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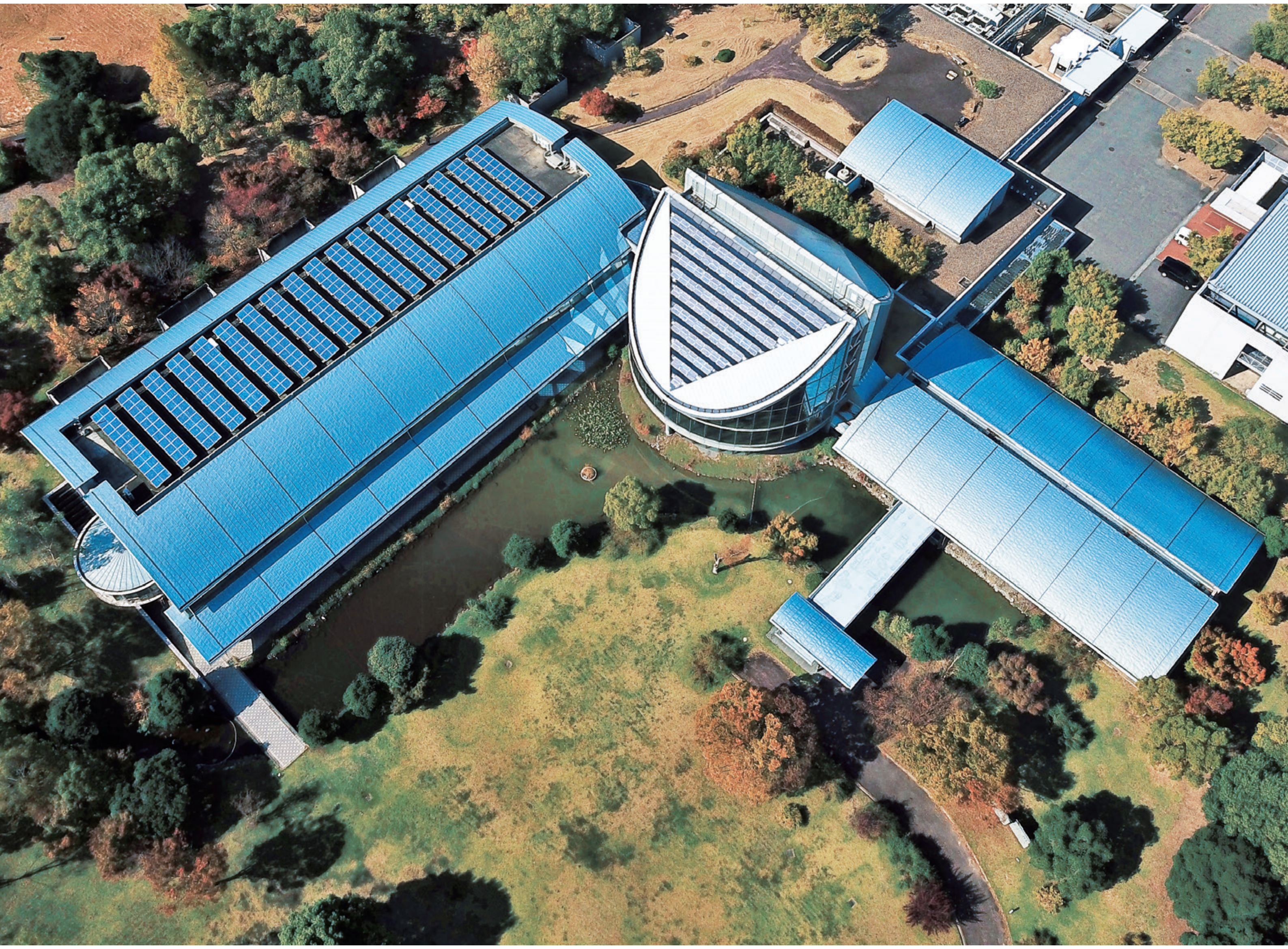
2019 Vol.14

RITE Today
Annual Report

Research Institute of Innovative Technology for the Earth



RITE Today 2019 Vol.14

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Achievements and Expected Role of RITE for Mitigating Climate Change

Nebojsa Nakicenovic
Deputy Director General/CEO,
International Institute for Applied Systems Analysis (IIASA)

I often think of the wonderful and productive time I spent at RITE back in 1993. My privilege was to be one of the first scientists at RITE. The science centre was still a greenfield, but RITE stood there with very innovative architecture and technology for keeping the earth cool. This included the lake around and below the building, the natural-gas fuel cell and many photovoltaic arrays. What remains in my memory were the CO_2 measurement meters in every meeting room. The research portfolio matched the innovative working environment and ranged from carbon dioxide separation from flue gases by membranes to modelling of techno-economic systems and possible response strategies to climate change.

The close collaboration between RITE and IIASA started with my stay and was followed by many colleagues from RITE working and visiting IIASA as well as IIASA colleagues spending extended periods at RITE.

In the meantime, RITE developed into one of the leading research institutes worldwide working on technological solutions and strategies for averting global climate change, undoubtfully a major challenge facing humanity twenty-five years ago and today. RITE has developed a large-scale integrated modelling approach for assessing global, regional and Japanese options and policies for mitigating and adapting to climate change. This work is highly valued in Japan and internationally. RITE is one of the key modelling teams to produce stabilization scenarios used by IPCC in its assessments. The high recognition is also reflected in seminal contributions to IPCC, Integrated Assessment Modelling Consortium and many other national and international activities. I am proud to have been a part of the establishment of RITE and devoted follower of its contributions and achievements.

There are too many achievements to list them all here. However, I do want to specially highlight two close to my own work.

A land mark in RITE contributions is the famous Kaya-Identity, which is the key for understanding emissions and it main component drivers including population, economic development and energy.

ALPS is another very important initiative to which my colleagues from IIASA have also contributed over the years since its inception. I was very privileged to be able to participate in all ALPS International Symposia organized by RITE to present findings.

I am writing these words as the COP24 in Katowice just started. The hope many have for the outcome is that the Paris Agreement can be reaffirmed with clear commitments. This is very difficult given that the global emissions are still increasing, at estimated 2.7% last year, while they need to be halved every decade to approach net-zero mid-century if the stabilization well below 2℃ is to be achieved. This means from about 40 billion tons of CO_2 in 2020, down to 20 in 2030, 10 in 2040 and so on. This means nothing less than a truly transformational change and would require a Herculean effort in diffusion of new carbon saving technologies, infrastructures, institutions and human behaviours. Consequently, world needs research institutes like RITE that can rise to this unprecedented challenge with new solutions and ways forward to avert climate change while securing further development.

Perspectives on IPCC Special Report "Global Warming of 1.5℃"

Mitsutsune Yamaguchi
Special Advisor

1. Origin of the Special Report 1.5℃

On October 8, 2018, IPCC (The Intergovernmental Panel on Climate Change) released its Special Report "Global Warming of 1.5℃" (SR1.5) as a response to the invitation for IPCC "... to provide a Special Report in 2018 on the impacts of global warming of 1.5℃ above pre-industrial levels and related global greenhouse gas emission pathways" contained in the Decision of the 21st Conference of Parties of the United Nations Framework Convention on Climate Change (COP) held in Paris in 2015. The IPCC accepted this invitation in April the next year, and its first lead authors' meeting was held in March 2017. SR1.5 was completed within 2 years. First of all, the author of this short paper truly appreciates all coordinating lead authors, lead authors, reviewers and all the persons involved in writing process for their devoted efforts in completing the report in such a short period.

2. Summary of SR1.5

2.1. Structure of SR1.5

SR1.5 consists of a Summary for Policymakers (SPM) and 5 chapters. Here the author focuses on the SPM, while touching upon 5 chapters as necessary. The titles of 5 chapters are as follows;

Chapter 1 Framing and Context
Chapter 2 Mitigation pathways compatible with 1.5℃ in the context of sustainable development
Chapter 3 Impacts of 1.5℃ global warming on natural and human systems
Chapter 4 Strengthening and implementing the global response
Chapter 5 Sustainable Development, Poverty Eradication and Reducing Inequalities

2.2. Outline of SPM

The SPM consists of 4 sections. Sections A, B, C and D each corresponding to a summary of chapters 1, 3, 2, and 4-5.

Section A. Understanding Global Warming of 1.5℃

This section mainly deals with climate science. The main messages are that the temperature has increased by around 1.0℃ since 1850-1900 period and that without further mitigation measures, temperature will likely to increase by 1.5℃ between 2030 and 2052.

So far the base year of temperature increase was set at the pre-industrialization era without any clear definition of what year it is. In SR1.5, the base year is defined as 1850-1900 period. Also, GMST (Global Mean Surface Temperature) is defined as the estimated global average of near-surface air temperature over land and the surface temperature over ice-free ocean regions. When estimating changes in GMST, however, near-surface air temperature over both land and oceans (Surface Air Temperature, SAT) are also used.

Section B. Projected Climate Change, Potential Impacts and Associated Risks

This section addresses "the impacts of global warming of 1.5℃ above the pre-industrial levels" as requested by the COP decision. The conclusion is quite simple, i.e. impacts and risks are smaller in a 1.5℃ increase case than in a 2℃ increase case. For example, the rise in sea level the year 2100 (since 1986-2005) in a 1.5℃ case will be 26-77 cm, and 10

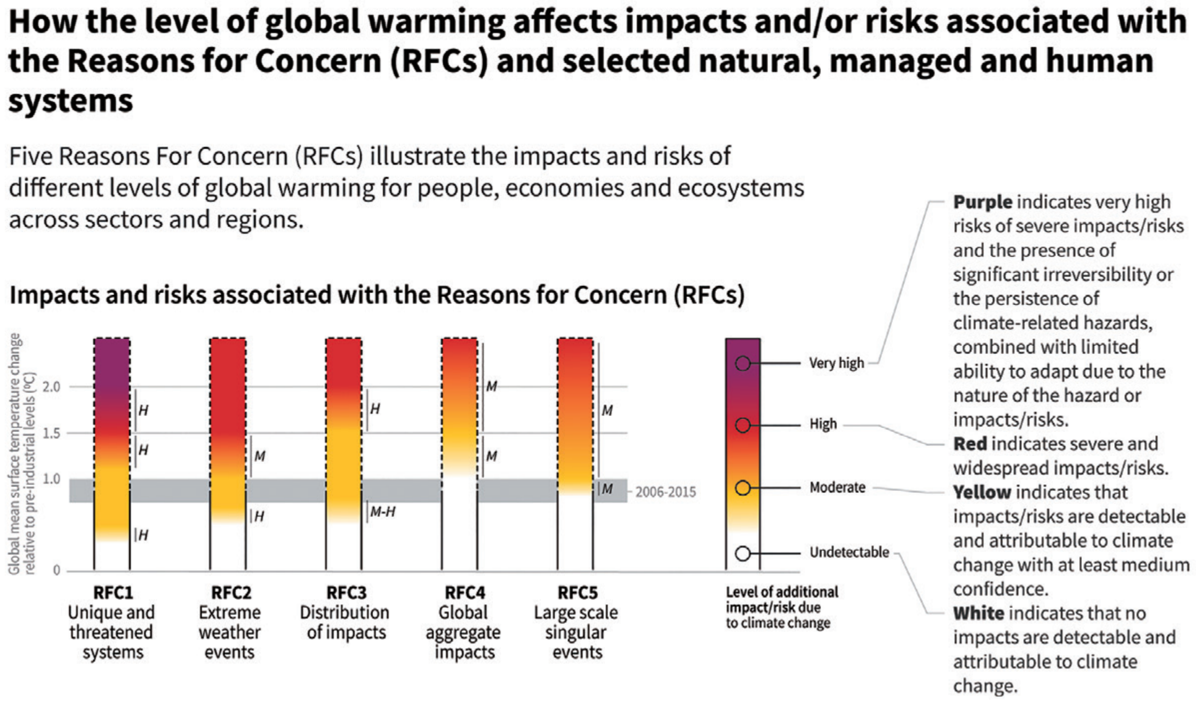


Figure 1 : Five Reasons For Concern (RFC)
Source: IPCC SR1.5 Figure SPM.2
Due to space limitations, only RFC Figure in SR1.5 has been shown here.

cm lower than in a 2℃ case, ice-free ocean in the Arctic sea during summer will occur once in every 100 years in a 1.5℃ case whereas it will occur once every 10 years in a 2℃ warmer world, and 70-90% of the coral reefs will disappear in a 1.5℃ case but more than 99% in a 2℃ case.

Besides, there is another important point that should not be ignored. In SR1.5, Reasons for Concerns (RFCs), that was shown in 5th Assessment Report (AR5), is also presented (Refer to Figure 1 above).

When we compare the above figure with that in AR5 (not shown due to space constraint), there is an important difference especially in RFC5, namely large-scale singular events. In chapter 3 of SR1.5, there is a description that "moderate risk is now located at 1℃ of global warming and high risk is located at 2.5℃ of global warming, as opposed to at 1.6℃ (moderate risk) and around 4℃ (high risk) in AR5, because of new observations and models of the West Antarctic ice sheet". As RCF5 is considered as imposing large scale and irreversible global impact, and as an increase in the global sea level by 6-9 m is expected if either the Greenland or West Antarctic ice sheet collapses, such information should be included in the SPM.

Section C. Emission Pathways and System Transitions Consistent with 1.5℃ Global Warming

This section includes responses to the request by the COP to provide global greenhouse gas emission pathways consistent with a 1.5℃ warmer world. There are 2 key observations that are discussed. Figure 2 represents the emission pathways modeled to maintain the temperature increase at 1.5℃ or less by the year 2100. Please focus on the global total net CO_2 emissions (the main panel). Two scenarios are shown: one pathway has no or limited overshoot (less than 0.1℃), while the other pathway has a higher overshoot. At the bottom of the figure, timing of net zero CO_2 line is illustrated. It implies that to achieve 1.5℃ goal, the net CO_2 emissions should be reduced by about 45% from 2010 levels by year 2030 and become zero around 2045-2060 and thereafter emissions should be negative. Just think of current pledges towards 2030 (NDCs) under which the global 2030 emissions are expected to increase (not decrease) from 2010, it is rather clear that 1.5℃ will be extremely hard to achieve.

Figure 3 (below) shows 4 different socio-economic development models (P1-P4) and emission pathways toward achieving the 1.5℃ goal. P1 illustrates a low emission demand society (LED), P2; a sustainable development society, P3; middle of the road, P4; fossil-fueled development society. Business as usual, emissions become larger from P1 to P4. The green lines for P1-P4 illustrate the net CO_2 emission pathways to achieve the 1.5℃ goal in the respective socio-economic society. The grey area represents the CO_2 emissions from fossil fuel use and industrial processes. The brown area represents CO_2 absorption by AFOLU (Agriculture, Forestry and Other Land Use) while the yellow area represents BECCS (bio-energy with carbon capture and storage). BECCS is considered to be a negative emission technology, whereas AFOLU could be negative or positive. As illustrated in Figure 3, if we follow the P4 model, we have to rely upon massive negative emissions by BECCS to achieve the 1.5℃ goal. On the other hand, if we follow the P1 model, it may be possible to achieve the goal with small nega-

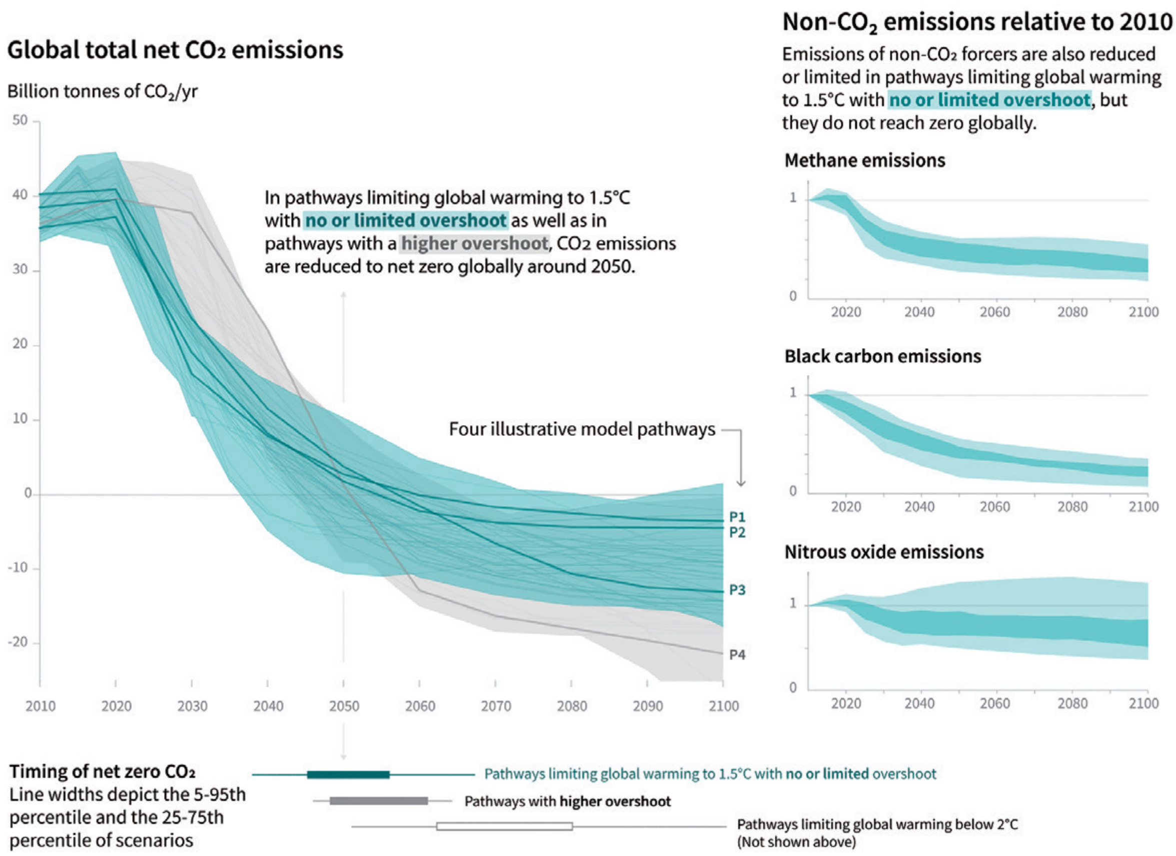


Figure 2 : Global emissions pathways consistent with 1.5℃ warmer world
Source: IPCC SR1.5 Figure SPM.3a

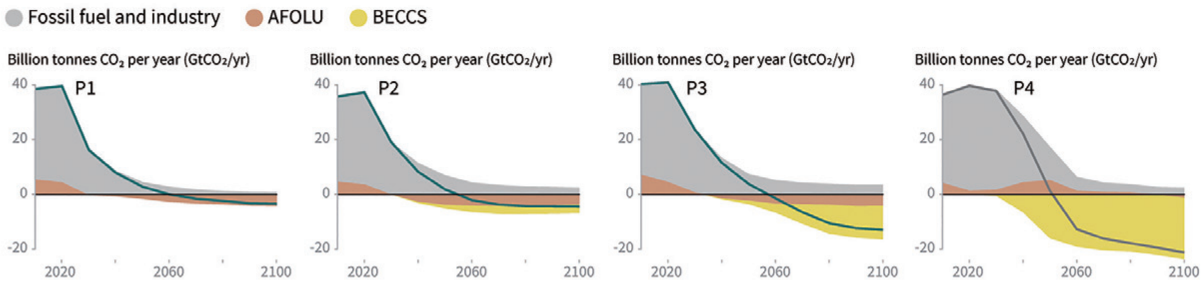


Figure 3 : Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways
Source: IPCC SR1.5 Figure SPM.3b

tive emissions by AFOLU. Thus, what kind of socio-economic society we should aim at is the key in our choice of a development model.

Section D. Strengthening the Global Response in the Context of Sustainable Development and Efforts to Eradicate Poverty

The most important message here is that current pledges, even if fully implemented, are never enough to keep temperature increase below 1.5℃. In other words, it is almost impossible to achieve the 1.5℃ goal unless each party drastically strengthen their pledges toward 2030.

This section summarizes chapters 4 and 5, which contain several statements with major implications for the implementation of climate policies, such as "whatever its potential long-term benefits, a transition to a 1.5℃ world may suffer from a lack of broad political and public support, if it exacerbates existing short-term economic and social tensions, including unemployment, … competitiveness issues …". Regrettably, this sentence does not appear in the SPM.

SR1.5 is the first IPCC report that has directly addressed the relationships between climate change and other Sustainable Development Goals (SDGs). Since literatures are quite limited and the scope is broad, the report was short of success at this point. Though SDGs have no priority among 17 goals, it is impossible for policymakers to pursue all those goals to the same extent. Policymakers may be indecisive to what extent they should put limited resources to climate change mitigation.

3. Evaluation of SR1.5

The efforts of the authors in completing the assessment report through extensive literature review within a short period in response to the COP invitation are commendable. SR1.5 surely would be referred to in future as one of the most reliable reports on climate change policy-makings. However, there are a few issues that lack in the report (such as mitigation cost) or that should be stressed a little bit more (such as uncertainty). The following are the author's personal comments on these issues.

3.1. Lack of information of economic cost

The SR1.5 report analyzed and showed in detail on how negative impacts and losses could be minimized if we were to succeed in limiting temperature increase at 1.5℃ instead of 2℃. From the report, it is evident that we should aim at 1.5℃, assuming all other factors are the same. For policymakers, it is impossible to make decision, however, without knowing economic cost (GDP loss or consumption loss). The report is silent on this critical point. If differences of mitigation costs were included, the report would be more *policy relevant*.

Remember that cost information was not included in COP's request to IPCC. Negotiators at COP in Paris may not have thought of the critical importance of cost information. Even in that case, however, SR1.5 should have included the cost information. SR1.5 cites the reason as "the literature on total mitigation cost of 1.5℃ mitigation pathways is limited and was not assessed". Even if the literature was limited, the cost information (more concretely, how many models calculated mitigation cost per GDP and the range of them) could have been included in the SPM. This may benefit the policymakers. In chapter 2 of SR1.5, there are 90 pathways for 1.5℃ (Table 2.1 of SR1.5). Readers may wonder how many among them have mitigation costs figures. In fact, several governments insisted in vain on the importance of including total mitigation costs in the report at the last-minute Governments Review meeting.

In this regard, the author would like to draw readers' attention to the fact that total mitigation costs are clearly mentioned in both the IPCC AR5 Synthesis and SPM of Working Group 3 reports. For example, the mitigation cost (reduction in consumption relative to baseline) in 2100 for 2℃ is estimated to be 4.8% (2.9-11.4%) of consumption, and reduction in the annual consumption growth rate is estimated to be 0.06%. This is based on the assumption that all parties adopt mitigation measures immediately and a global uniform carbon tax would be introduced, i.e. an idealistic assumption. In the AR5, additional costs in a non-idealistic assumption are also shown. One example is the case of lack of technologies. If CCS technology is not commercially available, then the mitigation cost will increase by 2.4 times as compared to a situation when this technology becomes available. All these descriptions indicate that the IPCC lead authors have considered the economic cost as one of the critical pieces of information for the IPCC report to be policy relevant.

SR1.5 SPM illustrates without showing numerical figures that marginal abatement cost (MAC) for 1.5℃ will be 3-4 times higher than that for 2℃. For policymakers, this information is meaningless. The MAC is the cost of abating an additional ton of CO_2 to reach the goals and is completely different from the concept of the total economic cost. The MAC for 1.5℃ is equivalent to the global carbon tax to achieve the 1.5℃ goal. In this sense, the MAC is a useful information for policymakers for their decision. Chapter 2 describes the MAC for 1.5℃. The MAC ranges for achieving the goal without overshoot are $135-6050 in 2030 and $690-30100 in 2100 (before discounting). While the ranges seem wide, including such information in the SPM may be useful for policymakers as opposed to having no numerical basis at all.

3.2. Efficient allocation of scarce resources and cost benefit analysis

SR1.5 SPM simply explains that cost-benefit analysis (CBA) for the 1.5℃ goal has not been conducted due to knowledge gaps. From chapters 1 and 2, however, it is evident that the lead authors are rather negative to apply CBA to climate change issues. The main reasons are as follows. First, it is difficult to estimate the non-market loss such as a monetary value of human life. Second, even if the total benefits exceed the total cost, these would not necessarily be the same in all the regions or countries. Third, we tend to rely on value judgement when applying the discount rates to calculate the current value of avoided damages (benefits). All of these are reasonable criticisms against CBA. William Nordhaus, the 2018 Nobel laureate in economics, while fully acknowledging those challenges, argues that rather than abandoning CBA, "natural and social scientists need to develop the research base for climate science and economics substantially to refine our estimates of the SCC"[1]. Here SCC (social cost of carbon) is similar to the monetary value of avoided climate damages. The author of this short article shares the same view.

CBA is not only a useful tool to decide the extent of introducing the mitigation measures, but also useful to allocate scarce resources efficiently among important global issues such as SDGs. Numerous urgent global and domestic issues exist in the world but resources to cope with them are scarce and limited. In some countries people suffer from poverty, inequality, and in other countries, budget deficit and unemployment will be the major concern in addition to climate change. For policymakers of all countries, CBA could be the most useful tool for the efficient allocation of global and domestic resources. CBA has many shortcomings as described above but receives too little attention. In view of the fact that climate change is not the sole issue in the world, we should pay a little bit more attention to the CBA and try to overcome the shortcomings of this tool.

3.3. Uncertainty (carbon budget etc.) and Risk Management

Given the near linear relationship between cumulative CO_2 emissions and temperature increase, the concept of carbon budget was introduced. Carbon budget is defined as the cumulative CO_2 emissions to limit the temperature at a certain level. In the AR5, the remaining carbon budget since 2011 to limit the temperature increase at 1.5℃ (66% probability) was estimated at 400 $GtCO_2$ (Table 2.2 in the synthesis report). Since emissions during the 2011-2017 period was estimated at 290 $GtCO_2$, the remaining budget should have been 110 $GtCO_2$. According to the SPM of the SR1.5, the remaining carbon budget is estimated at 420 $GtCO_2$ (SAT) and 570 $GtCO_2$ (GMST), respectively. Carbon budget in the AR5 was estimated using the SAT method in climate modeling. This implies an increase in the SR1.5 carbon budget (SAT) by 310 (difference between 420 and 110) Gt, and an increase in the remaining 150 (difference between 570 and 420) $GtCO_2$ is due to the difference in methodology (SAT vs. GMST).

The fact that the carbon budget has rapidly increased in a short period between AR5 (2013) and SR1.5 (2018) signals another change likely in IPCC AR6 report to be published in 2021. Also, the carbon budget in SR1.5 does not include the effect of possible feedback from the earth system, such as the CO_2 and CH_4 release from permafrost thawing. These events could contribute to reductions in the budget.

In addition to the carbon budget, there are other uncertainties in climate science. Equilibrium climate sensitivity (temperature increase following a doubling of the atmospheric CO_2) has remained unchanged since AR5 and has been assessed to be in the 1.5℃ to 4.5℃ range, with a three-times spread. It is impossible, therefore, to predict the extent of temperature increase for the same CO_2 concentration. Furthermore, CO_2 emissions and mitigation pathways are expected to differ substantially depending on the type of socio-economic developments occurring in future as described earlier. Technology development and availability is also one of critical uncertainties. In view of these uncertainties, the author believes that coping with climate change is a risk management issue under uncertainties and that we should be flexible to respond to new scientific findings. Fixing our goal and making a headlong rush to attain certain temperature target will not be effective in a long run.

4. Concluding remarks

Based on the current situation, one point is quite clear. Continuous emission of CO_2 certainly contributes to the increase in the surface temperature of the earth due to long life time of CO_2, and temperature continues to increase and never stabilizes. It is vital that we avoid such a situation. We must aim for zero CO_2 emissions in the long run, a paradigm shift from temperature target. All efforts should be focused on this purpose, including zero emission technology developments in all sectors of our economy.

1 Nordhaus, W.D., 2017: Revisiting the social cost of carbon. *Proceedings of the National Academy of Sciences*, **114(7)**, 1518-1523, doi:10.1073/pnas.1609244114.

Industrialization of RITE Bioprocess

Each research group at RITE is addressing the research and development of new technologies for reducing greenhouse gas emissions. As COE on the mitigation of global warming, it is an important mission for RITE to industrialize our technologies in collaboration with industry, government, and academic institutions around the world, through government and other publicly funded projects, by collaborative research with institutions and private companies around the world, and through activities with technology research associations. In this section, two examples of the industrialization of RITE's technologies in the field of biotechnology will be introduced.

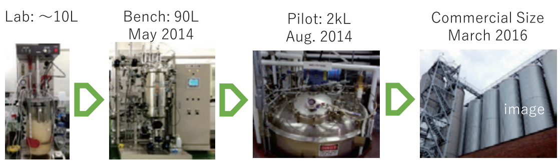
1. Green Earth Institute Co., Ltd. (GEI)

(Headquarters: Bunkyo-ku, TOKYO, Laboratory: Kisarazu-shi, CHIBA)

The Green Earth Institute Co., Ltd. was established on September 1, 2011, for the early industrialization of RITE's biorefinery technology using a highly efficient process called the RITE Bioprocess, which was developed by RITE. GEI has developed technologies for scaling up, using strains developed by RITE, that enable the highly efficient production of biofuels, such as ethanol and butanol, as well as other useful substances, such as amino acids. GEI scaled up cultivation and bioconversion processes from lab scale (1 L) to bench scale (90 L) in May 2014, to pilot scale (2 kL) in August 2014, and succeeded in the production of amino acids using a large-scale reactor of commercial size in March 2016. Now, through licensing agreements with companies both in Japan and overseas, production of amino acids has advanced to the commercial stage.

