the council due to this?

Yes, this is the most difficult point. The manufacturers are rivals with each other, and the needs of the user companies are connected directly to their business strategy. On the other hand, since the manufacturers shared a sense of crisis that it may be difficult to implement practical application and industrialization of inorganic membranes, there was a common ground to achieve cooperation. The user companies have realized that inorganic membranes have high potential, and increasingly desired to effectively utilize inorganic membranes. Although there are difficulties from the viewpoint of intellectual property rights, for example, I believe that we can overcome such difficulties.

—Please state the future activities and goals of the council.

The study groups will shift into high gear. This is the first step to implement practical application and industrialization of inorganic membranes. We will conduct further activities such as joint research based on the results of the study groups while sufficiently reflecting the members' demands.

We will also provide useful seminars and need-seed information to the members.

I hope that the Council can contribute to global environmental protection and strengthen Japan's industrial competitiveness through early implementation of practical application and industrialization of innovative environmental and energy technologies using inorganic membranes.

(Interviewer; Nami Tatsumi, Research & Coordination Group)

Industrialization Strategy Council General Meeting

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
Yasuhide Nakagami, Planning Manager
Hiroyuki Azuma, Vice Manager
Jun-ichi Shimizu, Vice Manager
Yuji Misumi, Vice Manager
So Kuranaka, Vice Manager

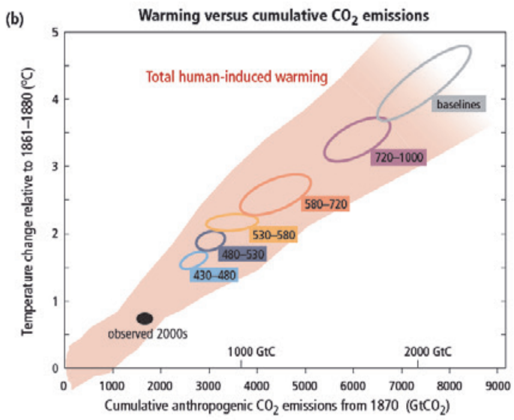
Measures in Future for Deployment of CCS

1. Introduction

“Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels”, “to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century” are set out in the Paris Agreement which was adopted in December 2015. It is critically important to implement various countermeasures in order to achieve the goals. Especially, the R&D of innovative technologies beyond conventional technologies framework is necessary to achieve a balance between anthropogenic emissions and removals by sinks, that is to say, “zero emission”.

In this situation, Carbon Capture and Storage (CCS) is largely expected as one of the measures to reduce carbon dioxide which is one of greenhouse gases. There are, however, various concerns and challenges for deploying CCS on a full scale.

This report provides an outline of the situation surrounding CCS, and the challenges and measures in future for the deployment of CCS on a full scale.



Source: Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) Synthesis Report Summary for Policymakers Figure SPM.5(b)

Figure 1 : Relationship between cumulative CO_2 emissions and projected global temperature change

2. Zero emission and CCS

Figure1 indicates “Relationship between cumulative CO_2 emissions and projected global temperature change” which is set out in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) Synthesis Report Summary for Policymakers. The IPCC report explains “Multiple lines of evidence indicate a strong, consistent, almost linear relationship between cumulative CO_2 emissions and projected global temperature change to the year 2100”. Therefore, it is necessary to make incremental emission of CO_2, i.e. emission of CO_2 per annum, zero in order to stabilize global mean surface temperature.

It is a very difficult challenge to achieve zero CO_2 emission per annum, but the challenge must be achieved in the future in order to stabilize global mean surface temperature.

Figure2 indicates the concept of countermeasure

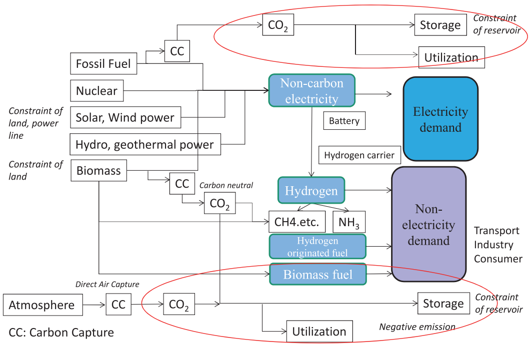


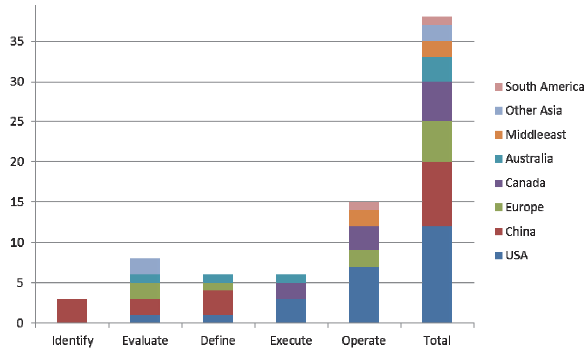
Figure 2 : The concept of countermeasure technologies for Zero Emission

technologies for zero CO_2 emission. First, renewable energies like solar, wind, hydro, geothermal and biomass and, what is more, nuclear energy are considered to be deployed for electricity demand for Zero CO_2 emission. However, renewable energies like solar, wind and so on are intermittent depending on climate and there is concern about safety of nuclear energy. And there is concern that these energies cannot provide enough power to meet global energy demand. Therefore, the deployment of thermal power stations equipped with CCS is necessary. On the other hand, hydrogen produced from carbon-free energy and carbon-neutral biomass and methane produced from carbon-neutral biomass are considered to be necessary for meeting non-electricity demand like thermal demand for industry. As CO_2 would go into atmosphere in the process of steel and cement production, CCS is a sole measure for steel and cement industry to reduce CO_2 emission drastically. In addition, "negative emission" which can reduce CO_2 in atmosphere directly is set out in IPCC Assessment Report as one of the measures to achieve 2℃ goal. The examples considered as "negative emission" are "BECCS" which is the combination of biomass energy and CCS, "direct air capture" which can capture and storage directly CO_2 in the atmosphere and so on. These technologies require combination with CCS. As mentioned above, CCS is crucially important to achieve zero emission.

3. Situations of CCS deployment

3.1. The current status of CCS large-scale projects in the world

According to "The Global Status of CCS: 2016", there are 15 large scale integrated projects (LSIPs) listed in the Operate stages and 6 projects in the Execute stage. The number of total LSIPs including the planning stages of development amounts to 38. The number of LSIPs in Execute stage decreases by 1 project. The number of total LSIPs decreases by 7 projects compared to those in last year (Figure 3).



Nation	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
Canada	0	0	0	2	3	5
Australia	0	1	1	1	0	3
Middleeast	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 2016 VOLUME 2

Figure 3 : The current status of CCS large-scale projects in the world

3.2. The mechanisms of CCS deployment in examples

Most of the large scale integrated projects in the Operate stage are implemented in natural gas production industry and captured CO_2 is used and stored for EOR in these projects. As the CO_2 capture process is an inherent component of natural gas production, additional cost for CCS is limited to transportation and storage. It is comparatively easy to deploy CCS in natural gas production industry. Selling CO_2 for EOR is bankable. These are the reasons why CCS projects are implemented in natural gas production industry and project for EOR. In these ways, the factors that make project bankable are indispensable for CCS deployment. The examples of CCS deployment mechanisms are explained as follows.

3.2.1. The Boundary Dam Integrated Carbon Capture and Storage Demonstration Project

The Boundary Dam Integrated Carbon Capture and Storage Project in Canada became operational in October 2014 as the world's first large-scale power sector CCS project. CO_2 emission performance standard applied for coal fired power station entered into force in Canada in July 2015. As this regulation would be applied to the Boundary Dam power station, CCS facilities were installed in the unit 3 of this station which was planned to be refurbished. Net generating capacity for production unit 3 was expected to be around 110 MW. CO_2 Capture capacity volume was expected to be 1 million tons per annum. Additional cost for CO_2 capture facilities was 900 million C$ and Canadian government gave a subsidy of 240 million C$. Most of CO_2 captured would be sold for EOR and a part of CO_2 captured would be utilized for CO_2 storage demonstration project.

It can be said that the Boundary Dam Integrated Carbon Capture and Storage Project is implemented under the mechanism of CO_2 emission regulation, government subsidy, selling CO_2 for EOR and so on. (Figure 4)

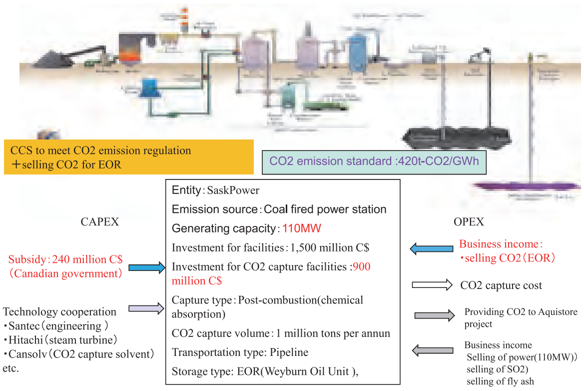


Figure 4 : The mechanisms of CCS deployment in the Boundary Dam Integrated Carbon Capture and Storage Demonstration Project

3.2.2. The Sleipner CO_2 Storage Project

The CO_2 captured in the natural gas refinery process has been injected and stored into geological formation under seabed in the Sleipner CO_2 Storage Project located in the middle of the Central North Sea. Since 1991, the Norwegian government has implemented a CO_2 tax. According to GCCSI, the tax varies across sectors and time. In 1996, when the Sleipner CO_2 Storage Project started, the CO_2 tax on offshore petroleum production on the Norwegian Continental Shelf was 210 NOK (35 USD) per ton of CO_2. This has progressively been raised to 544 NOK (65 USD) per ton in 2016. On the other hand, the additional cost of injecting and storing CO_2 into geological formation under seabed is assumed to be 17 USD per ton of CO_2. The annual cost would be assumed to be 100 million NOK. AS CO_2 tax would amount to 180 million NOK in 1996 and 460 million NOK in 2016, injecting and storing CO_2 is cheaper than paying CO_2 tax. Therefore, Statoil decided to adopt implementing CCS in order to evade CO_2 tax. As the CO_2 capture process is an inherent component of natural gas production, additional

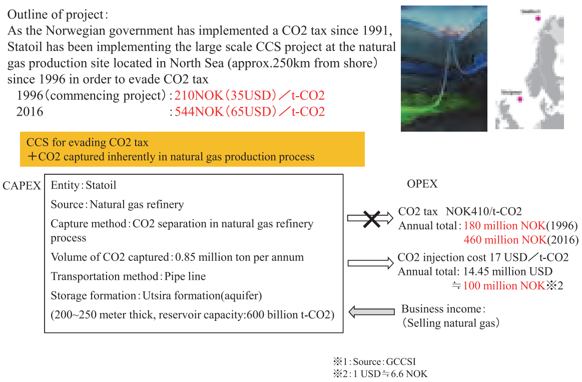


Figure 5 : The mechanisms of CCS deployment in The Sleipner CO_2 Storage Project

cost for CCS is limited to transportation and storage. In other ward, It can be said that the Sleipner Storage Project is implemented under the mechanism of CO_2 tax and because the CO_2 capture process is an inherent component of natural gas production. (Figure 5)

3.3. The current status of CCS regulation

3.3.1. The concept of CCS regulation

There is no legislation dedicated to CO_2 capture and transportation in Japan. “High Pressure Gas Safety Act”, “Industrial Safety and Health Act”, “Poisonous and Deleterious Substances Control Act” and so on are applied to CO_2 capture and transportation depending on the way of implementation. Environmental Impact Assessment and safety regulation are implemented as necessary.

In overseas where CCS projects are actually implemented, laws and regulations, such as amended conventional laws, are applied to CO_2 storage. As the sites where CO_2 can be injected safely are recognized as the finite resources, it is necessary to optimize the resources. As there are various oar and resources underground, it is necessary to coordinate CCS with other oar and resources legally. The governmental regulations are needed from this point of view. As a large amount of CO_2 will be injected into underground, it is a very important issue whether CCS is safe or not, and whether CCS has a negative impact on the environment or not. Regulation of safety by regulatory authorities and environmental impact assessment are necessary. As the volume of stored CO_2 is considered as the volume of reduced CO_2, it is necessary to secure a precise measurement of stored CO_2. In addition, monitoring the CO_2 leakage will continue for a long time, so it is not feasible to impose liability on a private company for several decades. Therefore, the responsibility for the custody of storage site will transfer to the regulatory authority abroad after 15 to 20 years, or up to 50years passes over. In this way, CO_2 storage needs building a regulatory framework.

Figure 6 indicates the concept of regulatory framework on CO_2 storage in reference to overseas regulation. At first, site selection will be done. If enough information is not acquired, site exploration will be done. Exploration authorization by government will be granted after reviewing from the viewpoints of effective utilization of underground space resource, harmonization among other underground resources and so on. When

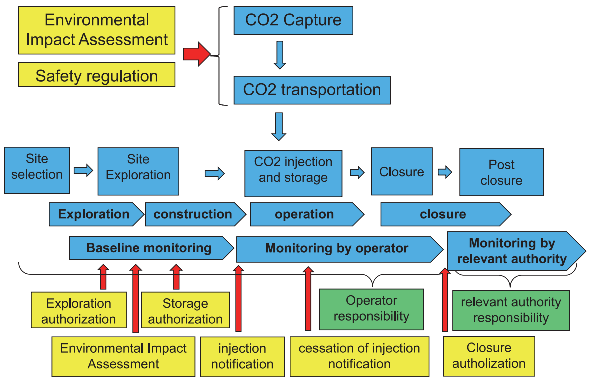


Figure 6 : Concept of regulation system on CCS

CO_2 storage at the site is feasible as the result of exploration, an environmental Impact assessment will be implemented and then, an exploration authorization application will be filed to relevant authority.

The application will be reviewed from the viewpoints of whether it can be implemented safely or not, whether it will adversely affects environment or not, and whether the applicant has financial and technical capability or not. It moves to construction stage of facilities and equipment after granting CO_2 storage authorization. It will be operational after the construction is completed and the applicant informs relevant authority of "injection notification". After the injection at site is implemented and ends as planned, the operator will inform relevant authority of "cessation of injection notification" and it will enter closure period. Then, the site is closed and monitoring for CO_2 leakage will be implemented. The responsibility for the custody of storage site will transfer to the regulatory authority after 15 to 20 years passes. It is also necessary to prescribe corrective measures and remediation measures in case of irregularities.

3.3.2. The status of regulation for CO_2 storage in the world

There is "Act on Prevention of Marine Pollution and Maritime Disaster" as CCS relevant law, and there are "High Pressure Gas Safety Act", "Mining Act", "Mine Safety Act", and so on as other relevant laws in Japan. These laws are aimed for conservation of environment and securement of safety. There is not a dedicated law for CCS which includes exploration authorization, safety criteria of injection and so on from the viewpoints of optimizing the underground resources etc. in Japan.

The CCS Directive had entered into force as CCS relevant law and regulation in Europe in 2009. Site selection, exploration, application, authorization, operation, liability of post closure and so on are prescribed in this Directive. This Directive is a comprehensive framework which prescribes from site selection and exploration permit to post closure. Most of the member states had already transposed CCS Directive into national law to date.

CO_2 storage is regulated in USA by UIC (Under Injection Control) under Safety Drinking Water Act (SDWA) from the viewpoint of securing safe drinking water. The content of regulation differs according to type of injection well. Class VI is prescribed as the criteria for CO_2 underground injection. As this regulation is aimed for securing safe drinking water, it does not have the concept of exploration authorization similar to those in Japan, but establish the criteria of injection safety.

"Offshore Petroleum Act" was amended as CO_2 storage relevant law in Australia. This act is a comprehensive one which prescribes site selection, exploration permit, injection permit, criteria of injection safety and post closure custody.

3.3.3. The status of transposition of EU CCS Directive into Member State's national law

Table 1 indicates the status of transposition of EU CCS Directive into Member State's national law. CCS Directive had been entered into force in 2009. Member States were expected to transpose the directive into national laws by 2011, and ensure the national law enters into force by 2012, but transposition of the CCS Directive was accepted by the EC only in Spain by 2011. Member States had gradually transposed afterward. By the end 2013, the CCS Directive has been transposed into national law in 28 EU Member States including Croatia which entered the EU in 2013 although some of them were still reviewed by EU.

As a result, UK, The Netherlands, France, Spain and other nations allow CO_2 Geological storage at all areas of its land. Belgium, Greece and Italy allow CO_2 storage excluding selected areas like seismically active areas and areas where the storage complex extends beyond territory. Norway and Sweden permit CO_2 storage only in offshore areas. In Germany, only limited CO_2 storage will be permitted until 2018 (up to 4 Mt CO_2 annually and maximum 1.3 Mt per one project). In Denmark, regulations have prohibited storage with the exception of offshore CO_2-enhanced oil recovery (EOR). CO_2 storage is prohibited in Poland except for demonstration projects. CO_2 storage is prohibited per-

Table 1 : The status of transposition of EU CCS Directive into national laws (limited to CO_2 storage)

The status of transposition of EU CCS Directive (limited to CO2 storage)		Nations
Permitting for the whole territory		Croatia, Cyprus, France, Lithuania, Malta, Romania, Slovakia, Spain, The Netherlands and UK
Permitting with restrictions		
	Excluding selected areas	Belgium, Greece and Italy
	Limiting volume of exploration area	Portugal (limiting volume), Bulgaria and Hungary (limiting surface area)
	Limiting volume of CO2 stored	Germany (up to 4 Mt annually and maximum 1.3 Mt per one project)
	Permitting only offshore	Norway and Sweden
No permitting except for research (<100 Kt)		
	Temporary	Czech Republic (until 2020), Denmark (until 2020 except for EOR offshore), Poland (until 2024 except for demo projects)
	Permanently	Austria, Brussels Capital Region and offshore Belgium, Estonia, Finland, Ireland, Latvia, Luxembourg and Slovenia

Source: Implementation of the EU CCS Directive in Europe: results and development in 2013

manently except for research and development in Austria, Finland, Ireland and other nations.

Only limited CO_2 storage will be permitted until 2018 (up to 4 Mt CO_2 annually) in Germany which is the largest CO_2 emitter in EU because new CCS Act was rejected by the Bundesrat (Federal Council) and then Bundestag and Bundesrat eventually reached a compromise. In Poland which is 5th large emitter in EU, CO_2 storage is prohibited except for-demonstration projects after long debate. It is reported as the background that the influence of Green NGOs on public opinion is high in Germany and Poland. It is thought that the deadline of transposing EU CCS Directive into Member State's national law caused compromise which is not good for CCS deployment in these examples. These things should be considered when framework of CCS deployment will be established in future in Japan.

3.3.4. 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 to this international framework, Japan set up the mirror committee of ISO/TC265 for the domestic discussion.

Table 2 and Figure 7 indicate the status of WG activities and development schedule. Each WG is developing International standards (IS) and Technical report (TR).

TR on CO_2 capture was finalized and published in May 2016. Japan took a lead of WG1 activity and this TR is the first published document from TC265. WG1 has also started to develop IS for post combustion capture technology integrated with power plant. Committee Draft was approved and now WG1 is developing Draft International Standard (DIS).

WG2 has developed IS on transportation by pipeline and this IS was published in November 2016.

WG3 is developing IS on onshore and offshore CO_2 storage. Draft International Standard was approved and now WG3 is developing Final Draft International Standard (FDIS).

TR compiled with the information of quantification and verification was approved and now in the process of publication. WG4 started to develop IS on quantification and verification based on this TR.

WG5 is developing IS on vocabulary. DIS on cross cutting terms is approved. TR for life-cycle risk management was approved and now in the process of publication.

Committee Draft for CO_2-EOR was rejected and WG6 is revising the contents of the CD.

As mentioned above, the first TR and IS were published in 2016. International standardization for CCS has been progressing steadily.

4. Trends of measures for deployment of CCS steadily

4.1. Challenges and things to tackle for deployment of CCS

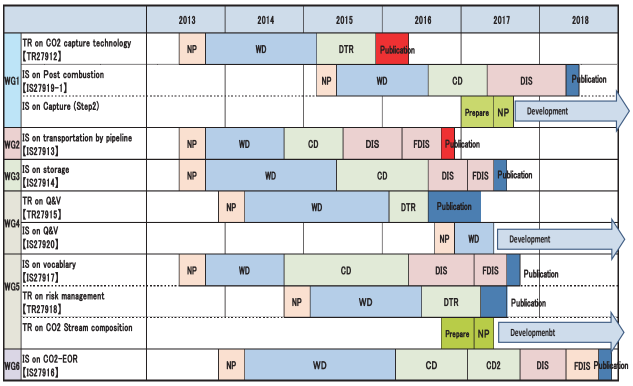
It is impossible to deploy CCS, the measure to global warming which is external diseconomy, under market mechanism. Therefore, it is required creating incentives such as subsidies, tax exemption and regulation system. Reducing cost and uncertainty of project is necessary to deploy CCS on a large scale. In particular, ① implementing R&D for cost reduction, ② understanding CO_2 storage capacity and making database, ③ development of economical and safe CCS

Table 2: Summary of WGs activities

WG	Work items	Target date	Note
WG1 (Capture)	● TR 27912 based on Japanese draft which compiles CO2 capture technologies had been published. (2016/5/15) ● DIS is in the process of the development. IS 27919-1 ● The next NWIP will be submitted.	TR:2016 (done) IS:2018	TR27912 is the first publication from TC265.
WG2 (Transportation)	● IS27913 is had been published. (2016/11/1)	IS:2016 (done)	IS27913 is the first IS from TC265.
WG3 (Storage)	● DIS was approved. WG3 is developing FDIS. IS 27914	IS:2017	Vote of FDIS is scheduled on May 2017.
WG4 (Q&V)	● TR 27915 is in the process of publication. WG4 started to develop IS. ISO/ AWI27920	TR:2017	Started to develop IS
WG5 (Cross-Cutting Issues)	● FDIS on CCS vocabulary is expected to be prepared. IS 27917 ● TR for Lifecycle risk management is in the process of the publication. TR27918 ● New item on CO2 stream composition	IS:2017 TR:2017	The development period of IS 27917 was extended to 4 years.
WG6 (CO2-EOR)	● 2nd CD is in the process of CD voting. ISO 27916	IS:2018	The development period will be extended.

(Reference) The outline of International standardization procedure

Source: RITE



NP:New work item proposal, WD:Working draft, CD:Committee draft, DIS:Draft International standrad, FDIS:Final DIS, DTR:Draft Technikal report

Figure 7 : Work plan of developing documents

suitable to Japanese geological formations, ④ establishing mechanisms and regulation systems for CCS deployment, and ⑤ promoting public understanding of CCS are indispensable.

4.2. Things to clarify for deployment of CCS

The establishment of regulation systems is necessary for the deployment of CCS in future. It is thought that we have to evade promoting it prematurely, considering the procedure of transposing EU CCS Directive to national laws in Germany and Poland. Therefore, it is necessary to get the enough understanding of stakeholders and public for CCS deployment. Following points are needed to be clarified at least for gaining the understanding by stakeholders and public. ① the outline of incentive mechanisms and regulation systems for CCS deployment, ② estimated cost for CCS deployment borne by stakeholders and public and ③ estimated volume of reduced CO_2 by CCS. It is indispensable for CCS deployment to investigate and consider above things and provide the results. In particular, commencing to investigate CO_2 storage capacity is desired as it takes a long time and many funds.

5. Conclusion

It is necessary to make incremental emission of CO_2, i.e. emission of CO_2 per annum, zero in order to stabilize global mean surface temperature. "Negative emission" is one of the measures to achieve zero emission. These technologies require combination with CCS. CCS is critically important for zero emission.

The factors that make project bankable are indispensable for CCS deployment. The Boundary Dam Integrated Carbon Capture and Storage Project is implemented under the mechanism of CO_2 emission regulation, government subsidy, selling CO_2 for EOR and so on. The Sleipner Storage Project is implemented under the mechanism of CO_2 tax and so on.

In overseas where CCS projects are actually implemented, laws and regulations, such as amended conventional laws, are applied to CO_2 storage. It is necessary in Japan to establish the regulation systems for CCS in future but to evade promoting it prematurely. It is necessary to get the enough understanding by stakeholders and public of CCS deployment. ① The outline of incentive mechanisms and regulation systems for CCS deployment, ② Estimated cost for CCS deployment borne by stakeholders and public and ③ Estimated volume of reduced CO_2 by CCS are needed to be clarified at least for understanding by stakeholders and public.

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Research Activities in Systems Analysis Group

The Systems Analysis Group aims to provide valuable information about measures on global warming and energy issues, both inside Japan and internationally by thinking them systematically and through systems analyses. We present here three research topics out of our research activities conducted in 2016; 1) the analyses on the 1.5 °C target which was touched upon in the Paris Agreement, 2) the evaluations of emission reduction strategies including co-benefit analyses of CO_2 and PM2.5 reductions considering current hot discussions in China, the U.S. and other countries, and 3) the evaluations of economically rational investments on global warming mitigation under volatilities of carbon price (the analysis for CCS was implemented). Our group contributes to the planning of better climate change policies and measures through such analyses and evaluations.

1. Evaluations on emission pathways and costs for the 1.5 °C target

The Paris Agreement which was adopted in December 2015 and entered into force in November 2016 contains: "To hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels." The Intergovernmental Panel on Climate Change (IPCC) decided to publish a special report by 2018. In this background, RITE analyzed the emission pathways and costs for the 1.5 °C target.

1. 1. Uncertainties regarding temperature target and the assumed temperature trajectories for the 1.5 °C target

While the Paris Agreement states the 1.5 °C target, large scientific uncertainties in temperature estimation exist as well as the ambiguity of the political statement. For example, timing and probability of the achievement, climate sensitivity and probability density function are uncertain.

Table 1 : The scenarios for the 1.5 °C target analyses

Temperature trajectories	Equilibrium climate sensitivity		
	a) 3.4 °C	b) 3.0 °C	c) 2.5 °C
I) 1.5 °C stabilization (below 1.5 °C over time)	I-a	I-b	I-c
II) Below 1.5 °C by 2100 (temperature overshoot; peak temperature: around 1.75 °C)	II-a	II-b	II-c
III) Below 1.5 °C by 2300 (temperature overshoot; peak temperature: around 2.0 °C)	III-a	III-b	III-c

This study assumes three kinds of temperature trajectories and three kinds of climate sensitivities as shown in Table 1. The climate sensitivity was likely to be 2.0-4.5 °C and the best estimate was 3.0 °C in the Fourth Assessment Report of IPCC (2007) (in this case, the climate sensitivity of 3.4 °C corresponds to the achievement of the temperature target with 66% probability). The sensitivity was likely to be 1.5-4.5 °C and no consensus of the best estimate was obtained in the Fifth Report (2013) (The range was 1.5-4.5 °C and the best estimate was 2.5 °C in the Third Report (2001)). Based on them, the climate sensitivity for the analyses for the temperature target was assumed as shown in Table 1.

