RITE Today
Annual Report

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Research Institute of Innovative Technology for the Earth

"RITE Future Forest" DAC system and Blue Impulse

Feature

- Exhibition Report:
  "RITE Future Forest" at Expo 2025 Osaka Kansai, Japan

Topics

- Launch of the RITE Biomanufacturing Center
- Fostering Group Synergy and Advancing Research Planning Capabilities
  — Design and Operation of Internal Seminar —

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Toward Achieving Carbon Neutrality by 2050

Takashi Honjo
Senior Managing Director,
Research Institute of Innovative Technology for the Earth (RITE)

The Research Institute of Innovative Technology for the Earth (RITE) was established on August 1, 1990, and has now been in existence for more than 35 years. Over this period, global efforts to prevent climate change have undergone significant shifts. Around five years ago, in 2020, countries around the world set the goal of achieving carbon neutrality by 2050, and the Government of Japan also adopted this target. The year 2050 will mark the 60th anniversary of RITE's founding—equivalent to the traditional *kanreki* milestone in a person's life. If the research achievements that RITE has steadily accumulated in the field of climate change mitigation can contribute to achieving carbon neutrality, it would represent a meaningful milestone.

Meanwhile, in recent years, the international landscape has grown increasingly complex, influenced by developments such as the outbreak of the war in Ukraine and the emergence of a second Trump administration. As a result, global efforts to combat climate change have become more uncertain. Discussions at last year's Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change and Intergovernmental Panel on Climate Change (IPCC) suggest that, in addition to the long-standing divide between developed and developing countries, the alignment among developed countries themselves has weakened. Furthermore, the outbreak of the conflict involving Iran have clouded the outlook for the global energy situation, prompting renewed debate over the role of fossil fuels.

Nevertheless, considering the recent rise in global average temperatures and the increasing frequency of extreme weather events worldwide, the need to address climate change is not diminishing; rather, it is becoming ever more urgent.

Under these circumstances, as a research institute dedicated to climate change mitigation, RITE is expected to fulfill its core mission while actively disseminating its research achievements to the global community. Expo 2025 Osaka, Kansai, Japan provided an excellent opportunity to do so. Recognizing this, RITE presented the RITE Future Forest, an exhibition centered on negative emission technologies, including Direct Air Capture (DAC) of carbon dioxide from the atmosphere, Carbon Capture and Storage (CCS), and carbon fixation in concrete materials (carbon sequestration).

The details of the RITE Future Forest is explained in the special feature section that follows. At the Expo venue, RITE introduced many visitors to the current state of climate change, the necessity of mitigation efforts, and the specific technologies involved—through visual presentations, live operation of actual plants, and displays of tools used in CCS. Through these efforts, RITE has deepened public understanding of climate change issues. RITE will continue such initiatives, not only advancing research on climate change mitigation but also strongly advocating the importance of achieving carbon neutrality. In doing so, RITE aims to contribute meaningfully to the realization of carbon neutrality by 2050.

Exhibition Report: "RITE Future Forest" at Expo 2025 Osaka Kansai, Japan

Office for Expo 2025 Osaka Kansai Members (as of April 2026)

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Deputy Director (Concurrent)	**Tetsuya Deguchi**
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At the World Expo 2025 Osaka Kansai, the Research Institute of Innovative Technology for the Earth (RITE) exhibited the RITE Future Forest to demonstrate negative emission technologies featuring direct air capture (DAC) and to communicate these technologies to the public. This exhibit presented the value chain of CO2 capture, utilization, and storage in the actual environment and provided easy-to-understand explanations to visitors, thereby enhancing their understanding. This article reports the summary and achievements of this exhibit.

1. Introduction: Significance of the Expo Exhibition

The World Expo 2025 Osaka Kansai was held under the theme "Designing Future Society for Our Lives" for 184 days from April 13 to October 13, 2025 as a world expo for showcasing state-of-the-art technologies and social systems aimed at achieving a sustainable society. The Expo was a large-scale international event with participants from 153 countries/regions and eight international organizations and received more than 25 million visitors.