Biojet fuel made from non-food biomass as a raw material is expected to contribute to solving the global

Scaling up RITE Bioprocess from lab to commercial size



Source: GEI Website, partly modified

warming problem without causing food shortages. GEI participates in the Japan Airlines Co., Ltd. (JAL) project "Let's fly with 100,000 used clothes!" In this project, GEI is responsible for the production of isobutanol from cotton fibers in used clothes using the RITE Bioprocess, and for producing biojet fuel conforming to international standard ASTM D7566 Annex5.

2. Green Chemicals Co., Ltd. (GCC)

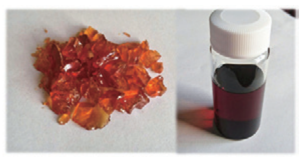
(Headquarters & Kyoto Site: Kizugawa-shi, KYOTO, Shizuoka Site: Fujieda-shi, SHIZUOKA)

RITE and Sumitomo Bakelite Co., Ltd. founded the Green Phenol Technology Research Association (GP Association) on February 15, 2010. The GP Association succeeded in developing a fundamental technology to produce "green" phenol from sugars, which was previously considered impossible, for the first time in the world. On May 27, 2014, the GP Association altered the structure of its organization to become a stock company, Green Phenol Development Co., Ltd. (GPD), to accelerate the industrialization of the biomass-based phenol-producing technology. With the aid of a NEDO grant, GPD completed an integrated production process, i.e., both the bioprocessing pilot plant and the facilities for the purification and concentration processes. Since phenol itself is extremely cytotoxic, phenol bioproduction was thought to be impossible. GP Association overcame this problem by developing a "Two-Step Bioprocess". The modulus of elasticity, bending strength, and tensile strength of "green" phenol molding parts are almost the same as for petroleum-derived products.

【Plant for bioconversion process】

【Plant for purification process】

【Green phenol resin】



【Molding parts made from green phenol】

Since the technology developed by GPD could also produce many other useful chemical compounds, GPD changed its trade name to Green Chemicals Co., Ltd. (GCC) on April 1, 2018. The targets of GCC are aromatic compounds, whose microbial production has been considered difficult due to their high cytotoxic effects on microbial host cells. GCC is making efforts to commercialize the production of the chemicals, which are in high demand in the market, such as functional resins, aromatic chemicals, and raw materials for medicines.

Green Earth Institute Co., Ltd.

Expanding a biorefinery business with domestic and foreign partner companies.


Chief Executive Officer
Tomohito Ihara

Green Earth Institute Co., Ltd. (GEI) was established on September 1, 2011 as a spin-off company from RITE (Research Institute of Innovative Technology for the Earth). We are continually working to commercialize the RITE Bioprocess®, a bio-refining process that was developed by RITE more than 20 years ago. In March 2016, in collaboration with RITE, we succeeded in producing the amino acid L-alanine on a commercial scale. Prior to that GEI had scaled up from lab scale to bench scale to pilot scale, while RITE improved the bacterial strains. The commercial-scale production presented some challenges we had not anticipated because it was the first trial of its kind in China. The GEI team overcame these challenges together with a researcher from RITE. I also visited the commercial plant over several days. I was very impressed when I saw the white crystallized product. Thus, it was proven that the RITE Bioprocess® is an innovative biorefinery process, and that it is a competitive technology on the market. In this sense, the achievement was very important for the RITE Bioprocess® as well as for GEI. Now, on the basis of this achievement, we are licensing this amino acid production technology not only in Japan but also in China and the U.S., and the amino acids produced by the RITE Bioprocess® have already been selling on the market.

Currently we develop not only amino acids but also biofuels and green chemicals, such as cosmetics materials with RITE. Through this development we have set out to transform petrorefinery into biorefinery. To achieve this goal, a commercially viable and sustainable business is very important. GEI, as a spin-off company from RITE, will endeavor to contribute to the development of the biorefinery business, to help realize a society that does not rely on fossil resources.

Green Chemicals Co., Ltd.


Representative Director
Shigeru Hayashi
(Sumitomo Bakelite Co., Ltd.
Representative Director Chairman)

RITE and Sumitomo Bakelite Co., Ltd. jointly set up the Green Phenol Technology Research Association (GP Association) in 2010, with the ambitious goal of substituting petroleum-based phenol with green phenol, which is produced from non-food biomass using bioprocesses.

Initially, because of its high cytotoxicity, it was thought to be extremely difficult to produce phenol from non-food biomass in a microbial bioprocess. However, the "RITE bioprocess," which is a growth-arrested bioprocess, has helped achieve this challenging goal. Furthermore, with the aid of grants from the New Energy and Industrial Technology Development Organization (NEDO) and the Economy, Trade and Industry Ministry, Sumitomo Bakelite Co., Ltd. constructed facilities for purification and concentration processes. In order to speed up the commercialization process, the GP Association changed its name to the Green Phenol Development Co., Ltd. (GPD) in 2014.

This was the first case in Japan where a technology research association had altered the structure of its organization to become a stock company.

Since the technology developed by GPD can produce value-added chemical compounds other than phenol, selectively and with high efficiency, GPD changed its trade name to the Green Chemicals Co., Ltd. (GCC) on April 1, 2018, to expand the business to include other chemical compounds. We are currently pursuing market development.

Today, working toward achieving the Sustainable Development Goals (SGDs) is part of corporate social responsibility initiatives. Accelerating the commercialization of aromatic compounds using bioprocesses, which was previously considered impossible, in order to contribute to a sustainable society is a challenging assignment, and one which for us is a big dream. To that end, microbial genetic engineering technology, highly efficient cultivation, and collective technology are key, and the combination of these features is GCC's unique competitive strength.

My mission as Representative Director of Green Chemicals Co., Ltd. is to deliver this world-class technology to customers for its practical application. I will therefore strive to accelerate the commercialization of products that satisfy our customers' needs.

Research & Coordination Group

Hiroyasu Horio
Group Leader,
Chief Researcher

[Key Members]

Makoto Nomura, Deputy Group Leader・Chief Researcher
Satoshi Nakamura, Deputy Group Leader
Masato Takagi, Chief Researcher
Takayuki Higashii, Chief Researcher
Yasuaki Minoura, Manager
Yoshinori Aoki, Manager・Associate Chief Researcher
Tetsuya Deguchi, Associate Chief Researcher
Taizo Uchimura, Associate Chief Researcher
Haruo Kanaboshi, Planning Manager
Jun-ichi Shimizu, Vice Manager
Daisuke Omoya, Vice Manager
Sou Kuranaka, Vice Manager

Outline of Research Activity in Research & Coordination Group

1. Global environment and the economy

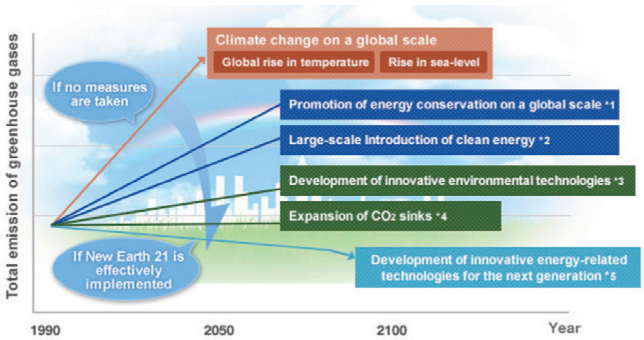
The Research and Coordination Group aims to i) searching for new research topics that enhance the research potential of RITE, proposing and implementing new research themes, ii) government support for the relation with international organizations such as IPCC (Intergovernmental Panel on Climate Change), ISO (International Standard Organization), iv) practical application of technology through industrial collaborative R&D, together with the research groups/center. These efforts lead to a creation of new policy implementation, R&D and innovation aiming at the global environment and the economy.

2. Economic development and the global environment

In 2016, the Paris Agreement came into force. It is necessary to limit the average temperature rise of the earth (global average temperature rise) to less than 2 ℃ compared to the level before the industrial revolution. Before 2100 at the end of this century, it is required to balance the emissions and absorption of greenhouse gases. It is an urgent task to promote substantial reductions in greenhouse gases throughout the world, including emerging countries and developing countries.

The mission of RITE

In 2018, important events related to global environmental issues were carried out. The 47th General Assembly of the IPCC (Paris ・ Mar.) and the 48th General Meeting (Incheon ・ Oct.) were held. Under the international discussions, the recognition of “balance between the global environment and the economy” as a common goal for both industrialized and developing countries is increasing. In 1990, RITE was established under this mission and aims to realize innovation that promotes sustainable growth by suppressing cost burden and inefficiency through innovative environmental technology development (Fig. 1).



*1.Energy conservation movements in society, increased energy efficiency from equipment, more efficient power plants, improved mileage from automobiles
*2.Solar cells, fuel cells, nuclear energy
*3.CO_2 separation, capture and storage, bioenergy, biodegradable plastics
*4.Forestation and forest preservation, greening of arid land by genetically engineered plants
*5.Space-based solar power generation, nuclear fusion

Fig. 1 : The Role of RITE (Toward Economic Development and Global Environment)

2.1. Quarter-century economic development and greenhouse gas

In 1990, the Japanese government started Global Warming Prevention Plan. In the following quarter century (1990-2015), the world population expanded from 5.3 billion to 7.3 billion (1.4 times) and the total world GDP expanded from 27 trillion dollars[1] to 116 trillion dollars[1] (4.3 times). The center of these changes is the Southeast Asian region such as China, India, Indonesia, developing countries and emerging countries of Africa region such as Nigeria. Meanwhile, international trade increased rapidly due to the increase in global trade (exports) from 3.6 trillion dollars[2] to 19.0 trillion dollars[2] (5.3 times). Looking at the worldwide greenhouse gas emissions, annual CO_2 emissions from combustion have expanded from 20.5 billion tons to 32.3 billion tons (1.6 times).

Industrialized countries have pursued the path of mass consumption of fossil resources based on mass production and mass consumption. As emerging and developing countries advance the same road, the problems of energy security and global warming further expand. It is pointed out that part of the energy demand of industrialized countries has also been transferred to emerging countries and developing countries due to international trade transactions, expansion of information processing across national borders, alternative production, etc.

There is a difference in the economic situation and social priority issues of each country. Among these, it is necessary to cooperate with international cooperation on reducing greenhouse gas emissions, pursue a common goal of richness = to prevent global warming at the same time without hampering economic development.

2.2. Creation of innovation

The new technology changes the supply and demand for energy and affects greenhouse gas emissions. It is necessary to constantly forecast how new society, economy, and life will change. About this innovation by innovative technology, the next section explains our group activities in various fields such as international collaboration, human resource development, intellectual property, industry-university collaboration.

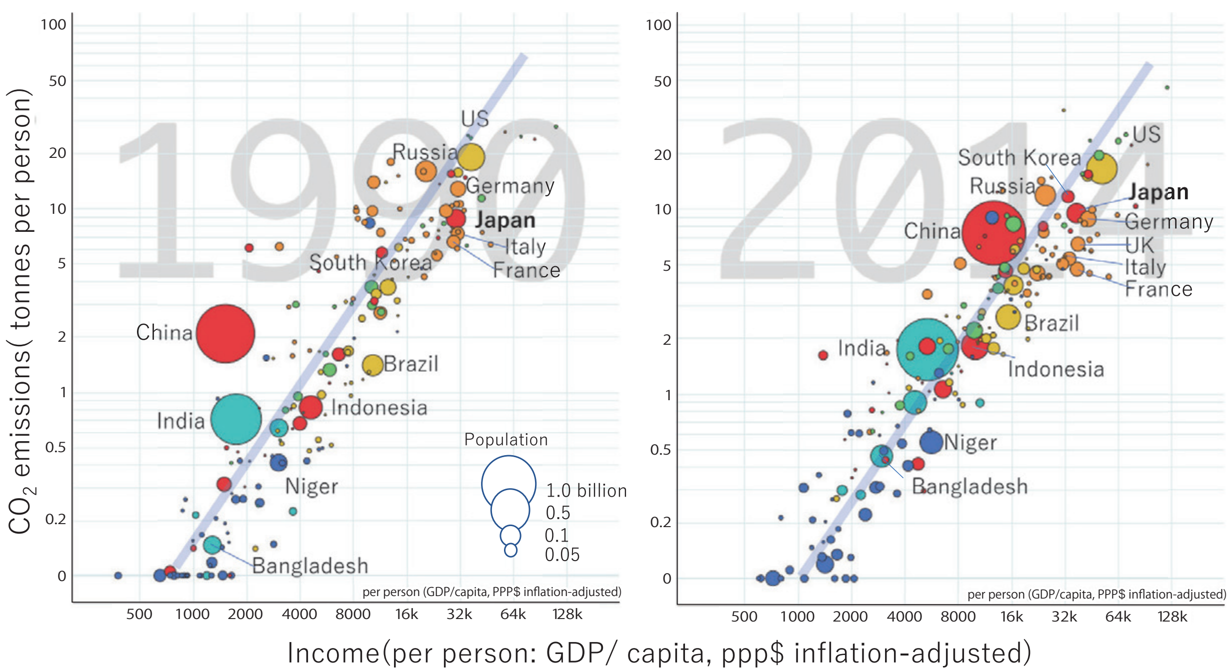


Fig 2 : Income and CO_2 emissions (1990-2014)

3. A quest for zero-emissions technology

To quest for new technical countermeasures, RITE established a "CO_2 Zero Emission Study Team" and conducted research on sector-specific countermeasures such as electricity, transportation, and industry. This section illustrates the results of the examination using energy-CO_2 intensive steel manufacturing which is one of the core industry as a sector-specific approach.

3.1. Sector-specific approach

The world's artificial CO_2 emissions account for 86% of the total in three divisions, 41% of power generation, 25% of transportation and 20% of industries (steel, cement, chemistry etc.). Regarding the production method without using fossil resources, i) Electric power sector: renewable energy (solar / wind power), ii) transport sector: electrification and zero emission electric power, biofuel, iii) industrial sector: zero-emissions hydrogen utilization in steel were analyzed. Furthermore, the possibility of CCS (CO_2 geological storage) / CCU (CO_2 capture and utilization) were examined with the examples from the latest technology development trends.

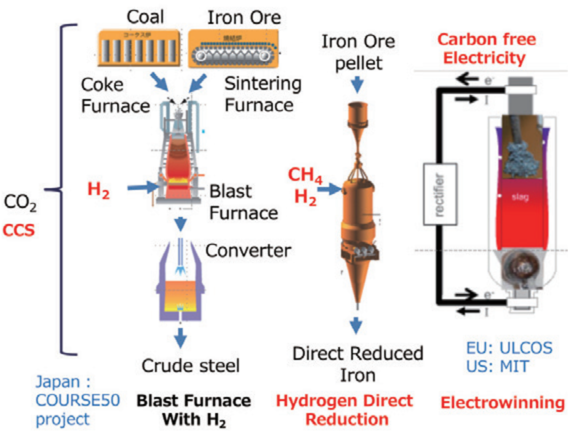
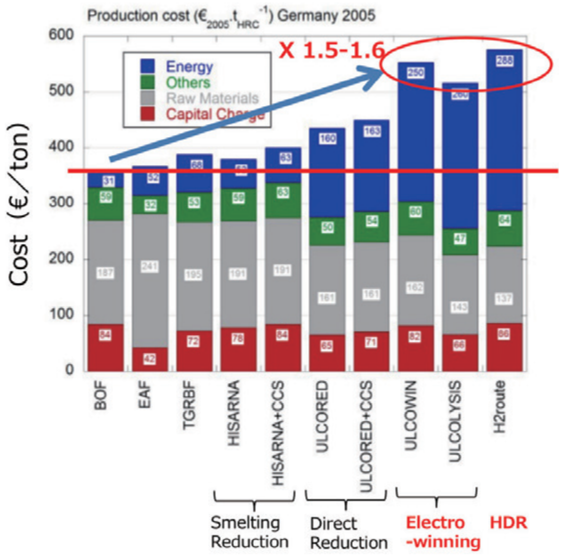


Fig. 3 : Industrial zero emissions technology (steel)

3.2. Example: Zero-emission of steel sector

The main materials in steel production are iron ore and coal. By sending hot air from the bottom of the blast furnace, CO (monoacid carbonate gas), iron ore is reduced at a high temperature of 2,000 ℃ and taken out as hot metal (Fig. 3 left). Those reduction process can be replaced by carbon-free hydrogen / electric power obtained from renewable energy. Those technology and Electrolytic Reduction Method (right in Fig. 3, right) was developed by governments and steel industry. However, since the electricity from renewable energy is used, the production cost is about 1.5 to 1.6 times expensive (Fig. 4).

The amount of electricity required for the new manufacturing method is 17,270 TWh, which is equivalent to about 70% of the worldwide electricity demand (Fig. 5).



Source: " Iron production by electrochemical reduction of its oxide for high CO_2 mitigation", *EU Law and Publication 2016*

Fig. 4 : Cost of Industrial zero emissions technology (steel)

Sector	Production Gt/year	Electricity TWh	Hydrogen Mt/year	Notes
Iron & Steel	Crude steel 1.7	4,420		Electrowinning : 2.6MWh/t-steel (*IEA2017*)
		electrolysis of water 6,120 ←	127.5	HDR : 75kg-H_2/t-DRI EAF etc. 0.8 MWh/t-steel (electrolysis of water: 3.6MWh/t-steel) (*IEA2017*)
Cement	Portland Cement 4.2	3,600		electricity : 0.86MWh/t-cement heat : 8300GJ/ t -cement (*IEA2017*)
Chemical Industries	Ammonia 0.18	1,730		electricity : 9.6MWh/t (*IEA2017*)
	Ethylene 0.12	electrolysis of water 2,400 ←	51.7	hydrogen 0.431t/t (Japan Cabinet Office 2018) electrolysis of water: 20MWh/t (*IEA2017*)
	Propylene 0.09	electrolysis of water 3,420 ←	38.8	hydrogen 0.431t/t (Japan Cabinet Office 2018) electrolysis of water:38MWh/t (*IEA2017*)

Total 15,570 (17,270 when using HDR)

Fig. 5 : Carbon-free hydrogen for zero emissions (steel)

4. Promotion of international partnership

4.1. IPCC

The IPCC (Intergovernmental Panel on Climate Change) has established in 1988 with a view to conducting a comprehensive assessment from a scientific, technical and socioeconomic standpoint on climate change, impact, adaptation and mitigation measures by anthropogenic sources, the United Nations Environment Program (UNEP), and the United Nations Environment Program (UNEP), and by the World Meteorological Organization (WMO).

IPCC examines scientific knowledge on global warming with three WGs, a global warming prediction (WG1), influence and adaptation (WG2), mitigation measures (WG3). RITE plays a role in linking R & D, survey and policies, playing the role of domestic support secretariat of mitigation measures (WG 3) (Fig. 6). This outcome is to have a high influence on international negotiations because the scientific basis is also given to the policies of each country. IPCC started the next sixth evaluation cycle (AR 6) for 2022, and in 2018 the author was selected. RITE also provides support through information gathering, analysis, and reporting.

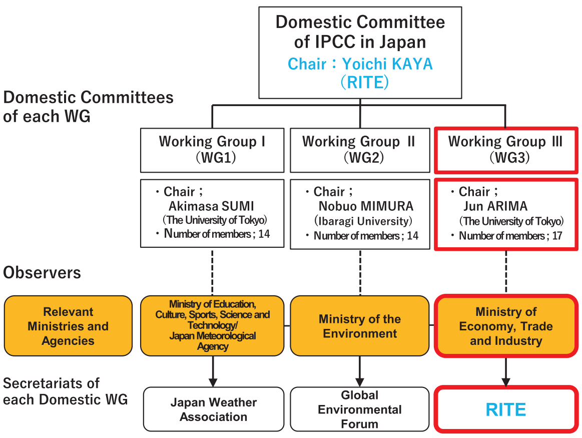


Fig. 6 : Committee Structure and RITE

4.2. ISO

ISO (International Standard Organization) is an organization composed of 162 standardization bodies of various countries. Carbon dioxide capture and storage (CCS) is one of the important options for global warming countermeasures because it has a great effect of reducing CO_2 emissions into the atmosphere. In the world, a number of CCS verification projects on a commercial scale are also implemented, and international collaboration is under way. The international standard plays an important role, contributing to the widespread use of safe and appropriate CCS technology.

RITE is a domestic deliberation organization on ISO / TC 265 (collection, transportation, and storage of CO_2) and is in charge of a secretariat of WG 1 (collection). Through these activities, we are conducting international standardization on design, construction, operation, environmental planning and management, risk management, quantification, monitoring and verification, and related activities in the CCS field through international standardization (Fig. 7). In 2018, RITE published an international standard on measurement, evaluation and reporting method of CO_2 recovery performance at combustion process at power plants (ISO 27919-1).

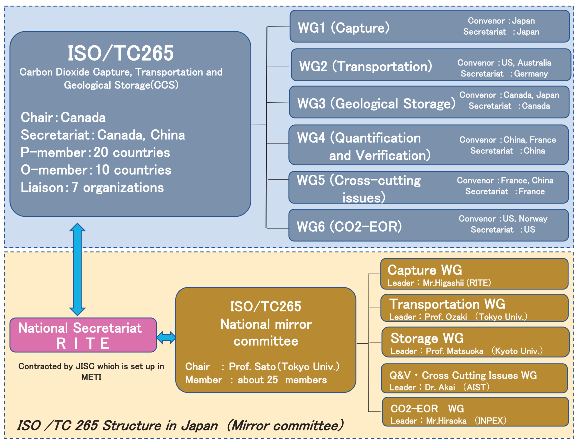


Fig. 7 : ISO/TC265 Structure

5. Human development and industry collaboration

5.1. Human development

<Elementary and high school students>

RITE promotes extracurricular learning using research facilities for elementary, junior high and high school students. And RITE also welcomes teaching requests where staff members visit schools using teaching materials and equipment. Such demands for human development are growing year by year. In 2018, we held classes and workshops for a total of 419 students. For example, we picked up CCS technology from RITE's research and explained the global warming mechanism. We are conducting activities based on the learning cycle such as deepening understanding through discussion and exchange of views (Fig. 8a).

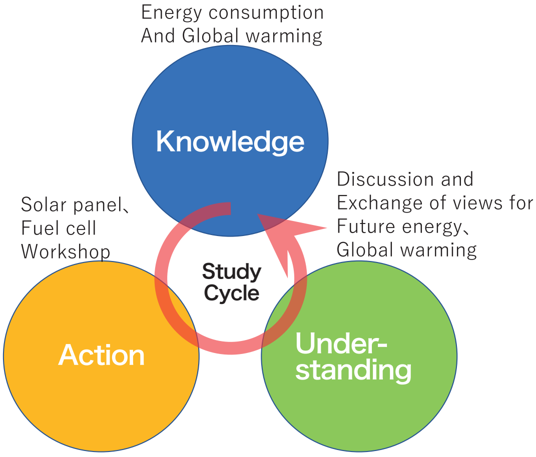
<University / Postgraduate student>

RITE is promoting collaboration of education with universities as part of human development supporting the next research and technology. We are accepting young talented people, mainly graduate students, to the research site. Here, we are developing education at the university and research guidance at the laboratory (Fig. 8b). RITE established a university collaborative laboratory in the field of bioscience with Nara Institute of Science and Technology. Here we are conducting research and education aimed at realizing a recycling-type and low-carbon society by using renewable resources effectively using biomass as a raw material

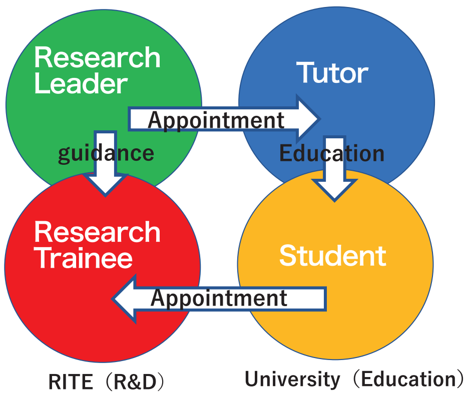
5.2. Intellectual property and industry collaboration

RITE acquires and manages intellectual property rights such as patents and know-how strategically and efficiently on results obtained in R&D. As of the end of 2018, the patents owned by RITE are 129 domestic rights (14 of which are licensed to companies) and 65 foreign. RITE has established an IP management Committee and operates it with intellectual property experts (Fig. 9).

In order to develop academic research, it is important to create knowledge as a public property of the world by publishing research papers. In addition, we have patented inventions of researchers' creation and granted licenses to challenging enterprises. As a result, it is possible to accelerate industrialization and simultaneously promote public interest and innovation as a public research institution. Intellectual property brings up opportunities to cooperate with industries. It is expected that a virtuous circle is created based on appropriate information management and contracts to create further intellectual property. It is also expected that the aspect of the intellectual property that enables related technologies to be used to support standards, such as collaboration with international standards (such as section 4.2). Based on the market and other research and development trends, RITE promotes intellectual property strategically.



(a) Elementary, middle and high school students



(b) University / Post graduate student

Fig. 8 : RITE and Environment Education (Primary, Middle and Higher Education)

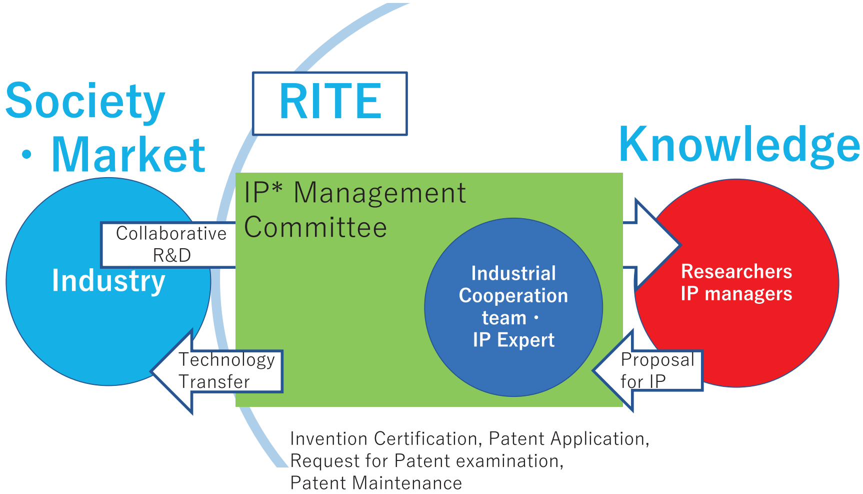


Fig. 9 : Strategic IP management and Industrial collaboration

6. Conclusion

The concern of the world is gathering up as measures against global warming by innovation. In IPCC 6th Evaluation Cycle (AR 6), where work has already begun, a new chapter called "Innovation, Technology Development, and Transfer" was established. i) Sustainable growth through innovation and achievement of the Paris Agreement, ii) Systems and policies to create innovation, iii) International partnership, iv) Environments to promote change and innovation, v) New destructive technologies, etc. RITE is to deepen the verification of this issue. This means that new perspectives such as compatibility of the wealth and the global environment are added by realizing a new society and life, rather than a accumulation of partial improvement by replacing old technology with new technology. The RITE mission is to conduct research on innovative technologies, as well as to promote international collaboration, address issues necessary for innovation such as human development, intellectual property development, industry collaboration contributing to the achievement of "a balance between the global environment and the economy".

1 GDP, current prices (Purchasing power parity; billions of international dollars)

2 Merchandise exports (annual, Million US dollar)

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Systems Analysis Group

Keigo Akimoto
Group Leader,
Chief Researcher

[Key Members]

Toshimasa Tomoda, Chief Researcher
Takahiro Nagata, Associate Chief Researcher
Kenichi Wada, Senior Researcher
Miyuki Nagashima, Senior Researcher
Takashi Homma, Senior Researcher
Fuminori Sano, Senior Researcher
Junichiro Oda, Senior Researcher
Hironobu Yamakawa, Senior Researcher
Haruo Kanaboshi, Senior Researcher (concurrent)
Ayami Hayashi, Senior Researcher
Yosuke Arino, Researcher
Keii Gi, Researcher
Nan Wang, Researcher
Shuning Chen, Researcher

Research Activities in Systems Analysis Group

The Systems Analysis Group aims to provide valuable information about response measures to global warming and energy issues through systemic approaches and analyses. We present here three research topics out of our recent research activities; 1) analyses on decoupling between GDP and CO_2 emissions, 2) evaluations on contribution of environmentally friendly products diffusions to global emission reductions, and 3) Evaluation of global warming mitigation measures under different socioeconomic scenarios considering developments of sharing economy. Our group has been contributing to the planning of better climate change policies and measures through such analyses and evaluations.