1. 2. Emission pathways for achieving the 1.5 °C target

The global CO_2 emission pathways for achieving the 1.5 °C target corresponding to the scenarios shown in Table 1 were estimated by using a simple climate change model MAGICC which is employed for the IPCC reports and a global energy and climate change mitigation model DNE21+ which is developed by RITE. As seen in Figure 1, the net negative global emissions are required in all scenarios. Particularly in the overshoot scenarios of Scenarios II and III, negative emissions of about 20 $GtCO_2$/yr are required in 2100. In the long run, zero CO_2 emissions are required even for any levels of temperature stabilization.

The 2030 global greenhouse gas (GHG) emission should be reduced by 85% relative to 2010 level in Scenario I-a which is the deepest reduction scenario within the assumed scenarios. The 2030 GHG emission for Scenario III-b which is the loosest reduction scenario is nearly consistent with the expected emission of NDCs; however, significant net negative global emission is required by 2030 and negative emissions should continue until 2300. It will be infeasible to achieve it by CO_2 fixation through reforestation/ afforestation due to the global land constraints.

1. 3. The emission reduction costs and measures for the 1.5 °C target

The global emission reduction measures and costs up to 2050 were analyzed with DNE21+ model.

There were no feasible solutions by DNE21+ in Scenarios I-a and II-a. In Scenarios I-b and II-b which assume 3.0 °C of climate sensitivity, there were feasible solutions by 2050, but the marginal abatement cost in 2050 is 710 and 5900 $/$tCO_2$ for Scenario II-a and I-a, respectively.

Figure 2 shows global primary energy supply for the 1.5 °C target. The amounts of coal supply are reduced and deployments of BECCS are required in 2030 in Scenario I-b. In Scenarios I-c and III-b, and Scenario III-C, the drastic changes were not observed until 2030 and 2050, respectively (However, the drastic

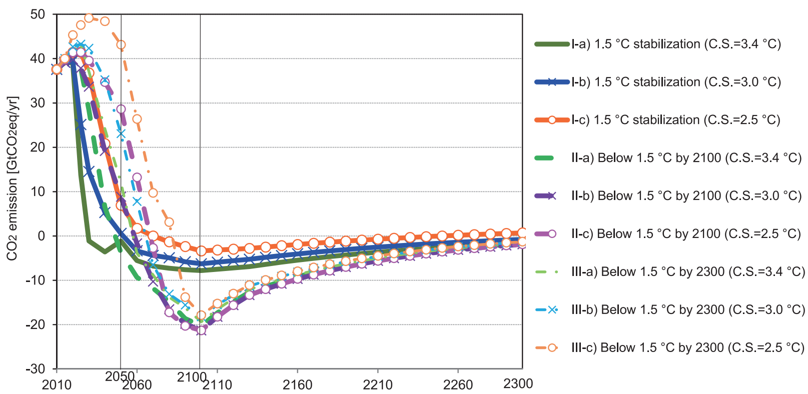

Figure 1 : Global CO_2 emission pathways for the 1.5 °C

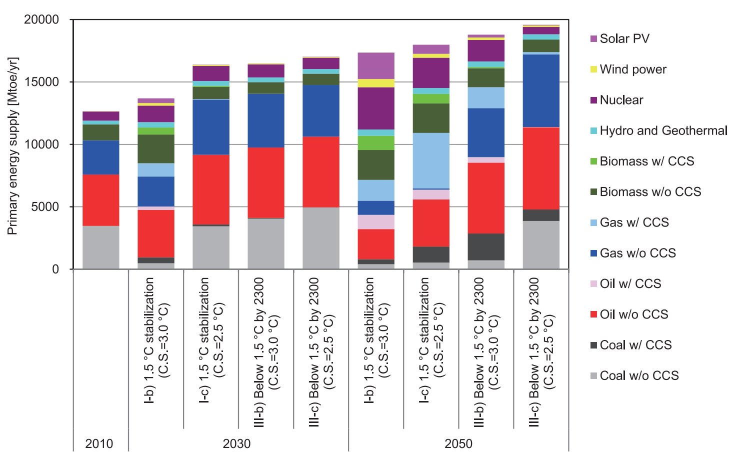

Figure 2 : Global primary energy supply for the 1.5 °C target

emission reductions are required after 2050).

While total primary energy supply decreases in the deeper emission reductions scenarios, the total electricity generation increases with lower CO_2 intensity. CO_2 fixation of about 10 $GtCO_2/yr$ is required by 2050 and achieved through reforestation/afforestation and CCS.

1. 4. Conclusions

The Paris Agreement contains not only the 2 °C target but also the 1.5 °C target. There are several uncertainties regarding the temperature targets and therefore a wide range of possible emission pathways. However, even if such large uncertainties are considered, there are large gaps between the expected global emission in 2030 by the submitted NDCs and most of the emissions for the 1.5 C target. Even in the scenario which has the small gap in 2030, the large negative emissions are required continuously, and there exists only a very small chance of realizing the 1.5 °C target.

2. An analysis on correlation between climate change mitigation and air pollution control

2. 1. Introduction

Serious impacts of suspended particulate matters on human health are concerned in some developed countries as well as many developing countries. On the other hand, climate change is one of the top agenda to be tackled in the world. In these backgrounds, the co-benefits of climate change mitigation on air pollution control are attracting attention. Correlation between climate change mitigation and air pollution control focusing on SO_2 and NO_2 emission reductions in power sector was analyzed by using a global energy systems model DNE21+.

2. 2. Assessment model for SO_2 and NO_2 emission reduction measures in power sector

Three types of the commercialized end-of-pipe technologies in fossil fuel power plant for reducing SO_2 and NO_2 are explicitly modelled: flue-gas desulfurization, combustion modification (e.g., low NOx burner), and selective catalytic reduction. Assumed SO_2 and NO_2 emissions per unit of electricity generation and capital cost for plants with and without emission reduction measures in 2030 are summarized in Table 2.

Table 2 : Assumed SO_2 and NO_2 emissions per unit of electricity generation and capital cost in 2030

	Efficiency	Emission reduction measures*1	SO_2 emission [gSO_2/kWh]	NO_2 emission [gNO_2/kWh]	Capital cost [US$/kW]
Coal power	Low	Without	9.88	4.39	600
		With	0.24	0.44	970
	Middle	Without	5.97	2.65	1250
		With	0.14	0.27	1470
	High*2	With	0.12	0.23	1700
Oil power	Low	Without	20.16	2.88	250
		With	0.86	0.29	620
	Middle	Without	12.06	1.72	650
		With	0.52	0.17	870
	High*2	With	0.39	0.13	1100
Gas power	Low	Without	0.29	1.80	300
		With	0.29	0.18	360
	Middle	Without	0.20	1.23	650
		With	0.20	0.12	690
	High*2	With	0.15	0.09	1100

*1 Assumed three emission reduction measures are adopted for 'With' cases; exceptions are 'With' cases of gas power plants where desulfurization is not assumed.

*2 Employment of all of the emission reduction measures is assumed for the "high" efficiency technologies.

2. 3. Analyzed scenarios

Baseline case (CO_2: Any climate change mitigation policies are not included. SO_2 and NO_2: Emission intensities of fossil fuel power plants are kept below 2010 level.) and the reduction cases in Table 3 were analyzed.

CO_2 reductions prioritized cases seek global CO_2 emission reduction without any explicit regional emission target of SO_2 and NO_2. Three levels of CO_2 emission reductions are assumed; CP4.5: stabilization at around 650 ppm-CO_2eq.; CP3.7: stabilization at around 550 ppm-CO_2eq.; CP3.0: +2 °C target. The amounts of SO_2 and NO_2 emissions brought about by the CO_2 emission reductions are obtained in CO_2 reductions prioritized cases. PM2.5 reductions prioritized cases seek the above amounts of SO_2 and NO_2 emissions reductions by region with least-cost measures without explicit CO_2 emission reduction targets.

Table 3 : Analyzed scenarios

		Assumption
CO_2 reductions prioritized case	Energy-related CO_2	Global emission caps with uniform marginal abatement cost are assumed. Three levels of emission reductions are assumed: CP4.5, CP3.7, and CP3.0.
	SO_2, NO_2	SO_2 and NO_2 emission intensities of fossil fuel power plants are kept below 2010 level by region.
PM2.5 reductions prioritized case	Energy-related CO_2	Any climate change mitigation policies are not included.
	SO_2, NO_2	SO_2 and NO_2 emissions induced by the CO_2 emission reduction targets in the CO_2 reductions prioritized cases are adopted as regional emission caps by region.

2. 4. Results

Figure 3 shows global electricity generation mix in 2030. For the CO_2 reductions prioritized cases, switching from coal to gas, nuclear and renewables for achieving CO_2 emission reduction are observed. In addition, decrease in total electricity generation through energy savings in energy end-use sectors is observed. Accompanying these CO_2 emission reduction, SO_2 and NO_2 emission reductions in power sector are obtained. In 2030, SO_2 and NO_2 emissions are almost same as those in 2010 for CP4.5. For CP3.7 and CP3.0, SO_2 emissions in 2030 are about 60% and 18% of the 2010 level, respectively, and NO_2 emissions are 26%.

On the other hand, coal power with the end-of-pipe type technologies is widely deployed in the PM2.5 reductions prioritized cases. If SO_2 and NO_2 emission reductions for air pollution control are principal targets, the end-of-pipe type technologies for fossil fuel power plants are major reduction measures.

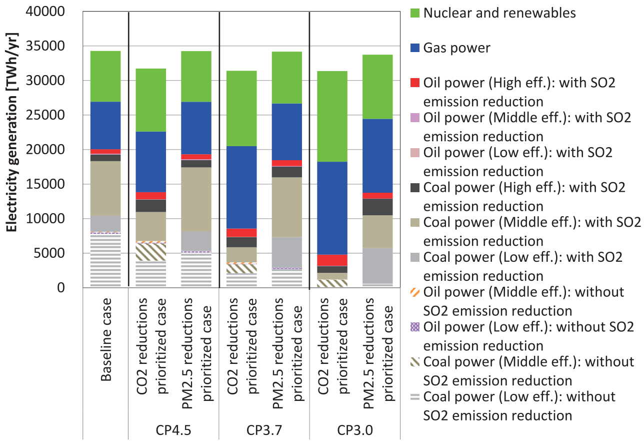

Figure 3 : Global electricity generation mix in 2030

Emission reduction contributions by measure are analyzed based on the Kaya identity. Figure 4 shows the contributions for CP3.7 for two time periods: 2015-2030, and 2030-2050.

For CO_2 emission reductions, energy savings (improvement in energy consumption per unit of electricity generation) contribute to emission reductions as a cost efficient measure at first. Following energy savings, fuel switching (disaggregated into improvement in energy consumption and gross emission per energy consumption) and CCS (improvement in net emission per gross emission) are introduced for achieving deeper CO_2 emission reduction. On the other hand, deployment of end-of-pipe type technologies (improvement in net emission per gross emission) are major response

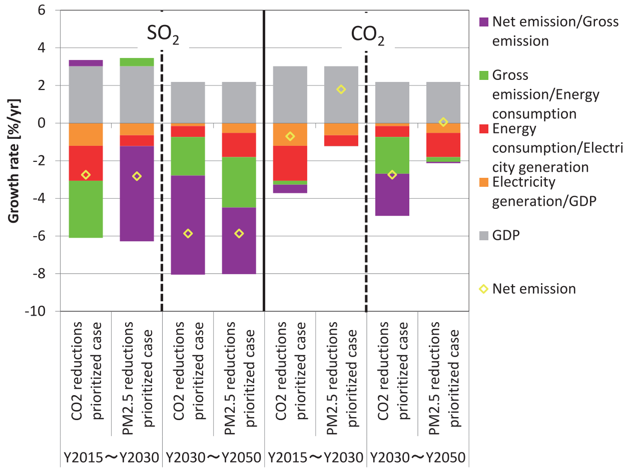

Figure 4 : SO_2 and NO_2 Emission reduction contributions by measure for CP3.7

measures for SO_2 emission reduction at first. In this way, the priority of the type of emission reduction measures under the least-cost measures is different between CO_2 emission and SO_2 and NO_2 emissions reductions.

Estimated cumulative global emission reduction costs from 2000 to 2050 (Discount rate: 5%) are 0.8 Trillion US$ (CP4.5)–5.3 Trillion US$ (CP3.0) for the CO_2 reductions prioritized cases. For the PM2.5 reductions prioritized cases, their costs are 0.1 Trillion US$ (CP4.5)–0.8 Trillion US$ (CP3.0). The costs of the CO_2 reductions prioritized case are much higher than those of the PM2.5 reductions prioritized case.

Climate change mitigation is important and co-benefits of CO_2 emission reduction to PM2.5 reduction are observed. However, if health impacts caused by PM2.5 are serious, the deployment of the end-of-pipe type technologies for SO_2 and NO_2 emission reductions prior to large CO_2 emission reductions, which cost much less, will be an economically rational strategy particularly for developing countries where PM2.5 levels are relatively high.

2. 5. Summary

The correlation between climate change mitigation and air pollution control was analyzed by using a global energy systems model, explicitly modelling SO_2 and NO_2 emission reduction technologies for fossil fuel power plant.

Climate change mitigation on PM2.5 reduction generates co-benefits through energy savings and fuel switching. However, these measures are not necessarily least-cost measures to reduce PM2.5.

If the benefits of PM2.5 reductions are larger than climate change mitigation benefits, SO_2 and NO_2 emissions reductions with cheaper costs such as the end-of-pipe technologies for SO_2 and NO_2 reductions will contribute to effective risk reductions.

3. Analysis of CO_2 capture and storage investment based on real options approach

3. 1. Introduction

CO_2 capture and storage (CCS) technology is recognized as an effective technology for deep CO_2 emission reductions. For CCS diffusions, circumstances that enable firms to invest in CCS are needed.

There are some obstacles to overcome for firms' investing in CCS, and this study focused on uncertainties and volatilities of LNG and carbon prices as obstacles. We analyzed cost-efficient decision-making behavior, such as whether to invest in CCS immediately or to wait and keep the investment options under uncertainties of LNG and carbon prices based on real options approach. Real options approach, which was originally developed in the field of finance, is applied to an analysis on real assets in this study.

We considered the case of a firm having an aged coal power plant. The firm can select the power plant type and investment timing. The firm's "waiting" means keeping options open and utilizing the aged coal power plant. In contrast, the firm's investment in coal power plant w/ CCS, for example, doesn't allow canceling the investment decision afterwards even if the carbon price decreases substantially. In this way, considering flexibility and irreversibility of decision-making is one of characteristics of real options approach.

CCS has another uncertainty, e.g., injectivity (injection rate in CO_2 storage site) and capacity factor of CCS systems which may be affected by authorization and local agreement. However, this study doesn't cover these uncertainties due to the difficulty of parameterization.

3. 2. Analysis framework

This study targets the firm as following:

- ✓ The firm owns and operates the aged coal power plant, and the maximum remaining lifetime of the plant is ten years. The firm has to replace the plant within ten years.
- ✓ There are four options for the replacement. Parameters of power plant are shown in Table 4. Lead time of coal power plant (w/ CCS) is five years, and that of gas power plant (w/ CCS) is three years.
- ✓ The firm's objective function is the expected total cost of base load power supply to be minimized in the period of 40 years, i.e., from *t*=0 to *t*=40.

Table 4. : Assumed parameters

	Aged coal power plant	New coal power plant: USC		New gas power plant: combined cycle	
		w/o CO_2 capture	w/ CO_2 capture	w/o CO_2 capture	w/ CO_2 capture
Net thermal efficiency (%, LHV basis)	32.9	41.1	34.0	56.8	48.8
Capital cost (US_{2007}\$/kW_{net})	-	2,719	5,005	1,549	2,926
Lead time (y)	-	5	5	3	3

The assumed costs of CO_2 transport and storage are 23.3 US_{2007}\$/tCO_2 transported, and 24.8 US_{2007}\$/tCO_2 stored, respectively.

LNG and carbon prices follow the geometric Brownian motion. Figure 5 illustrates the expected carbon price (initial value: 30 US_{2007}\$/tCO_2) and its sample paths. The volatility of LNG is assumed to be 0.24 based on the Japanese LNG CIF price. The volatility of carbon price is assumed to be 0.29 based on carbon price in the EU ETS. In general, the volatility of crude oil price was a level from 0.3 to 0.4 in the past few decades.

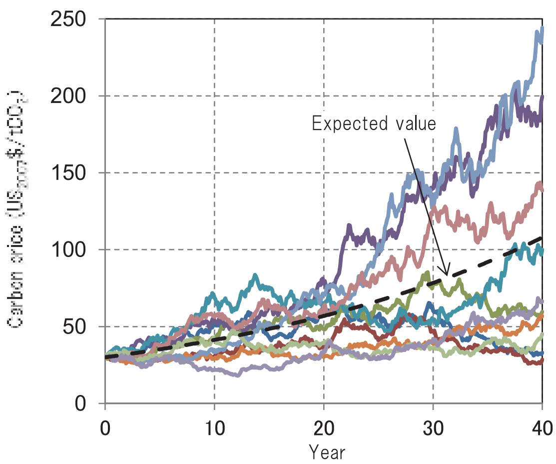

Figure 5. : Expected carbon price and its sample paths

3. 3. Simulation results

The least cost decision-making over 40 years (*t*=0 to 40 years) was solved by numerical calculations. Figure 6 shows economically rational investment decisions, at the time from *t*=0 (starting time point of decision making for power plant selection/investment), to *t*=7 (last time point of decision making). The Figure covers a wide range of LNG and carbon prices, and the Japanese LNG CIF prices were 16.2 US_{2007}\$/GJ_{LHV} in 2012, and 9.7 US_{2007}\$/GJ_{LHV} in 2015, respectively.

We show the results in inverse order of time. In the *t*=7, the firm has to select gas power plant w/o CCS or w/ CCS, since the remaining life of the aged coal power plant is three years in the *t*=7, and the assumed lead time of gas power plant is also three years.

In the *t*=6, the firm has some options: wait and invest in gas power plant. At the upper left in the Figure, investment in gas power plant w/ CCS is the least cost choice.

The *t*=5 is the last time to select coal power plant. At the upper right in the Figure, investment in coal power plant w/ CCS is the least cost choice.

In the *t*=0, the area for the option of “waiting” is relatively large, which means that expected cost of keeping options open is lower than the expected cost of “investing right now.” In other word, delaying investment decision is more cost-effective, because the conditions of prices are clearer at a later point of time. The simulation results suggest that one should not expect CCS diffusions in the short-term under the assumed uncertainties.

3. 4. Summary

This study analyzed a case that the firm cost-efficiently selects power plant type and its timing under uncertainties of LNG and carbon prices. The simulation results reveal that the area for the option of “waiting” is relatively large, which means that one should not expect CCS diffusions in the short-term. We reconfirm that a low volatility of carbon price, however, narrows the area for the option of “waiting.” In addition to the level of carbon price, predictability and stability of carbon price are important for CCS investment. This suggestion could apply to other mitigation technologies that have a long lead time.

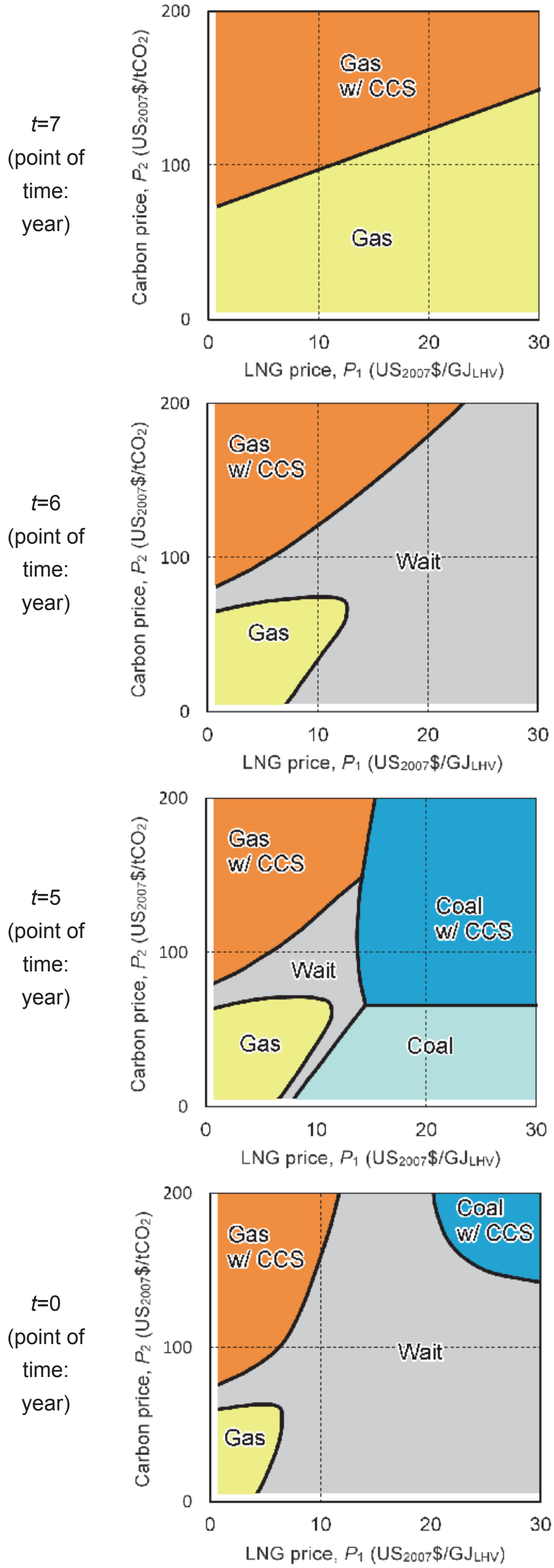

Figure 6. : Least cost threshold of investment and wait

Note: The both axes indicate prices at the point of time.

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Technology Development of Biofuels & Green Chemicals for the Realization of a Biorefinery Society

1. Introduction

Our group is advancing the research and development of biorefinery technologies to produce biofuels and green chemicals from non-food biomass (Fig. 1). In this section, we provide an overview of the global biofuel production and green chemical production.

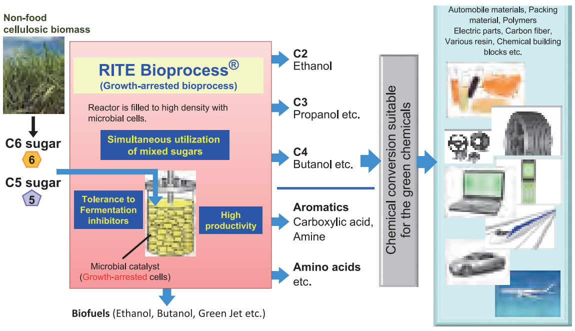


Fig. 1 : Concept of a Biorefinery

U.S. as a main raw material, and Europe is the largest consuming region where more than 50% of automobiles with diesel engines exist.

The U.S. Environmental Protection Agency (EPA) has been putting effort into promoting the use of biofuels. Last November, the EPA set the target for the 2017

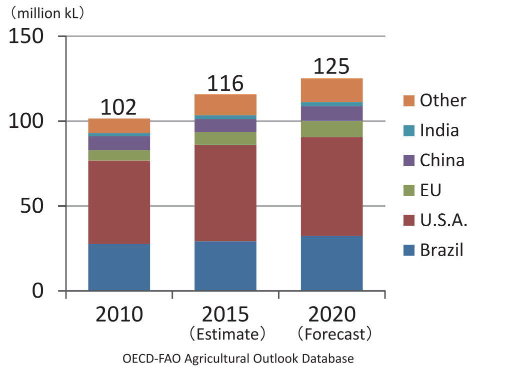


Fig. 2 : Prospects for global bioethanol production

Biofuels

Biofuels such as bioethanol and biodiesel, are fuels that are produced from biomass, which is a renewable resource. According to the OECD-FAO report, the global production of biofuels has been increasing in 2015, and 116 million kL and 31 million kL, respectively, were estimated to be produced in the world (Fig. 2). Bioethanol is produced from corn in the U.S. or from sugarcane in Brazil as a main raw material, and it is mixed with gasoline for use in automobiles. The largest production and consumption of bioethanol was in the U.S., where 14.5 billion gallons (55 million kL) of bioethanol was produced last year. Biodiesel is produced from rape seed in Europe or from soybean in the annual renewable fuel consumption at 19.3 billion gallons (73 million kL), which increased over 6% last year. Of this amount, cellulosic bioethanol (second generation biofuel) accounts for 0.31 billion gallons (1.2 million kL). Because cellulosic biofuels are produced from agricultural waste, such as corn stover, their production does not affect the food supply, which is expected to reduce the large CO_2 emission. Five large-scale commercial plants that have an approximate 100,000 kL capacity for cellulosic ethanol production per year are in operation in the U.S., in Brazil, and in Europe (Italy).

Regarding biojet fuels, the aim in technological development for the Tokyo Olympic Games in 2020 has become a topic in Japan. Meanwhile, more than 60 countries have agreed to introduce regulations on CO_2 emissions on international routes among their airlines that belong to the International Civil Aviation Organization (ICAO, http://www.icao.int/). According to the agreement, international airlines must buy eligible CO_2 emissions units through a carbon market. Therefore, it is expected to accelerate the utilization and technology development of biojet fuels in our country. In addition, the world's first commercial flight using cellulosic renewable jet fuel was carried out in the U.S. A start-up company converted cellulosic sugars that were derived from wood waste into renewable isobutanol, and were further converted into jet fuel. It was mixed with petroleum-based jet fuel (20%) (http://www.gevo.com/).