RITE co-sponsored the Future Society Showcase *Green Expo* and exhibited the RITE Future Forest. Since its establishment in 1990, RITE has promoted the development of technologies for resolving climate change issues. This exhibit was an important opportunity for communicating its research achievements and deepening related dialogues.

To achieve carbon neutrality, it is essential to implement, in society, negative emission technologies to capture, remove, store, and utilize CO_2 present in the air, in addition to the emission reduction measures such as energy saving and the introduction of renewable energy and other non-fossil energies. In particular, negative emission technologies play an extremely important role in achieving carbon neutrality amid the remaining industrial processes and transportation sectors where emission reduction is difficult. On the other hand, the recognition of these technologies in society has been low, calling for the enhancement of understanding.

The RITE Future Forest demonstrated and exhibited CO_2 Capture, Utilization and Storage featuring DAC (DAC-CCUS), thereby sharing these state-of-the-art technologies to visitors in an easy-to-understand manner and enhanced their understanding.

Figure 1 RITE Future Forest (panoramic view)

2. Concept and exhibit structure of RITE Future Forest

2.1. Basic concept

The RITE Future Forest was constructed on the basis of the concept of reproducing the roles of carbon absorption and circulation played by natural forests through science and technology. Just as natural forests absorb CO_2 through photosynthesis and fix carbon, the DAC and CCUS technologies function as artificial forests to capture, utilize, and store CO_2 from the air.

Through such a comparison with nature, the exhibit was so designed as to facilitate an intuitive understanding of specialized technology.

2.2. Three pillars

The exhibit had the following three technological pillars. The first pillar is the demonstration test of the DAC system conducted by the RITE Chemical Research Group as part of the New Energy and Industrial Technology Development Organization (NEDO) Moonshot Research and Development Project. The DAC system was actually operated to show visitors how CO_2 was captured from the air. The DAC systems of Nagoya University and Kyushu University, also participating in the project, were presented to showcase the technologies of these institutions. A key feature of the exhibit was the live operation of full-scale systems, demonstrating that negative emission technologies are already approaching practical deployment.

Figure 2 DAC system

The second pillar was the introduction of the CCS technology, which RITE has researched for many years. CCS is a technology to capture CO_2 and safely store it in the deep underground strata. To enhance social acceptance, measures were implemented to facilitate the intuitive understanding by visitors of the mechanism and safety of storage through easy-to-understand technical explanations and hands-on exhibits.

Figure 3 CCS exhibit section

The third pillar was CO_2 mineralization technologies. Maeda Road presented various initiatives for the effective use of CO_2, including the technology to use CO_2 as an asphalt pavement material. This introduced the viewpoint of regarding CO_2 not as mere waste to be disposed of but as a useful resource.

2.3. Participation in the Virtual Expo

For those who found it difficult to visit the Expo site, RITE also participated in the Virtual Expo and publicized online the details of the RITE Future Forest and its technical information. This provided information widely to those unable to visit the Expo site, raising awareness among the larger public.

3. Use of CO_2 captured by DAC and social demonstration: a demonstration test staged in the Expo site

3.1. Overview of the demonstration

One of the major characteristics of the RITE Future Forest was the demonstration of the value chain of CO_2 capture, utilization, and storage by actually using the CO_2 captured by DAC on and off the Expo site. This was not a mere exhibit, but a social demonstration to verify the technological linkage and operational feasibility of the technology in the real world.

3.2. Use on Expo site

The captured CO_2 was supplied to the adjoining methanation plant of Osaka Gas to produce synthetic methane (e-methane) through the reaction with hydrogen. The produced e-methane was used in the guest house kitchen and the heat supply system on the Expo site by functioning as a carbon-neutral energy source. This was the first practical demonstration test of methanation using DAC- CO_2 in Japan.

The CO_2 was also supplied to the adjoining plant of Air Water to produce dry ice, which was used for event staging and cooling purposes on the EXPO site.