1. Analysis on decoupling between GDP and CO_2 emission

1.1. Introduction

Relationships between GDP growths and CO_2 emission increases showed strong positive correlations until recently. However, for the recent several years, the correlations were not always observed, and it is pointed out that decoupling between GDP growth and CO_2 emission increase may start to take place. Figure 1 shows global GDP and CO_2 emissions. For 2013-2016, global emissions remained mostly leveled and for the limited short-terms the decoupling was observed, whereas in 2017 global emissions increased again. Based on the long-term trend, emissions for 2009-2013 increased greatly above the historical trend and since then the leveling for 2013-2016 can be regarded as short-term adjustments returning to the long term trend for the emissions. In addition, in some developed countries, decouplings were observed. In order to examine why those emission trends were observed, we analyzed consumption-based emissions and evaluated the relevant potential factors.

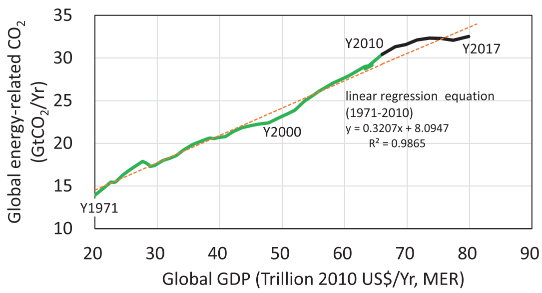


Figure 1 : Relationship between global GDP and energy-related CO_2 emissions

1.2. Estimations of consumption-based CO_2 emissions

We estimated consumption-based CO_2 emissions for the years 2000-2014 which include temporarily sluggish emissions at a global level. Evaluating contributions to global decoupling requires considerations on international allocation of productions, trades and national consumption structures. Importantly, these are reflected in consumption-based emissions evaluation.

Production-based CO_2 emissions are emissions from combustions of fossil fuels generated inside the territory of the country. These are equivalent to common CO_2 emissions statistics. On the other hand, consumption-based emissions are direct and indirect emissions generated to meet the domestic demand of the country, regardless of production sites. National consumption-based emissions include emissions embodied in imports and exclude emissions embodied in exports.

IEA statistics and international input-output tables (WIOD) were used. The results indicate that major developed countries have constantly higher consumption-based emission than production-based. However the time-series trends are different among countries.

Figure 2 shows production- and consumption-based CO_2 emissions for EU28. Growth of consumption-based CO_2 was larger until 2008 than that of production-based, expanding difference between consumption- and production-based CO_2. Those are because of increases in emissions embodied in imports (mainly of machinery from China). While production-based emissions for EU decreased, imports increased and then the embodied emissions in imports increased. As a result, the contributions to global emissions reduction were not large. But, after the financial crisis, the differences were shrinking. Although amounts of imports increased continuously, sectoral CO_2 intensities of imports in the production sites decreased considerably after late 2000s.

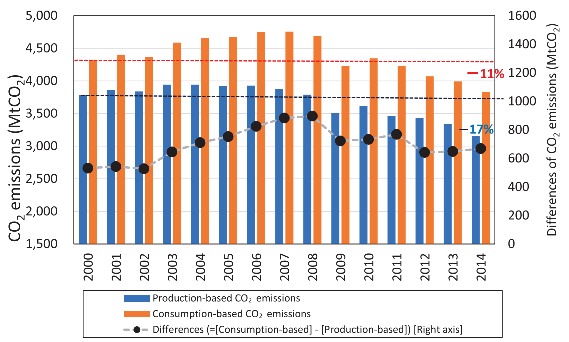


Figure 2 : Production-based and consumption-based CO_2 emissions for EU28

On the other hand, in Japan, changes in consumption-based CO_2 emissions were similar to those in production-based, and the differences were gradually shrinking (Fig.3). Those results indicate that manufacturing industries having relatively higher emission intensities maintained at relatively high levels in Japan, and then carbon leakage due to increases in import dependencies did not largely expand during the years.

In the U.S., difference between consumption- and production-based CO_2 emissions increased substantially towards 2006, which were similar to EU. However, the difference turned to decrease due to expansion of domestic production of shale gas launched around 2006, possibly inducing reshoring of manufacturing industry because of the availability of cheaper energy. The difference became almost flat after 2009.

CO_2 intensities of GDP (CO_2 divided by GDP) for major developed countries were compared. By using production-based emissions, Japan has lower growth rates of CO_2 intensity improvements compared to other regions (Fig.4(a)). However, when comparing by using consumption-based CO_2 intensity, the intensity of Japan was almost the same level as that in EU28 average or UK after 2011 (Fig.4(b)). The increase of Japan was caused by shutdown of nuclear power plants after 2011.

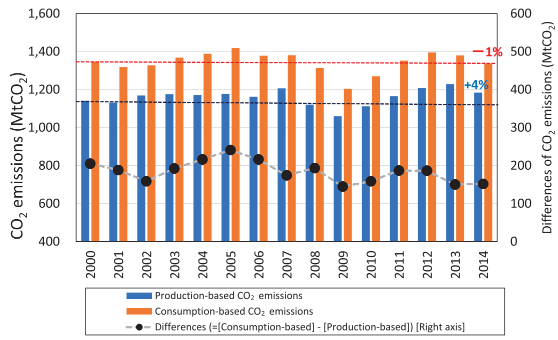


Figure 3 : Production-based and consumption-based CO_2 emissions for Japan

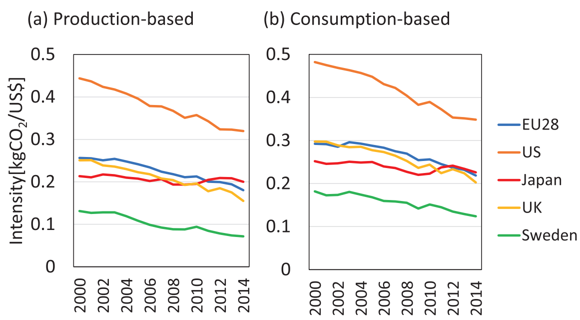


Figure 4 : CO_2 emissions per real GDP for major countries

Note: GDP is based on constant US$ at 2010 in market exchange rate.

1.3. Summary

Decoupling between GDP and CO_2 emissions increases is important for sustainable climate change mitigation. This study estimating consumption-based CO_2 emissions indicates that decouplings observed in regions like EU were caused by increases in import dependencies rather than changes in consumption structures, and then the emissions were transferred to other regions. Fundamental changes in consumption structures, that is innovation of final goods and services, leading to globally harmonized measures, are necessary to achieve deep decoupling globally.

2. Evaluations of contribution of diffusions and deployments of environmentally friendly products to global CO_2 emission reductions

2.1. Introduction

METI delivered a "Long-term Climate Change Platform" report in April 2017. The report recommends to enhance three pillars: "international contribution", "global value chain", and "innovations" for achieving deep emission reductions. In November 2018, Keidanren, a Japanese business association, delivered a report including some examples for "Emission reduction contributions through global value chain" in which several kinds of environmentally friendly products and services are deployed broadly in several sectors.

On the other hand, RITE has been estimating emission reduction contributions and economic impacts for 2050 through environmentally friendly products by using a global energy systems model DNE21+ and economic model DEARS for systematic evaluations on the global contributions in the whole of "global value chain (GVC)".

2.2. Assumptions on emission reduction scenarios

According to the IPCC, the GHG emission pathways for achieving the concentration levels at 430-480 ppm CO_2eq. in 2100 will be able to achieve below 2 ℃ compared to the preindustrial level with over 66% probability. As for emission reductions, the global GHG emissions in 2050 are required to be from 40 to 70% reductions compared to the 2010 level. This study estimated the emission reduction contributions and GDP impacts for the above two global levels, and three emission levels for Japan: 50%, 65%, and 80% reductions as compared to 2013.

2.3. Evaluations on global GHG emission reduction measures

Figure 5 shows the global GHG emission reductions by sector and measure in 2050 estimated with DNE21+ model. Under the baseline scenario, the emission will reach 80 $GtCO_2$eq./yr in 2050. For emission reductions of 40%-70% compared to 2010, various kinds of measures including efficiency improvement and fuel switching of fossil fuel power, large deployments of nuclear power and renewables, and CCS in power sector are necessary. In end-use sectors, all sectors also need to reduce their emissions including non-CO_2 GHG emissions.

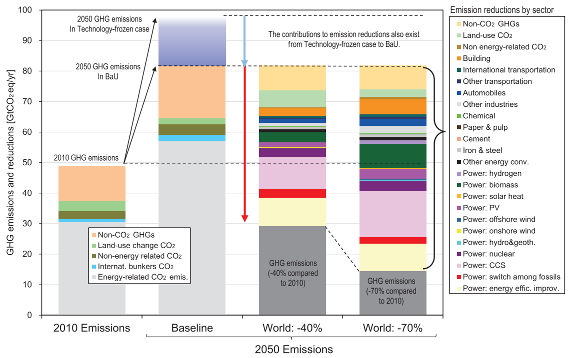


Figure 5 : Global GHG emission reductions by sector and measures in 2050 (estimated by DNE21+)

2.4. Methodology for estimating contributions to global emission reductions in the whole of GVC

Emission reduction contributions in the whole of GVC can be attributed to emission reductions of products in end-use of final energy and embodied energies in production processes. For the treatment in DNE21+, the contributions are estimated for the final energy consumptions in end-use of products, e.g., electric products and automobiles, and the energy consumptions in production process, e.g., power generation and steel making (Figure 6). This treatment covers all emis-

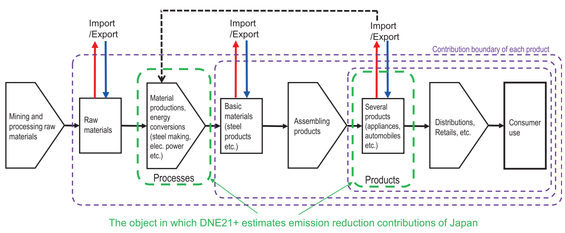


Figure 6 : System boundary image for estimating emission reduction contributions in supply-chain

sions in GVC without double counting of energy and emissions.

The following assumptions were employed for estimating contributions of Japan to the global emission reductions considering the limits of data availabilities.

- The recent historical share of the amount of productions by Japanese firms were basically adopted for estimating the contribution by final products.
- For the sectors and technologies whose shares cannot be obtained easily, the share of value added in machinery sector (7% for Japan) were adopted.

The assumed contribution shares for each sector and technology were adopted as shown in Table 1.

Table 1 : The assumed share in contribution of Japan by sector and technology for GVC

Sector	Technologies	Share of Japan
Power	Nuclear	19%
	Wind (onshore)	0%
	Wind (offshore)	6%
	Photovoltaics	4%
	Solar thermal	0%
	Hydro	0%
	Geothermal	55%
	High-efficiency fossil fuel	21%
	Other	7%
	Fuel switching among fossil fuels	0%
Other energy conversion sector		7%
Industry		7%
Transportation (automobiles)		28%
Transportation (other)		7%
Building		13%
Land-use change (afforestation etc.)		0%
Industrial process CO_2 and non-CO_2 GHG		7%

2.5. Global GHG emission reduction contributions and GDP positive impacts through GVC measures

The contributions of Japan in amounts of investment of environmentally friendly products by sector in the world were estimated from the global investment for 2 ℃ scenarios (corresponding to Fig. 5) and the assumed shares of contribution of Japan (Table 1). The amounts of investments estimated by DNE21+ include the construction costs which will be invested mainly by oversea firms. The share of machinery in total investments was 53% according to the report by Japan Machinery Center for Trade and Investment. But this number also includes general machineries which can be provided by domestic firms, and therefore 26% which is a half of the number was simply adopted for the contributions of Japanese firms. Impacts of investment increase for oversea deployment of environmentally friendly products on Japanese GDP are estimated for the different levels of global and Japan's emission reductions.

Table 2 shows the GDP impacts in Japan. There can be possibility to achieve compatibility of both environment and economy under 50% emission reductions in Japan if the investment increase of Japan which will be accompanied with the oversea deployment of environmentally friendly products of Japan are considered.

On the other hand, under the case of 80% reduction in Japan, the oversea contributions will become small due to constraints of productions in Japan and the contribution will not be able to offset the negative impacts on GDP due to domestic emission reductions in Japan. Then, totally negative GDP impacts were estimated.

Figure 7 shows the emission reduction effects in 2050 including the contributions to GVC considering the domestic impacts on productions which will be constrained by domestic emission reductions. The domestic emission reductions of 80% in Japan is larger but in global scale total reductions can be smaller than those of 50%, because the domestic productions for environmentally friendly products should become small under 80% reductions.

Table 2 : GDP impacts of Japan in 2050 compared to the baseline

	World: -40%		World: -70%	
	w/o oversea contribution	with oversea contribution	w/o oversea contribution	with oversea contribution
Japan: -50%	-0.9%	+0.8%	-1.0%	+1.6%
Japan: -65%	-2.0%	-0.3%	-2.7%	-0.4%
Japan: -80%	-7.2%	-6.5%	-7.1%	-6.1%

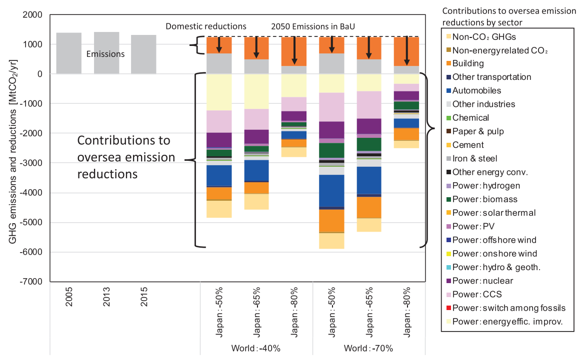


Figure 7 : The emission reduction of Japan including the contributions to GVC in 2050

2.6. Summary of the evaluations for GVC

The emission reduction potentials in Japan are limited mainly because high energy efficiency levels are already achieved. Under these situation, it will be very important to focus on reductions of global emissions in energy end-use stage by oversea deployments of environmentally friendly products as well as production processes. This is an approach with LCA thinking. Business-based competitions for larger diffusions and deployments of such products among firms will achieve a compatibility of environment and economy in a sustainable manner. This study tried to analyze the effects quantitatively and consistently.

3. Evaluation of global warming mitigation measures under different socioeconomic scenarios considering developments of sharing economy

3.1. Introduction

In recent years sharing economy is drawing attention. Although it covers various sectors widely, there are two kinds of services currently offered in mobility, i.e. car-sharing and ridesharing. These services have a potential to be made more efficient by the technology development like IT or AI. As for cars themselves, autonomous driving technology is under development utilizing these technologies. These technology development may realize a society that shares autonomous cars as one of possible futures.

This study evaluated global warming countermeasures under a socioeconomic scenario in consideration of car-sharing and ridesharing induced by fully autonomous vehicles, by enhancing the DNE21+ model.

3.2. Assumed shared autonomous car

When fully autonomous driving will be realized is uncertain because there exist a lot of issues not only technological ones but also legal ones. In this study, the autonomous vehicle is assumed to be available in 2030 and thereafter, and the analysis is for passenger cars only. Other assumptions are described in table 3.

Among passenger transportation demand within the road transportation sector, the DNE21+ model distinguishes passenger cars and buses. In this study, the demand by transportation mode is assumed to be the same, irrespective of the realization of shared autonomous car. However, there might be potentials of increase in transportation demand caused by its convenience and affordability, as well as competition against public transportation. Besides, users have various preference which might not be considered well in Table 3. These are future works.

Table 3 : Assumptions in shared autonomous car

Items	Assumptions
Additional cost of autonomous car per vehicle	10000$ in 2030, 5000$ in 2050, 2800$ in 2100, assuming cost reduction with technology development
Utilization rate	3 times more than conventional private car (ref. 30,000km per vehicle in Japan)
Lifetime	7 to 12 years, depending on the region (conventional private car is assumed as 13 to 20 years)
Number of passengers per 1 car	Assumed to increase with ride-sharing. 1.75 persons in 2050, 2 persons in 2100, irrespective of the region (1.1 to 1.5 in 2050, 1.1 to 1.3 in 2100 for conventional private car assumption)
Fuel economy	Same as conventional private car

3.3. Assumed scenario of crude steel production

Under the above assumptions, our evaluation shows that prevalence of shared autonomous car will suppress passenger car fleet and new car sales 25% and 41% in 2050, respectively, compared with the baseline. As a result, steel sheet demand for automobile is estimated to be 58% of the baseline, and total crude steel demand is to be 96% of the baseline.

This study evaluates global warming countermeasures in consideration of this decrease.

3.4. Results of model analysis

Impacts of shared autonomous car on 2 climate policies, the baseline scenario and the 2℃ scenario (emission pathways equivalent to NDCs until 2030, and -40% emissions in 2050 compared to 2010 with >50% chance to achieve 2℃), are evaluated under 3 socioeconomic scenarios described in Table 4. Assumed socioeconomic scenarios are SSP2, a medium scenario in SSPs (Shared Socioeconomic Pathways)

Table 4 : Analyzed scenarios

Scenarios	Description
SSP2	Medium (Middle of the Road)
SSP1	Higher technology development (Sustainability)
SSP1+shared autonomous car	Higher tech. development + shared autonomous car + decrease in crude steel production

that are studied among international research communities on climate change, and SSP1 which assumes sustainable future. SSP1 assumes a higher level of technology development and thus more cost reduction of EV or FCV than SSP2. SSP1+shared autonomous car is our original scenario that assumes more prevalence of shared autonomous car.

Figure 8 and 9 show passenger car fleet by technology and energy consumption in transportation sector under each scenario. Compared with SSP2 which mainly adopts conventional ICE, SSP1 achieves broader prevalence of EV or FCV and lower energy consumption in transportation sector even in the baseline. SSP1+shared autonomous car estimates much larger decrease in passenger car fleet caused by car-sharing and ridesharing, as well as substantial decrease in energy consumption due to the suppression of vehicle kilometers traveled while satisfying transportation demand(p-km) by ridesharing. Results show that socioeconomic scenarios (technology development or existence of shared autonomous car) cause larger difference in estimates than the climate policy scenario does between the baseline and the 2℃ target, because the passenger vehicle cost is relatively higher than the energy cost, and substantially higher carbon

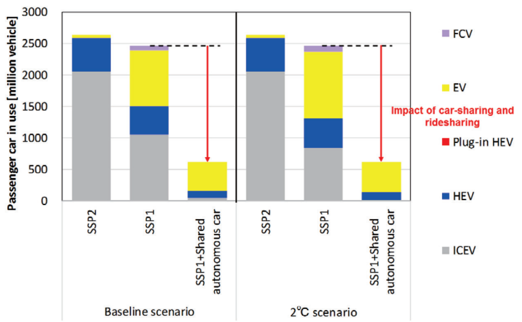


Figure 8 : Global passenger car fleet by technology in 2050

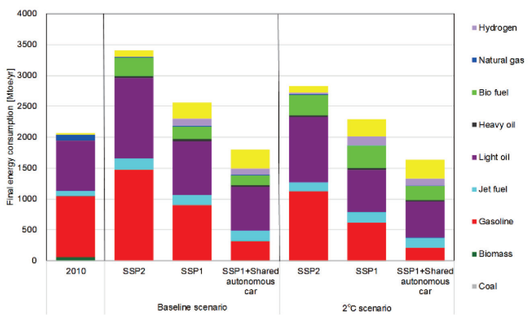


Figure 9 : Global energy consumption in transportation sector in 2050

price is necessary to compensate for the increased vehicle cost within 3 years of assumed payback period.

Marginal abatement costs (MAC) of CO_2 in 2050 are estimated to be 171\$/tCO_2 in SSP2, 125\$/tCO_2 in SSP1, and 94\$/tCO_2 in SSP1+shared autonomous car. Large decline in energy consumption in transportation sector may occur in SSP1+shared autonomous car with lower MAC, so this may induce lower emission reduction levels required for other sectors to achieve -40% compared with 2010, as well as a small amount of introduction of coal power plants without CCS which cannot be allowed under stringent emission reductions.

3.5. Summary

This analysis quantitatively estimates global warming countermeasures under different socioeconomic scenarios using the DNE21+ model, considering car-sharing and ridesharing that might be accelerated by fully autonomous car, as well as decrease in crude steel production caused by less car sales. Although there remain important issues such as assumptions regarding shared autonomous cars or consistency with other sectors, the result shows a potential of SSP1+shared autonomous car scenario to decrease energy demand toward 2℃ target by social innovation like massive prevalence of car-sharing and ridesharing induced by IT or AI without unrealistically high MAC.

Reference

1) L. Fulton et al.; Three Revolutions in Urban Transportation (2017)

Molecular Microbiology and Biotechnology Group

Masayuki Inui
Group Leader,
Chief Researcher

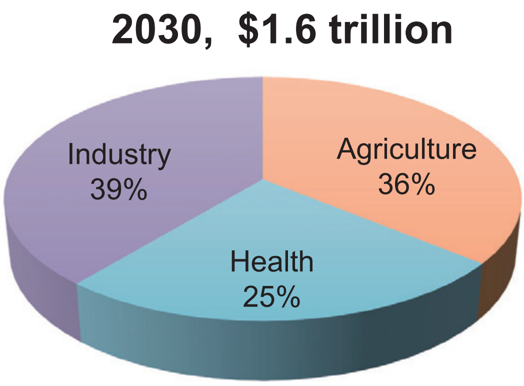
[Key Members]

Akemi Sasaki, Deputy Group Leader, Associate Chief Researcher
Ken-ichi Inatomi, Associate Chief Researcher
Haruhiko Teramoto, Associate Chief Researcher
Kazumi Hiraga, Associate Chief Researcher
Yuya Tanaka, Senior Researcher
Masako Suda, Senior Researcher
Yukihiro Kitade, Senior Researcher
Koichi Toyoda, Senior Researcher
Naoto Kato, Senior Researcher
Satoshi Hasegawa, Senior Researcher
Akira Watanabe, Senior Researcher
Takahisa Kogure, Senior Researcher
Takeshi Kubota, Senior Researcher
Toshihiro Oshima, Senior Researcher
Shinichi Oide, Researcher
Ryoma Hashimoto, Researcher
Tetsu Shimizu, Researcher
Masayoshi Hashizume, Researcher
Tomoaki Hara, Researcher
Akiyoshi Higo, Researcher
Natalia Maria Theresia, Researcher

Development of Green Bioprocesses to Realize a Sustainable Society

1. Introduction

Biotechnology, which involves the use of biological processes, organisms, or systems, widely contributes to the fields of agriculture, industry, environment, medical treatment, etc. Recently the concept of "bioeconomy" has emerged, which maintains economic development while solving global environmental problems by using biotechnology and renewable resources. It originated in Europe and the U.S. and is now gaining ground in countries across Asia. According to the Organization for Economic Cooperation and Development (OECD), it is predicted that biotechnology could contribute 2.7% (ca. $1,600 billion) to the GDP of OECD countries by 2030. The greatest potential economic contribution is predicted for industrial applications, with 39% of the total output of biotechnology expected in this sector (Fig. 1).

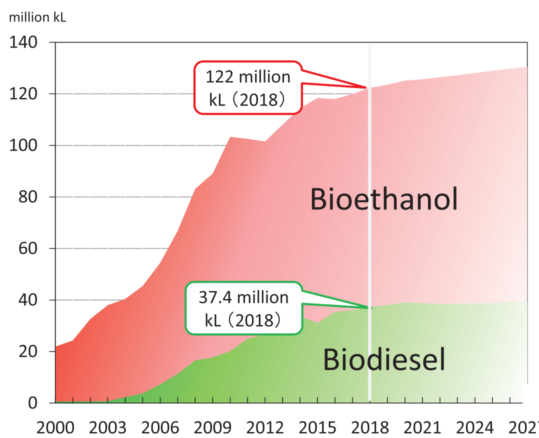


Source：The Bioeconomy to 2030. OECD(2009), METI

Fig. 1 : Economic contribution of biotechnology

Our group is advancing the research and development of biorefinery technologies, core technologies of the "bioeconomy," to produce biofuels and "green" chemicals from renewable sources (biomass). In this section, we provide an overview of global biofuel and green chemical production.

Bioethanol, a major biofuel, is produced from raw materials that include corn (in the U.S.) and sugarcane (in Brazil), and mixed with 10%-25% gasoline for use in automobile engines. The highest production and consumption of bioethanol is in the U.S., where corn is a major crop, with 15.9 billion gallons (60.1 million kL) of bioethanol produced in 2018, according to estimates provided by the U.S. Energy Information Administration. The obligation of renewable fuels of 19.3 billion gallons in 2018 was covered to ca. 75% by corn-based bioethanol, based on the U.S. Renewable Fuel Standard (RFS) proposed by Environmental Protection Agency (EPA).



Source：OECD/FAO (2018), "OECD-FAO Agricultural Outlook".

Fig. 2 : Biofuels outlook 2018-2027

According to the report Agricultural Outlook 2018-

2027, by OECD-FAO, 122 million kL of bioethanol were produced worldwide in 2018, with the U.S. accounting for approximately half of this production. This proportion does not change in these years.

Another major biofuel, biodiesel, is produced from raw materials that include rape seed (in Europe) and soybeans (in the U.S.), with 37 million kL of biodiesel produced worldwide (Fig. 2). In Europe, France and Germany are the highest biodiesel-consuming countries, where about half of all automobiles have diesel engines. In recent years, the export of raw materials for biodiesel production has been increasing from countries like Argentina and Indonesia. However, the British and French governments intend to end sale of fossil fuel-powered vehicles by 2040, and the judgment by which city driving of automobiles having diesel engines is prohibited was approved in Germany. Therefore, the use of conventional internal combustion engines is predicted to decline in the future, particularly in Europe.

Second generation cellulosic biofuels are produced from agricultural wastes such as corn stover, therefore their production does not affect food supply, which is expected to reduce large CO_2 emission. Large-scale commercial cellulosic ethanol production plants are in operation in the U.S. and Brazil, and a new plant was reported to have opened in Europe in 2018 (each company website). The EPA target for the production of cellulosic biofuel in 2019 is 418 million gallons (1.6 million kL), based on RFS rules.

Biojet fuels, which are a trump card for the reduction of CO_2 emission from aircraft, have become widely popular among global commercial airlines. Biojet fuels are produced from raw materials such as used cooking oil. Since 2018 RITE has also provided technical assistance to a new private project to produce biojet fuel, using bio-isobutanol as an intermediate material (see Topics).

Green chemicals

Environmental pollution by single-use throwaway containers, disposable plastic bottles, and similar items has gained prominence and received attention as a global problem. In addition, the prohibition of the importation of waste plastic in China and southeast Asia has had a big impact on plastic recycling systems in Japan. Given this background, the use of bioplastics and biodegradable plastics made from renewable resources, such as biomass, is expected to increase.

According to European Bioplastics, global bioplastics production will reach 2.14 million tons in 2019, and is expanding year by year. Legislation for the prohibition of sales of disposable plastic bottles at parks, and obligations to collect and recycle them have been approved in parts of Europe and the U.S. According to the Japan BioPlastics Association, the shipment volume of bioplastics in Japan is predicted to be 40,000 tons in 2019. The Ministry of the Environment is planning to start new projects from 2019 to reduce plastic waste, such as the development of products made of biodegradable plastics.

2. Features of RITE Bioprocess

In RITE Bioprocess, cells of a *Corynebacterium glutamicum* strain engineered to have an optimal metabolic pathway for a target chemical are grown on a large scale, packed to very high densities in a reactor, and allowed to produce the target metabolite (Fig. 3). The key to our process is a unique property of *C. glutamicum*. The bioconversion of feedstock to target product proceeds without microbial cell growth, achieving higher efficiency and productivity compared with conventional fermentative processes, in which the formation of products and biomass inevitably occurs in parallel. Metabolic engineering enabled our microbial catalyst to simultaneously utilize C5 & C6 sugars, and we also found that *C. glutamicum* is highly tolerant to fermentation inhibitors contained in cellulosic hydrolysates such as furans, demonstrating that the RITE Bioprocess is compatible with cellulosic non-food biomass (see RITE Today 2013-2018). Using the RITE Bioprocess, we have achieved production of ethanol, lactic acid, and various amino acids, with remarkably high yields. We are currently applying this technology to the microbial production of butanol, biojet fuels, and aromatic compounds belonging to high-functional chemical compounds. In the following sections, we de-

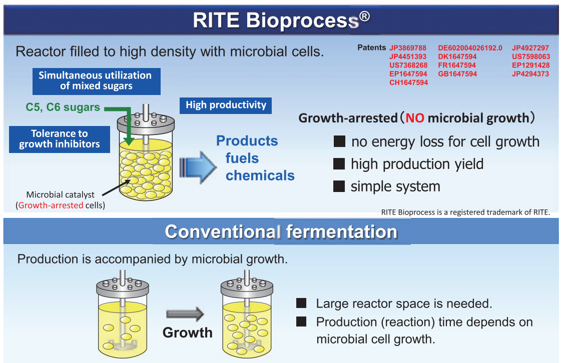


Fig. 3 : Features of RITE Bioprocess

scribe recent progress we have made in our research into the production of biofuels and green chemicals.

3. Biofuel production research and development

3.1. Biobutanol

Butanol is more suitable as a gasoline additive than ethanol due to its physicochemical properties, including higher energy content, lower vapor pressure, and lower water solubility. It can also be used as a starting material for the production of biojet fuel using conventional chemical reactions. Biojet fuel synthesized from biobutanol can be used in airplanes. Airlines and aircraft manufacturers have paid great attention to biojet fuel, since it has been recognized as being of key importance for reductions in CO_2 emissions. Biojet fuel synthesized from butanol is often referred to as "alcohol-to-jet" (ATJ) fuel. ATJ fuel has been approved by the American Society for Testing and Materials (ASTM) and is ready for use in commercial aircraft (http://www.gevo.com/).