Green chemicals

Like biofuels, markets for green chemicals, including biomaterials and biopolymers, are expanding in the world. Last year, global bioplastics production was predicted to be 2.1 million tons (http://www.european-bioplastics.org/), and the domestic shipment volume of bioplastics was estimated to be ca.0.32 million tons (http://www.env.go.jp/). The consumption of biodegradable poly (lactic acid)(PLA), bio-polyethylene terephthalate (Bio-PET), bio-polyethylene (Bio-PE), etc. is increasing in Japan, and the market in Asia is expanding with the increasing production in China and East Asia. Bioplastics, which have improved physicochemical properties, are also in use, for example, a heat-resistant polylactic acid is used for textile fibers and films, and a high-impact polyamide with enhanced chemical resistance is used for automobile parts.

2. Features of the RITE Bioprocess (Growth-Arrested Bioprocess)

RITE has developed an efficient biomass utilization technology based on an inherent feature of *Corynebacterium glutamicum*. Specifically, it retains the major metabolic pathways that are active, while its growth is arrested under anaerobic conditions. The "RITE Bioprocess," the growth-arrested bioprocess we developed, has so far enabled the cost-efficient production of biofuels and green chemicals, and we gained global recognition for this achievement.

In the RITE Bioprocess, cells of a *C. glutamicum* strain are engineered to have an optimal metabolic pathway for a particular target chemical and are grown on a large scale, packed to very high densities in a reactor, and allowed to produce the target metabolite under anaerobic conditions (Fig. 3). The key to this process is the unique property of *C. glutamicum* mentioned above. The bioconversion of feedstocks to target products proceeds without microbial cell growth, achieving a higher efficiency and productivity compared to conventional fermentative processes in which the formation of products and biomass inevitably occurs in parallel. Metabolic engineering enabled our microbial catalyst to utilize C6 and C5 sugars simultaneously, and we found that *C. glutamicum* is highly tolerant to fermentation inhibitors such as furans, that are included in cellulosic hydrolysates, demonstrating that the RITE Bioprocess is compatible with cellulosic non-food biomass (see RITE Today, 2013-2014).

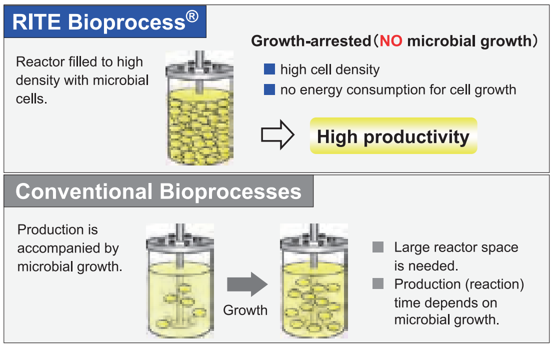


Fig. 3 : Features of the RITE Bioprocess

Through the RITE Bioprocess, we produced ethanol, lactic acids, and various amino acids with remarkably high yields. We are currently applying the technology to the microbial production of butanol, biojet fuels, and aromatic compounds such as phenol. In the following sections, we describe our recent research progress on biofuel production and green chemical production.

3. Research and development on biofuels production

3.1. Biobutanol

Butanol is more suitable as a gasoline additive than ethanol due to its physicochemical properties, including lower water solubility, higher energy content and lower oxygen content, and it can be a starting material for biojet fuel production via conventional chemical reactions. The biojet fuel synthesized from alcohols is often referred to as "alcohol to jet" or "ATJ." In 2016,

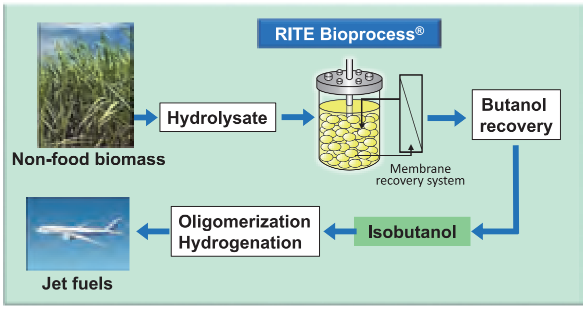


Fig. 4 : Production of biobutanol and biojet fuel via the RITE Bioprocess

ATJ has been approved by ASTM and is ready for use for commercial flights (http://www.gevo.com/). Because of the recent increase in social needs for tackling global climate change, airline companies have paid great attention to biojet fuel.

We have developed a genetically engineered *Corynebacterium* strain that exhibits a very high productivity of butanol. When the strain is used in the RITE Bioprocess, non-food biomass is efficiently converted to butanol (Fig. 4). The advantages of our production process include i) a high yield of butanol from lignocellulosic biomass and ii) a high volumetric productivity compared to other processes.

We have conducted 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). One of the main goals of the project is to further improve the cellulosic butanol productivity of our process by ameliorating the microbial biocatalyst with cutting-edge breeding technologies. The second goal is to establish a bioprocess to convert cellulosic hydrolysates that are derived from non-food biomass to butanol in an economical and efficient manner by collaborating with the U.S. National Renewable Energy Laboratory (NREL) expert on lignocellulose saccharification. Last year, we succeeded in developing a transgenic strain that attains the highest butanol yield from non-food biomass, and we continue to improve our process performance toward commercialization.

3.2. Green jet fuel

CO_2 emission from the aviation sector accounts for approximately 2% of the global CO_2 emission through human activities and will be further increased due to the rising demand for aviation in developing countries in the future. In addition to improvements in the fuel efficiency of aircrafts and efficient flight operations, as described in section one, biojet fuel is one possible solution to reduce CO_2 emissions from the aviation sector.

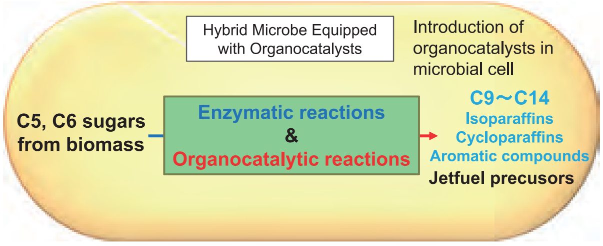


Fig. 5 : A hybrid microbe for the production of a 100% green jet fuel

Petroleum-based jet fuels are mixtures of hydrocarbons that consist mainly of linear, cyclic, and branched acyclic saturated hydrocarbons with 10-15 carbon atoms and aromatic compounds. The jet fuel must possess physical properties that are favorable for aviation fuels such as low freezing and flash points. In contrast to petroleum-based jet fuel, biofuels produced from biomass lack aromatic compounds; therefore, they are mixed with the petroleum-based jet fuels at up to 50%. With the support of the New Energy and Industrial Technology Development Organization (NEDO), we have been working on a project to produce various types of hydrocarbons that are required for jet fuels, including aromatic compounds, from biomass. The goal of the project is to establish a production process for biojet (100% green jet) fuel that can totally replace petroleum-based jet fuel.

Our strategy is to provide or express catalyst activity in a microbial cell in which an organocatalyst reaction occurs. The organocatalyst reaction has never been observed in microbial cells (Fig. 5). The microbe containing the organocatalyst activity is able to produce an array of hydrocarbons, and it is possible to make a 100% green jet fuel using this cell (hybrid microbe cell). In contrast to conventional biojet fuels, further processes, such as polymerization and isomerization of fermentative products, are unnecessary for this green jet fuel. Therefore, this process is advantageous regarding the manufacturing cost compared to that of other conventional biojet processes. Our strategy seems to be applicable to the production of various chemicals whose production through a bioprocess has never been achieved. Last year, we successfully demonstrated the production of precursor molecules of our green jet fuel using a metabolically engineered *Corynebacterium* strain that we developed. We are currently attempting to improve the productivity of our process to realize its industrialization.

3.3. Biohydrogen

Hydrogen is considered the ultimate clean energy because it is abundant on the Earth and because its combustion only generates water. However, CO_2 emission during the existing hydrogen production processes is one of the important issues because fossil resources are used as the 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 the technology is necessary to establish a cost-efficient biohydrogen process. In collaboration with the SHARP Corporation, our group has developed a biohydrogen production process that uses a reactor that is densely packed with a microbial catalyst, and the volumetric production rate achieved is two orders of magnitude higher than that of conventional fermentation processes. Since 2015, a new bio-hydrogen project supported by METI has proceeded with NREL, in which a biohydrogen production process from non-food cellulosic biomass is being developed to improve the hydrogen yield from feedstock (Fig. 6, and see RITE Today, 2016).

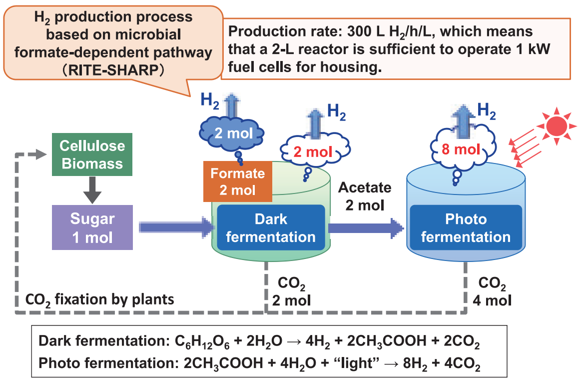


Fig. 6 : Two-stage fermentative process for hydrogen production

In Fig. 6, the fermentative hydrogen production is divided into "dark fermentation" and "photo fermentation." The latter uses light energy, but the former does not. The integration of these two processes will significantly improve the hydrogen yield from biomass feedstock. In the two-step process, a by-product (acetate) generated in the dark fermentative hydrogen production process is used as a substrate for the next photo-fermentative process. Currently, improved genetically engineered microbes are being developed for each process in our laboratory.

4. Development of manufacturing bioprocess for useful chemicals

4.1. Biomass-based phenol

Phenol is an essential material for the production of phenolic resin, epoxy resin, polycarbonate, and other polymers that are typically used in automotive parts and electronic materials. The domestic and global markets are quite huge, and their further increase is expected. However, commercial phenol is only derived from petroleum using organic solvents and strong acids at a high temperature and pressure (~250 °C, 30 MPa).

We have been challenged to develop the world's first manufacturing bioprocess of biomass-based phenol, which is considered to be difficult, for global environmental conservation and greenhouse gas reduction. As a result, we succeeded in developing a "two-stage bioprocess" for biomass-based green phenol production (Fig. 7), and it enabled higher phenol titers compared to the published data (see RITE Today, 2016). The energy consumption of green phenol production is estimated to decrease to ca. 70% in crude oil equivalent and CO_2 emission, compared to the current production from petroleum. An improvement in the *Corynebacterium* strain for high phenol concentration production, waste water recycling, etc. are now on being considered for industrialization.

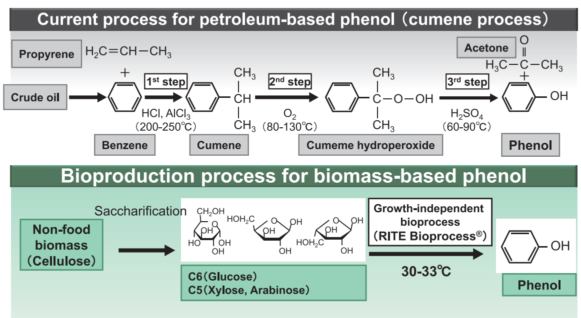


Fig. 7 : Comparison of the current phenol production process and the new bioprocess

4.2. Application of the technology to various aromatic compounds

As mentioned above, we succeeded in developing the world's first manufacturing bioprocess for biomass-based phenol. The manufacturing method has significant potential for expansion and can be applicable for the production of various aromatic compounds, e.g., the production of high-value substances, such as raw materials for polymers, pharmaceutical intermediates, agrochemicals, flavors, cosmetics, etc.

A new project on the “smart cell”, an information analysis technology based on integrated OMICS analysis, which is funded by NEDO, is being developed for the production of various aromatic compounds under optimized conditions (see Topics). OMICS refers to genomics, proteomics or metabolomics.

Furthermore, based on the results obtained in the project, the creation of high-performance “smart cells” and their use for the technology development of green chemical production is expected to provide a method for the effective production of high-value aromatic compounds and their new applications (Fig. 8).

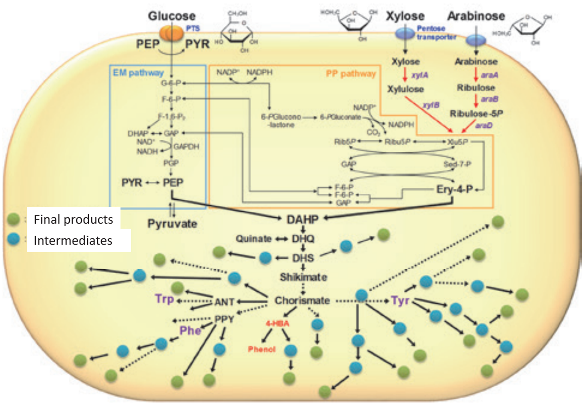


Fig. 8 : Development of manufacturing cells for various aromatic compounds

5. Towards the industrialization of our technologies

5.1. 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 inhomogeneous inside the fermenters. To overcome this problem, we have developed a new genetically modified *Corynebacterium* strain for amino acid production in the RITE Bioprocess where 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).

The Green Earth Institute Co., Ltd. (GEI) is a set-up company that will commercialize the RITE Bioprocess (for more information, see RITE Today, 2012). 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 we want to produce the amino acid from renewable resources to reduce the life cycle carbon footprint. In 2016, we succeeded in demonstrating the production by using commercial-scale facilities of our partner company (Fig. 9), 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. We continue to make great efforts to report full-scale commercial production in the next year.

Fig. 9 : Display of amino acid samples in BioJapan, 2016 (see topics)

5.2. Phenol

In May 2014, Sumitomo Bakelite Co., Ltd. and RITE established Green Phenol Development Co., Ltd. (GPD) to accelerate the industrialization of our biomass-based phenol-producing technology using the “two-stage bioprocess” as mentioned above.

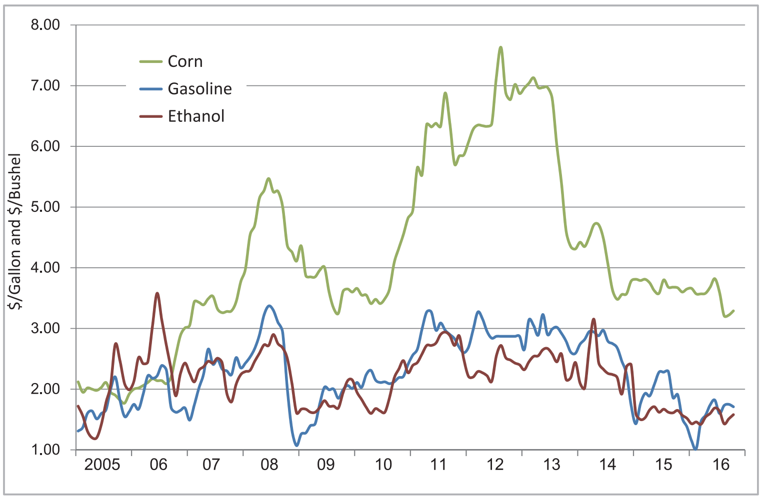
According to the NEDO project, “Development of manufacturing process for biomass-based phenol (2015~2017),” additional purification and concentration processes were constructed near the bioprocess pilot plant in June 2016 at the Shizuoka Plant at Sumitomo Bakelite Co., Ltd.

This enables the integrated production of biomass-based phenol from non-food biomass-derived mixed sugars. The next hurdles are as follows: supply of low-cost biomass-derived sugars, improvement of the processes, such as the bioprocess, purification, and concentration of phenol, recycling of waste water, etc. These processes are now in the process of industrialization.

6. Closing remarks

The global grain production in 2016 was blessed with both good weather and little crop damage from droughts, resulting in corn and wheat having the best past production volumes. Moreover, corn price fell to $3+ per bushel (ca. 25.4 kg), and crude oil prices have held steady at approximately $50 per barrel in the U.S. Therefore, the bioethanol production cost has also decreased. In addition, gasoline demand is predicted to stay stable this year; therefore, it is estimated that the U.S. corn-based bioethanol production will hold steady at approximately 15 billion gallons (57 million kL), which is as high as that of the last year (Fig. 10). However, the low oil prices also boost the advantage of green chemical production; but, it is necessary to make efforts toward low-cost production because the price competitiveness of commodity chemicals that are made from shale gas/oil also continues to be high.

Our group continues our efforts to develop technologies to produce the next generation of biofuels, including cellulosic ethanol, butanol, hydrogen, and green jet fuels. We also promote R&D that aims at efficient production of highly functional chemicals by using advanced biotechnology, such as the NEDO's "smart cell" project, as mentioned above. Through our research activities, we would like to contribute to environmental protection and help establish a sustainable society.



https://www.ers.usda.gov/data-products/us-bioenergy-statistics/us-bioenergy-statistics/#Prices

Fig. 10 : U.S. bioethanol price (2005-2016)

Chemical Research Group

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

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

Specifically, we have developed chemical absorbents that allow CO_2 capture at an energy consumption rate of 2.0 GJ/t-CO_2, and release the trapped CO_2 at temperatures below 100 ºC. One such chemical absorbent with particular promise was selected for application in a commercial CO_2 capture plant owned by a private Japanese company.

On the solid sorbent technology, we have been also developing sorbents for CO_2 capture to efficiently reduce energy consumption. Currently, the low-temperature regenerable solid sorbent we developed is under evaluation for practical use. In lab-scale cyclic tests, our novel solid sorbent is capable of achieving 1.5 GJ/t-CO_2 for regeneration energy. Research on the practical application is now underway in collaboration with a private company.

Membrane separation represents an effective means of separating high-pressure gas mixtures. As such, the Group is currently developing molecular gate membrane modules to selectively capture CO_2 from pressurized gas mixtures containing H_2, such as those generated in the integrated coal gasification combined cycle (IGCC), with a cost target of 1500 JPY/t-CO_2.

This work has resulted in a novel dendrimer/polymer hybrid membrane that exhibits excellent CO_2/H_2 separation capability. As a member of the Molecular Gate Membrane module Technology Research Association, RITE is developing these membranes along with membrane modules and separation systems for practical applications. Recently, we succeeded in achieving specific project targets under high-pressure conditions (2.4 MPa), using laboratory-scale membranes composed of modified materials. We are also currently developing the membrane elements. We plan to develop the membrane module systems by examining the separation performance and robustness of these membrane elements in pre-combustion CO_2 capture tests.

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 by an amine-based solution. Chemical absorption allows the separation of CO_2 from ambient pressure gas mixtures on an industrial scale.

Over the past decade, RITE has researched several highly efficient absorbents that allow CO_2 separation with decreased energy consumption, since energy costs represent one of the major concerns associated with chemical absorption systems.

Specifically, between FY 2004 and 2008, the Cost-saving CO_2 Capture System (COCS) project (funded by the Ministry of Economy, Trade and Industry (METI)) examined the capture and separation of CO_2 from steel industry blast furnace effluent gases. This work was followed by the CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50 (COURSE 50 Phase 1, Step 1) project, running from FY 2008 to 2012 and funded by the New Energy and Industrial Technology Development Organization (NEDO).

These projects achieved the target CO_2 capture energy consumption value of 2.0 GJ/t-CO_2. In addition, significant new absorbents were developed that enable CO_2 desorption at less than 100 ºC. This result represents an improvement over the current desorption temperature of 120ºC (Figs. 1 and 2).

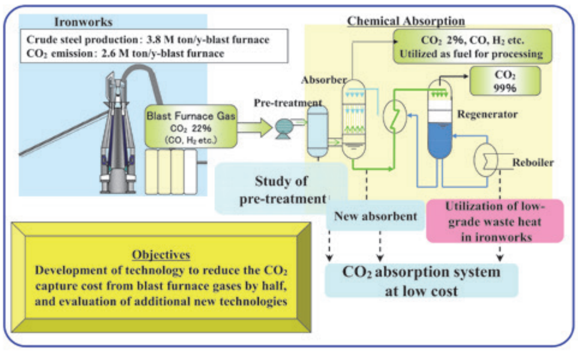

Fig.1 : A cost-saving CO_2 capture system scheme

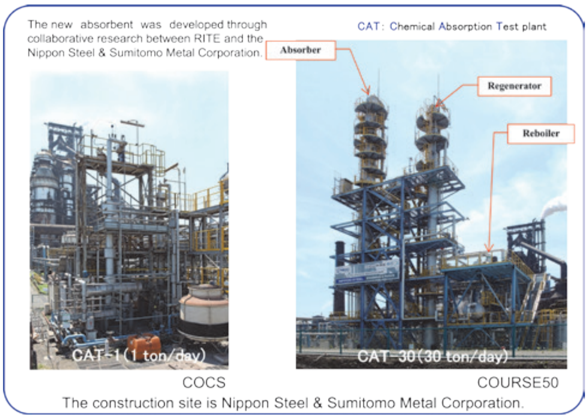

Fig.2 : Snapshots of test equipment

One of these 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 and the second CCS plant is scheduled to start operation in 2018.

Beginning in FY 2013, the COURSE 50 Phase 1 Step 2 project funded by NEDO was initiated, intended to run until FY 2017. During this work, RITE and the Nippon Steel & Sumitomo Corporation continue to develop new absorbents that have the potential to deliver high performance and to allow more efficient CO_2 capture (Fig. 3).

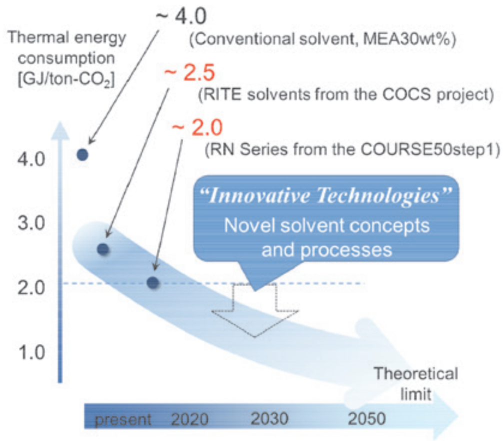

Fig.3 : Continuous development for the high performance liquid absorbent process

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.

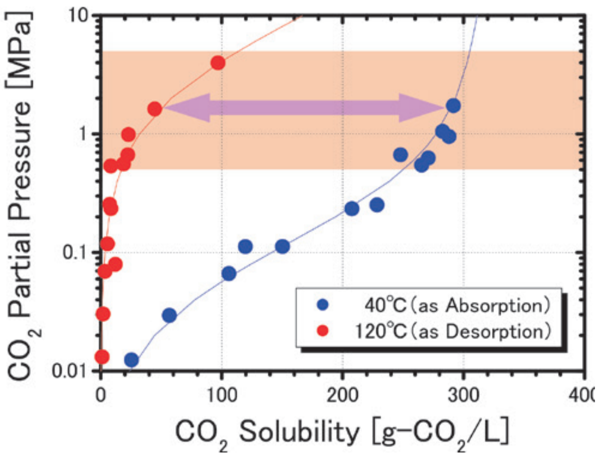

Fig.4 : CO_2 pressure-solubility relationships of "High-Pressure Regenerable Absorbents"

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.

3. Solid Sorbent Technology

Solid sorbent technology appears promising because it takes advantage of the anticipated lower heat duty cycle for regeneration processes obtained when using amines supported on porous materials. These systems have exhibited CO_2 adsorption characteristics similar to those of amine-based solvents (Fig. 5).

RITE has developed solid sorbents during a project aimed at the advancement of CO_2 capture technologies funded by METI from 2010 to 2014. 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 and having high adsorption capacities.

The characteristics of these solid sorbents were subsequently assessed using a lab-scale adsorption/regeneration test apparatus (Fig. 6). These tests demonstrated that steam-aided vacuum swing adsorption (SA-VSA) significantly enhances the extent of CO_2 recovery compared with the standard VSA process. Work was also performed to optimize the SA-VSA method. As a result, it was possible to desorb high-purity (98%) CO_2 from the RITE solid sorbent in high yields (93%) following capture from a simulated flue gas, at an energy cost of 1.5 GJ/t-CO_2 (Fig. 7). It is estimated that employing the RITE solid sorbent of an energy cost of 2.5 GJ/t-CO_2 would improve the energy efficiency of a coal-fired power plant with a CO_2 capture system by approximately 2%,

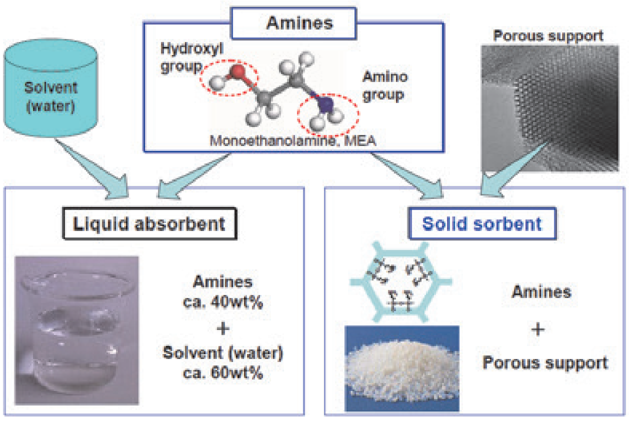

Fig.5 : Amine solvents and amine solid sorbents

Fig.6 : Lab-scale apparatus for CO_2 capture test

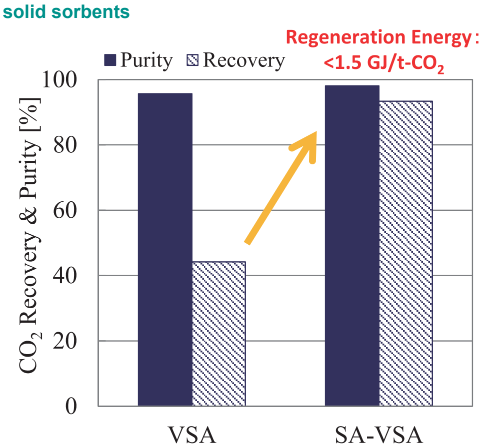

Fig.7 : CO_2 capture performance using RITE solid sorbent

Solid sorbents are also being researched in the world However, conventional solid sorbents generally require the application of high temperatures, which is deleterious with regard to both energy consumption and the stability of the sorbent. In contrast, the RITE solid sorbent uniquely allows regeneration at low temperatures and thus at a low energy cost.

In 2015, we launched a new project funded by METI with the goal of demonstrating the practical applications of CO_2 capture technologies (R&D of Advanced Solid Sorbents for Commercialization). Currently, lab-scale tests using a moving-bed system in conjunction with coal-fired flue gases, as well as simulations of moving-bed systems, are proceeding in collaboration with Kawasaki Heavy Industries, Ltd.