3.3. Use off Expo site

A part of the CO_2 was transported off the Expo site to be used for various purposes. To Mitsubishi Gas Chemical, the CO_2 was transported for the demonstration test of underground CO_2 storage and as a material for methanol production. Methanol is a basic raw material for chemical production and plays an important role in the transition to a sustainable chemical industry.

The CO_2 was also used for promoting the growth of plants in the greenhouse tea farm of Fukujuen. This indicated the possibility of the effective use of DAC- CO_2 in the agricultural sector.

4. Exhibition space and visitor tour

4.1. Design concept of Guidance Hall

The Guidance Hall, which welcomed visitors first, was a wooden building of the cross laminated timber (CLT) panel-folded structure and embodied sustainable architectural technology. The building was evaluated for its innovative structural design and environmental friendliness and received internationally acclaimed awards (iF DESIGN AWARD 2026 and Wood Design Award 2025). The architecture itself is a symbol of sustainability.

Figure 4 Guidance Hall

4.2. Guidance video

In the hall, visitors watched a video of about 12 minutes using the latest 3D imaging technology that dispensed with goggles. This guidance video depicted, in an easy-to-understand manner, the changes in carbon circulation on the earth after the Industrial Revolution, the progress of global warming, and the roles of negative emission technologies as a solution thereto so that visitors could gain a comprehensive understanding before starting the tour. The video helped visitors have a deeper experience on the subsequent tour.

Figure 5 Guidance video

4.3. Guided tour with attendant commentary

The tour was conducted seven times a day with 20 persons and took about 60 minutes per tour. An attendant provided commentary to enhance the understanding of visitors. After watching the video in the Guidance Hall, the tour walked visitors through the actual DAC system on the second floor, the CCS experience in the exhibition space on the first floor, and the introduction of the technologies for using CO_2. The structure helped visitors gradually deepen their understanding.

Many tours concluded with spontaneous applause, reflecting visitors' deeper understanding of the technologies.

Figure 6 Guided tour

5. Visitor data and evaluation

5.1. Visitors

The exhibit had 18,610 visitors. The demographics of the visitors ranged widely, including general consumers, students, businesspersons, and government officials. The exhibit was also visited by many VIPs, including ministerial-level officials from Japan and abroad, which provided an opportunity to present the technologies to policymakers.

5.2. Results of visitor questionnaire survey

The visitor questionnaire survey indicated that 96% were satisfied or very satisfied with the tour, and 96% considered that they had a deeper knowledge and understanding of CCUS.

5.3. Media coverage

The media coverage of the exhibit comprised 15 TV shows, 78 newspaper articles, and 27 magazine and web media articles (120 in total). Many related posts were made on social media. These led to the increased awareness of the negative emission technologies featuring DAC and of RITE.

Figure 7 Coverage in "IMPACTS: Climate Change the World," an NHK WORLD-JAPAN program

6. Expo Innovation Award and future prospects

6.1. Expo Innovation Award

The RITE Future Forest Group (RITE, Maeda Road, Nagoya University, and Kyushu University) received the Expo Innovation Award for Cross-Sectoral Enlightenment because the demonstration test of the state-of-the-art technologies and the enhancement of understanding and awareness among general visitors were highly evaluated. This award indicates that RITE's research achievements and awareness raising activities have been recognized in an international forum, providing a strong impetus for its future activities.

Figure 8 EXPO Innovation Award ceremony

6.2. Inheritance of legacy and future activities

After the Expo, the Guidance Hall is to be relocated to the RITE headquarters and is to be used as a place for sharing and inheriting the legacy of the exhibit at the Expo. A possibility will also be pursued to use the hall as a place for supporting RITE's education and development.

Figure 9 Relocated hall (a conceptual diagram)

7. Conclusion

This exhibit made important achievements in promoting social understanding of negative emission technologies. Initiatives toward the practical use of the technologies were widely communicated through a technical introduction to 18,610 visitors, achieving a high 96% satisfaction rate, and 120 media articles and posts.