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

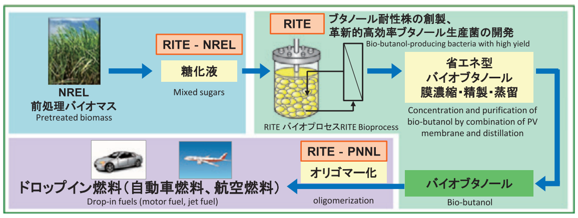


Fig. 4 : Production of biobutanol and biojet fuel by RITE Bioprocess

Since butanol is highly toxic, we have developed a genetically engineered *Corynebacterium* strain that has high tolerant against the toxicity of butanol. The strain exhibited very high productivity in the RITE Bioprocess. We accelerated the research and development of biobutanol production from non-edible biomass by collaborating with the U.S. National Renewable Energy Laboratory (NREL).

We have also been collaborating with the U.S. Pacific Northwest National Laboratories since 2017, researching and developing the production of jet fuels by chemical oligomerization of biobutanol. This was based on a new idea that if acetic acid is included in mixed sugars from pretreated biomass, it can be converted to ethanol by engineered *C. glutamicum* by introducing new genes. Therefore, the mixtures are utilized for bioproduction of butanol and ethanol, which can then be subjected to chemical oligomerization for jet fuels.

The distillation of biobutanol solution requires a large amount of energy. To reduce the amount of energy needed, we developed an energy-saving biobutanol-recovery process using a combination of distillation and pervaporation (PV), which achieved up to 90% energy savings. We achieved the highest biobutanol productivity in the world. We then attempted to further enhance this fast and highly efficient process for the production of biobutanol by improving butanol resistance, optimizing metabolic pathways, and developing energy-saving butanol purification techniques.

3.2. Green jet fuel

Petroleum-based jet fuels are mixtures of hydrocarbons that consist of n-paraffins, isoparaffins, cycloparaffins, and aromatic compounds with 9-15 carbon atoms. The proportion of each type of hydrocarbon in jet fuels varies, reflecting the type and geographical origin of the crude oils from which they are derived.

Jet fuel must meet strict standards with regard to its physical properties, such as a specified freezing point and density. Biojet fuels that have already been certified by ASTM mainly consist of isoparaffins, and are permitted for use when blended with petroleum-based jet fuels at a proportion of up to 50%. However, it is not always possible to meet the required density standard using a 50/50 blend.

Isoparaffins have lower densities than cycloparaffins and aromatics, and thus the density of petroleum-based jet fuels varies by production area, reflecting the proportion of each type of hydrocarbon (Fig. 5). The density of isoparaffin-based biojet fuels is not up to jet fuel standards because of the absence of cycloparaffins and aromatics (Fig. 5). If these biojet fuels were blended in a 50/50 mix with low-density jet fuels derived from crude oil from Africa or the Middle East, the resulting fuel would not be permissible as jet fuel because its density would not be up to jet fuel standard.

Thus, we are developing a novel green jet fuel that contains cycloparaffins and aromatics as well isoparaffins, so that it can meet ASTM density standards on its own. Our new green jet fuel can be blended with any jet fuels up to the limit full; furthermore, it can be used as 100% green jet fuel with carbon number distribution similar to that of petroleum-based jet fuels.

Our core strategy is to produce jet fuel range-branched and cyclic precursor compounds from various types of non-food biomass using an energy-saving bioprocess, and then convert them to isoparaffins, cycloparaffins, and aromatics using a simple chemical reaction. We have almost established these base technology, and successfully produced branched and cyclic precursors with various carbon numbers, some of which have been chemically converted to jet fuel components. Now we are improving their production yields toward next phase of establishment of a continuous process. As part of the development of our new green jet fuel, we also conducted a research project into novel versatile bioprocesses (see Topics in RITE Today, 2018), which was funded by METI.

Reference to CRC fuel survey

	JetA1	Density of jet fuel by area			
		USA	Europe	Africa	Middle East
Density (g/cm^3)	0.775-0.840	0.810	0.800	0.785	0.790

	HEFA FT-SPK ATJ	RITE method
Elements produced	Isoparaffins	Isoparaffins Cycloparaffins Aromatics
Density (g/cm^3)	0.75	0.79
Blending ratio	Up to 50%	Up to 100%

Fig. 5 : Comparison of the density of petroleum-based jet fuels and biojet fuels

3.3. Biohydrogen

Hydrogen is considered to be the ultimate clean energy source, because its combustion generates only water. Although residential fuel cells and fuel cell vehicles have been already put on the market, CO_2 emission during currently used hydrogen production processes is a problematic issue, because fossil resources are used as feedstock. This issue should be addressed by a medium- or long-term research and development project to investigate hydrogen production technologies that use renewable and sustainable resources. In this context, METI has set a goal to establish 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, innovative improvements in technology are necessary to establish a cost-effective biohydrogen production process. In collaboration with the Sharp Corporation, our group has developed a biohydrogen production process. The hydrogen production rate our process has achieved is two orders of magnitude higher than that of conventional fermentation processes. Based on this achievement, our group is now conducting an international collaborative research project, supported by METI. The purpose of this project is to bring about major improvements in hydrogen yield by integrating dark fermentative and photo-fermentative hydrogen production processes. The latter process harnesses light energy, whereas the former does not (Fig. 6).

For this project we are collaborating with Kyoto University, Japan, and the Center National de la Recherche Scientifique in France to develop expression systems for hydrogen-producing enzymes for dark fermentation. We are also metabolically engineering the acetate metabolism pathway used by a photosynthetic bacterium for photo-fermentation, to improve hydrogen yield from acetate, a by-product of dark fermentation. Furthermore, we are examining the conditions necessary for hydrogen production from corn stover, in collaboration with NREL.

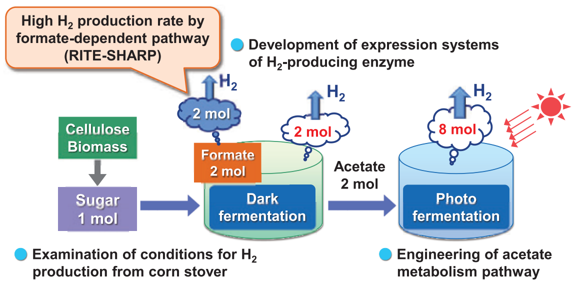


Fig. 6 : Research and development to investigate highly efficient biohydrogen production from cellulosic biomass

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

4.1. NEDO Smart Cell project

Innovations in biotechnology have made it possible to expand the potential of biological functions. In response to current trends, METI has developed and defined the concept of the "Smart Cell", a finely designed and expression-controlled cell. METI also presented a strategy to create a new industry (a "Smart Cell" industry), based on the cells.

To create this industry, the New Energy and Industrial Technology Development Organization (NEDO) launched a project named "Development of Production Techniques for Highly Functional Biomaterials Using Smart Cells of Plants and Other Organisms" (Smart Cell Project). RITE has participated in this project since it began.

The project is composed of two teams, the fundamental technology team and the validation team; RITE belongs to the latter. The members of the fundamental technology team predict and suggest effective metabolic modifications for better productivity, using analytical tools such as computer-assisted simulation technology (Smart Cell design system). RITE engineers *C. glutamicum* strains following their suggestions and acquires experimental data. The fundamental technology team improves the tools based on the data fed back to them. This development cycle is repeated to enhance predictability of the Smart Cell design system and productivity for obtaining target compounds (Fig.7).

We contributed to the improvement of the Smart Cell design system by providing a large amount of feedback data. We also achieved high productivity that went beyond our intermediate goal. We are continuing the development cycle to create hyperproducers suitable for practical uses.

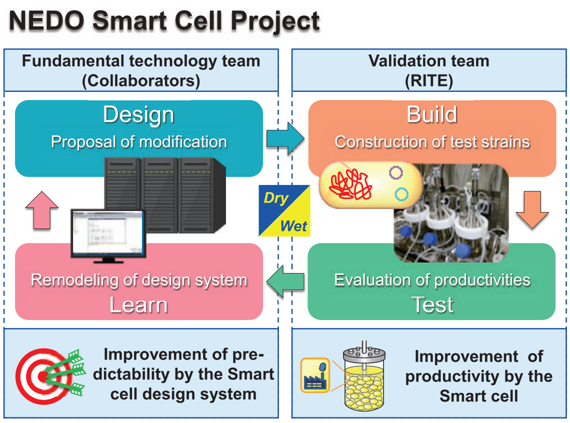


Fig. 7 : Overview of the Smart Cell Project

ids (phenylalanine, tyrosine, tryptophan), folate (vitamin B9), and coenzyme Q. All of these compounds are derived from the shikimate pathway (Fig. 8). By employing the metabolically engineered *C. glutamicum*, we have successfully established a highly efficient bioprocess to produce the following aromatic compounds from non-food ligno-cellulosic feedstock: shikimate, a key building block of the anti-influenza drug Tamiflu; 4-aminobenzoate, which is used as a building block of a potentially useful functional polymer; and aromatic hydroxy acids, which have potential applications in the polymer, pharmaceutical, cosmetics, and food industries. Now we are seeking to develop new strains by introducing genes derived from versatile biological resources for the production of useful aromatic compounds, which wild-type *C. glutamicum* is unable to produce. The techniques developed in the Smart Cell project, as described above, will help to accelerate strain development and improve strain productivity.

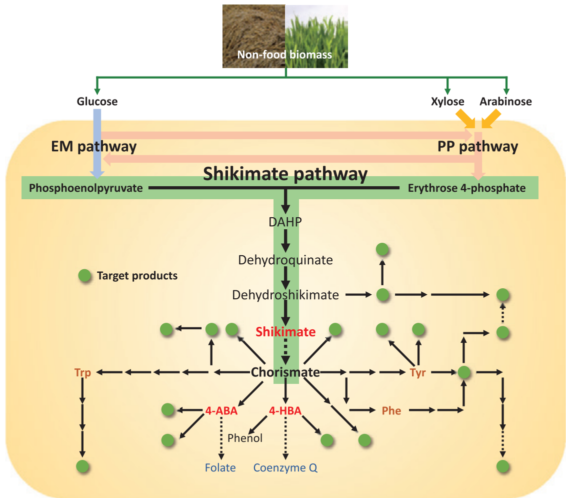


Fig. 8 : Biosynthetic pathway for various aromatic compounds

4.2. Expanding production technologies for various aromatic chemicals

Aromatic compounds are important industrial chemicals used for polymer synthesis and also a diverse group of value-added chemicals, which find applications in the pharmaceutical, nutraceutical, flavor, cosmetics, and food industries. While they are currently derived from petroleum or natural plant resources, their environmentally-friendly biotechnological production from renewable feedstocks is desirable from the viewpoint of creating a sustainable society that is no longer dependent on petroleum resources and that has efficient production processes. Bacterial cells synthesize various aromatic compounds, including amino ac-

5. Toward the industrialization of our technologies

5.1. Phenol / Aromatic compounds

Currently, commercial phenol can only be derived from petroleum. We took on the challenge to develop the world's first manufacturing bioprocess for biomass-derived phenol, which is considered to be difficult, to aid global environmental conservation and greenhouse gas reduction.

In May 2014, Sumitomo Bakelite Co., Ltd. and RITE established Green Phenol Development Co., Ltd. (GPD) to accelerate the industrialization of our biomass-derived phenol-producing technology called the "Two-Step Bioprocess" (Fig. 9). In April 2018, GPD changed its name to Green Chemicals Co., Ltd. (GCC) (see Topics).

Since GCC's phenol-producing technology and knowledge are applicable to the production of various other aromatic compounds, the establishment of each bioprocess for higher value-added chemicals and the commercialization of products matched with customers' needs are in progress.

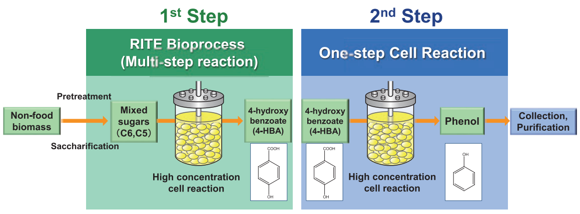


Fig. 9 : Biomass-derived phenol production by the Two-Step Bioprocess

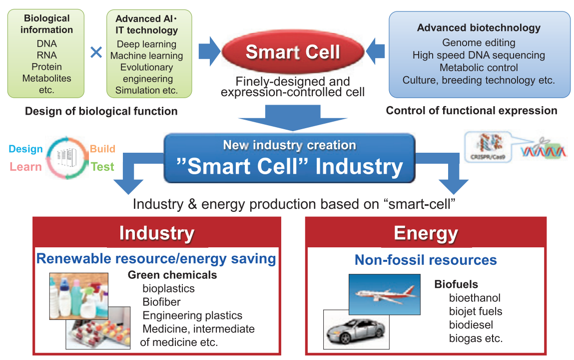
5.2. Amino acids

Normally, amino acid fermentation is carried out under aerobic conditions. This requires aeration and agitation to be properly controlled to attain high productivity, but this is often difficult to achieve in large-scale fermenters because the oxygen concentration inside them is not homogeneous. To overcome this problem, we have developed a new, genetically modified *Corynebacterium* strain for amino acid production in the RITE Bioprocess, allowing the production of amino acids to be 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 this technological hurdle and we published our research accomplishments in an international journal in 2010 (Appl. Microbiol. Biotechnol. 87: 159-165).

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

6.Closing remarks

METI announced 50,000 kL target of annual import volumes of foreign bioethanol for 5 years from 2018. Reduction standards for greenhouse gas (GHG) emissions in Japan were also revised, and diversification of suppliers has been made possible, so bioethanol produced in the U.S. may become available. In the green chemical sector, a new project in which biotechnologies are fused with digital technologies, such as the internet of things or artificial intelligence, was started by the Japanese government in 2018, and RITE has joined this project (see Topics). In this project, it is expected that biotechnology using Smart Cells, as described above, will perform a role as a core technology and create a wide range of spin-off effects for manufacturing technology in the industrial sector as well as the energy sector (Fig. 10).



Source: International trends for realization of Bioeconomy & efforts being by Japan (METI) 25 Sept. 2018

Fig. 10 : Fusion of industry and energy based on digital and biotechnologies

Our group continues to put efforts into technology development to achieve innovative green processes, using Smart Cells as a core technology, and through this research and development we hope to contribute to the formation of low carbon and sustainable societies.

Chemical Research Group

Shin-ichi Nakao
Group Leader,
Chief Researcher

[Key Members]

Keisuke Sugita, Deputy Group Leader, Chief Researcher
Koji Baba, Associate Chief Researcher
Katsunori Yogo, Associate Chief Researcher
Kenjiro Ishiguro, Senior Researcher
Teruhiko Kai, Senior Researcher
Kazuya Goto, Senior Researcher
Firoz Alam Chowdhury, Senior Researcher
Hidetaka Yamada, Senior Researcher
Shin Yamamoto, Senior Researcher
Makoto Ryoji, Senior Researcher
Fuminori Ito, Researcher
Tomohiro Kinoshita, Researcher
Nobuyuki Takayama, Researcher
Shuhong Duan, Researcher

Challenges Associated with the Advanced Industrialization of CO_2 Capture Technologies

1. Technologies for CO_2 capture

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

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

Specifically, we developed high performance chemical absorbents, and one such chemical absorbent with particular promise was selected for application in a commercial CO_2 capture plant owned by a private Japanese company and the second commercial plant started to work in July 2018.

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

Membrane separation is expected as an effective means of separating CO_2 from high-pressure gas mixtures at low cost and with low energy requirements. As a member of the Molecular Gate Membrane module Technology Research Association, RITE has been developing membranes and membrane elements using a novel dendrimer/polymer hybrid membrane called the molecular gate membrane to selectively capture CO_2 from pressurized gas mixtures containing H_2, such as those generated in the integrated coal gasification combined cycle (IGCC) at low cost and with low energy use. We are also developing membranes with large membrane areas using the continuous membrane-forming method and developing membrane elements for the mass production of membranes and membrane elements in the future. In addition, we have evaluated the separation performance and process compatibility of our membranes and membrane elements using coal gasification gas at the University of Kentucky - Center for Applied Energy Research (UK-CAER) in order to identify and then solve the technical problems of membranes and membrane elements. In addition, RITE joins the International Test Center Network (ITCN) and actively uses overseas networks towards the commercialization of CO_2 separation and recovery technology.

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

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

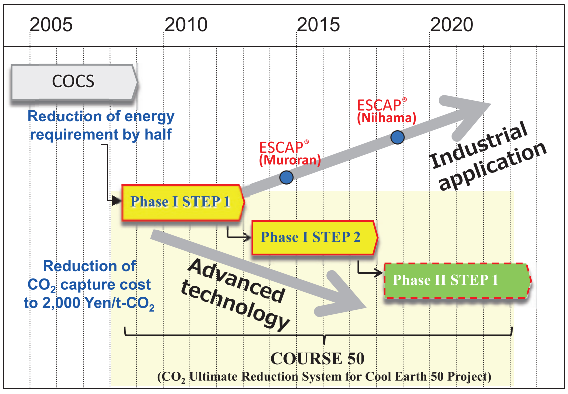


Fig. 1 : Timeline of CO_2 capture technology developments (absorption)

In the COURSE 50 project (entrusted by the National Energy Research Institute for New Energy and Industrial Technology Development [NEDO]), which began in 2008, developing CO_2 capture technology is responsible for two-thirds of the overall CO_2 reduction target. That means new results from RITE are highly anticipated.

In the Phase I Step 1 of COURSE 50 (FY 2008-2012), RITE achieved the target CO_2 capture energy consumption value of 2.0 GJ/t-CO_2. In addition, significant new absorbents were developed for CO_2 desorption at less than 100℃. This result represents an improvement over the current desorption temperature of 120℃. Beginning in FY 2013, the Phase I Step 2 was initiated and ran until FY 2017. During this work, RITE and Nippon Steel & Sumitomo Metal Corporation continued to develop new absorbents that had the potential to deliver high performance, and we clarified the mechanism of performance development and related factors of a high-performance solvent.

The latest R&D phase (Phase II Step 1) started in 2018. Based on the previous milestones, we are proceeding to develop advanced technologies in order to attain further innovative solvents (Fig. 2).

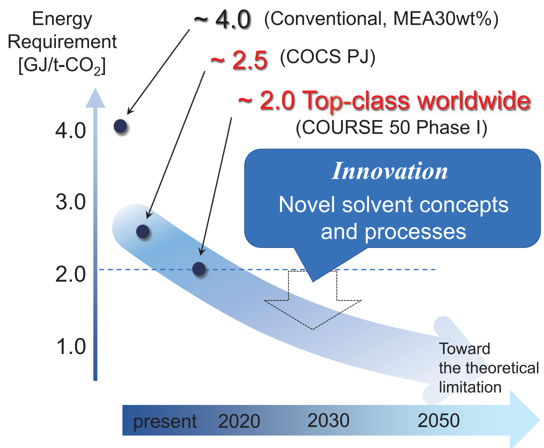


Fig. 2 : Challenge for higher performance solvents

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

Additionally, we have advanced the development of chemical absorbents for high-pressure gas mixtures containing CO_2 to obtain excellent CO_2 absorption and desorption performance. The purpose of these studies has been the research of highly efficient absorbents that enable CO_2 desorption while maintaining the high CO_2 partial pressure of the initial gas mixture. These are termed *high-pressure regenerable* absorbents. Using these novel absorbents, the energy consumption

Fig. 3 : Snapshot of the second commercial plant for supplying CO_2 as industrial gas
*The construction site is Sumitomo Joint Electric Power Co. Ltd. The photo is provided by Nippon Steel & Sumikin Engineering Co., Ltd..

during the CO_2 compression process following capture is significantly reduced owing to the high pressure of the captured CO_2.

Several new solvent systems designed previously have demonstrated high CO_2 recovery levels in conjunction with superior CO_2 absorption and desorption rates. These capabilities are in addition to a relatively low heat of reaction under high-pressure conditions above 1 MPa (Fig. 4). The total energy consumption rate for CO_2 separation and capture when using this process, including the energy required for compression, has been estimated to be less than 1.1 GJ/t-CO_2. (Absorption: 1.6 MPa-CO_2, desorption: 4.0 MPa-CO_2).

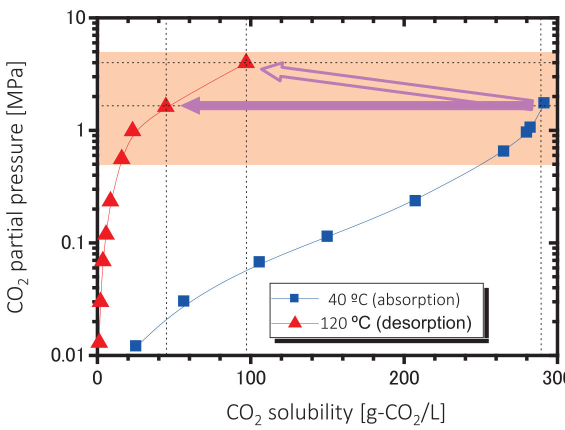


Fig. 4 : CO_2 pressure-solubility relationships for high-pressure regenerable absorbents

3. Solid sorbent technology

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

Novel amines synthesized by RITE have been employed for our developed solid sorbents (Fig. 6). We had introduced a functional group of specific configuration to a commercially available amine compound, and then RITE successfully fabricated innovative high-performance solid sorbents capable of low-temperature regeneration with high adsorption capacities. We have obtained U.S. and Japanese patents for these solid sorbents.

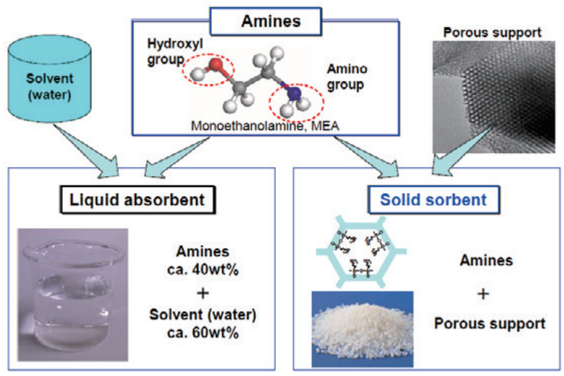


Fig. 5 : Liquid absorbent and solid sorbent

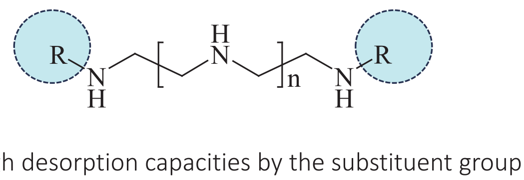


Fig. 6 : RITE Amine

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

Under a project aimed at the advancement of CO_2 capture technologies (R&D of Advanced Solid Sorbents for Commercialization) funded by METI since FY

2015 (since FY 2018, transferred to NEDO), we are conducting the optimization of materials for practical use, the optimization and the efficiency promoting of the solid solvent processes, and the construction of simulation technology for the system, additionally, working with Kawasaki Heavy Industries (KHI), Ltd., to develop a moving-bed system of bench-scale for coal combustion exhaust gas.

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

The solid sorbents prepared by the established method (10 m^3 scale) were evaluated by using a lab-scale fixed-bed test apparatus (Fig. 7). These tests were conducted by using the steam-aided vacuum swing adsorption (SA-VSA) process in which steam was supplied in a desorption process. The optimized operation process has shown that RITE solid sorbents are able to capture high-purity (> 99%) CO_2 from a simulated flue gas (12% CO_2) at high yields (> 90%) under 60℃. In this case, the energy consumption for regeneration steam at 60℃ was extremely low (< 1.2 GJ/t-CO_2), demonstrating that RITE solid sorbents had superior performance for CO_2 capture.

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

Currently, the bench-scale combustion exhaust gas test is underway by the moving-bed system installed at KHI using RITE solid sorbents prepared by the established method: the movement characteristic and the CO_2 capture performance of the solid sorbent are being evaluated. We also are improving equipment for high CO_2 purity, selecting suitable measuring devices for water in the gas, and extracting problems for actual gas testing. Thus far, we have achieved 5.5 t-CO_2/day as the scale of CO_2 capture (Fig. 8).

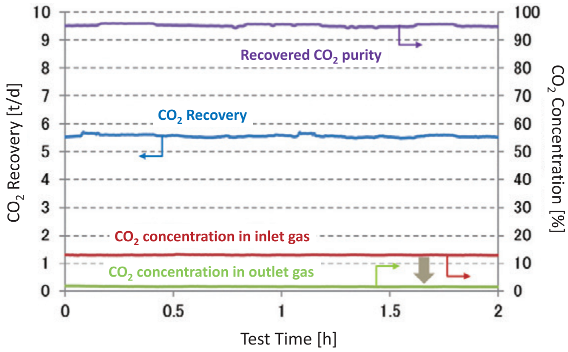


Fig. 8 : Result on bench-scale test for example

We plan to build a pilot-scale plant of 40 tons-CO_2/day in a coal-fired power station, and a practical exhaust gas test will be carried out (announced September 2017). We are working on the R&D roadmap to establish a solid sorbents system that has much higher performance in the capture of CO_2 from coal fired power generation (Fig. 9).

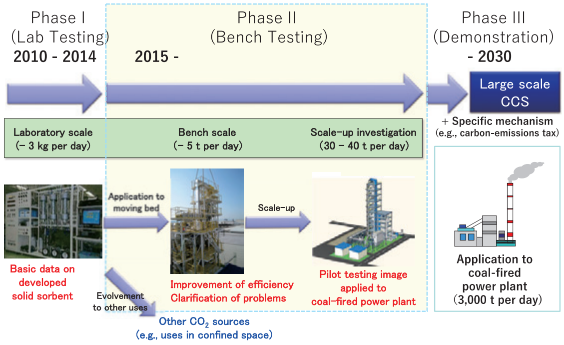


Fig. 9 : Project roadmap

4. CO_2 and H_2 separation using polymeric membranes

The Japanese government announced the Cool Earth 50 project in May 2007 with the aim of reducing the country's CO_2 emissions to half the current amount by 2050. One promising means of lowering CO_2 emissions is the development of Integrated coal Gasification Combined Cycle with CO_2 Capture and Storage (IGCC-CCS) using CO_2 selective membranes (Fig. 10). For this reason, we are currently developing novel CO_2 selective membrane modules that effectively separate CO_2 during the IGCC process.

We found that novel polymeric membranes composed of dendrimer / polymer hybrid materials (termed molecular gate membranes) exhibit excellent CO_2/H_2 separation performance. Fig. 11 presents a schematic that summarizes the working principles of a molecular gate membrane. Under humidified conditions, CO_2 reacts with the amino groups in the membrane to form either carbamate or bicarbonate, which then blocks the passage of H_2. Consequently, the amount of H_2 diffusing to the other side of the membrane is greatly reduced, and high concentrations of CO_2 can be obtained.

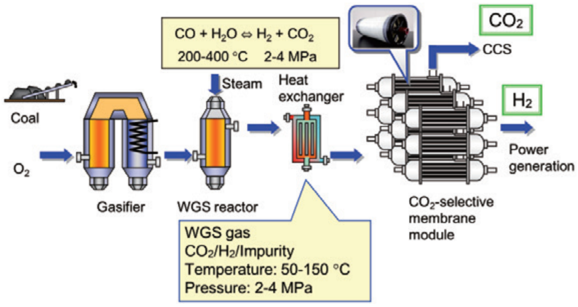


Fig. 10 : Schematic of the IGCC process with CO_2 capture by CO_2 selective membrane modules.

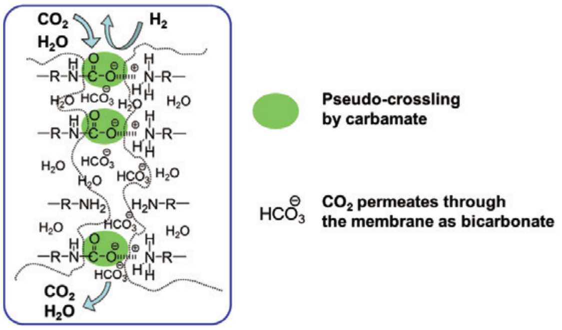


Fig. 11 : Schematic illustration of the working principles of the molecular gate membrane.

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

Based on this work, the Molecular Gate Membrane module Technology Research Association (MGMTRA; consists of Research Institute of Innovative Technology for the Earth [RITE] and a private company) is researching new membranes, membrane elements (Fig. 12), and membrane separation systems.