Simultaneously, we are optimizing our solid sorbents for the practical applications. The RITE solid sorbent uses novel amines that exhibit higher performance than standard commercially-available amines. In addition, this material is synthesized using a method that can readily be scaled up (Fig. 8).

These new amines, obtained by our improved large-scale synthesis method, have been assessed using bench-scale plant tests since Nov. 2016. As shown in the R&D road map (Fig. 9.), our goal is to develop a solid sorbent system with improved performance during CO_2 capture from coal-fired power plants by 2020.

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 of the current amount by 2050. One promising means of lowering CO_2 emissions is the development of an IGCC based on CO_2 capture by selective membranes (Fig. 10). For this reason, we are currently developing molecular gate membrane modules that effectively separate CO_2 during the IGCC process.

To date, the results have shown that novel polymeric membranes composed of dendrimer/polymer hybrid materials (termed molecular gate membranes) exhibit excellent CO_2/H_2 separation performance. Fig.

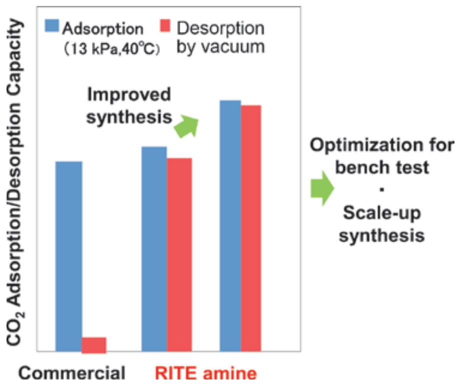

Fig.8 : Synthesis of the RITE amine for bench-scale tests

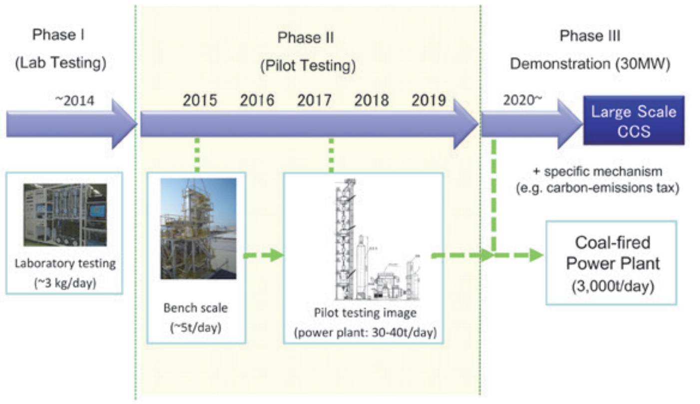

Fig.9 : R&D Road map of solid sorbent system

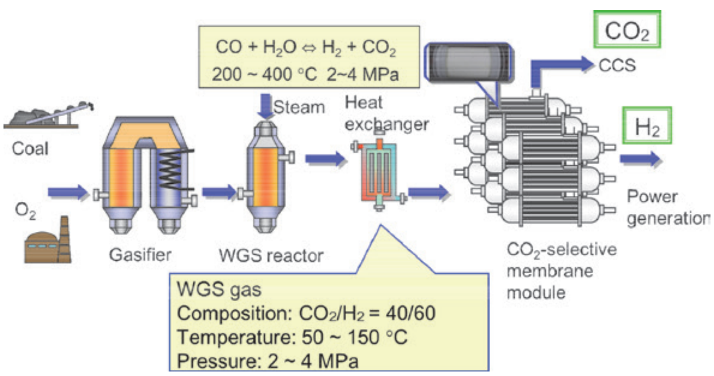

Fig. 10 : Schematic of the IGCC process with CO_2 capture by CO_2 selective membranes.

11 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 groups, 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.

During this project, we have 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 was established in 2011 for the purpose of researching new membranes, membrane modules and separation systems (Fig. 12). Recently, we succeeded in improving the separation performance of such membranes through the modification of poly(vinyl alcohol) (PVA)-based materials. The desired CO_2 separation performance was obtained under high-pressure conditions (2.4 MPa) using laboratory-scale membranes (Fig. 13). Currently, we are developing membranes and membrane elements that offer both good separation performance and robustness. As an example, a comparison of the separation of CO_2/He and CO_2/N_2 mixtures is presented in Fig. 14. In both cases, the CO_2 permeance of the membrane was roughly equivalent. However, the permeance of N_2 was less than that of He because of its larger molecular size. As a result, the CO_2/N_2 selectivity was an order of magnitude higher than the CO_2/He selectivity, demonstrating that the presence of N_2 does not affect the CO_2 permeation properties of the membrane.

In future, we plan to continue to improve these membrane module systems by examining the separation performance and robustness of these membrane elements in pre-combustion CO_2 capture tests.

The development of these CO_2 molecular gate membrane modules is being performed under a project recognized by the Carbon Sequestration Leadership Forum (CSLF), a ministerial-level international climate change initiative focused on the development of improved, cost-effective technologies for the separation and capture of CO_2 for transport and long-term safe storage.

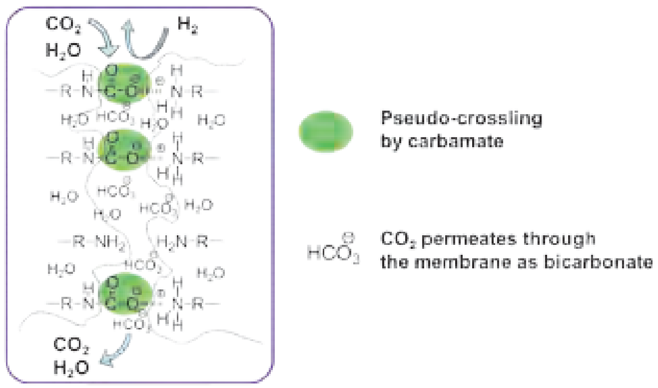

Fig.11 : schematic illustration of the working principles of the molecular gate membrane.

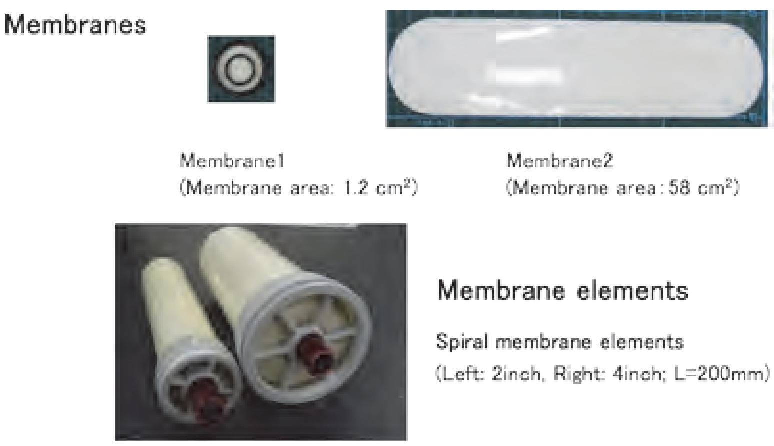

Fig.12 : CO_2 molecular gate membranes and membrane elements.

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 of dramatically reducing emissions on a worldwide basis. In April 2016, Japan released the National Energy and Environmental Strategy for Technological Innovation toward 2050, and 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 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 the 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.

*COP21; The 2015 United Nations Climate Change Conference

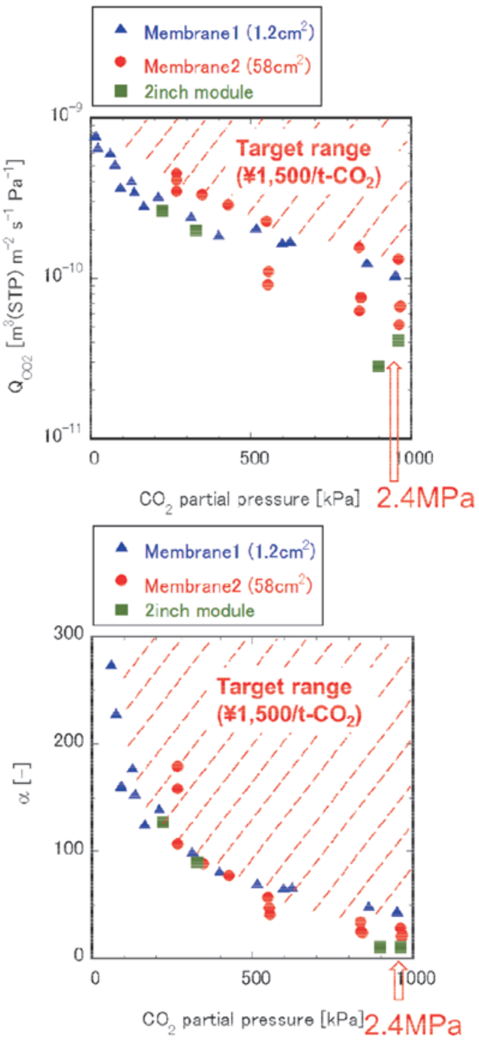

Fig.13 : Separation performance of CO_2 molecular gate membranes.
(85°C, Feed gas composition: CO_2/He=40/60~5/95%, Feed gas pressure: 0.1~2.4 MPa, Pemeate gas pressure: atmospheric pressure (Ar sweep))
(Membrane area: 1.2 cm^2 (Membrane1), 58 cm^2 (Membrane2))
He gas was used instead of H_2 gas, for safety reason.

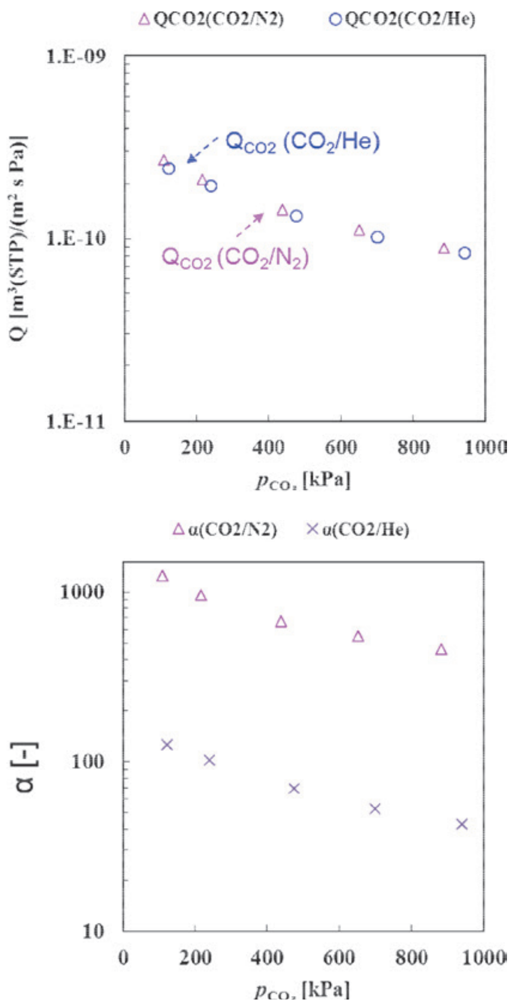

Fig.14 : Comparison of CO_2/He and CO_2/N2 Separation performance.
(85°C, Feed gas composition: CO_2/He=40/60~5/95%, Feed gas pressure: 2.4 MPa, Feed gas humidity: 60%RH, Pemeate gas pressure: atmospheric pressure (Ar sweep))

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Development of Safety Management Technology for Large-Scale Geological CO_2 Storage

1. Introduction

Sleipner Project started CO_2 injection at the North Sea in 1996 and stored around 16 million tonnes of CO_2 associated with natural gas production in a saline aquifer. Following the Quest project in Canada, two large-scale geological CO_2 storage projects will start CO_2 injection in near future: the Industrial CCS (Decatur site) in Illinois, USA and the Gorgon project in Australia. These projects all draw great attention from the viewpoint of their large scale injection of one million tonnes per year and also their incentives and CCS legal and regulatory frameworks. The North Sea Sleipner site has successfully injected CO_2 without any reports of CO_2 leakage and induced seismicity for 20 years and has been recognized as a good model of geological CO_2 storage in a deep aquifer.

For the implementation of geological CO_2 storage at scale, indispensable is up-scaling from pilot-scale injection to large-scale. In up-scaling, various relevant technologies should be verified and integrated, which will lead to cost reduction of CCS projects. With the aim of technology integration and cost reduction for CO_2 storage suitable for Japan's reservoir at a scale of one million tonnes per year, the Geological CO_2 Storage Technology Research Association (GCS) was established on April 1 in 2016 (See the Topics of the CO_2 Storage Reseach Group). They are undertaking R&D for CCS implementation by integrating expertise and know-how owned by the research institutes and the companies.

RITE is conducting technology development on the safety management of geological CO_2 storage; international collaboration and global development survey; and the improvement of social acceptance.

2. Major Research Themes and Roles of RITE in GCS

GCS became the contractor of the program of "the Development of Safety Management Technology for Geological CO_2 Storage", which was launched for a stage of making CCS technically viable, building on outcomes from "the Development of Technology for CCS Safety Evaluation", at the beginning of a fiscal year of 2016. The association is undertaking "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". The details of research themes and the roles of the members are shown in Table 1.

RITE has conducted pioneering CCS-related research. In GCS, RITE as a core member carries out research and development in collaboration with AIST and, building on outcomes from them, works on development to prove technical feasibility of CCS in conjunction with the members from the private sector.

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

Research Themes		Members Responsible
(1) Development on Safety Management Technologies for Large-scale CO_2 Injection and Storage	① The Development of Safety Management System for Injection	RITE, JAPEX, INPEX
	② The Development of Long-term CO_2 Monitoring Technologies	AIST
	③ Geological Modeling for Large-scale Reservoir, Evaluation of Reservoirs	RITE, JAPEX, Oyo
	④ The Development of Methodologies for CO_2 Behavior Simulation and Long-term Prediction for Large-scale Reservoirs	RITE, AIST, Taisei, Oyo
	⑤ The Development of Fiber-optics-based Monitoring Systems for the Stability of Geological Formation and the Integrity of Abandoned Wells	RITE, AIST, JAPEX, INPEX
	⑥ The Development of a CO_2 Leakage Detection System and an Integrated System for Environmental Impact Assessment	RITE
(2) Technologies for the Efficient Pressure Management and Utilization of Large-scale Reservoirs	① The Development of Techniques to Optimizing a Layout of CO_2 Injection Wells and Pressure Management Wells	RITE, Taisei
	② Improvement of Storage Efficiency by Applying Enhanced CO_2 Dissolution Technique	RITE, JAPEX
(3) Environment Setting for CCS Deployment and Standard Development	① The Development of CO_2 Storage Safety Management Protocol (IRP)	RITE
	② Production of Best Practice Manuals by Incorporating Data from the Tomakomai Demonstration and Co-operation with Overseas Organizations	RITE
	③ The Improvement of Social Acceptance and Compatibility with International Standardization	RITE

2.1. The Development of Safety Management Technologies for Geological CO_2 Storage

GCS develops safety management technologies for large-scale CO_2 injection and storage, including the development of geological models, the development of methodologies for simulation and long-term prediction of CO_2 behavior, and the development of integrity monitoring system with fiber optics and safety management system for injection.

◇The Development of a Safety Management System for Injection

GCS develops a management system to inject CO_2 safely, which we call the Advanced Traffic Light System (ATLS). Like a traffic light, ATLS shows red, yellow and green signals, based on observation results of natural earthquakes and microseismicity associated with injection and monitoring results of CO_2 behavior and the marine environment. GCS tests and verifies ATLS's performance with data from the Tomakomai site with the aim of rolling it out worldwide as Japan's unique advanced technology.

◇Geological Modelling and Reservoir Evaluation for Large-Scale Reservoirs

GCS develops evaluation techniques and geological modelling methodologies for storage potential estimation and applies them to the Tomakomai demonstration site and potential storage sites under survey.

◇The Development of Methodologies for CO_2 Behavior Simulation and Long-term Prediction for Large-scale Reservoirs

GCS develops methodologies for long-term prediction of CO_2 behavior in large-scale reservoirs, taking into account characteristics of geochemical reaction specific to reservoirs in Japan, for example low salinity in formation water and richness of reactive minerals. It applies it to the Tomakomai demonstration site and potential storage sites under survey.

◇The Development of Fiber-optics-based Monitoring Systems for the Stability of Geological Formations and the integrity of Abandoned Wells

GCS develops and verifies a system to measure the deformation of formations, changes in subsurface temperature and pressure continuously with ground burial optical fibers.

◇The Development of a CO_2 Leakage Detection System and an Integrated System for Environmental Impact Assessment

In case of CO_2 leak to the surface of the seabed from, for example, an abandoned well or cap rock, GCS develops leakage detection methodologies and simulation techniques for CO_2 diffusion in seawater. It also develops an integrated system for environmental impact assessment, the core component of which is database for the impacts of CO_2 on organisms.

2.2. The Development of Technologies for the Efficient Pressure Management and Utilization of Large-scale Reservoirs

To develop technologies for efficient pressure management and utilization of large-scale reservoirs, GCS conducts studies on techniques for optimal layouts of injection wells and pressure management wells and on enhanced CO_2 dissolution techniques using micro CO_2 bubbles.

◇The Development of Techniques for Optimizing a Layout of CO_2 Injection Wells and Pressure Management Wells

Since large-scale storage sites on the order of one million tonnes per year have a potential to use multiple injection wells/ pressure management wells for their complicated geological structure and heterogeneity of a reservoir, GCS develops a methodology to optimize the layout and functions of multiple wells, making the best use of data from, for example, Tomakomai and potential storage sites under survey.

◇Improvement of Storage Efficiency by Applying Enhanced CO_2 Dissolution Technique

GCS develops enhanced dissolution technology, which contributes to higher CO_2 dissolution into low-salinity formation water and mitigation of pressure rise in reservoirs, and improves CO_2 storage efficiency by injecting fine CO_2 bubbles into reservoirs. It evaluates the effectiveness of the enhanced dissolution techniques through lab tests and field tests.

2.3. Environment Setting for CCS Deployment and Standard Development

Considering that it is essential to set up an appropriate environment and to prepare standards for wider CCS deployment, GCS develops a safety management protocol (IRP), produces best practice manuals, collaborates with overseas organizations, improves social acceptance and checks the compatibility of our efforts with international standardization.

◇The Development of CO_2 Storage Safety Management Protocol (IRP)

Recognizing IRPs contribute to gaining social acceptance, GCS surveys IPRs for overseas sites, investigates their functions and then creates an IRP specific for Japan.

◇Production of Best Practice Manuals by Incorporating Data from the Tomakomai Demonstration and Co-operation with Overseas Organizations

GCS compiles experiences and expertise from large-scale geological CO_2 storage projects in Japan and other countries to complete best practice manuals as a reference for CCS implementers, covering from basic planning to post site closure management.

◇The Improvement of Social Acceptance and Compatibility with International Standardization

GCS works on the improvement of social acceptance, which is critical for the deployment of geological CO_2 storage projects. GCS also works on the compatibility of CCS projects with international standardization through co-operation with overseas organizations and promotes the improvement and dissemination of Japan's CCS technology.

3. Major Outcomes from RITE in FY2016

RITE works on technical challenges in geological CO_2 storage, including the development of safety management technologies for CO_2 injection and storage, the development of technologies for the efficient injection and utilization of large-scale reservoirs, setting-up of an environment for CCS deployment and the development of standards. In parallel with research on technical challenges, RITE works on research collaboration with overseas research institutes as part of international co-operation and information gathering through surveys on CCS developments in the world.

3.1. The Development of Geological Modelling Techniques

In order to predict the behavior of CO_2 injected in a reservoir, it is essential to develop highly reliable geological models which incorporate the heterogeneity of geological formations. Although the geological modelling can utilize techniques that have been developed for oil and gas production, geological CO_2 storage usually have much fewer wells in order to avoid leaks. Under the restriction of less available geological data, CO_2 storage requires to understand CO_2 storage potential, evaluate injectivity and assess the prevention of CO_2 leakage at the surface

The CO_2 Storage Research Group is developing a technique to develop a geological model by integrating as much as available information in a manner of effectively using geological information such as boring cores and physical logging data acquired at a restricted number of wells. A geological analysis and a methodology for the integration of data regarding reservoir characterization are shown as an example in Figure 1.

In the figure, the depositional environment analysis based on the X-ray CT images and the stratigraphic column shows that the reservoir consists of delta front and pro delta. It also clarifies that the distributions of pore space sizes, which show there is micro-level heterogeneity in the reservoir, affect largely on CO_2 injectivity. Assessment of storage performance at a reginal scale requires the use of data from 3D seismic surveys. Employing a GDI (Geology Driven Integration)

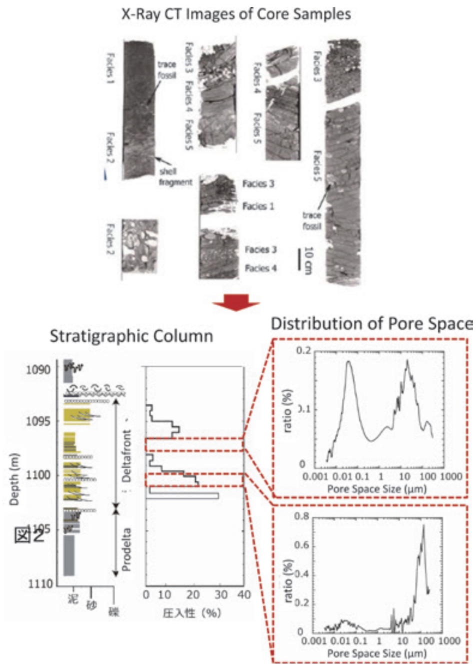

Figure 1 : Examples of Data Integration for Geological Modelling and Analysis for the Assessment of Heterogeneity

analytical technique as a case study and combining geological data acquired by, for example, physical well logging, and 3D seismic survey data, we developed a geological model with a high reliability for the Nagaoka site. The methodology is applicable for depositional formation based reservoirs and also for the assessment of CO_2 storage potential before injection.

3.2. The Development of Techniques for the Prediction of Long-term CO_2 Behavior

It is essential for large-scale geological CO_2 storage to monitor the behavior of CO_2 injected in a deep reservoir and to confirm and predict its stable retention. As techniques to predict CO_2 behavior for large-scale storage sites, it is required to develop a simulator applicable for large-scale models and a simulator that incorporates geochemical reaction for long-term prediction.

To address these issues, the CO_2 Storage Research Group parallelized TOUGHREACT V2.0, which is a simulator developed by the US Lawrence Berkeley National Laboratory, and modified the code to incorporate histolysis characteristics. To verify the developed code and evaluate its performance, we applied it to a detailed geological model (around 100,000 grids) of the Nagaoka site, which is the only domestic CO_2 injection test site. The results of resistivity monitoring shows that there are two separate plumes of supercritical CO_2, resistivity of which is high, and that dissolved CO_2, resistivity of which is low, exists above and below the plumes. We successfully reproduced the phenomenon accurately by CO_2 behavior simulation (Figure 2).

Our long-term prediction for 1,000 years, taking geochemical reaction into account, enabled us to understand kinds of minerals that are reacted (dissolved or produced) and temporal changes in their contribution to CO_2 trapping (Figure 3). The calculation can be

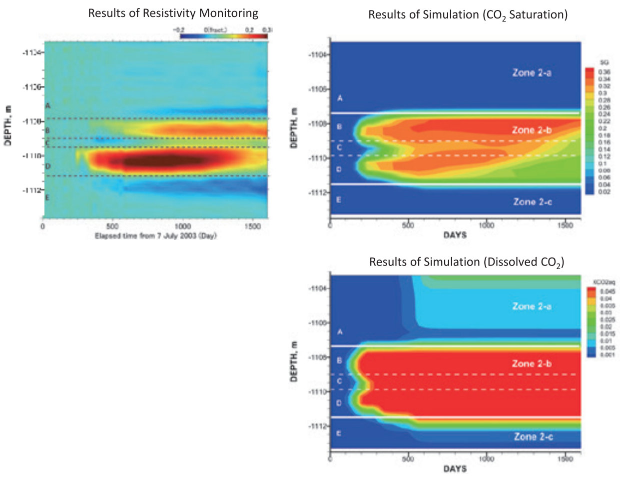

Figure 2 : Comparison between CO_2 Monitoring Results and CO_2 Simulation results

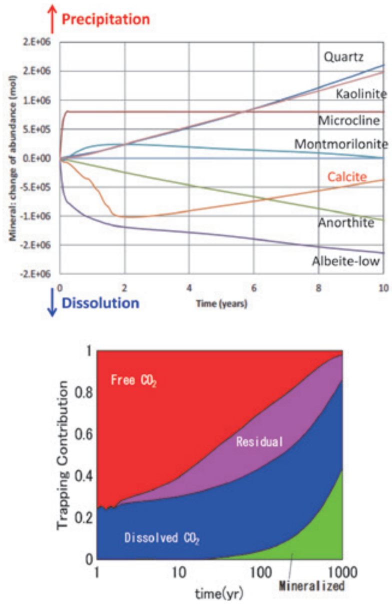

Figure 3 : Results of Mineral Reaction Simulation and Temporal Changes in Trap Mechanisms

done in a short time by increasing the number of calculators to be parallelized and is therefore applicable to large-scale sites.

3.3. The Development of Techniques for Marine Environment Impact Assessment

Geological CO_2 storage selects a reservoir capable of storing CO_2 stably and has therefore an extremely slight chance of CO_2 leak taking place. However, we need a technology to detect a leakage just in case. Assuming CO_2 storage under the seabed near the coast and develops technologies to detect CO_2 leakage in seawater. It is said that CO_2 leaks from the seabed mostly in the form of gas bubbles and that the bubbles dissolve into seawater as going upward in seawater due to buoyancy. Potential leakage detection technologies, therefore, include the techniques of detecting gas bubbles in seawater and the techniques of detecting increases in CO_2 partial pressure (pCO_2) caused by the dissolution of leaked CO_2.