Going forward, RITE will accelerate the dissemination and practical use of the negative emission technologies and other climate mitigation technologies by reducing DAC costs, the social implementation of CCS, and the expansion of carbon recycling. RITE will continue to promote the development and social implementation of technologies to resolve climate change issues and contribute to the achievement of a sustainable society.

Acknowledgements

This exhibition was achieved with cooperation from many companies and institutions, including the consortium member companies that supported RITE from the planning stage, the RITE Future Forest Group members (Maeda Road, Nagoya University, and Kyushu University), NEDO, Mitsubishi Heavy Industries Group, Osaka Gas, Air Water, and Mitsubishi Gas Chemical. RITE extends its sincere gratitude to all those concerned.

Research & Coordination Group

Members (As of Apr. 2026)

Group Leader, Principal Research Scientist	**Masato Kannen**
Deputy Leader, Principal Research Scientist	**Makoto Nomura**
Deputy Leader	**Tatsuro Ide**
Deputy Leader, Principal Research Scientist	**Naoki Oda**
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Vice Principal Research Scientist	**Tetsuya Deguchi** (concurrent)
Manager	**Minehiro Takahashi**
Planning Manager	**Sou Kuranaka**
Senior Research Scientist	**Yumi Kobayashi**
Senior Research Scientist	**Natsuko Yasumoto**
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Staff	**Mizuki Nagata**

Toward Creating Innovation for a Lasting Friendship between People and the Earth

1. Introduction

The year 2025 was marked by record-breaking heat, with the number of days exceeding 40°C reaching a historic high of nine. The surge in rice prices has also been attributed in part to the extreme heat, making it a year in which climate change became impossible to ignore.

Against this backdrop, expectations for the climate change mitigation technologies pursued by our institute and demands for their practical implementation have continued to grow steadily.

The relationship between human activity and the earth can be likened to human relationships: if either side is overburdened, the relationship cannot be sustained. We believe that research and development can help expand the foundation for a lasting friendship between people and the earth, and RITE is playing a part in this effort (Figure 1).

In short, while keeping in mind the current trend toward carbon neutrality, RITE is conducting R&D related to climate change and ensuring that people and the earth can form friendship for many years to come.

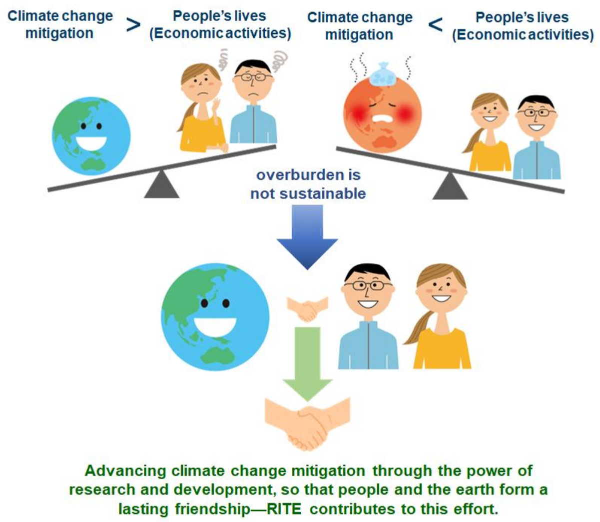


Figure 1 Enabling a lasting friendship between People and the Earth through Research and Development (Conceptual Illustration)

Based on this understanding, the Research & Coordination Group has four major functions: 1) explore new R&D topics while looking at domestic and overseas policies and technology trends and propose and implement new research themes by taking advantage of the research potential of RITE; 2) support the government with regard to the Intergovernmental Panel on Climate

Change (IPCC) and facilitate collaboration with international organizations, such as the International Organization for Standardization (ISO); 3) promote the dissemination of RITE's technologies and develop human resources for the future; and 4) promote the practical application of technologies through collaboration with the industry. We, together with research groups, have been actively working on policy support, technology development, and the creation of innovation in order to pursue both global environment protection and economic development.[1)]

In addition, by taking advantage of Expo 2025 Osaka, Kansai, Japan, held from April to October last year, RITE exhibited the RITE Future Forest, which introduced negative emission technologies. The exhibition attracted nearly 20,000 visitors and was very well received.