Based on the achievements of the project by the Ministry of Economy, Trade and Industry (METI), Ja-

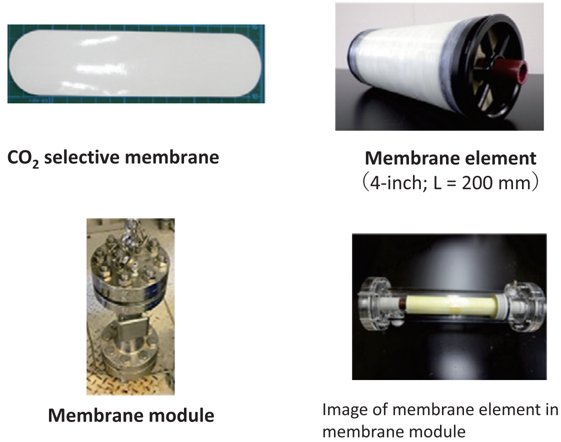


Fig. 12 : CO_2 selective membrane, membrane element, and membrane module.
Membrane element: The structure with large membrane area composed of the membrane, support, and spacer, etc.
Membrane module: The structure in which the membrane element is placed.

pan, CO_2 Separation Membrane Module Research and Development Project (FY 2011-2014) and CO_2 Separation Membrane Module Practical Research and Development Project (FY 2015-2018) in the current NEDO project, CO_2 Separation Membrane Module Practical Research and Development (FY 2018-), we are developing membranes with large membrane areas by a continuous membrane-forming method and developing the membrane elements. We started to conduct pre-combustion CO_2 capture tests using real gas from the coal gasifier of the University of Kentucky Center for Applied Energy Research (UK-CAER) in the U.S. to examine the separation performance and robustness of membranes and membrane elements.

To improve the CO_2 separation performance of the membranes by the continuous membrane-forming method, membrane preparation conditions were optimized to reduce membrane thickness, and the membranes were produced by the continuous membrane-forming method under optimized conditions. The relationship between relative thickness and CO_2 permeance and CO_2/He selectivity is shown in Fig. 13.

It was found that CO_2 permeance was improved without decreasing CO_2/He selectivity.

A long-term CO_2 separation test of the membrane was conducted at 2.4 MPa to evaluate the durability of the membrane under high pressure. The result is shown in Fig. 14. CO_2 separation was stable for at least 600 h.

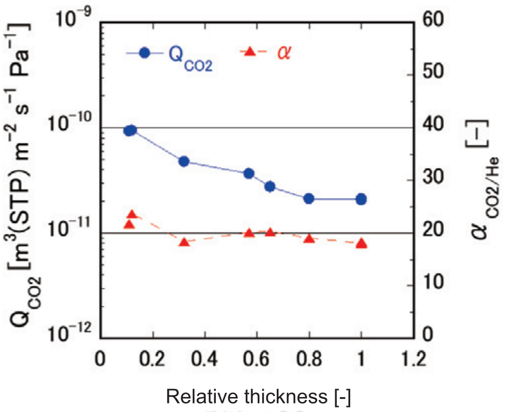


Fig. 13 : Relationship between relative thickness and CO_2 permeance and CO_2/He selectivity.
Operating conditions: Temperature: 85°C, feed gas composition: CO_2/He = 40%/60%, feed gas pressure: 2.4 MPa, relative humidity in feed: 60% RH, permeate gas pressure: atmospheric pressure.

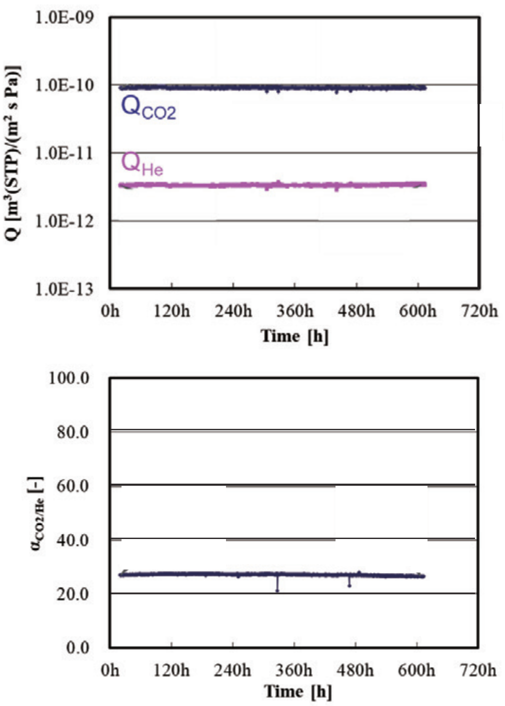


Fig. 14 : CO_2 separation performance of the membrane as a function of time
Operating conditions: Temperature: 85°C, feed gas composition: CO_2/He = 40%/60%, feed gas pressure: 2.4 MPa, relative humidity in feed: 60% RH, permeate gas pressure: atmospheric pressure.

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

5. Conclusion

In December 2015, the Paris Agreement was adopted at COP 21.* To meet the conditions of the agreement, it is essential to promote innovative ways to dramatically reduce emissions on a worldwide basis. In April 2016, Japan released the National Energy and Environmental Strategy for Technological Innovation toward 2050. In addition, in September 2017, a technical roadmap for 2050 was formulated. The capture and effective use of CO_2 were identified as promising technologies. Innovative CO_2 separation and recovery technologies contain medium- and long-term targets related to technological improvements that will reduce the energy used in separation and recovery by half (<1.5 GJ/t-CO_2) . In the technical roadmap, CO_2 separation and recovery technologies plan to be demonstrated at the system level around 2030, and then become popular around 2050. Furthermore, at the Round Table for Studying Energy Situations in April 2018, it is reportedly important to continue to tackle the issues for practical application of CCS both in the industrial sector and the electric power sector.

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

*COP 21: 2015 United Nations Climate Change Conference

CO_2 Storage Research Group

Ziqiu Xue
Group Leader,
Chief Researcher

[Key Members]

Nakaba Matsuda, Deputy Leader, Chief Researcher
Makoto Nomura, Chief Researcher
Nobuo Takasu, Associate Chief Researcher
Takahiro Nakajima, Associate Chief Researcher
Takeshi Myoi, Associate Chief Researcher
Keisuke Uchimoto, Senior Researcher
Ryozo Tanaka, Senior Researcher
Saeko Mito, Senior Researcher
Yi Zhang, Senior Researcher
Tetsuma Toshioka, Senior Researcher
Makoto Nishimura, Senior Researcher
Hironobu Komaki, Senior Researcher
Yuji Watanabe, Senior Researcher
Kazutoshi Hiwaki, Senior Researcher
Tsutomu Hashimoto, Senior Researcher
Atsushi Ibusuki, Senior Researcher
Nobutoshi Shimizu, Senior Researcher
Osamu Takano, Senior Researcher
Yasuhiro Okabayashi, Senior Researcher
Hyuck Park, Researcher
Takuma Ito, Researcher
Luchen Wang, Researcher
Takayuki Miyoshi, Researcher
Yankun Sun, Researcher
Hongyu Zhai, Researcher
Masafumi Kotani, Researcher

Research and Development on Geological CO_2 Storage for Safe CCS Operation

1. Introduction

The GHGT-14 Conference was held in Melbourne Australia in October 2018 and had more than 800 presentations on CCS. The event reiterated the importance of CCS as a countermeasure against global warming. Among global CCS news in 2018, it is noteworthy the USA, where the Trump Administration had decided to withdraw from the Paris Agreement, renewed the Section 45Q in a way that incentives for CCS is strengthen by increasing tax credits for geological CO_2 storage. In Europe, CCS-related activities are moving forward slowly. But the UK has taken a firm step toward CCS deployment, publicizing an action plan to enable the first CCUS facility to be operational by the mid-2020s. In developing countries, in particular, in China, where large-scale CCS project is making progress, efforts against climate change are anticipated to become more active.

In China, CCS projects are driven mainly by CO_2-EOR but the nation has a lot of oilfields where it is difficult to produce additional oil by conventional CO_2-EOR techniques due to low permeability. To improve the efficiency of CO_2 injection, the CO_2 Storage Research Group in collaboration with Tokyo Gas has been conducting R&D on microbubble technology, which draws attentions domestically and internationally. With the background, we concluded an agreement on licensing its microbubble technology with Junlun Petroleum Company in November 2018. We expect microbubble technology to have more and more opportunities to be employed in real projects such as CO_2-EOR operation in low-permeability oilfields in future.

The CO_2 Storage Research Group, as a member of the Geological Carbon Dioxide Storage Technology Research Association (GCS), works on various R&D under the NEDO-funded project titled "the Research and Development of on Geological CO_2 Storage Technology for Safe CCS Operation". In the project, we put the focus on R&D on improvement not only in operationability but also in safety. The most challenging themes include how to set out appropriate criteria to judge whether offshore CO_2 leakage occurs because it is difficult to differentiate the phenomenon from natural variation in water. In order to identify such optimal criteria by acquiring and analyzing field data, we are currently monitoring CO_2 concentration in seawater continuously in an offshore field.

The CO_2 Storage Research Group also engages in international collaboration and the survey of CCS development in the globe. We hosted an international

CCUS roundtable in collaboration with C2ES in Washington DC, USA, in February 2019. In addition, we work closely with the Tomakomai CCS demonstration project in pursuit of earlier CCS commercialization.

2. Major Research Themes and Outcomes

2.1. Development of Geological Modeling Techniques for Geological CO_2 Storage

Reducing geological uncertainties is a key factor to make large-scale CO_2 geological storage technically available. The effective ways to achieve this include further data acquisitions and appropriate data integration. Drilling new wells is, however, not an option suitable for the purpose due to financial constraints and associated risks of CO_2 leakage. Well data available to estimate the spatial distribution of reservoir parameters such as porosity and permeability is generally limited. To estimate these geological properties, techniques to utilize 2D/3D seismic data have been investigated in these decades. The approaches include attribute analysis such as the spectral decomposition. In 2018, as a technique for mapping one-dimensional well-log data into a three-dimensional space, we examined the machine-learning (ML) approach.

ML consists of sequential processes of (i) mechanically learning or identifying a relationship between existing data of a targeted property and those of a different kind of data, and (ii) estimating unknown data of the targeted property, corresponding to new data of the different kind, based on the relationship identified. In our study for the CO_2-injection demonstration site in Nagaoka, we used its seismic data as input data and its porosity profiles measured along wells as a target property to create seismic attribute volumes . Once developing a machine learning-based model of porosity along the wells, we attempted to estimate porosity distribution in an area away from the wells. The ML model used in this feasibility study was a fully-connected neural-network model, shown in Fig. 1(a). Accuracy of the model depends on the number of deeper hidden layers. Due to the mismatch of data intervals between seismic data and well-log data, the seismic data with wider data intervals are interpolated along the wells, and the well-log data with the narrower data intervals are smoothed in order to equalize the data frequencies and to maximize the accuracy of learning process.

In ML, learning processes proceed in a way of reducing training errors, which are differences between estimated properties and observed ones. Data not used for training can be used for validation, which has the potential of improving in the quality of estimation for targeted properties. In the ML approach for porosity distribution along the wells at the Nagaoka site, we, therefore, used 75 percent of the input data for training, and the remaining 25 percent for validation. The Fig. 1(b) shows the mean-absolute errors between the estimated data and the observed ones for training (blue) and validation (orange) data. The two sets of the errors have a similar trend, which indicates that the developed neural-network model has an appropriate capability to estimate the property.

We applied the developed porosity distribution along the wells to the estimation of the spatial distribution of porosity for the Nagaoka site. A three-dimensional view of the reservoir and a two-dimensional section including the observation and injection wells are depicted in Fig. 2. In the two-dimensional section, the porosity data acquired at the wells are superimposed on the well locations. In the estimated distribution of porosity, there is a high porosity area (red and warm

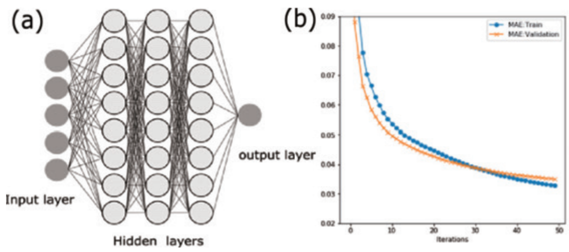


Fig. 1 : (a) The schematic diagram of the fully-connected neural-network model, (b) MAE for training and validation data.

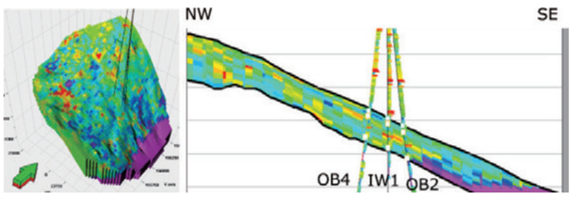


Fig. 2 : Estimated porosity model for CO_2 reservoir layers

color) in a thin layer at a middle depth of the reservoir and also a relatively high porosity area in the shallow part of the reservoir (the CO_2 injection intervals) in the northwest direction of the wells.

The ML is composed of the relatively simple steps and its processing time is short. The approach is, therefore, an effective technique to develop geological models for evaluating storage capacity and/or analyzing CO_2 injection scenarios in a site-screening/selection period. To build more accurate geological models, we plan to use deep-learning techniques including a 2D/3D convolutional neural network model, which have been remarkably advanced in recent years. The CO_2 storage research group is investigating further optimum processes to build more appropriate geological models.

2.2. Development of a Comprehensive System for Detection of CO_2 Leakage and Environmental Impact Assessment

For offshore CO_2 geological storage in Japan, marine monitoring is mandatory to confirm that stored CO_2 does not leak into the sea and to detect CO_2 leakage as soon as possible should it occur. Besides, the fact that monitoring is been carried out is important from the point of view of public acceptance.

When CO_2 goes out from the seabed, it is presumably in the form of bubbles, but CO_2 bubbles dissolve in seawater quickly after the release. The CO_2 Storage Research Group has been studying and developing methods to find CO_2 bubbles in the water column and to detect anomalous values of partial pressure of CO_2 (pCO_2) in seawater, which is an index of the concentration of CO_2 dissolved in seawater. The section here introduces our study of a threshold method for the judgement of anomalous pCO_2 using covariance between pCO_2 and the percentage Dissolved Oxygen saturation (DO(%)) with the focus on baseline data required.

We have analyzed data observed in Osaka Bay, a semi-enclosed bay in Japan, where Osaka Prefecture has observed several variables at fixed points for over 40 years on a quarterly basis (February, May, August and November). Among the data, we have used data between 2002 and 2010.

Dissolved CO_2 exists in natural seawater any time and its indicator pCO_2 fluctuates in a certain range. In methods to detect CO_2 leakage based on values of pCO_2, false-positives (misjudging data elevated due to natural variability as anomalies) and false-negatives (overlooking CO_2 leakage) are almost inevitable. High threshold values make false-positives decreased but false-negatives increased, whereas low threshold values make false-negatives decreased but false-positives increased. Thus, we should estimate the rates of false-positives and false-negatives. In this study, the upper limit of the 95 % prediction interval of the linear regression of pCO_2 on DO(%) is set out as the threshold, the false-positive rate of which is theoretically 2.5 %.

CO_2 leakage data are not included in the analyzed data as no CO_2 has been stored underneath Osaka Bay. Hence, we can regard the data exceeding the threshold line as the false-positives. Fig. 3a is a scatter plot of pCO_2 vs DO(%), with the 95 % prediction interval range (the green dashed lines) based on the all data acquired in a period of 9 years. There are 15 data plotted over the upper limit of the prediction interval (the threshold line). As the total number of the data is 465, the rate of false-positive is 3.2 %, which is close to but higher than the theoretical rate of 2.5 %. Threshold lines made with less data can, however, result in extremely high occurrence of false-positive. We made threshold lines based on data in a certain period of 1 year out of the 9-year data acquisition period, and compared all the 9-year-period data with each of the threshold lines. The highest false-positive rate, which is 49.2 %, appears in a case shown in Fig. 3b. The black crosses in the figure, which were used to make the threshold line (the upper black dashed line), are plotted mostly in the lower half part of the distribution area of all pCO_2 data for the 9 years. As a result, their 95% prediction interval is far narrower than that of the 9-year-period data and their threshold line (the upper black dashed line) is also lower than that of the 9-year data (the upper green dashed line). These results indicate that the threshold line has a possibility of confusing high-value data due to natural fluctuation with anomalies for every two measurements, although the theoretical false-positive rate is only 2.5%. The lowest false-positive rate in this study is 1.1 % in the case shown in Fig. 3c. The false-positive rate in this case is low, but its threshold line is relatively high, which would make it difficult to detect CO_2 leakage. We should keep it in mind that a threshold line with a low false-positive rate is not always good.

In the same way, we made threshold lines using N-year-period data (1≦N≦8). There are $_9C_N$ ways to select N years from the 9 years, for each of which we determined a threshold line and then calculated its false-positive rate (Table 1). For small numbers of N, false-positive rates have a higher potential of being much larger than theoretical 2.5 %. These results suggest that it is required to use data for 4-6 years or more to set out an adequate threshold line.

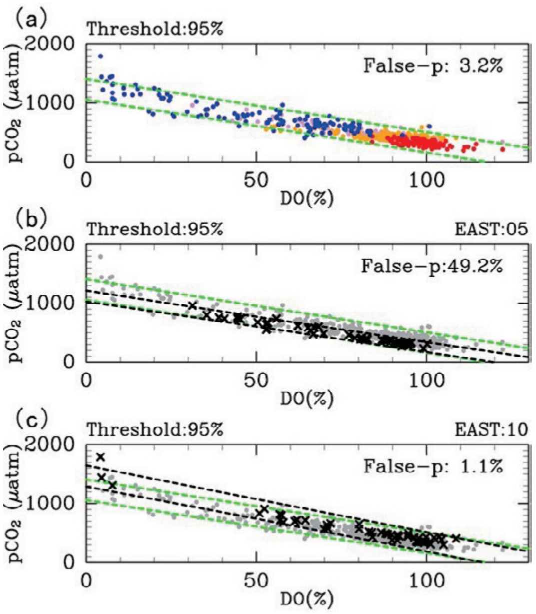


Fig. 3 : Scatter plots of pCO_2 vs DO% with (a) all 9 years data (red: February, pink: May, blue: August, orange: November) and the 95 % prediction interval based on them (the green dashed lines), (b) data of 2005 and (c) 2010 (crosses) and the 95 % prediction interval based on them (black dashed lines).

Table.1 : False-positive rates

years(N)	$_9C_N$	False-positive(%)
1	9	1.1～49
2	36	1.3～20
3	84	1.5～12
4	126	1.7～8.8
5	126	1.7～7.1
6	84	1.9～6.0
7	36	2.2～5.1
8	9	2.5～3.8
9	1	3.2

We have been conducting continuous observations of pCO_2 and DO in Osaka Bay since summer in 2018. By analyzing the continuously-observed data, together with the data seasonally acquired for 9 years, we will attempt to identify adequate frequencies and durations of baseline surveys for determining a threshold line to judge whether CO_2 leakage occurs or not at offshore CO_2 storage sites.

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

At the In Salah project site in Algeria, ground uplift around the injection wells due to CO_2 injection and subsidence due to the production of natural gas were observed. In fluid injection operation, if formation deformation becomes significant under inappropriate pressure management, caprock seal can be breached, which affects the safety of CO_2 geological storage. In order to understand how pressure buildup in a target formation caused by fluid injection affects the displacement of the ground surface, it is desirable to monitor from the deep underground to the earth surface continuously in a depth direction. For the vertically-continuous monitoring of underground displacement, conventional sensors are not practical because it is required to determine their exact installation locations and depths in advance and because it is far from easy work to embed so many sensors in field. These challenges can be solved for the vertically-continuous data acquisition when distributed optical fiber sensing technology is employed . In this section, we introduce results of laboratory experiments to show the effectiveness of monitoring geological deformation with optical fiber sensing technology.

Figure 4 shows a unique composite sandstone sample that has a physical system of a deep underground reservoir and a seal layer. In the laboratory experiments with the sample, the behavior of CO_2 under reservoir pressure and temperature conditions was visualized with a medical X-ray CT apparatus. CO_2 was injected to the coarse-grain part (a reservoir) at the left end of a sandstone sample. The fine-grain part at the right of the sample had a lower permeability and played a role of a caprock seal that had a function of keeping the injected CO_2 in the coarse-grain part. When injection pressure exceeded a shielding threshold of the fine-grain part, CO_2 entered the fine-grain part. The sandstone sample had a helically-twined optical fiber on its surface for monitoring rock deformation in the coarse-grain part during CO_2 accumulation and its mechanical influence on the fine-grain part.

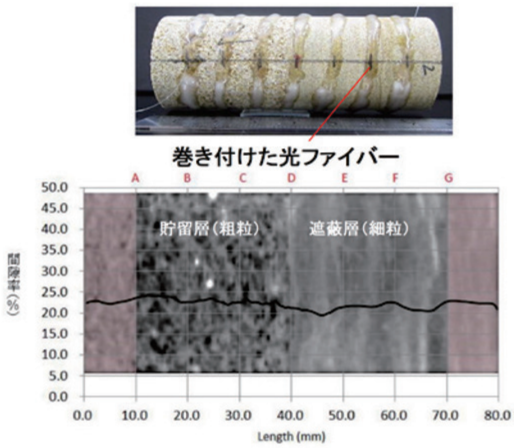


Fig. 4 : A sandstone sample with a helically-twined optical fiber and its X-ray CT image

Figure 5 shows the distribution of CO_2 saturation and the strain along the longitudinal direction of the sandstone sample as CO_2 gradually accumulated in the coarse-grain part since the injection commenced. CO_2 saturations were calculated based on the X-ray CT images and the strains of the rock were measured by the optical fiber. CO_2 was initially injected from the left end of the sample under a driving pressure that was less than the sealing threshold. The CO_2 plume was confined within the approximately-45 mm-long left part by the boundary between the coarse- and fine-grain parts However, slight expansion was observed in the section between 50 and 60 mm. This means that although the caprock seal was slightly deformed, the CO_2 in the reservoir was tightly trapped. After the injection pressure was elevated, CO_2 broke into the caprock seal. The strains in the seal part increased abruptly after the CO_2 percolation (see Fig. 6). The results indicate that it is possible to monitor the mechanical stability of the caprock and the leakage of CO_2 from the reservoir with an optical fiber installed in a monitoring well.

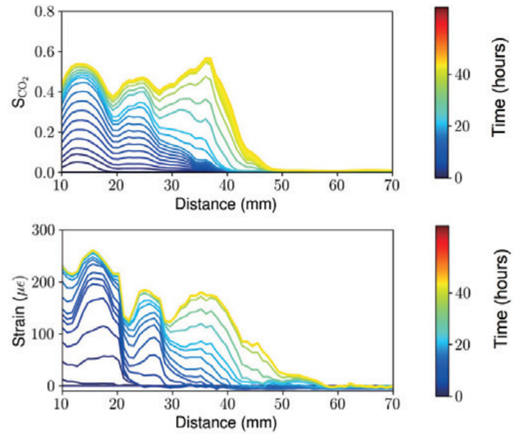


Fig.5 : Distribution of CO_2 saturation and expansive strain along the axis direction of the sandstone sample

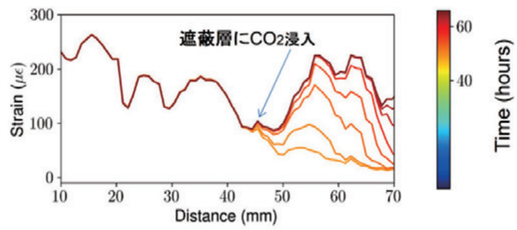


Fig. 6 : A sharp increase in strain accompanying the entry of CO_2 into the caprock seal

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

RITE contributes to CCS deployment through collaboration with international organizations and frameworks for CCS and also conducts a survey of CCS development in the world. Here are highlights in global CCS development and international frameworks in 2018:

(1) Highlights in Global CCS Development

In the UK, an expert task force formed by the government publicized a strategy proposed for CCS deployment in July 2018. Its major message is that the most effective way of CCS deployment is to promote CCS in the form of clusters, core of which are expendable shared infrastructures for CO_2 transport and storage. The strategy presents 16 recommendations with an assumption of commissioning at least two CCS clusters in the mid-2020s with the aim of full CCS deployment in the 2030s. It is noteworthy that it states private-sector-driven CCS deployment is achievable if the deployment is put forward as clusters and if adequate business models and risk allocations are identified. Following the publication, the government announced an action plan regarding CCS in November 2018. The action plans is based on the task force's recommendations, but the number of cluster to be commissioned in the mid-2020s is only one. This lists 19 actions, which can be categorized broadly into those for commissioning the first project and those for deploying CCS at scale in the 2030s.

In Norway, the Industrial CCS project has been considered and the number of its CO_2 sources was reduced from three to two. Its front-end engineering design (FEED), however, got a green light officially in the parliament in May 2018. The project adopts a shared infrastructure for CO_2 ship transport and offshore storage. Its final invest decision is due in the fiscal 2020.

What are often referred to as a pioneer of such shared infrastructures are CO_2 pipeline networks for enhanced oil recovery (EOR) in the USA. In the country in February 2018, a scheme of tax credits which is given in proportion to volume of CO_2 geologically stored was updated to raise the values of credits to be given. Prompting multiple new CO_2 capture projects to be explored, the amendment is expected to accelerate CCS deployment.

(2) Highlights in CCS International Frameworks

CCS shared infrastructures draw attentions globally and a task force on infrastructures was formed in an international framework, the technical group of the Carbon Sequestration Leadership Forum (CSLF) in a meeting held in October 2018. What was agreed there is that the task force will review the current status of shared infrastructures and that the technical group will discuss, based on outcomes, whether to continue the task force. If its continuation is agreed, the task force will develop a plan of its activities. In the October meeting, there was an election of vice chairs for the technical group and Japan was elected together with Australia and Canada. We are expected more to contribute to the international CCS community from the perspectives of Japan and also Asia.

In a ministerial meeting held in June 2018 under the framework of the Clean Energy Ministerial (CEM), it was formally agreed to launch a CCUS initiative that has been proposed by the USA in 2017. The initiative plans to work on improving the awareness of CCS in the community of clean energy and activating communications between the CCS community and the financial community.

The mission innovation, which is an international framework with the aim of doubling public investment in clean energy R&D over five years, publicized a report on CCS in May 2018. The report presents prioritized areas of innovative R&D in the four areas: CO_2 capture, storage, use and cross-cutting. The CCS community is now required to make great efforts to deploy CCS with existing technologies and also to undertake R&D for step-change reduction in CCS costs in order to further accelerate CCS deployment.

Inorganic Membranes Research Center

Shin-ichi Nakao
Director,
Chief Researcher

[Key Members]

Yuichiro Yamaguchi, Deputy Director, Chief Researcher
Hidetoshi Kita, Chief Researcher
Hitoshi Nishino, Chief Researcher
Katsunori Yogo, Associate Chief Researcher
Makoto Ryoji, Senior Researcher
Hye Ryeon Lee, Researcher
Masahiro Seshimo, Researcher
Hajime Nakano, Researcher
Bo Liu, Researcher

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

1. Introduction

Inorganic membranes, such as silica membranes and zeolite membranes, have the features of heat resistance and environmental resistance, in addition to their high separation performance, and are expected to be applicable to a variety of applications. Moreover, it is possible to achieve significant energy savings, and development is also being promoted for hydrogen separation and purification applications essential for CO_2 separation and recovery applications for hydrogen society construction compared to conventional separation and purification methods, such as the distillation and adsorption methods. And, it attracts a great deal of attention as an environment and energy technology that contributes to conservation of the global environment. However, practical application has been limited to such uses as dehydration of alcohol; from now on, efforts to promptly commercialize and industrialize innovative environmental and energy technologies using inorganic membranes are required.

The Inorganic Membranes Research Center (IMeRC) was established in April 2016 to promote the activities of research and development and industrial collaboration as the bilateral aim for the early commercialization and industrialization of innovative environmental and energy technologies using inorganic membranes. The organization comprises the Research Division and the Industrial Collaboration Division. In the Research Division, silica membranes, zeolite membranes, palladium membranes, which have superior features in each, are used as the core technology for hydrogen separation, purification, and recovery. We are working in the research fields of the effective use of CO_2. In the Industrial Collaboration Division, in order to share the vision of manufacturers and user companies and to plan and draft collaborative research at the Industrialization Strategy Council, which consists of the inorganic separation membrane and support manufacturer and 18 user companies, member companies meet regularly to actively promote the work of the research groups.

In 2018, in the development of membrane reactor for methylcyclohexane (MCH) dehydrogenation as an efficient transportation and storage technology of hydrogen, we developed the silica film with the world's highest hydrogen separation performance, and the seal structure between metal and ceramics. In addition, progress was also made in efforts related to carbon capture and utilization (CCU), which was newly adopted as the New Energy and Industrial Technology Development Organization (NEDO) project. In addition, at the industrial strategy council, activities such as a research group for the start-up of government expenses business etc. are full-scale. In this paper, we

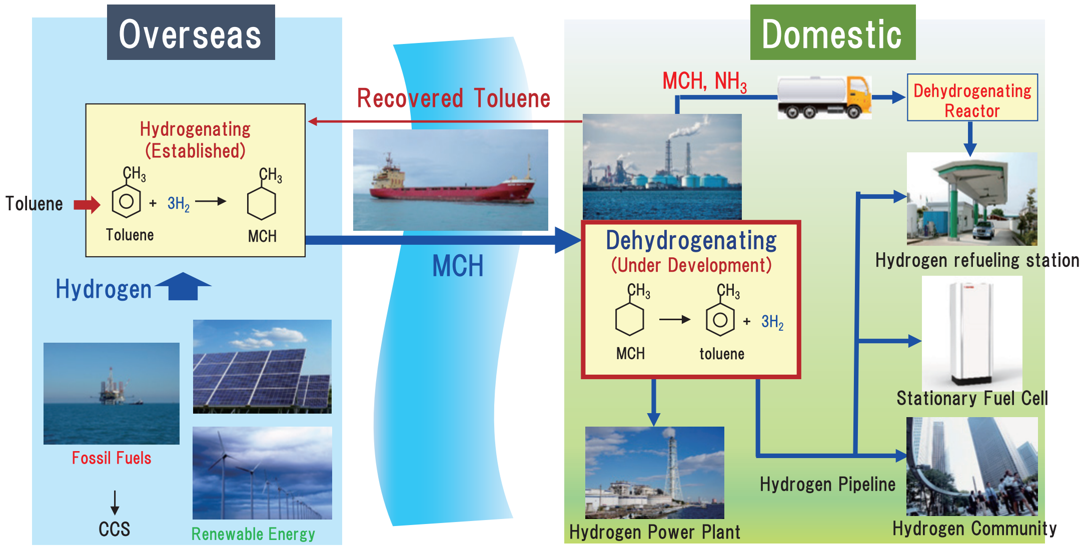


Fig. 1 : Energy Carrier

will introduce main results of the research department such as development of MCH dehydrogenation membrane reactor and development of CCU technology, future prospects, and activities of the industrialization strategy council.