As a technique of detecting gas bubbles in seawater, we examine acoustic probing with a side-scan sonar (SSS). SSS is a tool of acoustic probing that produces a 2D image of color contour to show the differences of the intensity of sonic waves that are transmitted from a transducer and return to it after reflected by an object (Figure 4). The tool is widely used in the surveys of seabed topography and marine geology. RITE focused on a nature of gas bubbles which reflect acoustic waves and confirmed that SSS is capable of detecting a gas bubble column generated by releasing pressurized air at a rate of 20 mL/min from the seabed at a water depth of 6 to 7 m. In a fiscal year of 2016, with the aim of checking its practical usability of the gas bubble detection technique with a SSS, we released pressurized air and CO_2 bubbles separately from the 30-meter-deep seabed and examined whether or not the distance between the gas bubble release point and a survey line (the offset, Figure 4) results in differences in the images of gas bubbles. The sea depth of the release point is as deep as offshore Tomakomai, where the subseabed storage demonstration project is taking place. In the case of pressurized air, when the offset is 20 m and 10 m, a gas bubble column standing from near the seabed is recognized whereas when the offset is 0 m and 2 m, gas bubbles are recognized at a water depth of 5 to 20 m (Figure 5a). In the case of CO_2, when the offset is 10 m, air bubbles are recognized at a water depth of 5 to 15 m, whereas the offset is 0 m and 2 m, gas bubbles are recognized around a depth of 5 m (Figure 5b). These results clarify that in the both case of pressurized air or CO_2, an offset distance influences a location of bubbles in an SSS image (i.e. a water depth). In acoustic probing in a real operation, we will define multiple survey lines in parallel and therefore we can expect to be able to identify an approximate location of a leak point with locations of gas bubbles in multiple SSS images. In this test, the intensities in the images in the case of CO_2 were lower than those for pressurized air (Figure 5), although the release rate of CO_2 was 10 times that of pressurized air. This can be interpreted that CO_2 bubbles that were released from the seabed went upward, dissolving into seawater, becoming smaller in size and losing reflection intensity. These results lead to a conclusion that there are differences between SSS-produced images for pressurized air and those for CO_2.

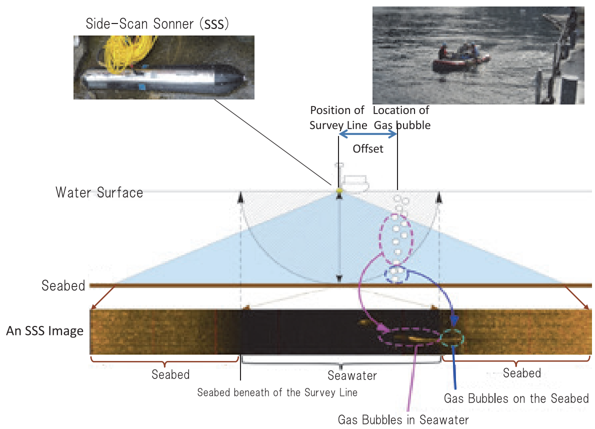

Figure 4 : A Conceptual Figure of Gas Bubbles Signals and their Location in Side-scanner Sonner Images

A challenge in the use of a technique of detecting increases of pCO_2 is how to set up a criterion for the judgement of anomalous values. RITE proposed a criterion that is defined with not only pCO_2 but also dissolved oxygen saturation (DO). Described here based on data observed in the Osaka Bay are that judging anomalous values solely with pCO_2 is controversial and that the problem is improvable by using DO. In the Osaka Bay, fixed-point observation has been conducted in February, May, August and November every year, showing that pCO_2 and DO have a clear inverse correlation (Figure 6). The RITE original methodology is to determine a linear regression of pCO_2 and DO as a criterion for the judgement of anomalous values. If a criterion is determined only with pCO_2 (e.g. the black dotted line in Figure 6), there is possibility to judge high pCO_2 values in natural fluctuation (① in Figure 6) as anomalous in an oxygen-poor environment and to judge high pCO_2 values which significantly exceed a natural fluctuation range (② in Figure 6) as normal values in an oxygen-rich environment. These problems are significantly remedied by employing the upper limit of a prediction interval of a regression line (e.g. the green bold dotted line in Figure 6). But it is still unavoidable that part of natural variation data are misinterpreted as anomalous values at a constant rate. As seen in Figure 6, which is drawn only with natural fluctuation data, there are a couple of data above the green bold dotted line. Looking at the data acquired in August (blue dots), we can see that they are scatted in a range from 400 to 1,800μatm, indicating that they are significantly varied year by year. These facts indicate that it is required to use data acquired at least for a couple of years in setting a criterion for the judgement of anomalous values.

4. Survey of Developments in CCS and Co-operation with International Organizations

RITE contributes to accelerating CCS deployment through co-operation with international organizations and monitors major CCS-related developments in the world. Summarized below are major developments in the global CCS community in 2016 and topics in the Carbon Sequestration Leadership Forum (CSLF), an international body to which RITE contributes and hosted a meeting in Tokyo in October 2016.

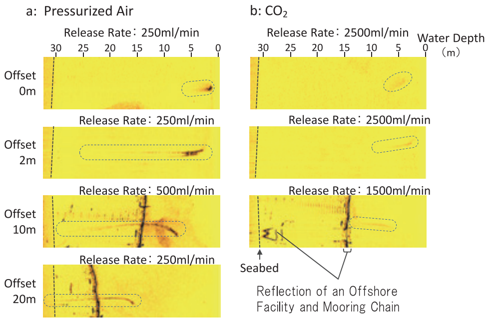

Figure 5 : Side-scan Sonner Images obtained in the Test

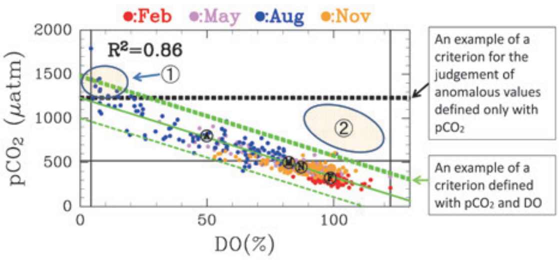

Figure 6 : A Distribution Map of Dissolved Oxygen Saturation (DO) and CO_2 Partial Pressure (pCO_2)
The black dotted line is the average + three-fold standard deviation. The green line and the green dotted line are the regression line and its 99% prediction interval. ① and ② are referred in the body text.

4.1. Major CCS Developments in 2016

A year of 2016 is a milestone for CCS to celebrate the 20th anniversary of CO_2 injection into a deep saline aquifer in the world first commercial-scale CCS project in Sleipner, Norway. The project had stored more than 16 million metric tons of CO_2 safely by 2016 and is a good example to demonstrate the safety of CCS technologies.

In Norway, there has also been a CCS project for three industrial plants under study. The results of its feasibility study were published in summer 2016 and it was decided to go to a next step for a detailed study with support of the Government. The captured CO_2 would be transported to a floating intermediate storage facility by ship and then be injected into an offshore saline aquifer via a pipeline. If the final invest decision due in spring 2019 is made positively, the project is slated to be operational in 2022.

The large-scale CCS project which became operational in 2016 is the world first one in the steel sector. This is to capture 800,000 metric tons of CO_2 from a steel plant in the United Arab Emirates and to use them for enhance oil recovery. The plant employs not a blast furnace but a direct reduction process, for which CO_2 capture is relatively easy.

The ROAD project in the Netherlands, with an announcement of support from the Government in December 2016, is expected to make the final investment decision in 2017. The large-scale CCS projects coming online in 2017 include industrial CCS projects such as Illinois industrial in the USA and Gorgon in Australia and also coal-fired power CCS projects such as Petra Nova and Kemper in the USA. A year of 2017 will be a great step for the CCS community.

4.2. CSLF Update

CSLF's 2016 annual meeting was hosted by RITE together with the Ministry of Economy, Trade and Industry (METI) in Tokyo in October. In the meeting, the Tomakomai CCS Demonstration Project was recognized as a project that contributes to the deployment and advancement of CCS. The Tomakomai project became Japan's second CSLF recognized project, following a project to develop membrane separation technology in RITE.

In the Technical Group, three taskforces have been in active since autumn in 2015 with a target of publishing a report before the ministerial meeting in autumn in 2017: effective use of pore space in reservoirs, offshore EOR and bio-CCS. In addition, it was agreed in the Tokyo meeting to initiate a taskforce on industrial CCS with the focus on CO_2 use. Proposed by Japan, it was also agreed to consider forming a joint taskforce with the Policy Group to look into a reasonable regulations for CCS.

In the Policy Group, the membership of Czech was discussed and approved in the Tokyo meeting. The country has great interest in CCS with high coal production and high dependence on coal-fired power generation. With Czech joining CSLF, the number of membership became 26, including the European Commission. As part of activities undertaken by a Policy Group taskforce called "Communications", which is to advocate CCS, the CSLF website was refurbished before the Tokyo meeting to be an information source useful even for those who are not involved in CSLF.

Inorganic Membranes Research Center

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Research and Development on Innovative Environmental and Energy Technologies that Use Inorganic Membranes, and Efforts toward their Practical Use and Industrialization

1. Outline of the Inorganic Membranes Research Center

In April 2016, the Inorganic Membranes Research Center (IMeRC) was established as a new research organization of RITE. The IMeRC conducts research and development (R & D) on innovative environmental and energy technologies that use inorganic membranes, aiming to put them into practical and industrial use.

Membrane separation is one of a number of separation techniques, which also include distillation and adsorption methods. Reverse osmosis and precision filtration membranes have been used for seawater desalination, and water treatment with organic polymer membranes has also been carried out. In recent years, the application of membrane separation to gas separation (including vapor separation) has also been promoted. Because of their remarkably low energy consumption, membrane separation technologies are expected to innovate production processes.

Membrane separation methods that use inorganic membranes, such as silica, palladium, and zeolite membranes, have received particular attention because their superior heat and environmental resistance means that they can be applied in a wide range of fields. In addition, they show promising separation performances that overcome the trade-off between selectivity and transmittance, or processing speed.

Although the research field began in Europe, Japan is currently leading the world in the R & D of inorganic membranes; however, the practical application of these membranes is still limited. Recently, research in China and other countries has been rapidly catching up with that in Japan, and it is thus imperative for us to further advance R & D and proactively engage in the practical application and industrialization of inorganic membranes.

In this context, the IMeRC is promoting activities that exploit Japanese knowledge for the following purposes:

a) To promote the R & D of inorganic membranes and put innovative environmental and energy technologies into practical use.
b) To present a pathway for establishing an inorganic membrane industry in Japan with cooperation from industry and academia;
c) To trust government-financed projects and to encourage collaborative or contract research with cooperation from private enterprises, manufacturers, and user companies;
d) To transfer technologies from leading experts in various inorganic membrane fields to mid-level and young researchers.

The IMeRC has two divisions, the “Research Section”, which promotes R & D on environmental and energy technologies that use inorganic membranes, and the “Industry Collaboration Section”, which aims for the practical application and industrialization of these membranes (Figure 1).

In the Research Section, we have developed three

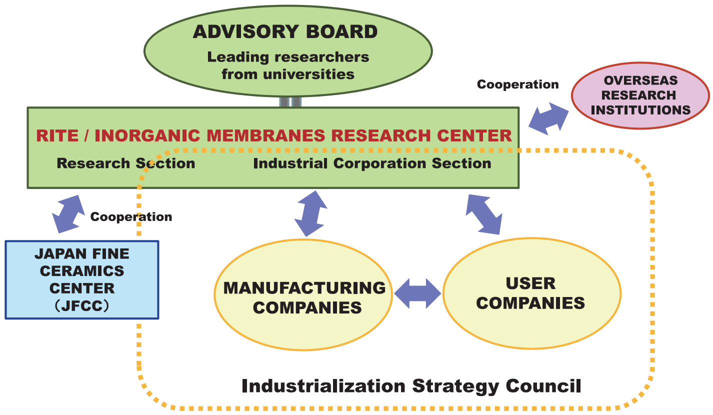


Figure 1 : Cooperative structure centered on the Inorganic Membrane Research Center

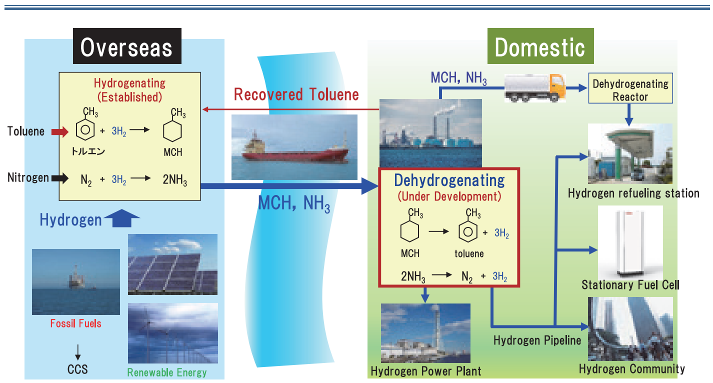


Figure 2 : Energy carrier concept

inorganic membranes, namely silica, palladium, and zeolite membranes, which have excellent characteristics. With these membranes as our core technologies, we are conducting R & D on the separation and purification of hydrogen, the separation of CO_2 and CH_4, and the separation of hydrocarbons and other organic compounds.

In the Industry Collaboration Section, we have established the “Industrialization Strategy Council”, which includes members from separation membrane and support manufacturers and their user companies.

A major feature of the IMeRC is its structure, which allows the creation of a synergy by the cooperation of the Research and Industry Collaboration Sections.

Another feature of the organization is its advisory board composed of leading experts in inorganic membranes as well as experts in hydrogen and fuel cell research, which is considered to be one of the major applications of these membranes. The advisory board is expected to provide valuable advice to the Research and Industry Collaboration Sections, and to play an important role in transferring technologies to young and mid-level researchers. The organization plans to enrich this function in the near future.

In this paper, we introduce our efforts toward the development of innovative environmental and energy technologies that use inorganic membranes. These technologies are advancing high-level R & D and efforts to commercialize and industrialize the results.

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. The “energy carrier” concept has been proposed as a promising method, whereby hydrogen is converted into chemical hydrides, such as methylcyclohexane and ammonia, that can be efficiently transported and stored. After transportation and storage, hydrogen can be released from the chemical hydride at the place and time it is required (Figure 2).

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

The IMeRC is developing membrane reactors that contain a silica membrane, prepared by counter-diffusion chemical vapor deposition (CVD), for the development and commercialization of a method for the efficient and stable production of highly pure hydrogen from methylcyclohexane. The technique is aimed at small- to medium-sized customers, such as commercial establishments and office buildings. This work is funded by the New Energy and Industrial Technology Development Organization (NEDO) under the "Advancement of Hydrogen Technologies and Utilization / Analysis and Development of Hydrogen as an Energy Carrier / Development of a Dehydrogenation System using Inorganic Hydrogen Separation Membranes for Organic Chemical Hydrides" project, in collaboration with Chiyoda Corporation.

In this project, we have developed longer silica membranes, achieved further improvements in hydrogen separation performance, developed single tubular membrane reactors for dehydrogenation or purification of methylcyclohexane, and carried out bench-scale dehydrogenation using apparatus consisting of seven membrane reactors.

A 20-cm-long silica membrane had already been achieved by FY 2015, and we have now succeeded in fabricating membranes of up to 50 cm, suitable for application in industrial membrane reactors, by further improving the CVD fabrication apparatus. In FY 2016, we further improved the hydrogen separation performance of these silica membranes.

We found that the configuration of the outer dehydrogenation catalyst in the single tubular membrane reactor, considered to be necessary for industrial application, could be successful without a protective film (Figure 3), and confirmed the shift in the equilibrium (i.e., we reduced the operating temperature while maintaining the same conversion rate) (Figure 4). Thus, increased catalyst lifetimes and suppression of side reactions can be expected. Moreover, we expect that a further shift in the equilibrium can be obtained, and that the dehydrogenation process can be simplified by enhancing the hydrogen separation performance of the silica membrane.

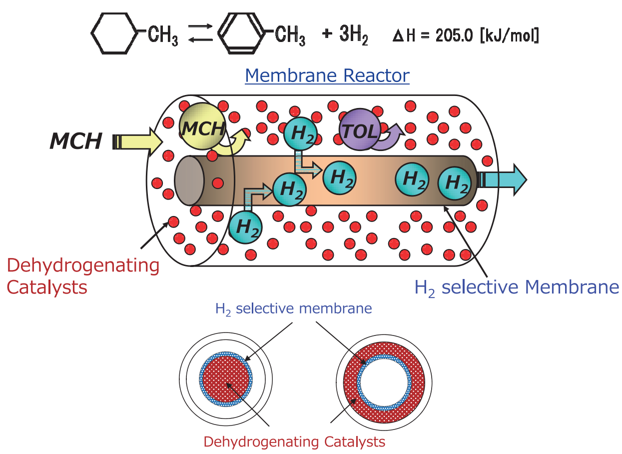


Figure 3 : Membrane reactor for dehydrogenation of MCH

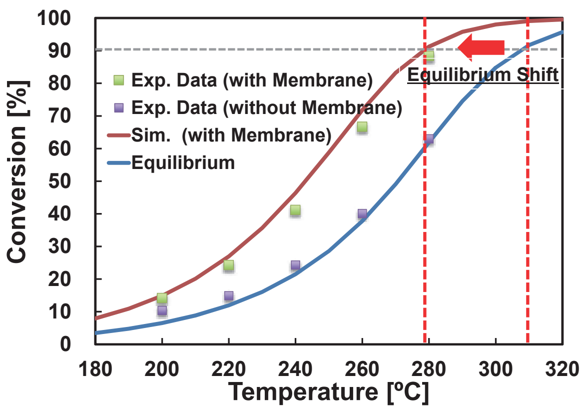


Figure 4 : Experimental and simulated results of the dehydrogenation of MCH with/without membrane

We have developed a low-cost sealing method for the mass production of bench-scale dehydrogenation apparatus and collected various engineering data. This has allowed us to fabricate an apparatus composed of seven tubular silica membrane reactors (Figure 5).

In FY 2016, the development of modular equipment for practical use was promoted owing to technical difficulties with the equipment identified in operational studies. By collecting various data, we confirmed that a good equilibrium shift could be obtained under various conditions even with modular apparatus.

We are developing dehydrogenation apparatus for mass production, continue to gather engineering data, and are aiming for the practical application of this apparatus.

3. Development of pore-fill-type membranes

Palladium membranes are expected to be applicable to the dehydrogenation of ammonia and steam re-

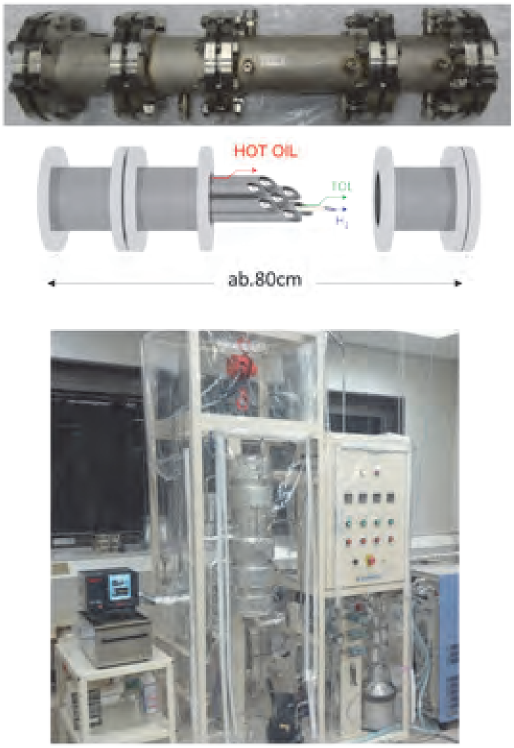


Figure 5 : Bench-scale dehydrogenation apparatus consisting of seven membrane reactors

forming of natural gas, and suitable for use in membrane reactors for high-efficiency hydrogen production. The pressure swing adsorption (PSA) method, the conventional method for hydrogen production, needs large-scale apparatus and multiple steps. In contrast, the membrane reactor, which is a newer method, can simplify the process and uses compact apparatus. Although conventional palladium membranes show high hydrogen selectivity, they have some problems due to the palladium layer on the surface of the support: a) membrane peeling due to the difference in the thermal expansion coefficients of the support and palladium, b) easy hydrogen embrittlement, c) membrane damage by contact with flying objects, and d) alloying with the metal of the catalyst. In addition, the preparation of conventional membranes is expensive because of the large amount used of palladium.

We are developing pore-fill-type palladium membranes (Figure 6). Our membrane has a unique structure with palladium particles inside the α-alumina porous support; the exposed α-alumina porous support thus acts as a protective layer. Our membranes have a high hydrogen permeability and selectivity, equivalent to those of conventional membranes. In addition, we have confirmed that the durability is improved over that

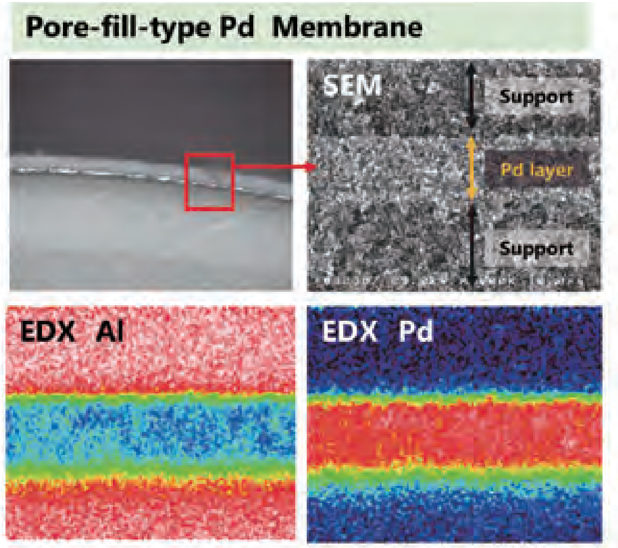


Figure 6 : Field emission scanning electron microscopy (FESEM) images and Energy dispersive X-ray spectrometry (EDX) mappings of a pore-fill-type Pd membrane

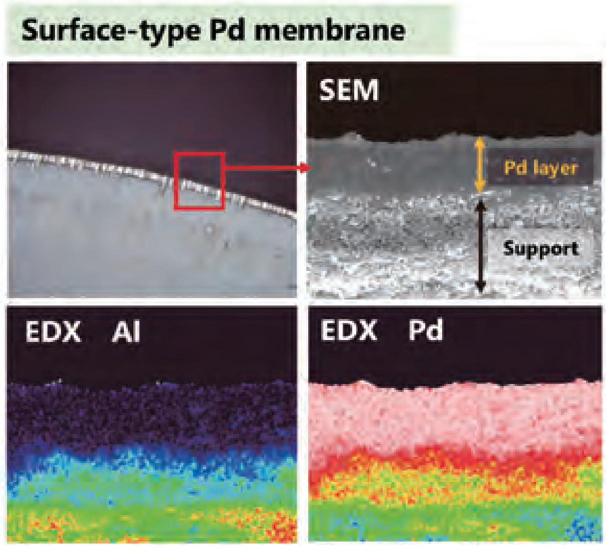


Figure 7 : FESEM images and EDX mappings of a surface-type Pd membrane

of conventional palladium membranes. Moreover, the amount of palladium required is reduced by about 70% compared with the same thickness of the conventional membrane (Figure 7) because the palladium particles are contained within the porous support.

We are currently focusing on the practical application of these membranes by improving their performance and evaluating membrane reactors.

4. Development of high-performance zeolite membranes.

CO_2 capture is important, not only for Carbon Capture and Storage (CCS), but also for energy production processes, such as natural gas or biogas purification.

Recently, the application of high-silica zeolite membranes in CO_2 separation processes has attracted considerable attention. The gas permeability of high-silica zeolite membranes tends to be higher than that of low-silica zeolite membranes because the large pore volumes of the high-silica membranes are advantageous for gas diffusion. Generally, low-silica zeolite membranes are known to have low gas permeation performances owing to water adsorption in their micropores. Therefore, pretreatment with a dehumidifier is needed for a CO_2 separation system that uses low-silica zeolite membranes. Conversely, because the pores of high-silica zeolite membranes are unlikely to be blocked by water adsorption, they are expected to be suitable for use in the presence of water (Figure 8).

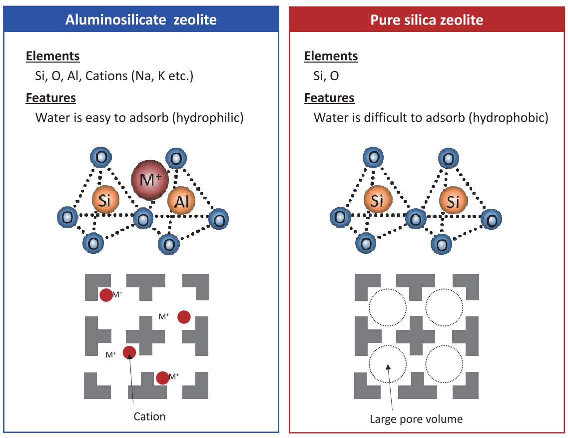


Figure 8 : Classification of zeolites

We are developing pure silica zeolite membranes that contain only Si–O–Si bonds in their framework (Figure 9). We have succeeded in developing a pure silica zeolite membrane (RITE-1 membrane) with a record CO_2 separation performance (Figure 10). It was confirmed that the RITE-1 membrane has a greater steam stability than the topologically analogous aluminosilicate zeolite membrane. We are now investigating the separation performance of pure silica zeolite membranes, including RITE-1, under various conditions.

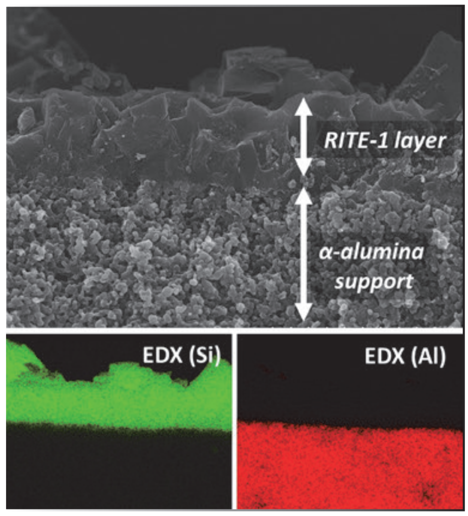


Figure 9 : FESEM image and EDX mappings of the pure silica zeolite RITE-1 membrane

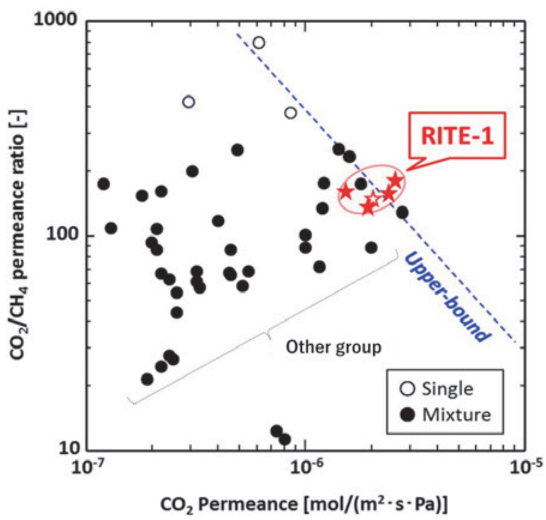


Figure 10 : CO_2 separation performance of the pure silica zeolite RITE-1 membrane

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 March 2017, 16 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:

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) Promoting researcher exchange programs among the Research Section of the IMeRC and member companies;

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.