Here, we would like to first provide an overview of the Japanese government's actions taken toward carbon neutrality in fiscal year 2025 and then touch on the specific R&D being carried out by this group.

1.1. Trends surrounding Japan's climate change mitigation efforts in FY2025

Fiscal year 2025 can be regarded as a year in which Japan's efforts toward climate change mitigation gained significant momentum, both in terms of institutional frameworks and concrete projects, despite developments such as the United States' withdrawal from the Paris Agreement and increasing global tensions.

Specifically, in May, the amended GX Promotion Act was enacted, clarifying the schedule for developing institutional frameworks toward Green Transformation (GX). In addition, in the field of carbon capture and storage (CCS), progress was made both in regulatory systems and project support following the development of CCS-related legislation. Concrete steps toward commercialization were also taken, including the granting of an exploratory drilling permit in Tomakomai and the designation of a specified area in Kujukuri.

Looking at global developments, at COP30 held in November, a policy package known as the Global Mutirão Decision was adopted. Furthermore, within the IPCC, a new phase, the Seventh Assessment Report (AR7), has commenced.

In this section, we will outline COP30 and the amended GX Promotion Act. The full-scale implementation of the CCS Business Act and IPCC-related developments will be discussed in detail in Section 2 and beyond.

1.2. COP30

COP30 was held in Belém, Brazil, in November last year. A comprehensive "cover decision" encompassing a wide range of areas such as mitigation and climate finance was adopted, known as the "Global Mutirão Decision" (mutirão meaning "collective efforts" in Portuguese). Its main points are as follows:

○ Mitigation (reduction of greenhouse gas emissions):

Acceleration of mitigation efforts toward achieving the 1.5°C target, raising ambition levels, and calling on countries that have not yet submitted their Nationally Determined Contributions (NDCs) to do so promptly.

○ Climate finance:

Under the New Collective Quantified Goal (NCQG) agreed at COP29, a target to triple adaptation finance was set as an aspirational goal, and a two-year work program was launched.

○ Unilateral trade-restrictive measures related to climate change:

A dialogue is to be held with the participation of Parties and relevant organizations such as the World Trade Organization (WTO).

○ Regarding the Global Goal on Adaptation (GGA), which focuses avoiding and reducing climate impacts, a list of indicators was adopted, although further consideration will continue.

1.3. Amended GX Promotion Act

The amended GX Promotion Act is a law designed to facilitate a smooth transition to a decarbonized, growth-oriented economic structure. It was enacted in May 2025 and came into force in April 2026. The main measures included in the Act are as follows:

○ Mandatory emissions trading system (GX-ETS)

Starting in April 2026, large-scale emitters producing 100,000 tons or more of CO_2 annually are required to participate in the emissions trading system. This enables the trading of emission allowances among companies and strengthens incentives for reducing emissions.

○ Introduction of a fossil fuel levy

From fiscal year 2028, a levy will be imposed based on the consumption of fossil fuels such as oil, coal, and natural gas, establishing a mechanism for sharing the cost of CO_2 emissions across society as a whole.

○ Mandatory use of recycled resources

For certain products, including plastics and metals, the use of recycled materials is mandated, thereby promoting more efficient resource use and advancing a circular economy.

In parallel with these developments, institutional design efforts are accelerating. For example, under the Emissions Trading Subcommittee of the Industrial Structure Council of the Ministry of Economy, Trade and Industry (METI), working groups such as the Manufacturing Industry Benchmark Working Group and the Power Generation Benchmark Working Group have been established.

2. Research and survey activities

2.1. Introduction

Achieving Green Transformation (GX) in sectors that are difficult to decarbonize will be a key challenge on the path toward carbon neutrality by 2050. In these sectors, the introduction of Carbon dioxide Capture and Storage (CCS)—which captures CO_2 after the use of fossil fuels and raw materials and stores it underground—is essential as a means of advancing decarbonization.