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

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

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

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

The membrane reactor uses the principle that equilibrium is shifted to the product side, and conversion is improved when a separation membrane is inserted into the reaction field. Since the reaction takes place under high temperature and high pressure, the membrane must be durable under these conditions.

This work is funded by NEDO as part of the Advancement of Hydrogen Technologies and Utilization Project for the analysis and development of hydrogen as an energy carrier and the development of a dehydrogenation system using inorganic hydrogen separation membranes for organic chemical hydrides in collaboration with Chiyoda Corporation.

In order to improve the performance of the silica membrane, it is necessary to have high hydrogen permeability (H_2 permeance) and not pass molecules other than hydrogen (separation coefficient α = H_2 permeance / SF_6 permeance is large), but in general, permeance and the separation factor α are in a trade-off relationship. The IMeRC developed silica membranes providing the world's top-level performance (permeance > 3.5×10^{-6} (mol / m^2 sec Pa), separation factor of α 63,000) with good reproducibility by breaking down the phenomena of this tradeoff into individual factors (Fig. 2).

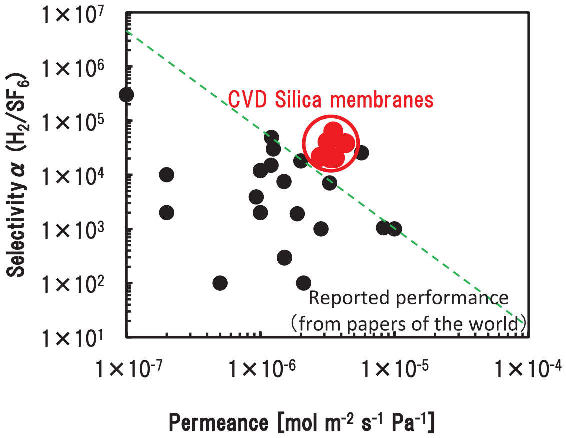
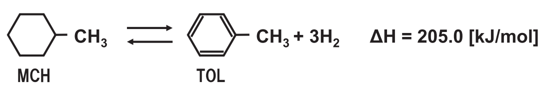


Fig. 2 : Performance of silica membranes

In the membrane reactor study, the improvement in the reaction efficiency of the dehydrogenation reaction from the MCH using several silica membranes of 200-500 mm was confirmed. The mechanism is illustrated in Fig. 3. When MCH is fed into a reaction where a hydrogen separation membrane and a catalyst are set, MCH is dehydrated into toluene and hydrogen by an equilibrium reaction, but only the generated hydrogen passes through the hydrogen separation membrane and is separated from the reaction field. Because the product is removed from the reaction field, the reaction shifts to the product side, and the conversion of hydrogen production is improved. At the same time, the hydrogen passing through the separation membrane becomes high purity hydrogen that does not contain toluene, so that hydrogen purification and improvement in the reaction efficiency simultaneously



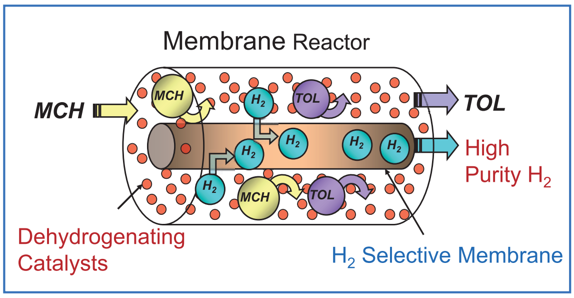


Fig. 3 : Diagram of a tubular single membrane reactor

proceed in a compact reactor.

In order to verify this phenomenon on an actual scale, we designed and fabricated a test apparatus composed of 3 x 500 mmL silica membranes (Fig. 4) and collected a variety of engineering data. As a result, it was verified that a remarkable equilibrium shift was confirmed using 500 mmL silica membranes, and a conversion rate of 95% or more, which was significantly higher than the equilibrium conversion rate of 42.1%, was obtained (Fig. 5).

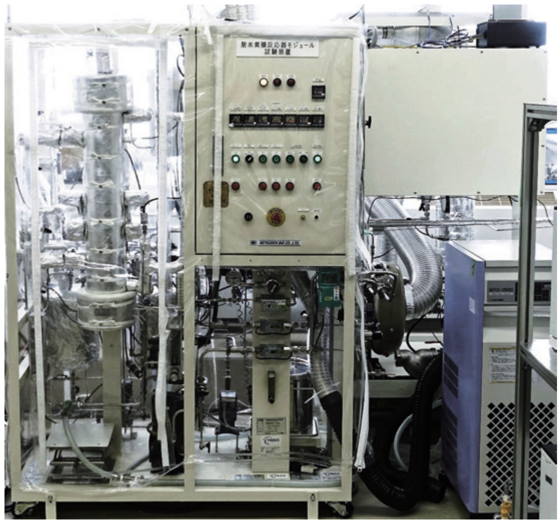


Fig. 4 : Membrane Reactor for Silica Modules

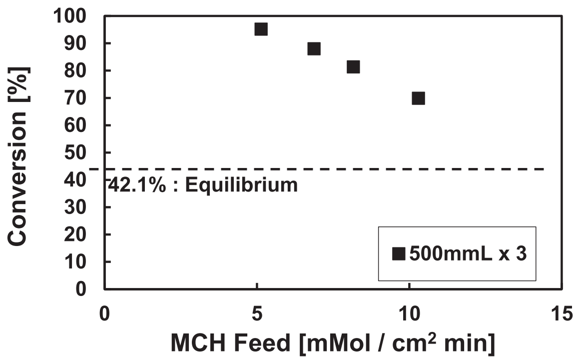


Fig. 5 : Operation result of the bench-scale membrane reactor

However, this study of the membrane reactor revealed the problem of sealing at the same time. In a membrane reactor, it is necessary to have airtight seals for the ceramic membranes with a metallic reactor, but since the expansion coefficient differs between metal and ceramics, rubber seals, such as O rings, have been adopted, so that the ceramics do not break. However, since the reaction field is exposed to organic solvents of MCH and toluene at high temperature and high pressure, a durability problem was found with the rubber seals.

The sealing structures were investigated, and the module structure was developed, which provides durability for pressure, temperature, and solvent, even at 300℃, and was easy to attach to and detach from the reactor. The developed prototype module with the structure is shown in Fig. 6.

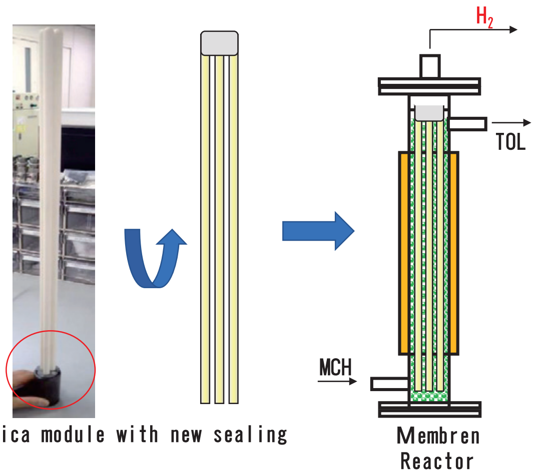


Fig. 6 : Silica membrane module using glass binder and reactor

The prototype silica module was made to bundle 500 mm L × 3 silica membrane tubes using a glass binder to bond the ceramics to metal with different expansion coefficients, and airtightness was confirmed at 300℃ and 500 kPa-G.

Through these studies, RITE has demonstrated that hydrogen generation from MCH can be designed compactly in a membrane reactor using a high performance silica membrane on the bench scale.

We continue to study and demonstrate the durability of a silica membrane and silica module to further accelerate the practical application.

3. Development of CCU Technology

To the end of fiscal year 2019, RITE, JFE Steel Corporation, the Institute of Applied Energy (IAE), INPEX Corporation, and Hitachi Zosen Corporation collaborate in the technological development of next generation thermal power generation, next generation thermal power development of power generation infrastructure technology, and the development of technology for effective utilization of CO_2 as a project of NEDO.

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

Therefore, in this project, we aim to establish promising future CCU technologies in anticipation of fiscal year 2030 and beyond and can further grant industrial competitiveness to Japan's excellent clean coal technology (CCT). We plan to establish a comprehensive evaluation of CCU technologies for the effective use of CO_2 in the product manufacturing process and system with the aim of establishing CCU technology. We plan to develop highly stable zeolite membranes, and investigate a membrane reactor for methanol synthesis. In addition, Prof. Kita (Yamaguchi University) works for the development of inorganic membranes, such as carbon membranes, and Prof. Hasebe (Kyoto University) works for process development work toward the same end.

4. Development of pure silica CHA type zeolite membrane

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

As shown in Fig. 7, the CO_2/CH_4 separation performance of the Si-CHA membrane shows a CO_2 permeation rate of 4.0 × 10^{-6} mol/m^{2}sPa or more and a CO_2/CH_4 permeation rate ratio of 100 or more. It shows better separation than the previously reported zeolite membranes. In addition, even when exposed to water vapor, there was no change in permeation performance, and since it had water vapor resistance, it is considered a membrane structure more suitable for practical use. To further increase the separation performance of Si-CHA membranes, it will be necessary to optimize the module structure and the method of introducing the supply gas into the module.

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

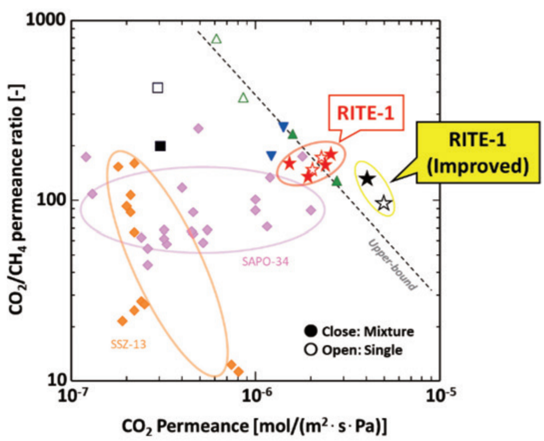


Fig. 7 : CO_2/CH_4 separation performance of Si-CHA membrane

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 January 2019, eighteen selective membrane and support manufacturers and user companies participate in this Council. Our goal is to establish an inorganic membrane industry that contributes to innovative environmental and energy technologies by promoting a common vision for manufacturers and user companies, as well as a joint research plan involving national projects and other initiatives.

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

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

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

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

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

e) Hosting exclusive technology seminars for council members

f) Offering exclusive supply services (needs and seeds technology information) to council members

As for the Research Group activities, we have been conducting various activities of the following three Research Groups set up in November 2016,

a) CO_2 Separation Research Group

b) Hydrogen Production Research Group

c) Common Base (Reliability Evaluation Method) Research Group

In fiscal 2018, we conducted deep surveys and studies through activities by both the Research Group and its subsidiary research workshop (each Research Group had four to five meetings, respectively, up to the end of 2018), and they are preparing for projects with the goal of practical application funded by the government. Hydrogen production and common base research groups are jointly aiming for projects funded by the government to start in FY 2019 by providing requests for information (RFI) to NEDO.

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

As an overseas investigation activity, we conducted a study tour of Nanjing University of China and the university related industrial area in May and four of the three council member companies participated. (Fig. 8) At Nanjing Tech University, we were able to deepen technical exchanges with lecturers as the Japan and China symposium of inorganic membranes. In the university related industrial area, we were very impressed by China's strong enthusiasm for industrialization of inorganic membranes.

Fig. 8 : Overseas investigation activity (Nanjing Tech University)

In December 2018, a two-day training workshop was held at RITE. Lectures included an outline of RITE, membrane separation technologies, and hydrogen separation CVD Si membrane; in addition, experimental membrane formation methods and guidance on performance and evaluation methods for prepared membranes were provided in the workshop. Two young researchers from two companies took part in the workshop. They were able to examine the most advanced CVD Si membrane experiment methods and gain valuable experience. (Fig. 9)


Fig. 9. : Exclusive training workshop for young researchers at IMeRC

We also conduct patent and literature surveys related to the seminar lectures and periodically provide council members with needs and seeds technology information and special comments from the IMeRC in the abstract.

In addition, we support the various activities of council members in promoting the practical use and industrialization of inorganic membranes by providing a summary of remarkable lectures with RITE comments on the 15th International Conference on Inorganic Membranes (ICIM 2018), which is one of the most popular international conferences related to inorganic membranes.

6. In conclusion

Three years have passed since the IMeRC was established, and in 2018, the organization steadily achieved results in research and development that involved hydrogen production, transportation and storage, and the effective use of CO_2. Activities toward commercialization and industrialization of research and development results are also full-fledged, and it can be said that the foundation as a center is solidifying. We would like to continue working diligently to become a core organization leading the development and practical application of inorganic membranes in the world in the future.

Research & Coordination Group

Environmental Education with CCUS Video Game

RITE has been conducting environmental education for younger generation, who is responsible for the future, through organizing workshops and engaging in school curriculum such as accepting visits from neighboring schools and offering guest seminars etc, where we provide lectures with science experiments and games. In 2018 summer, we organized a lecture combining with a video game so that children could learn about CCUS (Carbon dioxide Capture, Utilization and Storage) technology with fun.

This video game, produced by the Global Industrial and Social Progress Research Institute [GISPRI] (in collaboration with Daiko Advertising Inc.) to be exhibited at the Japan Pavilion under the theme of "Future Energy" at the International Expo 2017 held in Astana, the capital of the Republic of Kazakhstan, introduces CCUS through animation and game. GISPRI offered us to use the game during the summer, and we utilized it in the workshops for elementary school children and as a part of the programs for the junior high / high school students who visited RITE during this period. About 140 students in total experienced the game.

The aim of the game is to collect red balls resembling CO_2 by touching the screen and compete in ranking according to the number of CO_2 collected in a team. The children tried playing the game again and again to gather as many CO_2 balls as possible and got excited when they marked a higher ranking. We gained many favorable comments about the game from the participants, such as "it was great to learn with fun through the game," or "I enjoyed the game, which helped me understand the technology called CCUS."

As CCUS is generally unfamiliar to young people, it is important to first let them know the name and the rough idea of the technology. Therefore the video game, which includes the animated explanation of CCUS, must have been a great help for the participants to grasp the image of CCUS.

Research & Coordination Group

Symposium in Kansai on Global Warming Mitigation Technology for Future Society

RITE annually hosts Innovative Environmental Technology Symposium in Tokyo to present our latest research progress and achievements, and this year another symposium was held in Kansai first time in nine years for more participation from the region.

At the symposium, Prof. Yoshiyuki Shimoda, Osaka University, gave a special lecture on the appearance of low-carbon urban society in the future focusing on the perspective of the energy consumption in residential and commercial sectors where drastic energy saving measures are to be taken for mitigating global warming, and then we reported the latest achievements and future plans of our R&D activities regarding global warming mitigation technologies. Many people answered the event as useful according to the feedback collected from the audience, which shows that the symposium in Kansai was a good opportunity to introduce our research activities to the people in the region.

Date: 26 September 2018

Venue: Osaka Science & Technology Center (OSTEC)

Organized by RITE

Supported by Kansai Bureau of Economy, Trade and Industry (METI-KANSAI); Kansai Economic Federation (KANKEIREN); The New Industry Research Organization (NIRO); the Chemical Society of Japan (CSJ); The Society of Chemical Engineers, Japan (SCEJ); Japan Society for Bioscience, Biotechnology, and Agrochemistry (JSBBA); Japan Society of Energy and Resources (JSER); the Japan Institute of Energy (JIE)

Number of participants 156

Program

- Special lecture: Future outlook of low-carbon urban society
  Prof. Yoshiyuki Shimoda,
  Graduate School of Engineering, Osaka University
- Strategy to respond climate risks and role of countermeasure technologies based on the Paris Agreement
  Keigo Akimoto, Group Leader,
  Systems Analysis Group
- Development of biorefinery production technology toward realization of carbon cycle society
  Masayuki Inui, Group Leader,
  Molecular Microbiology and Biotechnology Group
- Development of highly efficient CO_2 separation and capture technologies in RITE
  Katsunori Yogo, Associate Chief Researcher,
  Chemical Research Group
- Current status and challenges for deployment of CO_2 geological storage technologies
  Ziqiu Xue, Group Leader,
  CO_2 Storage Research Group
- Activities of Inorganic Membranes Research Center to contribute to low-carbon society
  Yuichiro Yamaguchi, Deputy-Director,
  Inorganic Membranes Research Center

Research & Coordination Group

GHGT-14 Participation Report

The 14th International Conference on Greenhouse Gas Control Technologies (GHGT-14) was held in Melbourne, Australia on October 21st - 25th 2018. The conference series are held every two years as the principal international conference on greenhouse gas mitigation technologies especially focusing on CCS.

More than a thousand delegates from around the world had active discussions on 12 themes in 71 technical sessions. Among them, 27 sessions were about storage (including other storage options) and 20 were about capture, which accounted for 70 percent of all. The researchers from RITE delivered 8 oral presentations and 9 poster presentations in either storage or capture sessions. Also Dr. Xue, Group Leader of CO_2 Storage Research Group, acted as a chairperson for the "Tracking the Plume in the Reservoir" storage session.

As the IPCC Special Report on Global Warming of 1.5℃ had been published on October 8th just before the GHGT-14, how to deal with the issue especially regarding CCS was one of the topics of attention. Ms. Thelma Krug, Vice Chair of IPCC, explained in her keynote speech in the Opening Plenary that CCS would be required along with high efficiency, electrification, use of hydrogen and biomass and that CO_2 zero emission would be impossible without CCS in cement manufacturing etc. although it does not necessarily mean that the 1.5℃ target cannot be achieved without CCS. In the closing session "The CCS Narrative", there were discussions on the importance to communicate the significance of CCS to external communities.

The 5-day conference concluded with the announcement that the next GHGT-15 would be held in Abu Dhabi, United Arab Emirates in 2020.

Systems Analysis Group

FY2017 ALPS International Symposium Toward long term, deep emissions reductions

The Paris Agreement entered into force in November 2016, establishing a new international framework in which almost all nations should make efforts to reduce GHG emissions beyond 2020 through submitting their own reduction target. As to long term efforts, each nation is requested to submit its low emissions development plan to UN by 2020, and correspondingly discussions are becoming active to explore long term (beyond 2050) response strategies/measures to climate change. Under recognition of various risks of climate change, ALPS International Symposium was held to disseminate the research achievements of the project. Lectures were presented by eminent specialists from the various viewpoints such as the necessity of net zero CO_2 emission for a long term, the gap between the future goal and the current situation, the importance of risk management and the necessity of technological innovation.

Date 9 February 2018
Venue Toranomon Hills Forum (Tokyo)
Organization RITE
Co-organization METI
Number of participants 310
Program

・Toward long term, deep emission reductions -Needs of developing sectoral ZE technologies-
  Yoichi Kaya, President, RITE
・"Carbon Law" for deep emissions reductions and sustainable development
  Nebojsa Nakicenovic, Deputy Director General/ Deputy CEO, IIASA
・Some thoughts on global climate risks and the Paris goals
  Seita Emori, Chief,
  Climate Risk Assessment Research Section, NIES
・The state of the global energy transition: lessons from the IEA's World Energy Outlook
  Laura Cozzi, Head of Division,
  Energy Demand Outlook, IEA
・Misusing the Future
  Roger Pielke Jr., Professor, University of Colorado
・Net-Zero Emissions: the most actionable climate target
  Oliver Geden, Head of EU/Europe Division, SWP
・Techno-economic analysis of the decarbonisation of power mix in Europe - and particularly in France - by 2050
  Pascal Da Costa, Professor,
  Ecole CentraleSupelec - University Paris Saclay
・Climate change response strategy toward long-term zero CO_2 emissions
  Keigo Akimoto, Group Leader,
  Systems Analysis Group, RITE

Systems Analysis Group

International Workshop on Low-demand Scenarios

Although the Paris Agreement requires massive CO_2 emissions reduction, achieving 2℃ or 1.5℃ targets is extremely challenging. Actually model analyses estimate MAC in 2100 at around 1000$/t$CO_2$, with considerable reliance on BECCS. Given that, it is extremely important to consider potentials of transition to a society with lower energy demand without impairing utility.

In September, RITE and IIASA jointly held an international workshop to discuss opportunities and challenges for realizing a society with lower energy demand.

Participants from broader research fields worldwide pointed out opportunities for lowering energy demand by car-sharing or ridesharing which are expected to be induced by further development of IT and its expansion, as well as for reducing GHG emissions throughout the entire course from supply to consumption of food. Discussion indicated considerable potentials for transition to lower energy services and accompanying emissions decrease, thus need for researches focusing on technologies and actions in the demand side.

Summary of the workshop was uploaded at a Japanese official website for the Talanoa Dialogue "Talanoa Japan", introducing RITE's research effort to achieve the long-term goal of the Paris Agreement.

Date September 25 to 27, 2018
Venue Todaiji Culture Center (Nara)
Number of Participants 21

Systems Analysis Group

COP24 Side Event Mitigation Policy Choices and Levels of Effort

The RITE side events at COP24 in Poland were held both in Japan Pavilion and UNFCCC side event, to address scientific estimates of impacts of Nationally Determined Contributions (NDCs) on economy and international competitiveness.

After an introduction by Dr. Kopp of RFF, Dr. Akimoto presented RITE's analyses of comparison of emissions reduction in NDCs, arguing that marginal abatement costs (MAC) are considerably different among nations and globally total cost is much higher than ideally optimum cost due to social and political constraints. He also presented the importance of NDCs coordination through review processes because large differences among MACs may cause carbon leakage.

Speakers including Mr. Sieminski (KAPSARC), Dr. Flannery (RFF), Mr. Tezuka (KEIDANREN), Ms. Takeuchi (IEEI), and Prof. Arima (the University of Tokyo) pointed out the poor reality of high carbon pricing, importance of emissions reduction from product usage in Global Value Chain, cultivation of conditions for businesses to invest, and importance of various technology development or innovation.

Date 11 December 2018
Venue COP24 Japan Pavilion
Organization RITE
Co-organization RFF

Date 13 December 2018
Venue COP24 UNFCCC side event
Organization RITE, RFF

Molecular Microbiology and Biotechnology Group

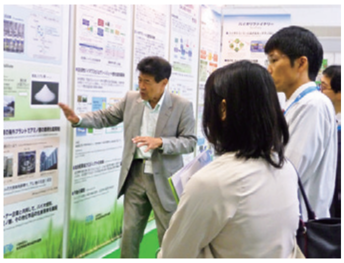
BioJapan 2018

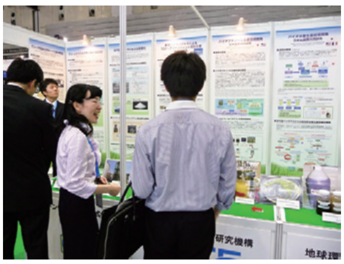
The World Business Forum "BioJapan 2018" was held at PACIFICO Yokohama on October 10-12, 2018, and it was jointly conducted with Regenerative Medicine JAPAN 2018 for the third consecutive year. The number of visitors was 15,133 in 2016, 15,711 in 2017, and 16,309 in 2018, the latter of which was the largest ever number of attendees. RITE had a joint booth at the exhibition in collaboration with Green Chemicals Co., Ltd.# (GCC).

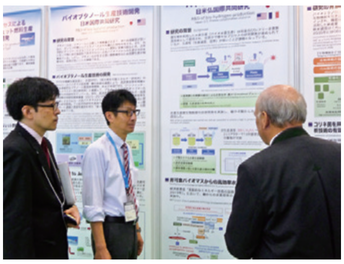
#Green Phenol Development Co., Ltd. (GPD) changed its trade name to Green Chemicals Co., Ltd. on April 1, 2018.

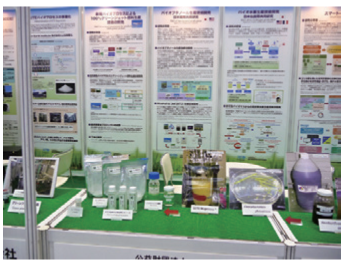
1. In the booth, we introduced our key technologies, as well as our current projects funded by METI and NEDO. We also explained the activities of Green Earth Institute Co., Ltd. (GEI), giving examples of the commercial uses of the RITE Bioprocess, and technologies to produce green-aromatic compounds, together with our introduction to GCC. We displayed the following posters in the exhibition booth.
   1) RITE Bioprocess, a key technology for biorefinery from non-food biomass
   2) "Smart Cell" project
   3) R&D of biohydrogen production
   4) R&D of bio-butanol production
   5) R&D for a novel bioprocess for production of 100% green jet fuel
   6) Industrialization of RITE Bioprocess
   7) Green Chemicals Co., Ltd. (GCC)
   8) New trends for biotechnological production of green-aromatic compounds

2. We also had exhibits that included various samples and pictures, such as several types of non-food biomass; amino acids, such as L-alanine and L-valine that are commercial products made by GEI using the RITE Bioprocess; GEI's ethanol for cosmetics; and green phenolic moldings from GCC.
   We would like to extend our appreciation to those who attended this event and visited our booth.







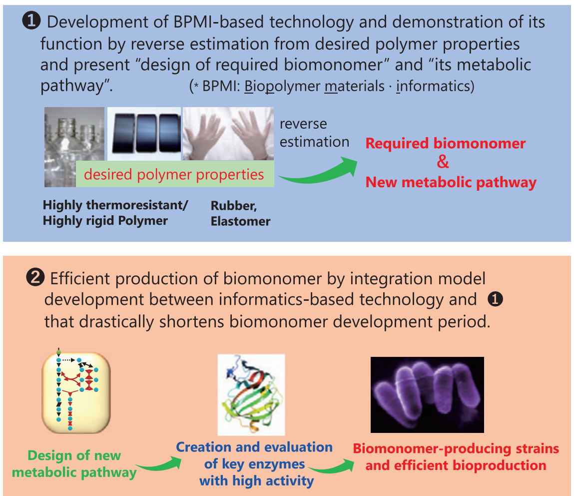


Molecular Microbiology and Biotechnology Group

Participation in Cross-ministerial Strategic Innovation Promotion Program (SIP)

SIP is a national project for science, technology, and innovation, spearheaded by the Council for Science, Technology and Innovation as it exercises its primary function to accomplish its role in leading science, technology, and innovation beyond the framework of government ministries and traditional disciplines.

In this project, we will develop informatics-based technology to accelerate the development of innovative biomaterials and highly functional polymers. Traditionally, desirable “polymer properties” were obtained by trial and error, but the “biopolymer materials informatics” (BPMI) approach that will be developed in this project enables the presentation of biomonomers and design of new, artificial metabolic pathway by reverse engineering from desired polymer properties. Furthermore, through the creation and evaluation of key high-activity enzymes and the development of biomonomer-producing strains, we aim to realize efficient bioproduction with a shorter development time of about a quarter of the time taken using conventional methods.



Development of informatics-based technology to accelerate development of innovative biomaterials / highly functional polymers by SIP

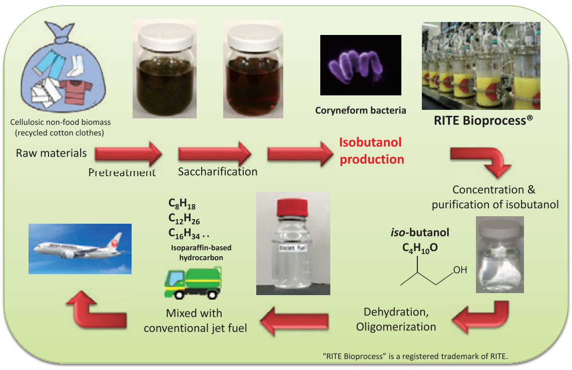
Molecular Microbiology and Biotechnology Group

Collaboration with the JAL biojet fuel flight project

Aviation is responsible for 2% of worldwide anthropogenic CO_2 emissions. Since it is difficult to replace jet fuel with electricity, biojet fuel made from non-food biomass as a raw material is expected to contribute to solving the global warming problem without causing food shortages. Given these circumstances, RITE began technical cooperation with the Japan Airlines Co., Ltd. (JAL) project “Let’s fly with 100,000 used clothes!” in October 2018.