In FY 2016, we spent approximately half a year from May to November examining and selecting themes to be taken up by the Research Section. As a result of this active investigation and discussion, which intensively considered the needs of user companies and proposals of seeds from separator membrane and support manufacturers, the establishment of three Research Groups was approved as Phase 1 (2 years) at the extraordinary general meeting held in November, and they started their activities.

a) CO_2 Separation Research Group

b) Hydrogen Production Research Group

c) Common Base (Reliability Evaluation Method) Research Group

In addition, exclusive technology seminars for council members are held four times annually (three times as of the end of 2016), in which the latest R & D trends, needs, and seeds are introduced in a total of 11 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 offer a place to acquire knowledge, but also because they provide the opportunity to interact with other frontline researchers from member companies and organizations.

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.

6. Conclusion

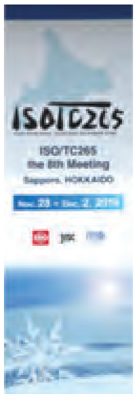
To strengthen Japan’s industrial competitiveness and protect the global environment, it is important to tackle the development of innovative environmental and energy technologies.

Although the IMeRC was only launched in April 2016, it has already established core technologies with excellent characteristics, including silica, palladium, and zeolite membranes. The Industrialization Strategy Council, which consists of separation membrane and support manufacturers and their user companies, is progressing smoothly with the active participation of member companies. We hope to expand the circle of collaboration between the IMeRC, our member companies, universities, and other parties, and hope to put innovative environmental and energy technologies that use inorganic membranes into practical use and promote their industrialization as soon as possible.

Figure 11 : Exclusive seminar for council members

Research & Coordination Group, ISO team

ISO/TC265 the 8th Plenary Meeting and WG Meetings (Sapporo)



The objective of ISO/TC265 is to develop international standards for carbon dioxide capture, transportation, and geological storage (CCS). Two meetings are held annually, consisting of a plenary meeting joined by all participating countries and working groups (WGs). Participating countries take turns hosting, and in past years France, Spain, China, Germany, USA (two times) and Norway have organized meetings. This most recent gathering was the first held in Japan and RITE acted as the facilitator. The venue was located in Sapporo City and participants visited JCCS's Tomakomai Demonstration Project site for the technical tour.

DATE Nov. 28th Mon.– Dec. 2nd Fri.
VENUE Sapporo Convention Center
1-1-1 Higashi-Sapporo 6 jo, Shiroishi-ku, Sapporo
HOST JISC (Japanese Industrial Standards Committee)
ORGANIZER RITE (Secretary of National mirror committee of ISO/TC265)
SPONSOR INPEX, JAPEX, MHI, OYO, TOSHIBA, JCCS
PARTICIPANTS about 90
SCHDULE
Nov. 28 9:00–17:00 WG meetings (WG1–WG6)
17:00–19:00 Convenor meeting
Nov. 29 9:00–17:00 WG meetings (WG1–WG6)
17:00–19:00 WG6 Workshop
Nov. 30 9:00–11:00 WG meetings (WG1–WG6)
12:30–18:00
Technical tour to Tomakomai CCS Demonstration Site
18:30–20:30 Reception
Dec. 1 9:00–17:00 Plenary meeting
18:00–20:00 Group dinner
Dec. 2 9:00–12:45 Plenary meeting

There are six working groups under ISO/TC265 for standardization: WG1: Capture; WG2: Transport; WG3: Storage; WG4: Quantification and Verification; WG5: Cross-Cutting Issues; and WG6: CO_2-EOR.

The development of international standards is process of drafting in stages with the goal of reaching a consensus, and international ballots are cast at each draft stage (*CD, DIS, FDIS and IS). Face-to-face meetings for WGs such as the ones held in Japan are essential for this work. In addition, the plenary meeting takes place with all members in order to solve issues across working groups, monitor progress, and consider the validation of procedures.

WG meetings were held on the first three days as always and the main scopes of the work were as follows: WG1: Resolving the comments for CD voting; WG3: Addressing the comments for DIS voting; WG4: Solving the matter of voting for new standard development; WG5: Drafting of FDIS; and WG6: Drafting of Second CD (No WG2 meeting).

In addition, WG6 organized a workshop for the first part of the week. The objective was to encourage the understanding of CO_2-EOR characteristics after their first CD did not pass in voting.

With the support of JCCS, the technical tour of Tomakomai included an overview of the site and a visit to injection wells, control room and monitoring room. This was followed by a presentation on the Demonstration Project. There was lively discussion during the Q&A session, which indicated high interest from overseas experts.

During the plenary meeting, the voting results of WG convenors were introduced, outcome of WG meetings were confirmed and discussions were conducted on "how to deal with cross-cutting terms" and other items.

The next plenary meeting was announced to be held May 8-12, 2017, in Xinjian-Uygur Autonomous Region in China.

*CD : Committee Draft, DIS: Draft IS, FDIS: Final Draft IS, IS: International Standard

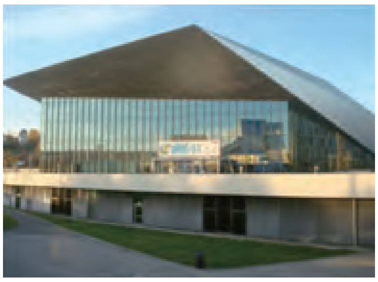
Research & Coordination Group

GHGT-13 Participation Report

GHGT-13 (13th International Conference on Greenhouse Gas Control Technologies) was held in November 14-18th in Lausanne, Switzerland, hosted by the Swiss Federal Institute of Technology (École Polytechnique Fédérale de Lausanne (EPFL)) , the Swiss Federal Office of Energy (SFOE) and the IEA Greenhouse Gas R&D Programme (IEAGHG). This is the largest international conference that focuses on mitigation technologies especially CCS (Carbon dioxide capture and storage) and are held every two years in IEAGHG's member countries. The conference series rotates between North America, Europe and Asia.

Participants were about 1,000 from 39 countries and discussed on 13 themes in 77 technical sessions: geological storage has 24 sessions (including other storage options) and capture has 23. These two themes were major, about 60% of all sessions. RITE gave nine oral and ten poster presentations in technical sessions on geological storage, capture, and others. In addition, Dr. Ziqiu Xue, Chief Researcher/Project Leader of CO_2 Storage Research Group, RITE, served as a session chair for technical sessions on storage.

At the end of five days conference, the next GHGT-14 was announced to be held in Melbourne, Australia in October 21-26th, 2018.



Swiss Tech Convention Centre

Keynote Address

Systems Analysis Group

COP22 Side Event

Evaluations on the emission reduction efforts of Nationally Determined Contributions (NDCs) in cost metrics

A side event at COP22 in Marrakech was held to discuss on the evaluations of emission reduction efforts of Nationally Determined Contributions (NDCs), which will become very important in the review under the Paris Agreement. After an introduction by Dr. Kopp, Dr. Aldy presented the framework and the principles of the NDC evaluation, as well as a brief overview of results obtained with the four models (DNE21+ etc.). Dr. Akimoto presented NDC comparison based on several indicators including mitigation costs. He and Dr. Aleluia Reis compared the outcome of several scenarios of NDC implementation combined or not with other policies such as energy pledges.

Date 15 November 2016
Venue COP22 Japan Pavilion (Marrakech)
Organization RITE
Co-organization Resources for the Future (RFF), Fondazione Eni Enrico Mattei (FEEM)

Program

- Introduction; Raymond Kopp, RFF
- Transparency, Policy Surveillance, and the Comparison of Mitigation Efforts; Joseph E. Aldy, Harvard Kennedy School
- Evaluations on the emission reduction efforts of NDCs in cost metrics; Keigo Akimoto, RITE
- Transparency, Policy Surveillance, and Levels of Efforts; Lara Aleluia Reis, FEEM/CMCC
- Discussions and Q&A

Molecular Microbiology and Biotechnology Group

Green Sustainable Chemistry (GSC) Award—Incentive Award

The 15th Green Sustainable Chemistry (GSC) Incentive Award was given to "Development of manufacturing process for biomass-based phenol" developed by RITE, Sumitomo Bakelite Co., Ltd., and Green Phenol Development Co., Ltd. received, which was given for achievements that contributed to the promotion of green sustainable chemistry.

In May 2 to 3 at Kobe, three members from RITE, Sumitomo Bakelite Co., Ltd., and Green Phenol Development Co., Ltd. attended an awards ceremony and gave lectures with support of The Japan Association for Chemical Innovation (JACI).

Phenol is an essential material for the production of phenolic resin, epoxy resin, polycarbonate, and other polymers that are typically used in automotive parts, electronic materials, and building blocks, and its demand is further increasing in the world.

The typical industrial process for phenol production is the petroleum-based cumene process with high energy consumption due to the operation at a high temperature and pressure using organic solvents and strong acids. Therefore, an environmentally friendly phenol production technique is desired.

Based on this background, we succeeded in developing a manufacturing process for biomass-based phenol with the RITE Bioprocess (two-stage bioprocess, see text), using genetically modified *Corynebacterium glutamicum*, a workhorse for industrial amino acid production. Our technology is expected to be applied for the production of other aromatic chemicals such as medical intermediates, in addition to phenol.

GSC incentive award winners

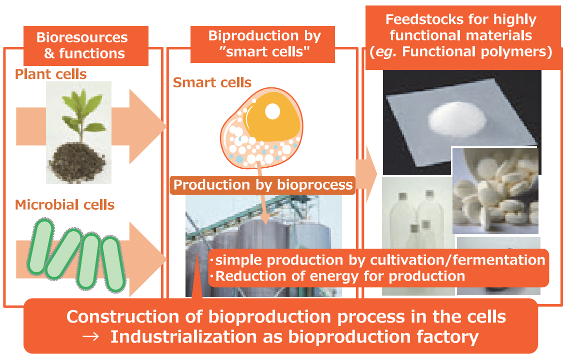
Introduction of new NEDO project "smart cell"

Our group joined NEDO's project on the "Development of high production technology for highly functional materials by plants and microorganisms" (research and development period: 5 years).

Recently, the efficient production technology for highly functional materials via plants and microorganisms has drawn a great deal of global attention, and it is estimated to grow up to 20 trillion yen by 2030. Due to international competitiveness, bioinformation-based logical and speedy gene design, large scale gene recombination technology, and their fusion are necessary to develop the technology.

A new system to obtain the large amount of biological data required for gene design, the quick design of intracellular metabolic process, and the development of technology for industrialization of genome editing technology and its use for controlling the microbial production system is our goal to realize energy efficient and low-cost production of highly functional materials.

In this project, the most advanced methods of biotechnology will be applied to the artificial construction of "smart cell," for the production of functional materials, useful chemicals etc. We have developed an information analysis system to achieve quick and efficient creation of the "smart cell," by using intracellular metabolic pathway design and its verification in *C. glutamicum* strain. Thus, we can create specially optimized microorganisms for the production of useful compounds, and we will also verify their production ability to maximize. We hope to create a "smart cell industry" for realization of a sustainable society through the project.



Creation of a smart cell industry (Ref. METI)

Molecular Microbiology and Biotechnology Group

BioJapan2016

The World Business Forum, 'BioJapan 2016', was held at PACIFICO Yokohama on October 12–14, 2016, and it was jointly conducted with Regenerative Medicine JAPAN 2016 for the first time.

The number of visitors was 12,724 in 2014, 14,153 in 2015, and 15,133 in 2016, which was the largest ever. RITE actively participated in this event by giving a lecture at an organizer seminar, making presentations by researchers, and putting up a joint booth an exhibition in collaboration with Green Phenol Development Co., Ltd.

Takashi Honjo, senior managing director, RITE

Takashi Honjo, the senior managing director at RITE, gave a lecture entitled 'The Role of Green Biotechnology to Establish Zero-Emission Society', in the special session 1 of the organizer seminars named 'Toward Establishing a Sustainable Society', on October 13.

[The session's coordinator & speakers]

#Akihiko Kondo, Professor, Graduate School of Science, Technology and Innovation, Kobe University, 'Systems and Synthetic Biology is Boosting a Creation of Bio-economy'

#Osamu Azegami, General Manager, Biotechnology & Afforestation Laboratory / New Business Planning Div., TOYOTA MOTOR, 'Toyota's R&D Activities in the Biological Field'

#Takashi Honjo, Senior Managing Director, RITE, 'The Role of Green Biotechnology to Establish Zero-Emission Society

#Hiroyuki Yano, Professor, Kyoto University, 'Application of Cellulose Nanofibers for Sustainable Society'

RITE's four senior researchers made presentations about the RITE Bioprocess as follows at the JBA Open Innovation Zone in the Exhibition Hall on October 13.

Presentations at the JBA Open Innovation Zone

#Naoto Kato, 'Advantage of RITE Bioprocess and its commercialization'

#Yukihiro Kitade, 'Practical development of green phenol production by RITE Bioprocess'

#Takahisa Kogure, 'Overproduction of shikimate as a starting material for the anti-influenza drug'

#Takeshi Kubota, 'Challenges to the production of high value-added chemicals: aromatic compounds'

RITE put up a joint booth in the exhibition in collaboration with Green Phenol Development Co., Ltd. for the second consecutive year. 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. as examples of the RITE Bioprocess' commercial uses and technologies of green phenol.

[Hangings 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-butanol and bio-hydrogen production
4) R&D for production of 100% green jet fuel
5) Industrialization of RITE Bioprocess
6) Green Phenol Development Co., Ltd.
7) Development of bioprocess for production of green phenol
8) New trends for biotechnological production of green-aromatic compounds

We also had exhibits that included various samples, such as several non-food biomasses, the amino acid that is the first commercial product from Green Earth Institute Co., Ltd. using the RITE Bioprocess, and green phenolic moldings.

We appreciate your attending this event and visiting our booth.

RITE/GPD exhibition booth

Chemical Research Group

6th Symposium for Innovative CO_2 Membrane Separation Technology — Recent trends of membrane separation technology contributing to the prevention of global warming — Molecular Gate Membrane module Technology Research Association (MGMTRA)

COP21 (Paris Agreement) reaffirmed the goal of keeping average warming below 2 degrees Celsius, while also urging parties to “pursue efforts” to limit it to 1.5 degrees. Carbon dioxide Capture and Storage (CCS) is expected to be one of the important options for global warming measures. Molecular Gate Membrane module Technology Research Association (MGMTRA) is conducting a project entrusted by METI to develop a low-cost innovative CO_2 separation membrane for high-pressured gas from Integrated coal Gasification Combined Cycle (IGCC) etc., which is considered a promising candidate for the efficient coal gasification power generation with CO_2 capture (“CO_2 Separation Membrane Module practical R&D Project”).

In this symposium, we would like to inform people with latest information on CO_2 separation by reporting recent results of CO_2 separation membrane technologies by MGMTRA, and the overview of the CO_2 separation membrane technologies development in overseas.

Program

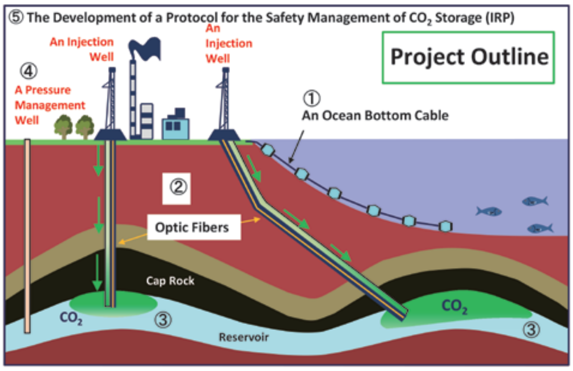
- Lecture 1: Plenary lecture
  “CO_2 zero emission and CCS”
  Prof. Yoichi Kaya PhD, President of RITE
- Lecture 2: Plenary lecture
  “Next-generation thermal power plant and CO_2 reduction”
  Prof. Takayuki Takarada PhD, Division of Environmental Engineering Science, Graduate School of Science and Technology Gunma University
- Lecture 3: Invited lecture
  “Membrane Testing at the US National Carbon Capture Center”
  Frank Morton*, Director, Technology Development, Southern Company Services, Inc.
  *Mr. Frank Morton was absent on that day. Teruhiko Kai, Technical Director of MGMTRA, read the report in his place.
- Lecture 4: Invited lecture
  “Membrane Gas Separation Applications for CO_2 EOR Natural Gas Processing Plant”
  Atsushi Morisato PhD, Functional Director of Membrane R&D, Cameron, a Schlumberger company
- Lecture 5
  “On R&D of next-generation membrane module by MGMTRA”
  Prof. Shin-ichi Nakao PhD, Senior Managing Director of MGMTRA
- Lecture 6
  “Latest trend of CO_2 separation membrane technologies in overseas”
  Teruhiko Kai PhD, Technical Director of MGMTRA

CO_2 Storage Research Group

The Launch of the Safety Management Technology Development Project and the Establishment of GCS Technology Research Association

○Project on the Safety Management Technology of Large Scale Geological CO_2 Storage in FY2016

Aiming at making carbon capture and storage (CCS) – a promising global warming mitigation technology - technically viable around 2020, RITE started a project on safety management technology for CCS in 2016. We develop monitoring technologies for CO_2 injection and storage and simulation technology for the prediction of long-term CO_2 behavior. We are commissioned the project for five years by a fiscal year of 2020 by the Ministry of Economy, Trade and Industry. Our ultimate goal is to employ a methodology of safety assessment for CO_2 injection and storage at a site at a large scale and to establish the safety management technology



① The Safety Management of Injection with ATLS based on Observation Results of Natural Earthquakes and Micro Seismicity
② Fiber Optics-based Monitoring of the Stability of Geological Formations and the Integrity of Abandoned Wells
③ The Prediction of Long-term CO_2 Behavior based on Monitoring of CO2 Behavior during Injection
④ The Optimization of a Layout of CO_2 Injection Wells and Pressure Management Wells and the Improvement of Storage Efficiency

In the development of monitoring technologies, we conduct research on the monitoring of geological formation stability and well integrity through measuring temperature, pressure and deformation of formation when injecting CO_2. We will verify the developed technology by implementing at the CCS demonstration site in the waters of Tomakomai in Hokkaido. We also attempt to develop a technology of monitoring CO_2 continuously for a long term to detect CO_2 leakage if CO_2 leak is happened.

In order to inject and store CO_2 efficiently, we are aimed at improving storage efficiency by the establishment of techniques for optimizing a layout of wells and methodologies for applying a technology to enhance CO_2 dissolution to reservoirs.

In addition, we compile expertise accumulated through our technical development, projects in other countries and the Japan's demonstration project and will complete best practice manuals for CCS deployment. We also promote technical exchange with overseas organizations such as research institutes proactively.

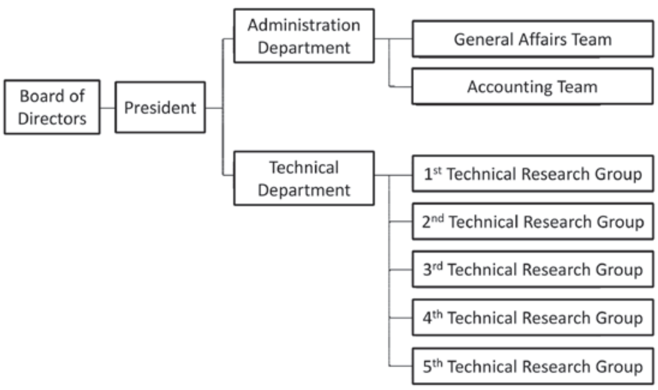
○Geological Carbon Dioxide Storage Technology Research Association (GCS)

In order to make CCS technology practically available, private companies and research institutes should jointly conduct R&D, building on research that has been conducted mainly by RITE. For this purpose, the Geological Carbon Dioxide Storage Technology Research Association (GCS) was established on April 1 2016.

In addition to RITE, GCS consists of another research institute and four private companies: the National Institute of Advanced Industrial Science and Technology (AIST), Oyo Corporation, INPEX Corporation, Taisei Corporation, and Japan Petroleum Exploration Co., Ltd.

GCS develops geological CO_2 storage technologies suitable for Japan's reservoirs at a large scale of one million tonnes of CO_2 per year. It also conducts social acceptance oriented R&D.

GCS works on R&D, collaborating closely with the large-scale demonstration project that Japan CCS Co., Ltd. is conducting, commissioned by the Ministry of Economy, Trade and Industry (METI).



CO_2 Storage Research Group

Win the Society of Exploration Geophysics of Japan Award 2015 — Stain Measurement with Distributed Fiber Optic Sensors under Hydrostatic Conditions —

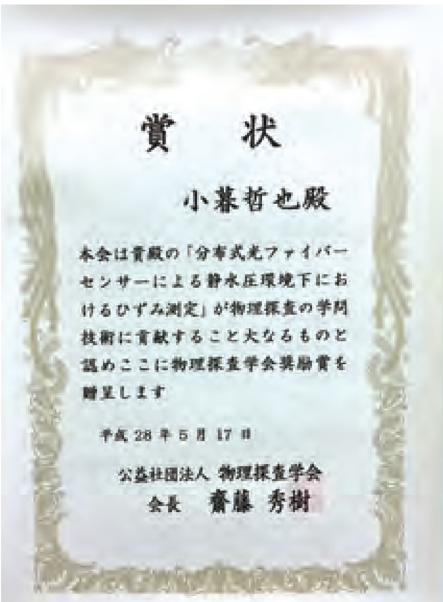
Received the Society of Exploration Geophysics of Japan Award 2015 for a paper titled “Stain Measurement with Distributed Fiber Optic Sensors under a Hydrostatic Condition”, a research team in RITE, Dr Xue, Dr Kiyama and Dr Kogure (Shimane University at present), got a prize at the International Conference Center Ibuka Memorial Hall of Waseda University in May 2016.

The award is given for the accomplishment that contributes to the advancement of exploration technologies.

RITE conducts R&D to monitor the deformation of geological formations by measuring strains and other parameters from the surface to the subsurface vertically with an optic fiber embedded along a well as distributed sensors.

The paper presented a methodology to calculate changes in strains with data acquired with distributed fiber optic sensors under a hydrostatic environment and its viability of the measurement. The award was given for its novelty and technological competence as an exploration technology.

We continue the development to put it in a practically applicable level as a tool of monitoring the integrity of geological formations in geological CO_2 storage through lab-scale tests and field tests.



CCS Technical Workshop 2016 — For Safe Large-Scale Geological CO_2 Storage —

With large-scale CO_2 storage projects having become operational in Canada and USA recently, Japan started the Tomakomai CCS Demonstration Project to inject 100,000 tonnes of CO_2 annually in aquifers in 2016. People have greater hope for safe large-scale CO_2 storage.

The workshop was organized with an eye on realizing safe large-scale CO_2 storage in aquifers. The event was aimed at learning DOE supported policies for large-scale projects and R&D strategy; and expertise compiled through commercial-scale CCS projects such as the Quest project in Canada and the Industrial CCS project in USA.

There was also a report on “R&D in the Geological Carbon Dioxide Storage Technology Research Association”, which was established in 2016 to conduct R&D on CO_2 storage suitable for reservoirs specific to Japan at a scale of one million tonnes of CO_2 per year.

Agenda

- Talk 1: U.S Department of Energy Supported CCS R&D
  Darin Damiani, Carbon Storage Program Manager, DOE
- Talk 2: Scaling up of Deep Saline Storage in Illinois, USA
  Sallie E. Greenberg, University of Illinois
- Talk 3: Setting the Stage for Commercial-Scale CCS
  Robert J.Finley Ph.D., Independent Consultant
- Talk 4: The Quest CCS Project
  Simon O’Brien, Quest Storage Manager, Shell Canada
- Talk 5: R&D in the Geological Carbon Dioxide Storage Technology Research Association
  Ziqiu Xue, Manager, Technical Department, GCS

Inorganic Membranes Research Center

Inorganic Membranes Research Center Inaugural Symposium

This symposium was held in commemoration of the establishment of the Inorganic Membranes Research Center (IMeRC) in April 2016. Following the speech from President Kaya on behalf of the organizers, and the greeting from Mr. Hiroshi Fukushima of the Ministry of Economy, Trade and Industry, there were two keynote lectures, one special lecture, and a panel discussion on the current status of the use of inorganic membranes to support innovative environmental and energy technologies and the prospects for their future industrialization. A dedicated discussion session with questions from participants was also held. Popular comments from the participants concerned the possibilities and problems of inorganic membranes.