To this end, it has been decided to establish a business environment that will enable private companies to launch CCS projects by 2030 (GX Promotion Strategy, approved by the Cabinet in July 2023), and the CCS Business Act[2)]has been promulgated. In addition, discussions on the framework for government support have started in the Carbon Management Subcommittee[3)] (hereinafter referred to as the "CM Subcommittee") of the Advisory Committee for Natural Resources and Energy. This section presents an overview of Japan's CCS initiatives to date, along with the results of surveys and research conducted by our group regarding support measures for CCS projects in Japan.

2.2. CCS initiatives in Japan

To date, efforts in Japan have progressed to a stage where scheme design for implementing CCS both domestically and internationally, as well as the consideration of business models across the entire CCS value chain (CO_2 capture, transportation, and storage), can be initiated. This progress has been supported by activities such as confirming a storage potential of approximately 16 billion tons through surveys of suitable storage sites, as well as the development and demonstration of technologies across the CCS value chain. Looking ahead, in alignment with investment decisions expected from CCS operators around 2026, discussions are underway on the design of support systems that will enable smooth market entry and operation by CCS project developers, with the aim of launching CCS projects in the early 2030s.

(1) CCS Business Act [2)]

The CCS Business Act was promulgated in May 2024. On August 5, a permit system for exploration was introduced, including provisions on exploration methods and application procedures. Subsequently, on November 18, 2024, systems related to exploratory drilling came into force, including the designation of specified areas (for exploratory drilling), the introduction of a permit system for exploratory drilling, and an approval system for exploratory drilling plans. Furthermore, by May 2026, additional systems are scheduled to be implemented, including the designation of specified areas (for storage projects), a permit system for storage projects, an approval system for storage project plans, the transfer of relevant functions to JOGMEC, and a notification system for pipeline transportation projects.

In February 2025, offshore area of Tomakomai city was designated as the first specified area.[4)] Following a public call for operators, consultations with the prefectural governor, a public inspection process, and other steps, exploratory drilling permission was granted to Japan Petroleum Exploration Co., Ltd. on September 17 of the same year.[5)] A exploratory drilling survey commenced on November 4, and a second exploratory drilling is scheduled for July 2026.

In addition, offshore area of Kujukuri in Chiba Prefecture was designated on September 17, 2025 as the second specified area[6)], and exploratory drilling permission was granted to Metropolitan CCS Co., Ltd. on April 17,2025.[7)]