This project aims to produce biojet fuel from used clothes collected from across the country by JAL and JEPLAN, INC. Ltd. In 2020, JAL aims to launch a charter flight using this biojet fuel. The Green Earth Institute Co., Ltd., which was established in 2011 for industrialization of RITE Bioprocess, is participating in this project and is responsible for the production of isobutanol from cotton fibers in used clothes, and for producing biojet fuel conforming to international standard ASTM D7566 Annex 5.

Corynebacterium glutamicum R, which was developed by RITE, is a key component in the production of isobutanol. It is possible to use the RITE Bioprocess® to efficiently produce isobutanol from sugars after the saccharification of used cotton fibers, which is an innovative bioprocess invented by RITE.



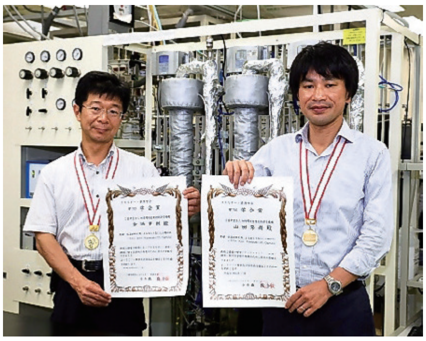
Chemical Research Group

Win the 7th Award of Japan Society of Energy and Resources

Dr. Katsunori Yogo and Dr. Hidetaka Yamada won the seventh Award of the Japan Society of Energy and Resources with their collaborators from Kawasaki Heavy Industries, Ltd., (KHI) for the study on the energy-saving CO_2 capture system. This award is given to researchers who have made remarkable achievements in the development, analysis, and investigation of technologies and systems that contribute to the progress of the academic fields of energy, resources, and the environment.

For conventional CO_2 capture technologies using aqueous amine solvents, CO_2-loaded solvents are heated above 100℃ for regeneration. Thus, the process operation requires a lot of energy. The solid sorbent method developed by the winners realizes significant energy savings by using amine-modified porous materials with low specific heat when compared to the conventional solvent method. Furthermore, a novel amine invented by RITE makes it possible to use waste heat of ca. 60℃ because of its high ability even at low temperature.

Currently, RITE's solid sorbent is applied to KHI's moving-bed system. So far, a capture amount exceeding 5 t per day has been achieved by using 60℃ steam and KHI's bench-scale plant equipped with the coal combustion furnace. By steadily demonstrating the energy-saving CO_2 capture system using low-temperature waste heat that we developed, it is expected that the CCS cost will be greatly reduced, leading to early CCS deployment.



Chemical Research Group

8th Symposium for Innovative CO_2 Membrane Separation Technology

The Molecular Gate Membrane module Technology Research Association (MGMTRA) is conducting a project entrusted by NEDO to develop a low-cost innovative CO_2 separation membrane for high-pressured gas from IGCC. In this symposium, lectures were given on the recent results of CO_2 separation membrane technologies by MGMTRA along with an overview of the CO_2 separation technologies overseas. A total of 179 people attended, including government, university, and company officials.

Date: Friday, January 18, 2019

Place: Ito hall, The University of Tokyo

Program:

< Plenary lecture >

・"On the goal of global warming mitigation" Prof. Yoichi Kaya PhD, President of RITE

< Invited lecture >

・"New Amine-Based Membranes for Post- and Pre-Combustion CO_2 Capture " Prof. W.S. Winston Ho, The Ohio State University

・"CO_2 capture with membranes : lessons learned from field trials in the USA " Dr. Tim Merkel, Membrane Technology and Research, Inc. Vice President of Technology

・"On the progress of field testing of Osaki CoolGen oxygen-blown IGCC with CO_2 capture" Mr. Kenji Aiso, President of Osaki CoolGen Corporation

< Lecture >

・"On R&D of next-generation membrane modules by MGMTRA" Prof. Shin-ichi Nakao PhD, Senior Managing Director of MGMTRA

・"Latest trend in CO_2 separation technologies overseas" Dr. Teruhiko Kai, MGMTRA

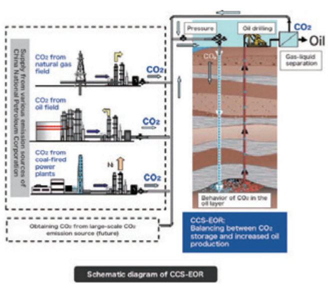
CO_2 Storage Research Group

License Agreement with Junlun Petroleum Company on a Patent Technology for Microbubble CO_2 Injection

At the 12th Japan-China Energy Conservation and Environment Forum held in Beijing in November 2018, RITE and Tokyo Gas Co., Ltd concluded a license agreement on our developed-microbubble CO_2 injection technology with Junlun Petroleum Company, Chinese technology service company for oil production.

In depleted oilfields, a new technique called CO_2-EOR（Enhanced Oil Recovery） is occasionally applied to increase oil recovery by injecting large volume of CO_2 into oil formations to improve the mobility of oil. The technology licensed in the agreement has the potential of having higher oil recovery because it is to inject CO_2 as microbubbles, which potentially enter low-permeability oil formations.

Junlun Petroleum Company has high-level technologies for heavy oil production and operates business with China National Petroleum Corporation (CNPC) in the area, but faces difficulties in oil production in low permeability oilfields. Applying the patent technology to such oilfields, the company plans to increase oil production in China. Wider deployment of CO_2-EOR through the technology licensing will contribute to the reduction of CO_2 emissions and the mitigation of the global warming.



Schematic diagram of CO_2-EOR

CO_2 Storage Research Group

CCS Technical Workshop 2019

In the CCS Technical Workshop 2019, our invited international experts shared their expertise on the current status of CCS policies and regulations and up-to-date risk assessments on CO_2 leakage and microseismicity in the context of public perception There was also a presentation to update the status of R&D in the Geological Carbon Dioxide Storage Technology Research Association (GCS).

Date 16 January 2019
Venue Toranomon Hills Forum (Tokyo)
Organization Geological Carbon Dioxide Storage Technology Research Association (GCS)
Co-organization Ministry of Economy, Trade and industry / New Energy and Industrial Technology Development Organization (NEDO)
Number of Participants 362

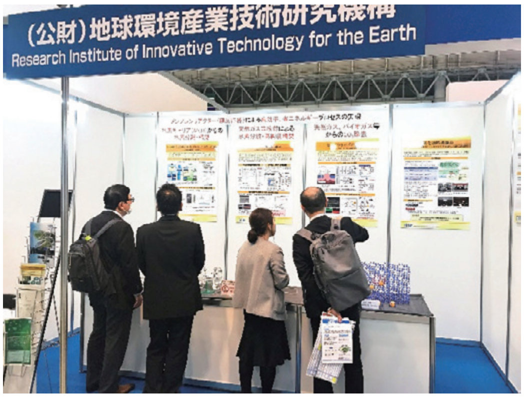
Program

・Talk1: Current States of Legislation and Regulation on CCS
Tim Dixon, IEA Greenhouse Gas R&D Programme
・Talk2: CO_2 Risk Assessment on Leakage at CO_2 Storage Site
Katherine Romanak,
The University of Texas at Austin
・Talk3: Progress and Challenges in Risk Management at CCS Sites: US Perspective
Joshua White,
Lawrence Livermore National Laboratory
・Talk4: Developments on Microseismic Monitoring and Risk Assessment of Large-scale CO_2 Storage
Bettina Goertz-Allmann, NORSAR
・Talk5: Progress of R&D in the Geological Carbon Dioxide Storage Technology Research Association (GCS)
Ziqiu Xue, GCS, Japan

Inorganic Membranes Research Center

Highly Functional Ceramics Expo

The third Highly Functional Ceramics Expo, organized by Reed Exhibitions Japan Ltd., was held at Makuhari Messe from 5-7 December 2018. 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 employing inorganic membranes into practical and industrial use. Over 130 people, including potential user companies, came to the RITE booth and discussed the use and advantages of inorganic membranes when applying the ordinary process. We will put the opinions of the attendees to good use in future R&D activities and in strengthening industrial collaborations. Finally, we would like to thank all visitors for coming.



RITE exhibition booth


Symposium

Inorganic Membranes Research Center

Inorganic Membrane Environment and Energy Technology Symposium to Explore the Future

This symposium focused on the latest trends in hydrogen energy uses and inorganic membranes and efforts to put it into practical use, lectures by NEDO, universities and companies, as well as the latest research by the IMeRC. We introduced the results and efforts of the Industrialization Strategy Council as an opportunity to think about promoting the development of innovative environmental and energy technologies using inorganic membranes and creating the inorganic membrane industry together with participants.

We received favorable comments from visitors, such as “I understood the international trend of inorganic membranes, and I realized that they are practical technologies in the near future.”

Program

- Keynote Lecture ①: The latest trend in hydrogen energy utilization
  Daishu Hara, Director, Advanced Battery and Hydrogen Technology Department, Fuel Cell and Hydrogen Technology Group, NEDO
- Lecture ①: Development Status of SOFC toward the commercialization in the market
  Kazuo Ieyama, Executive Officer,
  Business and Product Department,
  Hitachi Zosen Corporation
- Keynote lecture ②: Present state and new development of nano / subnano porous silica membrane
  Toshinori Tsuru, Professor,
  Hiroshima University Graduate School of Engineering
- Lecture ②: Feature and application of high silica CHA type zeolite membrane
  Takahiko Takewaki, Principal Scientist,
  Mitsubishi Chemical Corporation Yokohama R&D Center
- Activity report: Research results of inorganic membrane research center and plan for the future
  Shin-ichi Nakao, Director, IMReC, RITE

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.
23 Jan. 2018	**CCS Technical Workshop** ・Venue: Iino Hall ・Organizer: Geological Carbon Dioxide Storage Technology Research Association (GCS) ・Number of participants: 320	CO_2 Storage Research Group
9 Feb. 2018	**FY2017 ALPS International Symposium** ・Venue: Toranomon Hills Forum ・Organizer: RITE ・Number of participants: 310	Systems Analysis Group
13 Feb. 2018	**7th Symposium for Innovative CO2 Membrane Separation Technology** ・Venue: Ito Hall ・Organizer: Molecular Gate Membrane module Technology Research Association (MGMTRA) ・Number of participants: 179	Chemical Research Group
26 Sep. 2018	**Symposium in Kansai on Global Warming Mitigation Technology for Future Society** ・Venue: Osaka Science & Technology Center ・Organizer: RITE ・Number of participants: 156	Research & Coordination Group
6 Nov. 2018	**Inorganic Membrane Environment and Energy Technology Symposium to Explore the Future** ・Venue: Ito Hall ・Organizer: RITE ・Number of participants: 136	Inorganic Membranes Research Center
19 Dec. 2018	**Innovative Environmental Technology Symposium 2018** ・Venue: Ito Hall ・Organizer: RITE ・Number of participants: 430	Research & Coordination Group
16 Jan. 2019	**CCS Technical Workshop 2019** ・Venue: Toranomon Hills Forum ・Organizer: Geological Carbon Dioxide Storage Technology Research Association (GCS) ・Number of participants: 362	CO_2 Storage Research Group
18 Jan. 2019	**8th Symposium for Innovative CO_2 Membrane Separation Technology** ・Venue: Ito Hall ・Organizer: Molecular Gate Membrane module Technology Research Association (MGMTRA) ・Number of participants: 179	Chemical Research Group

Exhibitions

Dates	Event Description	Related Dept.
10-12 Oct. 2018	**BioJapan 2018** ・Venue: Pacifico Yokohama ・Organizer: BioJapan Organizing Committee, JTB Communication Design, Inc.	Molecular Microbiology and Biotechnology Group
5-7 Dec. 2018	**3rd Highly Functional Ceramics Expo** ・Venue: Makuhari Messe ・Organizer: Reed Exhibitions Japan Ltd.,	Inorganic Membranes Research Center

Press Releases

Date	Title
5 Jan. 2018	Announcement of ALPS International Symposium
3 Jul. 2018	Announcement of Symposium in Kansai on Global Warming Mitigation Technology for Future Society
7 Sep. 2018	Announcement of Inorganic Membrane Environment and Energy Technology Symposium to Explore the Future
26 Oct. 2018	Announcement of Innovative Environmental Technology Symposium 2018
15 Nov. 2018	Announcement of CCS Technical Workshop2019
15 Nov. 2018	Announcement of 8th Symposium for Innovative CO_2 Membrane Separation Technology
28 Nov. 2018	License Agreement with Junlun Petroleum Company on a Patent Technology for Microbubble CO_2 Injection

Environmental Education

◇Facility Visit Program and Lecture

Date	Place	Participants	Number of participants
18 Jan.	RITE	Seikaminami Junior High School	5
29 Jan.	RITE	Kizugawadai Elementary School	37
20 Feb.	Seikaminami Junior High School	Seikaminami Junior High School	54
22 Mar.	RITE	Nara Prefectural Institute for Educational Research, Career Seminar for High School Students	3
1 May	RITE	Narakita High School	39
18 May	RITE	Seika Junior High School	11
13 Jul.	RITE	Tezukayama Junior High School	25
3 Aug.	RITE	Nishimaizuru High School	40
27 Aug.	RITE	Todaijigakuen Junior High School	27
27 Aug.	RITE	Kaisei Junior & Senior High School, Chemistry Club	33
27 Sep.	RITE	Naragakuen Tomigaoka Junior High School	11
9 Oct.	Suzaku Daiyon Elementary School	Suzaku Daiyon Elementary School	48
18 Oct.	RITE	MASUDA Senior High School	21
16 Nov.	RITE	Seikanishi Junior High School	6

◇Workshop and Exhibition

Date	Place	Title	Number of participants
3 Feb.	Keihanna-Plaza	KEIHANNA Science Festival 2018	
Jul. - Aug.	RITE	Global Warming and CCS Study Workshop “Experiment and Game”	59

Directors・Research & Coordination Group

Other Paper

	Title	Researchers	Journal
1	Climate Pledges: The Need for Greater Transparency	Mitsutsune Yamaguchi	The Japan Journal, MAY/JUNE, pp.24-25, 2018
2	Issues Concerning the Paris Agreement on Global Warming: Limitations of Negative Emissions Dependence— Make Zero Emissions the Guiding Principle	Y. Kaya and M. Yamaguchi	Discuss Japan—Japan Foreign Policy Forum, No.50, 2018

Oral Presentation (International Academic Society)

	Title	Researchers	Forum
1	Development of Educational Materials and Programs for Public Outreach of CCS	Naoko Onishi, Nami Tatsumi, Satoshi Nakamura and Yoshinori Aoki.	14th International Conference on Greenhouse Gas Control Technologies (GHGT-14), Melbourne, Australia October 21-26, 2018

Oral Presentation (Domestic Academic Society)

	Title	Researchers	Forum
1	A Proposal for climate change strategies up to and after 2030 from short and mid-long term perspectives	M. Yamaguchi	The 23rd Annual Meeting of Society for Environmental Economics and Policy Studies, Sep. 8, 2018

Systems Analysis Group

Original Paper

	Title	Researchers	Journal
1	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, Vol. 23, Issue1, pp. 51-79, Jan. 2018
2	Low-carbon investments from the perspective of electric utilities: The burden of the past	B. Shoai-Tehrani, K. Akimoto, F. Sano	Utilities Policy, Vol. 51, pp. 18-32, April 2018
3	A model-based analysis on energy systems transition for climate change mitigation and ambient particulate matter 2.5 concentration reduction	K. Gi, F. Sano, A. Hayashi, K. Akimoto	Mitigation and Adaptation Strategies for Global Change, Published online Apr. 2, 2018
4	An Analysis on Global Energy-Related CO_2 Emission Reduction and Energy Systems by Current Climate and Energy Policies and the Nationally Determined Contributions	K. Gi, F. Sano, T. Homma, J. Oda, A. Hayashi, K. Akimoto	Journal of the Japan Institute of Energy, Vol. 97, pp. 135-146, 2018
5	Global energy sector emission reductions and bioenergy use: overview of the bioenergy demand phase of the EMF-33 model comparison	N. Bauer, S. K. Rose, S. Fujimori, D. P. van Vuuren, J. Weyant, M. Wise, Y. Cui, V. Daioglou, M. J. Gidden, E. Kato, A. Kitous, F. Leblanc, R. Sands, F. Sano, J. Strefler, J. Tsutsui, R. Bibas, O. Fricko, T. Hasegawa, D. Klein, A. Kurosawa, S. Mima, M. Muratori	Climatic Change, Published online July 2, 2018
6	GHG emission pathways until 2300 for the 1.5℃ temperature rise target and the mitigation costs achieving the pathways	K. Akimoto, F. Sano, T. Tomoda	Mitigation and Adaptation Strategies for Global Change, Vol. 23, No. 6, August 2018
7	Next step in geoengineering scenario research: Restrained deployment scenarios and beyond	M. Sugiyama, Y. Arino, T. Kosugi, A. Kurosawa, S. Watanabe	Climate Policy, Vol. 18, No. 6, pp 681-689, 2018
8	Interaction of consumer preferences and climate policies in the global transition to low-carbon vehicles	D. L. McCollum, C. Wilson, M. Bevione, S. Carrara, O. Y. Edelenbosch, J. Emmerling , C. Guivarch, P. Karkatsoulis, I. Keppo, V. Krey, Z. Lin, E. O Broin, L. Paroussos, H. Pettifor, K. Ramea, K. Riahi, F. Sano, B. S. Rodrigues, D. P. van Vuuren	Nature Energy 3, pp. 664-673, 2018
9	Changes in terrestrial water stress and contributions of major factors under temperature rise constraint scenarios	A. Hayashi, F. Sano, Y. Nakagami, K. Akimoto	Mitigation and Adaptation Strategies for Global Change, Vol.23 No.8, pp. 1179-1205, December 2018

Oral Presentation (International Academic Society)

	Title	Researchers	Forum
1	Ex-post evaluation of cost effectiveness of residential solar PV diffusion policy in Japan: The case of feed-in tariff	Y. Arino	Grand Renewable Energy 2018 (GRE2018), Jun. 19, 2018, Japan
2	An analysis of large-scale supply cost of energy crops under climate change scenarios	A. Hayashi, F. Sano, K. Akimoto	Grand Renewable Energy 2018 (GRE2018), Jun. 21, 2018, Japan

Systems Analysis Group

	Title	Researchers	Forum
3	Evaluations on emission reduction efforts of NDCs and their economic impacts by sector	K. Akimoto, T. Homma, F. Sano, B. Shoai-Tehrani	WCERE 2018 - 6th World Congress of Environmental and Resource Economists, Jun. 26, 2018, Sweden
4	Toward a strategic design of the CCS demonstration projects: A statistical approach	N. Wang, K. Akimoto	14th International Conference on Greenhouse Gas Control Technologies (GHGT-14), Melbourne, Australia October 21-26, 2018
5	Contribution of fusion energy to low-carbon development under the Paris Agreement and accompanying uncertainties	K. Gi, F. Sano, K. Akimoto, R. Hiwatari, K. Tobita	27th IAEA Fusion Energy Conference, Oct. 24, 2018, India
6	Assessment of Equity of Feed-in Tariff in Japan	T. Nagata, Y. Arino, Y. Nakano, K. Akimoto	ICUE2018 on Green Energy for Sustainable Development, Oct. 24, 2018, Thailand
7	The interplay of climate policy and electric sector deregulation: the perspective of firm's investment strategy in renewable energy	N. Wang, K. Akimoto	6th IAEE Asian Conference, Nov. 3, 2018, China
8	Alternative pathways for deep emission reductions with low energy demands and low carbon prices considering a car- and ride-sharing society	K. Akimoto, F. Sano, K. Gi	IAMC annual meeting, Nov. 13-15, 2018, Spain

Oral Presentation (Domestic Academic Society)

	Title	Researchers	Forum
1	Assessment of Equity of Feed-in Tariff	T. Nagata, Y. Arino, Y. Nakano, K. Akimoto	The 34th Conference on Energy, Economy, and Environment, Jan. 25, 2018
2	An Impact Analysis of Subsidizing Program for Energy-Efficient Housing by the Income Groups	Y. Nakano, K. Akimoto, T. Nagata, Y. Arino	The 34th Conference on Energy, Economy, and Environment, Jan. 25, 2018
3	Economic Analysis on climate change impacts and adaptation considering coastal and agricultural sectors	T. Homma, Y. Arino, A. Hayashi, M. Nagashima, K. Akimoto	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
4	Evaluations on Contributions through Diffusions and Deployments of Environmentally-friendly Products to Global CO_2 Emission Reductions	K. Akimoto, T. Homma, F. Sano, J. Oda	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
5	A Consideration of Service Demand in Terms of Time Use Consumption	K. Gi, K. Akimoto, F. Sano, T. Homma, J. Oda	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
6	Assessment of Concentrated Solar Power Generation with World Energy Model DNE21+	B. Shoai-Tehrani, K. Akimoto, F. Sano, N. Nakamura	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
7	Evaluation of Steel Product Trade Elasticity of Substitution	J. Oda, T. Homma, K. Akimoto	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
8	A Bottom-up End-use Model for Myanmar Regional Residential Electricity Demand	N. Wang, J. Oda, K. Akimoto	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
9	Support to developing countries under the Paris Agreement	K. Wada	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
10	Assessment of the Effective Allocation of Climate Finance for Mitigation	M. Nagashima, F. Sano, K. Akimoto, K. Gi	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
11	An Analysis on Land-Use Change and Food Access Under Scenarios for Long-term-temperature Targets	A. Hayashi, F. Sano, T. Homma, K. Akimoto	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
12	Potential estimates of renewable energy based on GIS data for a world energy system model	N. Nakamura, F. Sano, K. Akimoto, B. Shoai-Tehrani, K. Gi	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
13	A Study on diffusion of Sharing Economy in Mobility	F. Sano, K. Akimoto, J. Oda, K. Gi	The 34th Conference on Energy, Economy, and Environment, Jan. 26, 2018
14	Strategies of Energy and Global Warming Response Measures and the Roles of Fusion Energy	K. Akimoto	12th Joint Conference on Fusion Energy, Jun.28, 2018
15	An analysis of development targets of fusion energy under the Paris Agreement	K. Gi, F. Sano, K. Akimoto, R. Hiwatari, K. Tobita	12th Joint Conference on Fusion Energy, Jun. 28, 2018
16	Global energy prospects: Social landscape and technology development	K. Gi	12th Joint Conference on Fusion Energy, Jun.29, 2018
17	Analyses of effects of volatility in electricity wholesale prices on investment in power plant	J. Oda, Y. Nakano, K. Akimoto	JAROS2018, Dec. 2, 2018

Other Oral Presentation and Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Let's learn more on energy	K. Akimoto	Seminar for workshop for women on daily environmental issues in Takayama, Jan. 13, 2018

Systems Analysis Group

	Title	Researchers	Magazine, Newspaper, etc.
2	Countermeasure scenario on energy based on uncertainties of socioeconomy and climate change	K. Akimoto	Japan Atomic Energy Commission regular meeting, Jan. 30, 2018
3	Evaluation of Relationship between Embodied Energy and Transport Energy of Cities in Japan	J. Oda, K. Akimoto	Japan-Brazil Joint Workshop "Towards Sustainable Urban Energy Systems: Experiences from Asia and Latin America", Feb. 2, 2018
4	Long-term strategy toward deep emission reductions under several kinds of uncertainties	K. Akimoto	International Symposium-Prospect of Decarbonization after the Paris Agreement, Feb. 8, 2018
5	Climate change response strategy toward long-term zero CO_2 emissions	K. Akimoto	ALPS International Symposium, Feb, 9, 2018
6	National and international situation regarding Basic Energy Plan and discussion about its revision	K. Akimoto	ANRE regional information exchanging program workshop, Feb. 15, 2018
7	Differences among emission reduction costs due to uncertainties of climate projection	K. Akimoto	Scenario initiative meeting, Feb. 20, 2018
8	Differences among emission reduction costs due to uncertainties of climate projection	K. Akimoto	Integrated Research Program for Advancing Climate Models (TOUGOU), Mar. 8, 2018
9	Progress and issues on long-term global warming countermeasures and energy policies	K. Akimoto	Industrial policy committee of the Federation of Electric Power Related Industry Worker's Unions of Japan, Mar. 27, 2018
10	Outcomes of CTCN advisory committee and TEC	K. Wada	The 72nd TECUSE Study Meeting, Apr. 18, 2018
11	A study on the scenario of progress in sharing economy	F. Sano	TPES (Tokyo Professional Energy Seminar), Apr. 20, 2018
12	A position of LNG towards long-term emission reduction and trends in policies for energy and global warming	K. Akimoto	Plenary meeting of Tokai-Hokuriku Division, Japan Gas Association, May 15, 2018
13	Trends of energy consumption and CO_2 reduction in industry sector: focused on iron and cement sectors	J. Oda	Energy chain WG, Research Institute for Advanced Network Technology, Advanced Collaborative Research Organization for Smart Society, Waseda University, May 17, 2018
14	Talanoa Dialogue	K. Wada	The 73rd TECUSE Study Meeting, May 23, 2018
15	Direction of the 5th Basic Energy plan	K. Akimoto	Round-table conference on energy policy, Japan Society of Energy and Resources, May 29, 2018
16	Strategies of Japanese steel sector for the contribution of worldwide reduction of CO_2 emissions	K. Akimoto, J. Oda	the 233rd Nishiyama memorial lectures of technology, Jun. 7, 2018
17	Strategies of Japanese steel sector for the contribution of worldwide reduction of CO_2 emissions	J. Oda, K. Akimoto	the 234th Nishiyama memorial lectures of technology, Jun. 21, 2018
18	Chapter 2: The Paradoxes of the European Energy Market Regulation: A Historical and Structural Analysis of the Electricity Mix	B. Shoai-Tehrani, P. da Costa	Towards a Sustainable Economy, July 2018
19	Scenario analysis for developing long-term low emission development strategy	K. Akimoto	RITE Association Meeting, Jul. 6, 2018
20	An economic assessment of renewable energies and their issues	K. Akimoto	Society for scientific study on renewable energy and public policy of the University of Tokyo, Jul. 11, 2018
21	An assessment of the 5th Strategic Energy Plan, its impact on SME and required measures	K. Akimoto	The 5th Energy and Environment Committee of the Japan Chamber of Commerce and Industry/the Tokyo Chamber of Commerce and Industry, Jul. 11, 2018
22	The 5th Strategic Energy Plan	K. Akimoto	Saga Prefectural Government, Aug. 30, 2018
23	Global warming and energy strategy	K. Akimoto	Workshop for women "weather tomorrow, future earth", Sep. 20, 2018
24	Strategy for responding to climate risk under Paris Agreement and roles of various mitigation technologies	K. Akimoto	Symposium on technologies for global warming countermeasures towards future society in Kansai, Sep. 26, 2018
25	A Consideration of Service Demand in Terms of Time Budgets: A case study of passenger travel demand in Japan	K. Gi	Rethinking Energy Demand Discussion Workshop, Sep. 26, 2018

Systems Analysis Group

	Title	Researchers	Magazine, Newspaper, etc.
26	The 5th Strategic Energy Plan and future measures of energy and global warming	K. Akimoto	Keynote seminar in Advanced energy technology exhibition, 2018 Eco-technology exhibition, Oct. 10, 2018
27	The 5th Strategic Energy Plan	K. Akimoto	CCS Forum, Oct. 12, 2018
28	Outline of RITE Global model for energy and climate change mitigation, and economic assessment of CCS under various scenarios	F. Sano	CCS Forum, Oct. 12, 2018
29	Comments based on IEEJ Outlook 2019	K. Akimoto	430th Forum on Research Works, The Institute of Energy Economics, Japan, Oct. 15, 2018
30	The 5th Strategic Energy Plan	K. Akimoto	Liaison council for affiliate organizations of nuclear fuel tax, Nov. 1, 2018
31	IPCC 1.5℃ Special Report	K. Wada	The 78th TECUSE Study Meeting, Nov. 21, 2018
32	Science technology, energy and global warming issues	K. Akimoto	Tokai University Shizuoka Shoyo Senior High School, Nov. 22, 2018
33	Trends and the future of global warming policies under the Paris Agreement	K. Akimoto	The Japan Society of Industrial Machinery Manufacturers, Nov. 26, 2018
34	Chapter 10 Industry & living Environment (Editor)	K. Gi, K. Akimoto	Chronological Environmental Tables 2019-2020, Maruzen Publishing, Nov. 30, 2018
35	Evaluations on Emission Reduction Efforts of NDCs for Sustainable Measures Responding to Climate Change	K. Akimoto, T. Homma, F. Sano	COP24 Japan Pavilion side event, Dec. 11, 2018, Poland
36	Evaluations on Emission Reduction Efforts of NDCs and the Implications of Global Effectiveness on Climate Change Mitigation	K. Akimoto, T. Homma, F. Sano	COP24 UNFCCC official side event, Dec. 13, 2018, Poland
37	Global warming and energy	K. Akimoto	Seminar on weather anomalies and environmental issues, Dec. 18, 2018
38	Potentials of low-energy demand and its impact on global warming countermeasures	K. Akimoto	Innovative Environmental Technology Symposium 2018, Dec. 19, 2018
39	Summary of IPCC 1.5℃ Special Report and COP24	K. Wada	JMIP Workshop, Dec. 21, 2018