Date	15 April 2016
Venue	Ito Hall (Tokyo)
Organized by	RITE
Number of participants	227

Program

– Keynote Lecture 1: The role of membrane technologies in energy and environmental policy
  Kenji Yamaji, Director General, RITE

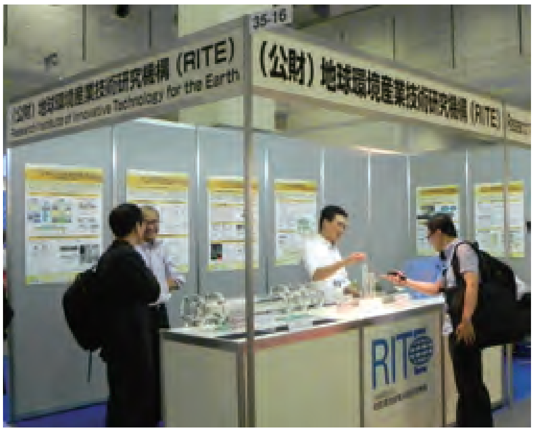
– Keynote Lecture 2: Aims of the Inorganic Membranes Research Center
  Shin-ichi Nakao, Director of the Inorganic Membranes Research Center, RITE

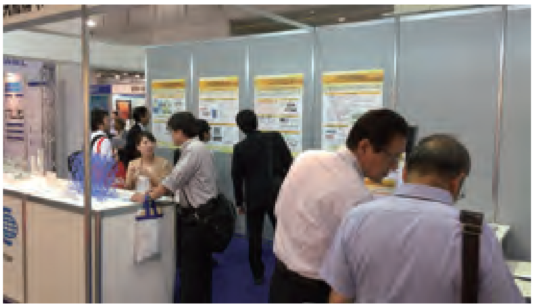
– Special Lecture: Development of inorganic membranes for environmental and energy technologies
  Hidetoshi Kita, Professor, Yamaguchi University

– Panel Discussion: Inorganic membranes for innovative environmental and energy technologies
  Coordinator: Shin-ichi Nakao, RITE
  Panelists:
    Masataka Kajiwara, Iwatani Corporation
    Takashi Ono, Kyocera Corporation
    Takashi Yasuda, JGC Corporation
    Kazuhiro Yano, Hitachi Zosen Corporation
    Prof. Toshinori Tsuru, Hiroshima University

Highly Functional Ceramics Expo Osaka

The 1st Highly Functional Ceramics Expo Osaka, organized by Reed Exhibitions Japan Ltd., was held at INTEX Osaka on 5–7 October 2016. 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 our activities with us. The lecture, "Current and prospective gas separation membranes made of ceramics—towards the practical implementation of innovative environmental and energy technologies" by the deputy director of the IMeRC, Ryoichi Nishida, on 7 October was full and widely informed those present of the activities of RITE. 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

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.
10 Feb. 2016	**ALPS International Symposium 2016** —COP21 results and Long-term Reductions of Greenhouse Gas Emissions beyond COP21— • Venue: Otemachi Sankei-Plaza • Organizer: RITE • Co-organizer: Ministry of Economy, Trade and Industry • Number of participants: 320	Systems Analysis Group
7 Mar. 2016	**COP Paris Agreement and next IPCC Reports** • Venue: Dai-ichi Hotel Tokyo • Organizer: RITE • Co-organizer: Ministry of Economy, Trade and Industry • Number of participants: 210	Research & Coordination Group
15 Apr. 2016	**Inorganic Membranes Research Center Inaugural Symposium** • Venue: Ito Hall (Tokyo) • Organizer: RITE • Number of participants: 227	Inorganic Membranes Research Center
7 Dec. 2016	**Innovative Environmental Technology Symposium 2016** —Establishment of zero emission society through innovation of energy environment technologies— • Venue: Ito Hall (Tokyo) • Organizer: RITE • Number of participants: 390	Research & Coordination Group
19 Jan. 2017	**CCS Technical Workshop 2016** —For Safe Large-Scale Geological CO_2 Storage— • Venue: Toranomon Hills Forum, Main Hall • Organizer: Geological Carbon Dioxide Storage Technology Research Association (GCS) • Co-organizer: Ministry of Economy, Trade and Industry • Number of participants: 365	CO_2 Storage Research Group
23 Jan. 2017	**6th Symposium for Innovative CO_2 Membrane Separation Technology** —Recent trends of membrane separation technology contributing to the prevention of global warming— • Venue: Ito Hall (Tokyo) • Organizer: Molecular Gate Membrane module Technology Research Association (MGM-TRA) • Co-organizer: Ministry of Economy, Trade and Industry • Number of participants: 201	Chemical Research Group
26 Jan. 2017	**Measures for tackling Global Warming** —IPCC Activities and Perspectives in AR6 Cycle— • Venue: Hatsumeikaikan • Organizer: Ministry of Economy, Trade and Industry • Co-organizer: RITE • Number of participants: 250	Research & Coordination Group

Exhibitions

Dates	Event Description	Related Dept.
5-7 Oct. 2016	**1st Highly Functional Ceramics Expo Osaka** • Venue: INTEX Osaka • Organizer: Reed Exhibitions Japan Ltd.,	Inorganic Membranes Research Center
12-14 Oct. 2016	**BioJapan 2016** • Venue: Pacifico Yokohama • Organizer: BioJapan Organizing Committee, JTB Communication Design, Inc.	Molecular Microbiology and Biotechnology Group

Press Releases

Date	Title
6 Jan. 2016	Announcement of ALPS International Symposium 2016
9 Feb. 2016	Announcement of Symposium "COP Paris Agreement and next IPCC Reports"
29 Feb. 2016	Establishment of Inorganic Membranes Research Center and Announcement of Inaugural Symposium
31 Mar. 2016	Geological Carbon Dioxide Storage Technology Research Association Established in Japan
21 Oct. 2016	Licensing of chemical solvent
21 Oct. 2016	Announcement of Innovative Environmental Technology Symposium 2016
28 Nov. 2016	Announcement of CCS Technical Workshop 2016
1 Dec. 2016	Announcement of 6th Symposium for Innovative CO_2 Membrane Separation Technology
20 Dec. 2016	Japan's first CTCN Technical Assistance Project with Japanese unique low-carbon technology
22 Dec. 2016	Announcement of Symposium "Measures for tackling Global Warming"
26 Dec. 2016	Technological exchange of CCS with Korea CCS R&D Center

Environmental Education

◇Facility Visit Program and Lecture

Date	Place	Participants	Number of participants
21 Jan.	RITE	Seikaminami Junior High School	4
1 Mar.	Seikaminami Junior High School	Seikaminami Junior High School	Approx. 60
3 Mar.	Higashihikari Elementary School	Higashihikari Elementary School	Approx. 110
6 May	RITE	Narakita High School	40
2 Aug.	RITE	Nishimaizuru High School	8
15 Sep.	RITE	Naragakuen Tomigaoka Junior High School	9
13 Oct.	RITE	MASUDA Senior High School	22
18 Nov.	RITE	Seikanishi Junior High School	10

◇Workshop and Exhibition

Date	Place	Title	Number of participants
6 Feb.	Keihanna-Plaza	Global Warming and CCS Study Workshop “Science Experiment”	22
Jul. – Aug.	RITE	Global Warming and CCS Study Workshop “Experiment and Game”	72
23 Aug.	RITE	Global Warming and CCS Study Workshop “Science Show”	56
6 Feb.	Keihanna-Plaza	KEIHANNA Science Festival 2016	

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Original Paper

	Title	Researchers	Journal
1	Evaluations on the Japan's Greenhouse Gas Emission Reduction Target for 2030	F. Sano, K. Akimoto, T. Homma, K. Tokushige	Journal of Japan Society of Energy and Resources, Vol.37 No.1, 2016, pp51-60
2	The uncertainty of climate sensitivity and its implication for the Paris negotiation	Y. Kaya, M. Yamaguchi, K. Akimoto	Sustainability Science, May 2016, Volume 11, Issue 3, pp 515-518
3	Comparing emission mitigation efforts across the countries	J. Aldy, B. Pizer, K. Akimoto	Climate Policy (online)
4	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, R. Watanabe, N. Yamagishi, G. Yoshizawa	Sustainability Science (online)
5	Estimating option values of solar radiation management assuming that climate sensitivity is uncertain	Y. Arino, K. Akimoto, F. Sano, T. Homma, J. Oda, T. Tomoda	Proceedings of the National Academy of Science of the United States of America, vol. 113 no. 21, pp.5886-5891, 2016
6	Economic Tools to Promote Transparency and Comparability in the Paris Agreement	J. Aldy, W. Pizer, M. Tavoni, L. A. Reis, K. Akimoto, G. Blanford, C. Carraro, L. E. Clarke, J. Edmonds, G. C. Iyer, H. C. McJeon, R. Richels, S. Rose, F. Sano	Nature Climate Change 6, 1000-1004, 2016
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 (online)
8	Decomposing passenger transport futures: Comparing results of global integrated assessment models	O.Y. Edelenbosch, D.L. McCollum, D.P. van Vuuren, C. Bertram, S. Carrara, H. Daly, S. Fujimori, A. Kitous, P. Kyle, E.O. Broin, P. Karakatsoulis, F. Sano	Transportation Research Part D (online)
9	Study on Coal Power Plant and Carbon Capture and Storage Investments based on Real Options Approach	J. Oda, K. Akimoto	Journal of Japan Society of Energy and Resources, Vol.37, No.6, pp.13-22, 2016
10	A global analysis of residential heating and cooling service demand and cost-effective energy consumption under different climate change scenarios up to 2050	K. Gi, F. Sano, A. Hayashi, T. Tomoda, K. Akimoto	Mitigation and Adaptation Strategies for Global Change (online)

Other Paper

	Title	Researchers	Magazine, Publication
1	Best energy mix under electricity system reformation - forecasts and issues in renewable energy, nuclear power and thermal power -	K. Akimoto	Electrical Review, April 2016
2	Required cost for achieving nationally determined contributions(NDC)	K. Akimoto	Monthly Keidanren, April 2016
3	Trends in Japanese Energy Policy & the “Innovative Energy Strategy”	K. Akimoto	JEF Japan Spotlight Jul./Aug. 2016
4	Global warming mitigation trends after COP21	K. Akimoto	Petroleum Technology Dec. 2016 Vol.39 No.12, pp.939-944
5	A vision towards global energy supply and demand	K. Akimoto	Energy Review, Jan. 2017

Oral Presentation (International Academic Society)

	Title	Researchers	Forum
1	Carbon intensity and its determination in Japanese steel industry	J. Oda, K. Akimoto, T. Homma	The 5th IAEE Asian Conference, The University of Western Australia Business School, Perth, Australia, Feb. 14, 2016
2	Evaluation of 2030 GHG emissions based on the submitted NDCs and their consistency with temperature rise target emission pathways considering scientific and policy uncertainties	K. Akimoto	wholeSEM 3rd Annual Conference, Jul. 4, 2016
3	A Review of Micro and Macro-economic Conditions for Off-grid Integration of Renewable Energies	B. Shoai-Tehrani, K. Akimoto, F. Sano	The Sixth Congress of the East Asian Association of Environmental and Resource Economics, Aug. 8, 2016

Systems Analysis Group

	Title	Researchers	Forum
4	Impacts of continuing low fossil fuel prices on the global greenhouse gas emissions reduction pledged in INDCs	Y. Arino, F. Sano, K. Akimoto	The Sixth Congress of the East Asian Association of Environmental and Resource Economics, Aug. 9, 2016
5	An analysis on correlation between climate change mitigation and air pollution control by using a global energy systems model	F. Sano, K. Akimoto, K. Gi, Y. Nakagami	11th SDEWES Conference, Sep. 6, 2016
6	Assessment of Potential and Breakeven Prices of Fusion Power Plants Under Low-Carbon Development Scenarios	K. Gi, F. Sano, K. Akimoto	26th IAEA Fusion Energy Conference, Oct. 21, 2016
7	Are Deregulated Electricity Market and Climate Policy compatible? Lessons from overseas, from Europe to Japan	B. Shoai-Tehrani, P. Da Costa, K. Akimoto, Y. Nakagami	USAEE2016, Oct. 25, 2016
8	Preliminary Study on Policy Mix Effects on Economic Viability of Carbon Capture and Storage Project in Japanese Steel Industry	J. Oda, K. Akimoto	13th Conference on Greenhouse Gas Control Technologies (GHGT-13), Nov. 16, 2016
9	GHG emission pathways for the 1.5 °C temperature rise target and their challenges	K. Akimoto, F. Sano, T. Tomoda	9th Annual Meeting of the IAMC (Integrated Assessment Modeling Consortium), Dec. 5, 2016
10	Underlying policies and evaluations of Japan's Nationally Determined Contribution	K. Gi	9th Annual Meeting of the IAMC (Integrated Assessment Modeling Consortium), Dec. 6, 2016

Oral Presentation (Domestic Academic Society)

	Title	Researchers	Forum
1	Evaluations on Emission Reduction Efforts of INDCs Submitted by Governments	K. Akimoto, F. Sano, T. Homma, J. Oda, K. Tokushige	The 32nd Conference on Energy, Economy, and Environment, Feb. 2, 2016
2	An Evaluation on the Large Scale Supply Costs of Energy Crops	A. Hayashi, K. Akimoto, F. Sano	The 32nd Conference on Energy, Economy, and Environment, Feb. 2, 2016
3	Expert Questionnaire Survey on Climate Change Risk Management	J. Oda, K. Akimoto, K. Tokushige, A. Hayashi	The 32nd Conference on Energy, Economy, and Environment, Feb. 2, 2016
4	Analysis of Industrial Structures under the SSPs and Mitigation Scenarios	T. Homma, K. Akimoto, F. Sano	The 32nd Conference on Energy, Economy, and Environment, Feb. 2, 2016
5	Off-grid Integration of Renewable Energies: a Techno-Economic Assessment	B. Shoai-Tehrani, K. Akimoto, F. Sano	The 32nd Conference on Energy, Economy, and Environment, Feb. 2, 2016
6	Evaluating the option values of solar radiation management under scenarios regarding ocean acidification	Y. Arino, K. Akimoto, F. Sano, T. Homma, J. Oda, T. Tomoda, A. Hayashi	The 32nd Conference on Energy, Economy, and Environment, Feb. 2, 2016
7	Climate Change-related Investment Trends <A Review on the classification and Estimates of Climate Funds>	K. Wada	The 32nd Conference on Energy, Economy, and Environment, Feb. 2, 2016
8	An Analysis on Long-term Climate Change Mitigation Under the Scenarios Harmonizing SSP Storylines	F. Sano, K. Akimoto, T. Homma, J. Oda, A. Hayashi, K. Gi	The 32nd Conference on Energy, Economy, and Environment, Feb. 3, 2016
9	Analysis of Long-term Residential Usage Demand and Energy Consumption Scenarios Using the Global Energy Assessment Model: DNE21+	K. Gi, F. Sano, A. Hayashi, K. Akimoto	The 32nd Conference on Energy, Economy, and Environment, Feb. 3, 2016
10	Evaluations on Impacts due to Climate Change in Major Global Cities	A. Hayashi, M. Kii	The 53rd Conference of the Committee of Infrastructure Planning and Management (Spring Conference), May 29, 2016
11	An Analysis on Correlation between Climate Change Mitigation and Air Pollution Control by Using a Global Energy Systems Model	F. Sano, K. Akimoto, K. Gi, Y. Nakagami	The 35th Annual Meeting of Japan Society of Energy and Resources, Jun. 6, 2016
12	Japan's GHG emission reductions for 2050 in consistency with the 2°C target	K. Akimoto, F. Sano	The 35th Annual Meeting of Japan Society of Energy and Resources, Jun. 7, 2016
13	Estimation on Potential Land Areas for Energy Crop Production and a Large-scale Afforestation Under the Scenarios Harmonized with SSP Storylines	A. Hayashi, K. Akimoto, F. Sano	The 35th Annual Meeting of Japan Society of Energy and Resources, Jun. 7, 2016
14	Study on Coal Power Plant and Carbon Capture and Storage Investments based on Real Options Approach	J. Oda, K. Akimoto	The 35th Annual Meeting of Japan Society of Energy and Resources, Jun. 7, 2016
15	Analysis of Industrial Structures under the SSPs and the Climate Scenarios	T. Homma, J. Oda, K. Akimoto, F. Sano	The 35th Annual Meeting of Japan Society of Energy and Resources, Jun. 7, 2016
16	Analysis of targets of fusion energy development in Japan under low-carbon scenarios using a global energy system model: DNE21+	K. Gi, F. Sano, K. Akimoto	The 11th Joint Conference on Nuclear and Fusion Energy, Jul. 15, 2016

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	Title	Researchers	Forum
17	Evaluation of Bioenergy Potentials for Negative Emissions	A. Hayashi, K. Akimoto, F. Sano	The 25th Annual Meeting of Japan Institute of Energy, Aug. 9, 2016
18	Energy Policy Trends under Paris Climate Agreement	K. Akimoto	The 48th Autumn Meeting of the Society of Chemical Engineers, Sep. 6, 2016
19	Evaluations on International Comparison of Emission Reduction Efforts of the INDCs	K. Akimoto	The 21th Annual Meeting of Society for Environmental Economics and Policy Studies, Sep. 11, 2016

Other Oral Presentation and Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	International Comparison of Ambitions of INDCs and the Expected Global Emissions	K. Akimoto	The 117th Symposium of The 21st Century Public Policy Institute “Strategies under COP21”, Jan. 15, 2016
2	Considering energy mix and energy policy from a wide, deep point of view	K. Akimoto	National Institute of Technology, Kagoshima College, Jan. 25, 2016
3	Accomplishments and future issues of COP21	K. Akimoto	Energy and Environment Education Workshop Seminar in Kansai, Feb. 13, 2016
4	Co-benefits Policy and Research beyond Paris	K. Wada	Japan-IIASA Workshop, Feb. 23, 2016
5	Analysis of Pathways towards the Achievement of 1.5°C Target and its Evaluation	K. Akimoto	Symposium “COP Paris Agreement and Future IPCC Report”, Mar. 7, 2016
6	Paris Agreement - A Valuable, New Framework for Greenhouse Gas Reduction	K. Akimoto	THE SEIKEI ORAI The Review of Business & Politics, April 2016
7	A Quantitative Analysis of Nuclear Energy from a 3E Perspective	K. Akimoto	The 49th JAIF Annual Conference, Apr. 13, 2016
8	Achievements of COP21 and CTCN Meeting	K. Wada	The 53rd TECUSE Study Meeting, Apr. 20, 2016
9	International Orientation of NDCs and their Long-term Emission Pathways	K. Akimoto	Open Symposium of Science Council of Japan “A Future Course of Energy and Global Warming Mitigation in accord with Paris Agreement”, May 18, 2016
10	An Analysis of Japan’s INDC and Long-term Target by RITE	K. Wada	Japan Energy MIP Workshop, Jun. 16, 2016
11	Energy Strategies in accord with Global Warming Mitigation Policy	K. Akimoto	A Lecture on Future Energy Vision of Japan as a Resourceless Nation in Wakayama, Jun. 21, 2016
12	Evaluation of 1.5°C Target by Global Model Comparison Project	K. Akimoto	IPCC WG3 Executive Committee, Jul. 20, 2016
13	Paris Agreement and Future Global Warming Mitigation Strategy	K. Akimoto	Energy and Environment Education Seminar (Mihama-cho Board of Education), Aug. 26, 2016
14	Analysis and Evaluation Case Study for 1.5°C Target by RITE	K. Akimoto	Researchers’ Meeting on “Pursuit of Efforts to limit to 1.5°C (Paris Agreement)”, Sep. 5, 2016
15	Expectation for Business Sector towards an Achievement of Paris Agreement	K. Wada	The 12th Japan-Peru Economic Council, Sep. 12, 2016
16	Energy Mix under the Deregulation of the Electric Power in Japan	K. Akimoto	A Lecture on Future Energy Vision of Japan as a Resourceless Nation in Osaka, Sep. 12, 2016
17	Underlying policies of Nationally Determined Contribution by Japan	K. Akimoto	ICEF2016, Oct. 6, 2016
18	Clarifying Issues on Carbon Pricing - from Quantitative Data and Analysis -	K. Akimoto	Task Force for the Expansion of Inward Investment under Long-term Global Warming Countermeasures Platform, Oct. 13, 2016
19	A Review of Micro and Macro-economic Conditions for Off-grid Integration of Renewable Energies	B. Shoai-Tehrani, K. Akimoto, F. Sano	Workshop of Policy Alternatives Research Institute of the University of Tokyo, Nov. 1, 2016
20	Considering Energy Mix from a viewpoint of Global Warming Mitigation	K. Akimoto	A Lecture on Future Energy Vision of Japan as a Resourceless Nation in Matsuyama, Nov. 8, 2016
21	Energy Mix in accord with Global Warming Mitigation Policy and Issues towards its Achievement	K. Akimoto	The 11th Environment and Energy Symposium, Nov. 12, 2016

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	Title	Researchers	Magazine, Newspaper, etc.
22	Evaluations on the emission reduction efforts of Nationally Determined Contributions (NDCs)	K. Akimoto	COP22 Side Event, Nov. 15, 2016
23	Transparency, Policy Surveillance, and the Comparison of Mitigation Efforts	J. Aldy, B. Pizer, K. Akimoto	RFF Discussion Paper, Nov. 2016
24	A Review of Micro and Macro-economic Conditions for Off-grid Integration of Renewable Energies	B. Shoai-Tehrani, K. Akimoto, F. Sano	Workshop of Policy Alternatives Research Institute of the University of Tokyo, Dec. 1, 2016
25	Evaluation of a Long-term Target of Paris Agreement using multiple Socioeconomic Scenarios	K. Akimoto	Innovative Environmental Technology Symposium, Dec. 7, 2016
26	Future Vision of Global Warming Mitigation and Energy Policies	K. Akimoto	Seminar on "Mental and Environmental Issues", Dec. 7, 2016
27	Expectation for IPCC in the course of UNFCCC Process	K. Wada	Japan Energy MIP Workshop, Dec. 12, 2016

Molecular Microbiology and Biotechnology Group

Original Paper

	Title	Researchers	Journal
1	Expectations for 100% drop-in green jet fuel	A. Watanabe, M. Inui	Kagakukeizai, Vol.62, pp.32-38, 2015
2	Regulons of global transcription factors in *Corynebacterium glutamicum*	K. Toyoda, M. Inui	Appl. Microbiol. Biotechnol., Vol.100, pp.45-60, 2016
3	RNase III mediated cleavage of the coding region of *mraZ* mRNA is required for efficient cell division in *Corynebacterium glutamicum*	T. Maeda, Y. Tanaka, N. Takemoto, N. Hamamoto, M. Inui	Mol. Microbiol., Vol.99, pp.1149-1166, 2016
4	The extracytoplasmic function σ factor $σ^C$ regulates expression of a branched quinol oxidation pathway in *Corynebacterium glutamicum*	K. Toyoda, M. Inui	Mol. Microbiol., Vol.100, pp.486-509, 2016
5	Improving process yield in succinic acid production by cell recycling of recombinant *Corynebacterium glutamicum*	T. Jojima, R. Noburyu, M. Suda, S. Okino, H. Yukawa, M. Inui	Fermentation, Vol.2, 5, 2016
6	Technology development of phenol production from plant-derived materials and its future development	H. Miyauchi, M. Inui	Palnt and Process, Vol.58, pp.34-38, 2016
7	Mass production of bio-mass derived phenol "Green-phenol"	H. Miyauchi, M. Inui	BIO INDUSTRY, Vol.33, pp.47-54, 2016
8	R&D for production of 100% drop-in green jet fuel	A. Watanabe, T. Jojima, M. Inui	The Piping Engineering Vol.58, pp.6-11, 2016
9	Current state of technology development of biorefinery and its future prospects	M. Inui	Hiroshimahakkokai, Vol.35, pp.11-12, 2016
10	Production of para-aminobenzoate by genetically engineered *Corynebacterium glutamicum* and non-biological formation of an *N*-glucosyl byproduct	T. Kubota, A. Watanabe, M. Suda, T. Kogure, K. Hiraga, M. Inui	Metab. Eng., Vol.38, pp.322-330, 2016
11	Metabolic engineering of *Corynebacterium glutamicum* for shikimate overproduction by growth-arrested cell reaction	T. Kogure, T. Kubota, M. Suda, K. Hiraga, M. Inui	Metab. Eng., Vol.38, pp.204-216, 2016
12	Production of green phenol from non-food biomass by microorganisms	K. Hiraga, M. Inui	Electrical Review, Vol.631, pp.52-53, 2016
13	Current R&D status of production of green jet fuel	A. Watanabe, M. Inui	ELECTRICAL REVIEW, Vol.632, pp.38-39, 2016
14	Shale revolution and bioplastics	K. Inatomi, M. Inui	ELECTRICAL REVIEW, Vol.633, pp.54-55, 2016
15	Development of bio-hydrogen production technology toward the realization of a hydrogen society	H. Teramoto, M. Inui	ELECTRICAL REVIEW, Vol.634, pp.52-53, 2016

Magazine article

	Title	Researchers	Magazine, Forum
1	1st Laboratory visit, Revolution in chemical industry, Production of aromatic compounds by microorganisms	—	Nikkei Biotechnology & Business, pp.39-40, Feb. 1, 2016
2	"RITE Bioprocess" to Realize the Clean Production of Phenol	—	The Japan Journal, Vo.13, No.1, pp.26-27, Apr., 2016

Molecular Microbiology and Biotechnology Group

Oral Presentation (International Academic Society)

	Title	Researchers	Forum
1	Aerobic quinol oxidation pathways in *Corynebacterium glutamicum* are under the control of the extracytoplasmic function σ factor σ^C	Koichi Toyoda, Masayuki Inui	The 13th International Symposium on the Genetics of Industrial Microorganisms (GIM2016), Oct. 18, 2016
2	Metabolic engineering for shikimate overproduction by *Corynebacterium glutamicum* with mixed sugar utilizing ability	Takahisa Kogure, Takeshi Kubota, Masako Suda, Kazumi Hiraga, Masayuki Inui	The 13th International Symposium on the Genetics of Industrial Microorganisms (GIM2016), Oct. 17-19, 2016
3	Overpoduction of *para*-aminobenzoate using metabolically engineered *Corynebacterium glutamicum*	Takeshi Kubota, Akira Watanabe, Masako Suda, Takahisa Kogure, Kazumi Hiraga, Masayuki Inui	The 13th International Symposium on the Genetics of Industrial Microorganisms (GIM2016), Oct. 17-19, 2016
4	Development of Manufacturing Process for Bio-mass Derived Phenol	Takanobu Masuda, Hiroyuki Miyauchi, Kazumi Hiraga, Masayuki Inui	The 11th SPSJ International Polymer Conferences 2016 (IPC2016), Dec. 13, 2016

Oral Presentation (Domestic Academic Society)

	Title	Researchers	Forum
1	Control of RNA degradation by riboswitches	Norihiko Takemoto, Shinya Watanabe, Yuya Tanaka, Masayuki Inui, Tohru Miyoshi-Akiyama	The 89th Annual Meeting of Japanese Society for Bacteriology, Mar. 23-25, 2016
2	Identification of the σ^C regulon in *Corynebacterium glutamicum*	Koichi Toyoda, Masayuki Inui	The 2016 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 28, 2016
3	Adaptive Laboratory Evolution conferred tolerance to thermal stress to *Corynebacterium glutamicum*	Shinichi Oide, Wataru Gunji, Yasuhiro Moteki, Shogo Yamamoto, Masako Suda, Toru Jojima, Hideaki Yukawa, Masayuki Inui	The 2016 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 28, 2016
4	Analysis of expression of ribonuclease J and ribonuclease E/G genes in *Corynebacterium glutamicum*	Nagisa Hamamoto, Yuya Tanaka, Norihiko Takemoto, Tomoya Maeda, Masayuki Inui	The 2016 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 28, 2016
5	Regulation of the expression of *de novo* pyrimidine biosynthesis genes in *Corynebacterium glutamicum*	Yuya Tanaka, Haruhiko Teramoto, Masayuki Inui	The 2016 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 28, 2016
6	Engineering *Corynebacterium glutamicum* for arabinoxylan utilization	Takayuki Kuge, Akira Watanabe, Haruhiko Teramoto, Masayuki Inui	The 2016 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 28, 2016
7	Characterization of phenol 2-monooxygenase from *Corynebacterium glutamicum*	Junya Maeda, Kazumi Hiraga, Takeshi Kubota, Masayuki Inui	The 2016 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 28, 2016
8	Production of 4-hydroxybenzoate by *Corynebacterium glutamicum*	Kazumi Hiraga, Ryoma Hashimoto, Yukihiro Kitade, Masako Suda, Masayuki Inui	The 2016 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 28, 2016
9	Analysis of *pfkB1* deletion in *Corynebacterium glutamicum* that resulted in considerably increase in glucose consumption and which use for production of useful chemicals	Satoshi Hasegawa, Yuya Tanaka, Masako Suda, Toru Jojima, Masayuki Inui	The 2016 Annual Meeting of Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 28, 2016
10	Glucose consumption rate critically depends on redox state in *Corynebacterium glutamicum* under oxygen deprivation	Yota Tsuge, Kimio Uematsu, Shogo Yamamoto, Masako Suda, Masayuki Inui	68th SBJ Annual Meeting, Sep. 28, 2016
11	The transcriptional regulatory mechanism of the *ldhA* gene encoding lactate dehydrogenase in *Corynebacterium glutamicum*	Koichi Toyoda, Masayuki Inui	68th SBJ Annual Meeting, Sep. 30, 2016
12	Production of *para*-aminobenzoic acid by metabolically engineered *Corynebacterium glutamicum*	Takeshi Kubota, Akira Watanabe, Masako Suda, Takahisa Kogure, Kazumi Hiraga, Masayuki Inui	68th SBJ Annual Meeting, Sep. 30, 2016
13	Participation of protein factors in riboswitch based gene regulation in bacteria	Norihiko Takemoto, Shinya Watanabe, Yuya Tanaka, Masayuki Inui, Tohru Miyoshi-Akiyama	The 39th Annual Meeting of The Molecular Biology Society of Japan, Dec. 1, 2016

Other Oral Presentaion and Non-Journal Publication

	Title	Researchers	Magazin, Newspaper, etc.
1	Development of production process for green aromatic chemicals	Masayuki Inui	The 11th Conference on Biomass Science, Jan. 21, 2016
2	1st Laboratory visit, Revolution in chemical industry, Production of aromatic compounds by microorganisms	—	Nikkei Biotech ONLINE, Feb. 1, 2016

Molecular Microbiology and Biotechnology Group

	Title	Researchers	Magazin, Newspaper, etc.
3	Bioproduction of valuable aromatic chemicals by Coryneform bacteria -Phenol production from non-food biomass-	Kazumi Hiraga	The 36th public meeting of the biotechnical seeds, Feb. 9, 2016
4	Production of biofuels and green chemicals from non-food biomass	Masayuki Inui	Symposium by Research Center for Thermotolerant Microbial Resources of Yamaguchi University, Mar. 4, 2016
5	Trend and efforts to practical use for biorefinery technology	Masayuki Inui	GREEN FORUM21, Jul. 4, 2016
6	Bioproduction of phenol and various kinds of chemicals indispensable for automobile resin parts -Social application of RITE bioprocess-	Kazumi Hiraga	Workshop of "Biotechniques in the future" "All kinds of flowers profusion for biomaterials 9" -eco-innovation for containers, packaging, and distribution-, Jul. 14, 2016
7	Production of biofuels and green chemicals from non-food biomass by a growth-arrested bioprocess	Masayuki Inui	Congreso de Microbiologia Industrialy Biotecnologia Microbiana 2016, Sep. 12, 2016
8	MASAYUKI INUI Instituto de innovación tecnológica de Japón «Japón introducirá biocombustible en la flota aérea»	Masayuki Inui	DIARIO DE LEÓN ONLINE, Sep. 13, 2016
9	Present status and future prospects of biofuels and green chemicals production from non-food biomass	Masayuki Inui	Hiroshima Fermentation Association, 2016 general meeting, Oct. 29, 2016

Chemical Research Group

Original Paper

	Title	Researchers	Journal
1	Highly efficient post-combustion CO_2 capture by low-temperature steam-aided vacuum swing adsorption using a novel polyamine-based solid sorbent	Junpei Fujiki, Firoz A. Chowdhury, Hidetaka Yamada, Katsunori Yogo	Chemical Engineering Journal 307, 273-282 (2017)
2	Potential of Amine-based Solvents for Energy-saving CO_2 Capture from a Coal-fired Power Plant	Kazuya Goto, Firoz A. Chowdhury, Hidetaka Yamada, Takayuki Higashii	Journal of the Japan Institute of Energy 95, 1133-1141 (2016)
3	Comparison of Solvation Effects on CO_2 Capture with Aqueous Amine Solutions and Amine-Functionalized Ionic Liquids	Hidetaka Yamada	Journal of Physical Chemistry B 120, 10563-10568 (2016)"
4	Analysis of CO_2 absorption behavior of solid sorbent containing purified components of tetraethylenepentamine	Ryohei Numaguchi, Firoz Alam Chowdhury, Hidetaka Yamada, Katsunori Yogo	Energy Technology, published online (2016)
5	Sustainable Aspects of Ultimate Reduction of CO_2 in the Steelmaking Process (COURSE50 Project), Part 2: CO_2 Capture	Masami Onoda, Yoichi Matsuzaki, Firoz A. Chowdhury, Hidetaka Yamada, Kazuya Goto, Shigeaki Tonomura	Journal of Sustainable Metallurgy 2, 209-215 (2016)
6	Computational Chemistry Study on the Molecular Interactions for CO_2 Loaded Diethylene Glycol, Triethylene Glycol, and Diethylene Glycol Dimethyl Ether	Yukihiro Muraki, Ryo Nagumo, Hidetaka Yamada, Shuichi Iwata, Hideki Mori	Journal of the Japan Petroleum Institute 59, 211-218 (2016)
7	A Molecular Dynamics Simulation Study on CO_2 Physical Absorption Mechanisms for Ethylene Glycol-Based Solvents using Free Energy Calculations	Ryo Nagumo, Yukihiro Muraki, Shuichi Iwata, Hideki Mori, Hiromitsu Takaba, Hidetaka Yamada,	Industrial & Engineering Chemistry Research 55, 8200-8206 (2016)
8	Modeling of CO_2 Solubility in Tertiary Amine Solvents using pKa	Hiroshi Machida, Shin Yamamoto, Hidetaka Yamada	Journal of Chemical & Engineering Data 61, 2144-2148 (2016)
9	Optimization of a simple technique for preparation of monodisperse poly (lactide-co-glycolide) nanospheres	Fuminori Ito	Journal of Nanoparticle Research 18, 262-269 (2016)
10	Characteristics of OH production by O_2/H_2O pulsed dielectric barrier discharge	Shuiliang Yao, Shan Weng, Yi Tang, Chenwei Zhao, Zuliang Wu, Xuming Zhang, Shin Yamamoto, Satoshi Kodama	Vaccum 126, 16–23 (April 2016)

Oral Presentation

	Title	Researchers	Forum
1	Advanced CO_2 Capture Technologies at RITE (invited)	Takayuki Higashii	The 6th Korea CCS International Conference, Jeju, Korea 27-29 January 2016
2	Chemically Tunable Ionic Liquid-Amine Solutions for CO_2 Capture	Firoz A. Chowdhury, Tsuguhiro Kato	The 6th Korea CCS International Conference, Jeju, Korea 27-29 January 2016
3	Effect of Carbonic Anhydrase on CO_2 Separation Properties of Poly (amidoamine) Dendrimer/Poly (ethylene glycol) Hybrid Membranes	Teruhiko Kai, Shuhong Duan, Ikuo Taniguchi, Shingo Kazama	The 10th Coference of Aseanian Membrane Society (AMS10),Nara, Japan 26-29 July 2016

Chemical Research Group

	Title	Researchers	Forum
4	Molecular Dynamics Study on CO_2 Solution-Diffusion Mechanisms in Ethylene Glycol-Based Materials	Yukihiro Muraki, Ryo Nagumo, Hidetaka Yamada, Shuichi Iwata, Hideki Mori	The 10th Coference of Aseanian Membrane Society (AMS10),Nara, Japan 26-29 July 2016
5	Calorimetric Study of Absorption of CO_2 in Amine-Based Solvents	Hidetaka Yamada	22nd International Congress of Chemical and Process Engineering,Prague, Czech Republic 27-31 August 2016
6	Development of Novel Amine Solid Sorbents for Post-Combustion CO_2 Capture	Hidetaka Yamada, Junpei Fujiki, Ryohei Numaguchi, Koji Kida, Firoz A. Chowdhury, Kazuya Goto, Katsunori Yogo	11th European Conference on Coal Research and its Applications, Sheffield, UK 5-7 September 2016
7	Influence of Post-combustion CO_2 Capture on Energy performance of a Thermal Power Plant	Kazuya Goto	ASCON-IEEChE 2016,Yokohama, Japan 13-16 November 2016
8	Cost study of high-pressure CO_2 capture processes	Takashi Nakamoto, Yusuke Waratani, Toshinori Muraoka, Shin Yamamoto, Tsuguhiro Kato	ASCON-IEEChE 2016,Yokohama, Japan 13-16 November 2016
9	Development of Post-Combustion CO_2 Capture System Using Amine-Impregnated Solid Sorbent	Ryohei Numaguchi, Junpei Fujiki, Hidetaka Yamada, Firoz A. Chowdhury, Koji Kida, Kazuya Goto, Takeshi Okumura, Katsuhiro Yoshizawa, Katsunori Yogo	13th Conference on Greenhouse Gas Control Technologies(GHGT-13), Lausanne, Switzerland 14-18 November 2016
10	Development of CO_2 molecular gate membrane for IGCC process with CO_2 capture	Teruhiko Kai, Shuhong Duan, Fuminori Ito, Satoshi Mikami, Yoshinobu Sato, Shin-ichi Nakano	13th Conference on Greenhouse Gas Control Technologies(GHGT-13), Lausanne, Switzerland 14-18 November 2016
11	Development of Chemical CO_2 Solvent for High-Pressure CO_2 Capture (3) : Analyses on Absorbed Form of CO_2	Shin Yamamoto, Hidetaka Yamada, Mitsuhiro Kanakubo, Tsuguhiro Kato	13th Conference on Greenhouse Gas Control Technologies(GHGT-13), Lausanne, Switzerland 14-18 November 2016
12	Results of RITE's Advanced Liquid Absorbents Develop for Low Temperature CO_2 Capture	Firoz A. Chowdhury, Kazuya Goto, Hidetaka Yamada, Yoichi Matsuzaki, Shin Yamamoto, Takayuki Higashii, Masami Onoda	13th Conference on Greenhouse Gas Control Technologies(GHGT-13), Lausanne, Switzerland 14-18 November 2016

Other Oral Presentation and Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Recent Activity of ISO/TC265/WG1 on Capture (invited)	Takayuki Higashii	2016 CSLF Annual Meeting in Tokyo, Japan Technical Group Meeting October 4, 2016
2	Results from CSLF-recognized Project: CO_2 Separation from Pressurized Gas (invited)	Shin-ichi Nakao	2016 CSLF Annual Meeting in Tokyo, Japan Technical Group Meeting October 4, 2016
3	Development of CO_2 Capture Technology by Chemical Absorption System	Kazuya Goto	2016 CSLF Annual Meeting in Tokyo, Japan Technical Workshop October 5, 2016
4	Development of Molecular Gate Membrane for CO_2 Capture CSLF Project: CO_2 Separation from Pressurized Gas Stream	Teruhiko Kai	2016 CSLF Annual Meeting in Tokyo, Japan Technical Workshop October 5, 2016
5	Advanced Development of CO_2 Capture by Solid Sorbents	Junpei Fujiki	2016 CSLF Annual Meeting in Tokyo, Japan Technical Workshop October 5, 2016

CO_2 Storage Research Group

Original Paper

	Title	Researchers	Journal
1	A novel high-pressure vessel for simultaneous observations of seismic velocity and in situ CO_2 distribution in a porous rock using a medical X-ray CT scanner	Lanlan Jiang, Osamu Nishizawa, Yi Zhang, Hyuck Park, Ziqiu Xue	Journal of Applied Geophysics 135, 67-76, 2016
2	Observation of Cement/Sandstone Interface after Reaction with Supercritical CO_2 using SEM-EDS, μ-XRD, and μ-Raman Spectroscopy	Kazuhiko Nakano, Saeko Mito, Ziqiu Xue, Atsushi Ohbuchi	e-Journal of Surface Science and Nanotechnology, 14, 198-203, 2016
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, in print

CO_2 Storage Research Group

4	Evaluation of mineral reactive surface area estimates for prediction of reactivity of a multi-mineral sediment	Beckingham, L.E., Mitnick, E.H., Steefel, C.I., Zhang, S., Voltolini, M., Swift, A.M., Yang, L., Cole, D.R., Sheets, J.M., Ajo-Franklin, J.B., DePaolo, D.J., Mito, S., Xue, Z.	Geochimica et Cosmochimica Acta, 188, 310-329, 2016
5	Evaluation of accessible mineral surface areas for improved prediction of mineral reaction rates in porous media	Lauren E. Beckingham, 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 J DePaolo, Saeko Mito, Ziqiu Xue	Geochimica et Cosmochimica Acta, Submitted
6	Rock physics research with application to CO_2 geological storage II: relationship between CO_2 saturation and P-wave velocity in a porous sandstone.	Osamu Nishizawa, Yi Zhang, Ziqiu Xue	BUTSURI-TANSA, 69, 3, 5, p195-214, 2016
7	Depositional environments and characteristics of grain size and pore-throat size distributions of CO_2 storage aquifer as a controlling factor of injectivity: a case study of the Nagaoka site, Japan	Takuma Ito, Takahiro Nakajima, Ziqiu Xue	Journal of Sedimentological Society of Japan, 75,3-15, 2016
8	Rock physics research with application to CO_2 geological storage I: CO_2 behavior in capillary-dominated region and effects of multi-scale heterogeneity on CO_2 trapping	Osamu Nishizawa, Yi Zhang, Takuma Ito, Ziqiu Xue, Tetsuya Kogure, Tamotsu Kiyama	BUTSURI-TANSA, 69, 127-147, 2016
9	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	Adv. X-Ray. Chem. Anal., Japan, submitted
10	Effects of fluid displacement pattern on complex electrical impedance in Berea sandstone over frequency range 10000–1000000 Hz	Yi Zhang, Hyuck Park, Osamu Nishizawa, Tamotsu Kiyama, Yu Liu, Kwangseok Chae, Ziqiu Xue	Geophysical Prospecting, DOI: 10.1111/1365-2478.12451
11	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
12	Identification of natural gamma-ray source in shallow-marine siliciclastic strata and its significance for assessing reservoir quality: 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. submitted
13	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
14	Pathway-flow relative permeability of CO_2: measurement by lowering pressure drop	Yi Zhang, Osamu Nishizawa, Hyuck Park, Ziqiu Xue	Water Resource Research. Submitted
15	Optical fiber sensing the deformation of rock caused by fluid front migration	Yi Zhang, Ziqiu Xue, Hyuck Park, Tamotsu Kiyama,	Nature Geoscience, submitted
16	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, submitted
17	Active acoustic sonar detectability of gas bubbles on shallow seafloor for environmental monitoring at offshore CO_2 storage sites	Takamichi Nakamura, Keisuke Uchimoto, Makoto Nishimura, Yuji Watanabe, Ziqiu Xue	International Journal of Greenhouse Gas Control, submitted

Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Trapping mechanism of CO_2 storage	Saeko Mito	Electrical Review, Jun 2016
2	CO_2 fixation technology	Ziqiu Xue	Journal of Environmental coservation engineering, 45, 4, 2016
3	Simulation of leaked CO_2 in the sea for marine environmental impact assessment	Keisuke Uchimoto	Electrical Review, Jun 2016
4	Geological storage of CO_2 and deep biosphere, geomicrobiology	Takamichi Nakamura	Electrical Review, Jul 2016

CO_2 Storage Research Group

Oral Presentation (International Conference)

	Title	Researchers	Forum
1	Tomakomai demonstration project, Japan and its collaboration opportunities	Jun Kita	British Geological Survey(BGC) Keyworth. Mar 2, 2016
2	Nagaoka Project, Japan, and its collaboration opportunities	Ryozo Tanaka	International Workshop on Offshore Geological CO_2 Storage. Apr 19, 2016
3	How to reach an offshore injection phase, Japan case study	Ryozo Tanaka	International Workshop on Offshore Geological CO_2 Storage. Apr 19, 2016
4	How to do environmental monitoring offshore, Japan case study	Jun Kita	International Workshop on Offshore Geological CO_2 Storage. Apr 19, 2016
5	A reactive transport modelling at the Nagaoka pilot-scale CO_2 injection site	Saeko Mito, Ziqiu Xue	Goldschmidt2016, Jul 1, 2016
6	Experimental study on capillary trapping characteristics in porous media for CO_2 geological storage	Lanlan Jiang, Ziqiu Xue, Hyuck Park, Yongchen Song	AOGS(Asia Oceania Geoscience Society) meeting2016, Aug 2, 2016
7	1.Long-term sea water monitoring in coastal Japanese waters 2. Modelling marine impact	Jun Kita	Combined Meeting of the IEAGHG Modelling and Monitoring Networks, Jul 6, 2016
8	Optimization Study of Seismic Monitoring Network at the CO_2 Injection Site – Lessons Learnt from Monitoring Experiment at the Cranfield Site, Mississippi, U. S. A.	Makiko Takagishi, Tsutomu Hashimoto, Tetsuma Toshioka, Shigeo Horikawa, Kinichiro Kusunose, Ziqiu Xue, Susan D. Hovork	13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, Lausanne, Switzerland, Nov 17, 2016
9	Geological reservoir characterization and modeling of a CO_2 storage aquifer: A case study of the Nagaoka site, Japan	Takuma Ito, Takahiro Nakajima, Ziqiu Xue	13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, Lausanne, Switzerland, Nov 17, 2016
10	Trapping mechanisms in field scale: Results from Nagaoka geologic CO_2 storage site	Takahiro Nakajima, Ziqiu Xue	13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, Lausanne, Switzerland, Nov 17, 2016
11	Numerical simulation of the CO_2 behavior to obtain a detailed site characterization: A case study at Nagaoka pilot-scale injection site	Takahiro Nakajima, Takuma Ito, Ziqiu Xue	13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, Lausanne, Switzerland, Nov 17, 2016
12	A novel method to detect CO_2 leak in offshore storage: focusing on relationship between dissolved oxygen and partial pressure of CO_2 in the sea	Keisuke Uchimoto, Jun Kita, Ziqiu Xue	13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, Lausanne, Switzerland, Nov 17, 2016
13	Geomechanical monitoring of caprock and wellbore integrity using fiber optic cable: Strain measurement from the fluid injection and extraction field tests	Ziqiu Xue, Tsutomu Hashimoto	13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, Lausanne, Switzerland, Nov 17, 2016
14	Research and development of a permanent OBC system for time-lapse seismic survey and microseismic monitoring at the offshore CO_2 storage sites	Ziqiu Xue, Tetsuma Toshioka, Naoshi Aoki, Yoshiaki Kawabe, Daiji Tanase	13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, Lausanne, Switzerland, Nov 17, 2016
15	Self-sealing of wellbore cement under the CO_2 batch experiment using well composite sample	Kazuhiko Nakano, Saeko Mito, Ziqiu Xue	13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, Lausanne, Switzerland, Nov 17, 2016
16	Availability of a simplified coarse grid model for history matching at the Nagaoka post-injection CO_2 monitoring site	Saeko Mito, Ziqiu Xue	13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, Lausanne, Switzerland, Nov 17, 2016

Oral Presentation (Domestic Conference)

	Title	Researchers	Forum
1	Estimation of supercritical CO_2 threshold pressure by the mercury intrusion method and direct method	Tamotsu Kiyama, Ziqiu Xue	Japan Geoscience Union Meeting 2016, May 24,2016
2	Visualization and measurement of CO_2 flooding in heterogeneous sedimentary rock	Hyuck Park, Lanlan Jiang, Tamotsu Kiyama, Osamu Nishizawa, Yi Zhang, Ryo Ueda, Masanori Nakano, Ziqiu Xue	Japan Geoscience Union, May 24. 2016
3	An Experiment study on dynamic displacement and non-equilibrium dissolution for CO_2 in porous media	Lanlan Jiang, Ziqiu Xue, Hyuck Park,Yongchen Song	Japan Geoscience Union, May 24. 2016
4	Development of geological model using core-well-seismic integration technique at the Nagaoka CO_2 storage site, Japan	Takuma Ito, Takahiro Nakajima, Ziqiu Xue	Japan Geoscience Union, May 24. 2016
5	Simulation study on trapping processes of CO_2 at Nagaoka pilot project	Hajime Yamamoto, Takahiro Nakajima, Ziqiu Xue	Japan Geoscience Union, May 24. 2016
6	A study on seismic stability safety evaluation of the cap rock for geological CO_2 storage using non-linear dynamic response analysis	Shigeo Horikawa, Takeshi Sasaki, Naohide Takada, Tsutomu Hashimoto, Takahiro Nakajima, ZiqiuXue	Japan Geoscience Union, May 24. 2016

CO_2 Storage Research Group

	Title	Researchers	Forum
7	Construction of an integrated geological model characterized by a seismic survey data and chalibrated by log-based monitoring data: A case study at Nagaoka CO_2 injection site	Takahiro Nakajima, Takuma Ito, Ziqiu Xue, Shun Chiyonobu	Japan Geoscience Union, May 24. 2016
8	Numerical study mitigation of pressure build-up mitigation by production of formation water during CO_2 injection	CLAUDIA FUJITA, Yusuke Hiratsuka, Hajime Yamamoto, Takahiro Nakajima, Ziqiu Xue	Japan Geoscience Union, May 24. 2016
9	Development of acoustic methods for detection of CO_2 leakage from sub-seabed storage site	Takamichi Nakamura, Makoto Nishimura, Keisuke Uchimoto	Japan Geoscience Union, May 24. 2016
10	A numerical model for calculating the behavior of leaked CO_2 in the sea for assessing the potential impacts on the marine environment	Keisuke Uchimoto, Yoshimasa Matsumura, Jun Kita	Japan Geoscience Union, May 24. 2016
11	Application of Sequentially Discounting AR Learning (SDAR) Algorithm to Real-time Event Detection	Makiko Takagishi, Tetsuma Toshioka, Akira Narita, Nobuhiro Furuse, Ziqiu Xue	Japan Geoscience Union, May 24. 2016
12	Incentives for operational CCS projects in the World	Ryozo Tanaka	Japan Geoscience Union, May 24. 2016
13	Compilation of Best Practice Manuals toward CCS commercialization	Hironobu Komaki, Michimasa Magi, Atsushi Ibusuki, Osamu Takano, Ziqiu Xue	Japan Geoscience Union, May 24. 2016
14	Geomechanical monitoring of caprock and wellbore integrity using fiber optic cable	Ziqiu Xue,Tsutomu Hashimoto	Japan Geoscience Union, May 24. 2016
15	Simulation study on trapping processes at the Nagaoka geological CO_2 storage project	Hajime Yamamoto, Takahiro Nakajima, Ziqiu Xue	Japan Society of Civil Engineers 2016 Annual Meeting, Sep 8. 2016
16	Evaluation of pressure build-up at a geological CO_2 storage sites and study of pressure mitigation method	Craudia Fujita, Yusuke Hiratsuka, Hajime Yamamoto, Takahiro Nakajima, Ziqiu Xue	Japan Society of Civil Engineers 2016 Annual Meeting, Sep 8. 2016
17	Comparison between spectral gamma-ray and geo-chemical features of the shallow-marine siliciclastic strata: as a case study of the Nagaoka site, Japan	Takuma Ito, Kazuhiko Nakano, Atsushi Ohbuchi, Takahiro Nakajima, Ziqiu Xue	Geological Society of Japan, Sep 12. 2016
18	Preparation for inhomogeneous samples in XRF analysis	Hikari Takahara, Astushi Ohbuchi, Takao Moriyama, Kazuhiko Nakano and Kensuke Murai	The 52nd Annual Conference on X-Ray Chemical Analysis, Oct 27. 2016
19	Trial for modelling of microbial behavior that responded to elevated CO_2 in marine sediment	Takamichi Nakamura, Masaru Akiyama	2016 Japanese Society of Microbial Ecology annual meeting, Oct 23. 2016

Inorganic Membranes Research Center

Original Paper

	Title	Researchers	Journal
1	Preparation and gas permeation properties on pure silica CHA-type zeolite Membranes	Koji Kida, Yasushi Maeta, Katsunori Yogo	Journal of Membrane Science, Vol.522, pp.363-370,2017
2	Application of MFI Zeolite Membrane Prepared with Fluoride Ions to Hydrogen/Toluene Separation	Izumi Kumakiri, Lingfang Qiu, Bo Liu, Kazuhiro Tanaka, Hidetoshi Kita, Takashi Saito, Ryoichi Nishida	Journal of Chemical Engineering of Japan, Vol.49, No.8, pp.753-755, 2016

Oral Presentation

	Title	Researchers	Forum
1	Development of Practical Membrane Reactores for Dehydrogenating Methylcyclohexane to Supply High-purity Hydrogen	Ryoichi Nishida, Emi Matsuyama, Ryohei Numaguchi, Hiromi Urai, Shin-ichi Nakano	21th World Hydrogen Energy Conference 2016, June 14, 2016

Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Synthesis of MFI Zeolite Membranes in Fluoride Media and Their Applications for Hydrogen Separation	I.Kumakiri, L.Qui, B.Liu, K.Tanaka, H. Kita, T.Saito, R.Nishida	The 10th Conference of Aseanian Membrane Society, July 27, 2016

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