Molecular Microbiology and Biotechnology Group

Original Paper

	Title	Researchers	Journal
1	Production of 4-hydroxybenzoic acid by an aerobic growth-arrested bioprocess using metabolically engineered *Corynebacterium glutamicum*	Y. Kitade, R. Hashimoto, M. Suda, K. Hiraga, M. Inui	Appl. Environ. Microbiol., Vol.84, e02587-17, 2018
2	Efficient construction of xenogeneic genomic libraries by circumventing restriction-modification systems that restrict methylated DNA	S. Hasegawa, T. Jojima, M. Inui	J. Microbiol. Methods., Vol.146, pp.13-15, 2018
3	Glutamine-rich toxic proteins GrtA, GrtB and GrtC together with the antisense RNA AsgR constitute a toxin-antitoxin-like system in *Corynebacterium glutamicum*	T. Maeda, Y. Tanaka, M. Inui	Mol. Microbiol., Vol.108, pp.578-594, 2018
4	Development of green chemical production technology to realize a low carbon society	M. Inui	BioPla Journal, Vol.17, pp.15-19, 2018
5	Development of biofuel & green chemical production technologies to realize a low carbon society	M. Inui	Society of Biomass Utilization, Vol.19, pp.25-34, 2018
6	Strategies for metabolic engineering of *Corynebacterium glutamicum* on the comprehensive analyses	K. Toyoda, T. Kubota, T. Kogure, M. Inui	Smart Cell Industry -Prospect of Bio-Based Material Production Using Microbial Cells-, CMC Publishing Co.,Ltd., pp.183-188, 2018
7	Recent advances in metabolic engineering of *Corynebacterium glutamicum* for bioproduction of value-added aromatic chemicals and natural products	T. Kogure, M. Inui	Appl. Microbiol. Biotechnol., Vol.102, pp.8685-8705, 2018 (Mini-Review)
8	Bioproduction of aromatic compounds by *Corynebacterium glutamicum*	T. Kubota, M. Inui	Agricultural Biotechnology, Vol.27, pp.38-40, 2018
9	Enhanced production of D-lactate from mixed sugars in *Corynebacterium glutamicum* by overexpression of glycolytic genes encoding phosphofructokinase and triosephosphate isomerase	Y. Tsuge, N. Kato, S. Yamamoto, M. Suda, M. Inui	J. Biosci. Bioeng. (in press)

Molecular Microbiology and Biotechnology Group

	Title	Researchers	Journal
10	Introduction of the glyoxylate bypass increases hydrogen gas yield from acetate and L-glutamate in *Rhodobacter sphaeroides*	T. Shimizu, H. Teramoto, M. Inui	Appl. Environ. Microbiol. (in press)

Oral Presentation (International Academic Society)

	Title	Researchers	Forum
1	Mutation analysis of an ECF sigma factor-dependent promoter in *Corynebacterium glutamicum*	Koichi Toyoda, Masayuki Inui	The 43rd FEBS CONGRESS, Jul. 7-12, 2018

Oral Presentation (Domestic Academic Society)

	Title	Researchers	Forum
1	Regulation of cspA gene expression in *Corynebacterium glutamicum*	Yuya Tanaka, Masayuki Inui	The 2018 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 16-18, 2018
2	Identification of the σ^D regulon in *Corynebacterium glutamicum*	Koichi Toyoda, Masayuki Inui	The 2018 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 16-18, 2018
3	Improvement of H_2 yield from acetate by metabolic engineering of *Rhodobacter sphaeroides*	Tetsu Shimizu, Haruhiko Teramoto, Masayuki Inui	The 2018 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 16-18, 2018
4	Aptitude analysis of microorganism for producing aromatic compounds by evaluating stress tolerance	Ryoji Ogura, Takeshi Kubota, Masayuki Inui	The 2018 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 16-18, 2018
5	Functional analysis of asparagine and aspartic acid metabolism-related genes in *Corynebacterium glutamicum*	Akihiro Domon, Ikumi Fukui, Masako Suda, Taku Nishimura, Koichi Toyoda, Kazumi Hiraga, Masayuki Inui	The 2018 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 16-18, 2018
6	Expression of RNase III regulation analysis in *Corynebacterium glutamicum*	Masato Sawa, Yuya Tanaka, Masayuki Inui	The 2018 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 16-18, 2018
7	Construction of a screening system for isoprenoid biosynthesis enzymes	Hiroki Machida, Shinichi Oide, Masayuki Inui	The 2018 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 16-18, 2018
8	Thermotolerance of *Corynebacterium glutamicum* on production of lactate and succinate under anaerobic conditions	Hikaru Mizuno, Koichi Toyoda, Kazuaki Ninomiya, Masayuki Inui, Akihiko Kondo, Kenji Takahashi, Yota Tsuge	The 2018 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 16-18, 2018
9	Glutamine-rich proteins with antisense RNA constitute a toxin-antitoxin system in *Corynebacterium glutamicum*	Yuya Tanaka, Tomoya Maeda, Masayuki Inui	The 70th Annual Meeting of the Society of Biotechnology of Japan, Sep. 5-7, 2018
10	Overproduction of 4-hydroxybenzoic acid using metabolically engineered *Corynebacterium glutamicum*	Yukihiro Kitade, Ryoma Hashimoto, Masako Suda, Kazumi Hiraga, Masayuki Inui	The 70th Annual Meeting of the Society of Biotechnology of Japan, Sep. 5-7, 2018
11	A study on the ECF σ factor-specific promoter sequence in *Corynebacterium glutamicum*	Koichi Toyoda, Masayuki Inui	The 70th Annual Meeting of the Society of Biotechnology of Japan, Sep. 5-7, 2018
12	Trehalose acts as a uridine 5'-diphosphoglucose-competitive inhibitor of trehalose 6-phosphate synthase in *Corynebacterium glutamicum*	Shinichi Oide, Masayuki Inui	The 70th Annual Meeting of the Society of Biotechnology of Japan, Sep. 5-7, 2018
13	The differene between optimal temperature for cell growth and central metabolic pathway in *Corynebacterium glutamicum*	Hikaru Mizuno, Koichi Toyoda, Kazuaki Ninomiya, Kenji Takahashi, Masayuki Inui, Yota Tsuge	11th Hokuriku Combination Bio Symposium, Oct. 26-27, 2018

Other Oral Presentation and Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Development of biofuel & green chemical production technologies to realize a low carbon society	Masayuki Inui	Sentan Seeds Forum, Feb. 1, 2018
2	Microbial degradation of poly (ethylene terephthalate) (PET) and its mechanism	Kazumi Hiraga	Symposium of The 2018 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 18, 2018
3	Development of biorefinery technology using functionally improved Corynebacteria	Masayuki Inui	Symposium of The 2018 Annual Meeting of The Japan Society for Bioscience, Biotechnology and Agrochemistry, Mar. 18, 2018

Molecular Microbiology and Biotechnology Group

	Title	Researchers	Magazine, Newspaper, etc.
4	Development of biorefinery technology toward realizing a carbon recycling society	Masayuki Inui	Nagase R&D Center, NAGASE & CO., LTD., Jul. 3, 2018
5	Development of biorefinery technology toward realizing a carbon recycling society	Masayuki Inui	Symposium in Kansai on Global Warming Mitigation Technology for Future Society, Sep. 26, 2018
6	"Let's fly a jet plane with 100,000 clothes"	-	Press Releases (Japan Airlines Co., Ltd.), Oct. 11, 2018
7	Development of green bioprocess to realize a sustainable society	Masayuki Inui	Innovative Environmental Technology Symposium 2018, Dec. 19, 2018

Chemical Research Group

Original Paper

	Title	Researchers	Journal
1	Preparation of Biodegradable Polymer Nanospheres Containing Manganese Porphyrin (Mn-Porphyrin)	Fuminori Ito, Hidetaka Yamada, Kiyoshi Kanamura, Hiroyoshi Kawakami	Journal of Inorganic and Organometallic Polymers and Materials (online) pp1-9, 11 October 2018
2	Exploring the Role of Imidazoles in Amine-Impregnated Mesoporous Silica for CO_2 Capture	Quyen T. Vu, Hidetaka Yamada, Katsunori Yogo	Industrial & Engineering Chemistry Research Vol.57 No.7 pp 2638-2644, 2018
3	Development and fabrication of PAMAM-based composite membrane module with a gutter layer of Chitosan/PAA polymer double network for CO_2 separation	Shuhong Duan, Teruhiko Kai, Shingo Kazama	IOP Conference Series: Materials Science and Engineering (NMCI2018) Vol.296 pp 1-9, 2018

Oral Presentation (International Academic Society)

	Title	Researchers	Forum
1	Liquid-liquid phase separation induced by carbon dioxide absorption in amine-water systemB39:D46s	H. Yamada, R. Numaguchi, F. A. Chowdhury, S. Yamamoto, K. Goto, Y. Matsuzaki, M. Onoda	23rd International Congress of Chemical and Process Engineering, Prague, Czech Republic, August 26-29, 2018
2	Development of Chemical CO_2 Solvent for High-Pressure CO_2 Capture (4) : Potentiality for Low-Temperature Regeneration	Shin Yamamoto	14th International Conference on Greenhouse Gas Control Technologies (GHGT-14), Melbourne, Australia October 21-26, 2018
3	Development of novel solvents of CO_2 removal from blast furnace gas	Kazuya Goto, Firoz Alam Chowdhury, Hidetaka Yamada, Shin Yamamoto, Yoichi Matsuzaki, Masami Onoda	14th International Conference on Greenhouse Gas Control Technologies (GHGT-14), Melbourne, Australia October 21-26, 2018
4	A guide to evaluate non-aqueous solvents and amine absorbent structures for post-combustion CO_2 capture	Firoz Alam Chowdhury, Kazuya Goto, Hidetaka Yamada, Yoichi Matsuzaki, Masami Onoda	14th International Conference on Greenhouse Gas Control Technologies (GHGT-14), Melbourne, Australia October 21-26, 2018
5	Development of CO_2 molecular gate membrane modules for IGCC process with CO_2 capture	Teruhiko Kai, Shuhong Duan, Fuminori Ito, Satoshi Mikami, Yoshinobu Sato, Shin-ichi Nakano	14th International Conference on Greenhouse Gas Control Technologies (GHGT-14), Melbourne, Australia October 21-26, 2018
6	Advanced post-combustion CO_2 capture system using novel polyamine-based solid sorbents	Hidetaka Yamada, Shin Yamamoto, Junpei Fujiki, Firoz A. Chowdhury, Nobuyuki Takayama, Kazuya Goto, Katsuhiro Yoshizawa, Takeshi Okumura, Ryohei Numaguchi, Shohei Nishibe, Katsunori Yogo	14th International Conference on Greenhouse Gas Control Technologies (GHGT-14), Melbourne, Australia October 21-26, 2018
7	Development of Amino-Functionalized New Task Specific Ionic Liquids (TSILs) for Efficient CO_2 Capture	Firoz Alam Chowdhury, Kazuya Goto	14th International Conference on Greenhouse Gas Control Technologies (GHGT-14), Melbourne, Australia October 21-26, 2018
8	Demonstration Plant of the Kawasaki CO_2 Capture (KCC) System with Solid Sorbent for Coal-fired Power Stations	Takeshi Okumura, Katsuhiro Yoshizawa, Atsushi Kanou, Yusuke Hasegawa, Shigeki Inoue, Koujirou Tsuji, Satoshi Fujita, Mizuki Nabeshima, Hidetaka Yamada, Shin Yamamoto, Nobuyuki Takayama, Katsunori Yogo	14th International Conference on Greenhouse Gas Control Technologies (GHGT-14), Melbourne, Australia October 21-26, 2018

Chemical Research Group

Oral Presentation (Domestic Academic Society)

	Title	Researchers	Forum
1	Development of Non-aqueous Amine Based Absorbents for Post-combustion CO_2 Capture	Firoz A. Chowdhury, Shin Yamamoto, Hidetaka Yamada, Kazuya Goto, Yoichi Matsuzaki, Masami Onoda	The Society of Chemical Engineers, Japan 83rd Annual Meeting March 13-15, 2018

Other Oral Presentation and Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Development of the Kinetics Simulator Based on Transition State Theory and its Application to CO_2 Absorption Reactions	H. Yamada, T. Yamaguchi, T. Fujiwara, K. Hori	34th Symposium on Chemical Kinetics and Dynamics June 7, 2018

CO_2 Storage Research Group

Original Paper

	Title	Researchers	Journal
1	Geophysical monitoring at the Nagaoka pilot-scale CO_2 injection site in Japan	Takahiro Nakajima, Ziqiu Xue	Active Monitoring, 2nd ed., Elsevier, 2019
2	Fiber optic sensing for geomechanical monitoring: (1)-Distributed strain measurements of two sandstones under hydrostatic confining and pore pressure conditions	Ziqiu Xue, Ji-Quan Shi, Yoshiaki Yamauchi, Sevket Durucan	Applied Sciences, 8, 11, 2103, 2018
3	Fiber optics Sensing for geomechanical monitoring (2) distributed strain measurements at a pumping test and geomechanical modeling of deformation of reservoir rocks	Xinglin Lei, Ziqiu Xue, Tsutomu Hashimoto	Applied Sciences, in press
4	Laboratory Measurement of Submicrogal Gravity Change in Time Domain Using a Portable Superconducting Gravimeter without a Cryogenic Refrigerator	Hiroki Goto, Hiroshi Ikeda, Mituhiko Sugihara	Geophysical Research Letters, submitted
5	Detecting CO_2 leakage at offshore storage sites using the convariance between the partial pressure of CO_2 and the saturation of dissolved oxygen in seawater	Keisuke Uchimoto, Makoto Nishimura, Jun Kita, Ziqiu Xue	International Journal of Greenhouse Gas Control, 72, 130-137, 2018
6	Seismic and strain detection of heterogeneous spatial distribution of CO_2 in high-permeable sandstone	Keigo Kitamura, Osamu Nishizawa, Kenneth T. Christensen, Takuma Ito, Robert J. Finley	International Journal of Greenhouse Gas Control, 72, 65-73, 2018
7	Fiber optic distributed sensing technology for real-time monitoring water jet test: implications for wellbore integrity diagnostics	Yankun Sun, Ziqiu Xue, Tsutomu Hashimoto	Journal of Natural Gas Science & Engineering, 58, 241-250, 2018
8	Tracking CO_2 plumes in clay - rich rock by distributed fiber optic strain sensing (DFOSS): a laboratory demonstration	Yi Zhang, Ziqiu Xue, Hyuck Park, Ji-Quan Shi, Tamotsu Kiyama, Xinglin Lei, Yankun Sun, Yunfeng Liang	Water Resource Research, https://doi.org/10.1029/2018WR023415
9	A field experiment of inside CT walk-away DAS-VSP at a deep and highly deviated well for time-lapse subsurface monitoring	Yuki Kobayashi, Ryohei Naruse, Keita Adachi, Yusuke Morishima, Masanori Tani, Ziqiu Xue	Journal of the Japanese Association for Petroleum Technology, 83, 11, 2018
10	The potential of application of micro bubble technology to EOR	Ryo Ueda, Utaro Kaito, Kazunori Nakagawa, Masanori Nakano, Ziqiu Xue	Journal of the Japanese Association for Petroleum Technology, 83, 6, 2018
11	On the feasibility of the monitoring of earthquake event utilizing an optical fiber deployed inside a well - An example of an earthquake event detected by passive DAS recording in a deep well in Japan -	Yuki Kobayashi, Ryohei Naruse, Ziqiu Xue	Geophysical Exploration, 71, 56-70, 2018
12	Changes in migration mode of brine and supercritical CO_2 in imbibition process under steady flow state of very slow fluid velocities	Tetsuya Kogure, Yi Zhang, Osamu Nishizawa, and Ziqiu Xue	Geophysical Journal International, 214, 2, 2018, 1413-1425
13	Use of SEM-EDX analysis for conventional measurement of major element compositions and its geological application	Takuma Ito, Atsushi Obuchi, Kazuhiko Nakano, Tokio Sasai, Ziqiu Xue	Analytical Chemistry, submitted
14	Deformation-based monitoring of water migration in rock by distributed fiber optic strain sensing	Yi Zhang, Ziqiu Xue	Water Resources Research, submitted
15	Experimental and numerical simulation of supercritical CO_2 microbubbles injection into a brine saturated porous medium	Patmonoaji Anindityo, Yi Zhang, Ziqiu Xue, Tetsuya Suekane	International Journal of Greenhouse Gas Control, submitted
16	Swelling phenomena of kaolinite induced by CO_2 and water	JiangTao Pang, Yunfeng Liang, Yoshihiro Masuda, Toshifumi Matsuoka, Yi Zhang, Ziqiu Xue	Nature Communications, submitted

CO_2 Storage Research Group

	Title	Researchers	Journal
17	Distributed fiber optic sensing system for well-based monitoring water injection tests - a geomechanical responses perspective	Yankun Sun, Ziqiu Xue, Tsutomu Hashimoto, Xinglin Lei, Yi Zhang	Water Resources Research, submitted
18	Correction of salinity effect on pH measurement to evaluate geochemical reaction related with CO_2 geological storage	Saeko Mito, Ziqiu Xue	Journal of MMIJ, submitted
19	Shear-induced permeability reduction and shear-zone development of sand under high vertical stress	Kimura Sho, Hiroaki Kaneko, Shohei Noda, Takuma Ito, Hideki Minagawa	Engineering Geology, 238, 86-98, 2018
20	Depressurization and electrical heating of methane hydrate sediment for gas production: Laboratory-scale experiments	Hideki Minagawa, Takuma Ito, Sho Kimura, Hiroaki Kaneko, Shohei Noda, Norio Tenma	Journal of Natural Gas Science and Engineering, 50, 147-156, 2018

Non-Journal Publication

	Title	Researchers	Magazine, Newspaper, etc.
1	Application of marine engineering to offshore CO_2 storage: A method to detect CO_2 leakage using pCO_2	Keisuke Uchimoto, Makoto Nishimura , Ziqiu Xue	Bulletin of the Society of Sea Water Sciencem Japan, 72, 1, 2018
2	Report on Global CCS Symposium 2017	Ryozo Tanaka	IEEJ Transactions on Power and Energy,, 142, 5, 2018
3	Microbubble CO_2 flooding: an innovative technology for the development of low-permeability oil fields	Ziqiu Xue	CHINA CHEMICAL NEWS, 2018

Oral Presentation (International Academic Society)

	Title	Researchers	Forum
1	Microbubble CCUS(CO_2EOR) application effort	Ryo Ueda, Ziqiu Xue	CCS Seminar, Jakarta, Indonesia, 2018/2/7
2	Tomakomai lessons learned in offshore CO_2 storage regulations	Ryozo Tanaka	3rd International Workshop on Offshore Geologic CO_2 Storage, Oslo, Norway, 2018/5/3
3	Discussion on London Protocol application to Norway and EOR	Ryozo Tanaka	3rd International Workshop on Offshore Geologic CO_2 Storage, Oslo, Norway, 2018/5/3
4	Update on leakage detection	Keisuke Uchimoto	3rd International Workshop on Offshore Geologic CO_2 Storage, Oslo, Norway, 2018/5/3
5	Advantages of Distributed Deformation Monitoring by Fiber-Optic Sensor in Geomechanical Modelling	Xinglin Lei, Ziqiu Xue, Tsutomu Hashimoto	15th Annual Meeting Asia Oceania Geosciences Society AOGS2018 Hawaii, US, 2018/6/5
6	Inside CT-DAS-VSP acquisition using a highly-deviated deep well, onshore Japan	Ryohei Naruse, Yuki Kobayashi, Yusuke Morishima, Ziqiu Xue	Society of Exploration Geophysicists International Exposition and 88th Annual Meeting, California, US, 2018/10/16
7	Microbubble CO_2 injection for Enhanced Oil Recovery and Geological Sequestration in Heterogeneous and Low Permeability Reservoirs	Ziqiu Xue, Hyuck Park, Ryo Ueda, Masanori Nakano, Takumi Nishii, Shin Inagaki	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
8	A preliminary experiment on the detection of bubbles in the sea with side-scan sonor	Keisuke Uchimoto, Makoto Nishimura, Yuji Watanabe, Ziqiu Xue	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
9	Rock reaction experiments in CO_2-dissolved hot spring waters to evaluate effects of carbonate dissolution on caprock's sealing performance	Masao Sorai	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
10	Numerical Study on the Effects of Contact Angle Change on Capillary trapping	Yuki Kano, Tsuneo Ishido, Masao Sorai	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
11	Introduction to ISO Technical Report on Lifecycle Risk Management for Integrated CCS Projects	Xiaochun Li, Guizhen Liu, Sarah Forbes, Atsuko Tanaka, Ken Hnottavange-Telleen, Franz May, Sallie Greenberg, Philip Stauffer, Rick Chalaturnyk, Hubert Fabriol, Xiaoliang Yang, Andy Brown	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
12	Experimental study of microbubble CO_2 flooding in heterogeneous sedimentary rock	Hyuck Park, Lanlan Jiang, Tamotsu Kiyama, Ziqiu Xue,	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
13	Field measurement using distributed fiber-optic sensing technology and numerical simulation of geomechanical deformation caused by CO_2 injection	Yunkun Sun, Ziqiu Xue, Yi Zhang, Tsutomu Hashimoto, Hyuck Park	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22

CO_2 Storage Research Group

	Title	Researchers	Forum
14	Gas-tight pH measurements to assess an effect of CO_2 on groundwater	Saeko Mito, Ziqiu Xue, Bracken T. Wimmer, Abbas Iranmanesh, Hongbo Shao, Randall A. Locke, Sallie E. Greenberg	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
15	Advanced well log analyses using image data at the Nagaoka CO_2 injection site	Takahiro Nakajima, Ziqiu Xue	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
16	Utilization of wave attenuation in time-lapse sonic logging data for the monitoring of CO_2 migration along the well	Takahiro Nakajima, Luchen Wang, Ziqiu Xue	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
17	Micro-seismic monitoring data analysis system based on sequentially discounting autoregressive and its application to offshore CO_2 storage safety operation	Luchen Wang, Tetsuma Toshioka, Takahiro Nakajima, Akira Narita, Ziqiu Xue	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
18	Can we detect CO_2 plume by distributed fiber optic strain measurements?	Yi Zhang, Hyuck Park, Tamotsu Kiyama, Yankun Sun, Ziqiu Xue	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
19	Two Dimensional Numerical Simulation of CO_2 Injection into Brine Saturated Berea Sandstone with Normal Bubble and Micro Bubble Injection Modules	Anindityo Patmonoaji, Yi Zhang, Ziqiu Xue, Tetsuya Suekane	14th International Conference on Greenhouse Gas Control Technologies, GHGT-14, Melbourne Australia, 2018/10/22
20	CO_2 Storage R&D Priorities in Japan	Ryozo Tanaka	Research and Innovation Priorities for CCUS Event, Edinburg, UK, 2018/11/28

Oral Presentation (Domestic Academic Society)

	Title	Researchers	Forum
1	Detection of CO_2 bubbles in shallow sea using side-scan sonar (SSS)	Makoto Nishimura, Keisuke Uchimoto, Ziqiu Xue	JPGU Meeting 2018, 2018/05/23
2	Thresholds of anomalous pCO_2 in sea water	Keisuke Uchimoto, Makoto Nishimura, Ziqiu Xue	JPGU Meeting 2018, 2018/05/23
3	Effective use of drill cuttings analysis for wellsite geological investigation in the CO_2 geological storage: a case study of the Nagaoka site, Japan	Takahiro Nakajima, Takayuki Miyoshi, Shun Chiyonobu, Ziqiu Xue	JPGU Meeting 2018, 2018/05/23
4	Detection CO_2 flooding by optical fiber; Example of a long core specimen	Hyuck Park, Yi Zhang, Lanlan Jiang, Tamotsu Kiyama, Ziqiu Xue	JPGU Meeting 2018, 2018/05/23
5	Image well log data analysis to evaluate reservoir quality: Application to the Nagaoka storage site	Takuma Ito, Takahiro Nakajima, Takayuki Miyoshi, Shun Chiyonobu, Ziqiu Xue	JPGU Meeting 2018, 2018/05/23
6	Application of sequentially discounting autoregressive (SDAR) on seismic event detection for CO_2 injection safety management	Luchen Wang, Tetsuma Toshioka, Takahiro Nakajima, Akira Narita, Ziqiu Xue	JPGU Meeting 2018, 2018/05/23
7	The first field experiment of DAS-VSP using fiber optics deployed inside coiled tubing, onshore Japan	Yuki Kobayashi, Ryohei Naruse, Ziqiu Xue	JPGU Meeting 2018, 2018/05/23
8	Earthquake events monitoring in a well using Optical Fiber and DAS Technology	Tsunehisa Kimura, Yuki Kobayashi, Ryohei Naruse, Ziqiu Xue	JPGU Meeting 2018, 2018/05/23
9	Sedimentological approaches for CO_2 geological modeling	Yoshinori Yamanouchi, Mizue Nishimura	JPGU Meeting 2018, 2018/05/23
10	A parallel scheme for accelerating optimization of well placement for geologic CO_2 storage	Mitsuhiro Miyagi, Hajime Yamamoto, Yohei Akimoto, Ziqiu Xue	JPGU Meeting 2018, 2018/05/23
11	Study for the mechanism to the effect of improvement of CO_2 storage efficiency by micro bubble injection technology	Utaro Kaito, Masanori Nakano, Ziqiu Xue	JPGU Meeting 2018, 2018/05/23
12	Classification of pCO_2-DO Correlations of Seawater off Tomakomai	Shunsuke Nishimura, Toru Sato, Hiroyuki Oyama, Georgios Fytianos, Keisuke Uchimoto, Koichi Goto	OCEANS'18 MTS/IEEE Kobe / Techno-Ocean 2018/5/31
13	The investigation on the higher sweep efficiency by micro-bubble CO_2 flooding	Kazunori Nakagawa, Ryo Ueda, Ziqiu Xue	JAPT 2018 Spring Meeting, 2018/6/13
14	The potential of application of micro bubble technology to EOR	Ryo Ueda, Utaro Kaito, Kazunori Nakagawa, Masanori Nakano, Ziqiu Xue	JAPT 2018 Spring Meeting, 2018/6/13
15	Quality Control Processing of DAS-VSP data with the Surrounding Well Data	Keita Adachi, Yusuke Morishima, Masanori Tani, Yuki Kobayashi, Ziqiu Xue	JAPT 2018 Spring Meeting, 2018/06/14
16	The First Field Experiment of DAS-VSP using Fiber Optics Deployed Inside Coiled Tubing, Onshore Japan	Yuki Kobayashi	JAPT 2018 Spring Meeting, 2018/06/14

CO_2 Storage Research Group

	Title	Researchers	Forum
17	High speed optimization for well placement	Mitsuhiro Miyagi, Hajime Yamamoto, Yohei Akimoto, Ziqiu Xue	Japanese Society of Civil Engineers, 2018/08
18	Practical application of optic fiber measurement technology in rock engineering: subsurface strain distribution measurement field test	Ziqiu Xue, Tsutomu Hashimoto	MMIJ2018, 2018/09/10
19	International standardization works for CO_2 capture, transportation and geological storage (CCS)	Atsuko Tanaka	MMIJ2018, 2018/09/10
20	Preliminary study on gravity change related to water table response to tidal fluctuations	Hiroki Goto, Mitsuhiko Sugihara, Hiroshi Ikeda, Yuji Nishi	130th Meeting of the Geodetic Society of Japan,2018/10/16
21	Measurement of major elements in sedimentary rocks by SEM-EDX for geological applications	Takuma Ito, Atsushi Obuchi, Kazuhiko Nakano, Tokio Sasai, Ziqiu Xue	54th X-ray analysis conference, 2018/10/25
22	A study of the environmental impact assessment standard of leaked CO_2	Toshihiro Nishimura, Toru Sato, Hiroyuki Oyama, Keisuke Uchimoto	JASNAOE 2018 Annual Autumn Meeting & Conference, 2018/11/26

Inorganic Membranes Research Center

Oral Presentation

	Title	Researchers	Forum
1	Inorganic membranes and the applications	Masahiro Seshimo	I2CNER International Workshops 2018, Kyushu University, Feb. 02, 2018
2	Operation of small scale membrane reactors with CVD sillica membranes for MCH dehydrogenation reaction	Shin-ichi Nakao, Hiromi Urai, Kazuaki Sasa, Hitoshi Nishino, Ryohei Numaguchi, Ryoichi Nishida	158th The International Conference on Inogranic Membranes, Dresden, Jun. 22, 2018
3	Structural change of CHA-type aluminophosphate membrane under HF-free synthesis conditions	Masahiro Seshimo, Hiromasa Fukuda (Waseda Univ.), Masahiko Matsukata (Waseda Univ.)	The11th conference of the Aseanian Membrane Society (AMS11), Brisben, Jul. 04, 2018
4	Effect of gel composition for the HF-free synthesis of AlPO4-34	Masahiro Seshimo, Hiromasa Fukuda (Waseda Univ.), Motomu Sakai (Waseda Univ.), Masahiko Matsukata (Waseda Univ.)	International Symposium on Zeolites and Microporous Crystals 2018, Yokohama, Aug. 08, 2018

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9-2, Kizugawadai, Kizugawa-Shi,
Kyoto 619-0292 JAPAN
Telephone: +81 774-75-2300
Facsimile: +81 774-75-2314