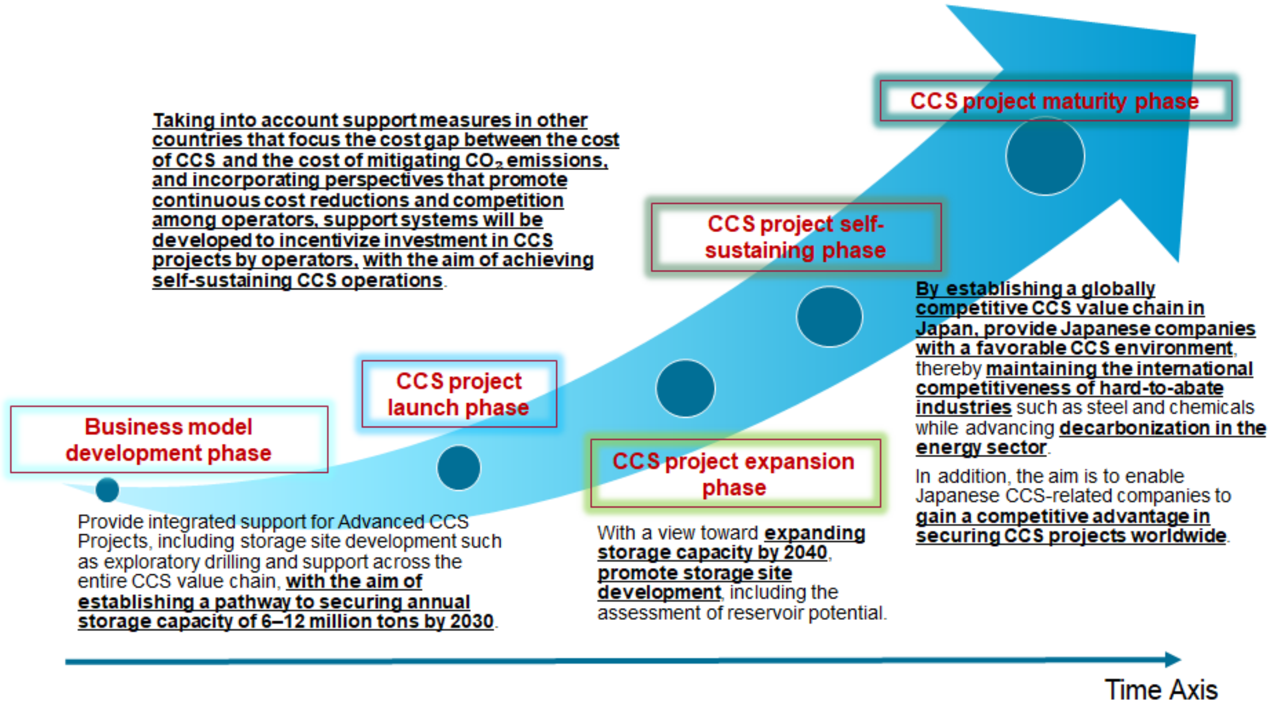


Figure 2 Conceptual Roadmap for the Promotion of CCS

Source: Reference materials from the 8th Carbon Management Subcommittee meeting (December 18, 2024)—Conceptual illustration of future CCS project promotion

https://www.meti.go.jp/shingikai/enecho/shigen_nenryo/carbon_management/pdf/008_03_00.pdf (in Japanese)

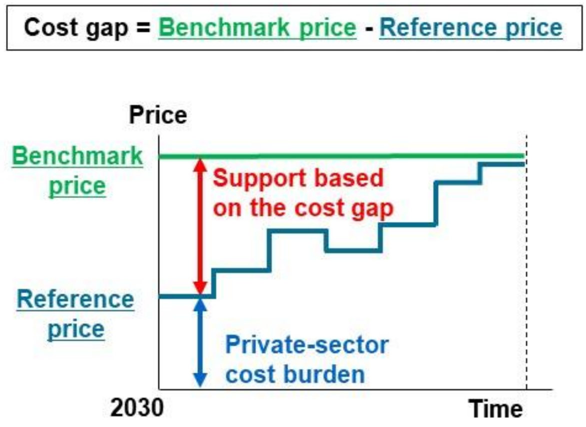
(2) Support for CCS commercialization[8)]

According to the CCS Long-Term Roadmap[9)], integrated support will be provided for Advanced CCS Projects, including storage site development such as exploratory drilling and support across the entire CCS value chain, with the aim of establishing a pathway to securing annual storage capacity of 6–12 million tons by 2030. The Seventh Strategic Energy Plan[10)] (approved by the Cabinet in February 2025) states that, taking into account support measures in other countries, support scheme will be considered to incentivize investment in CCS projects by CCS operators. These measures will also incorporate perspectives that promote continuous cost reductions and competition among operators.

Discussions began at the 5th meeting of the CM Subcommittee in September 2024, and a draft framework was presented in December. Subsequently, detailed institutional design has been discussed within a Working Group (WG) on support measures for CCS projects, established in February of the following year.

In July 2025, as discussions on support measures for pipeline-based CCS projects progressed, an interim summary was compiled. An interim summary for ship-based transportation projects is also expected to be prepared, after which both will be consolidated into a final report.

The interim summary identifies a key condition for achieving self-sustaining CCS projects, that CCS costs must be lower than the cost borne by emitters for CO_2 mitigation. As CCS costs decline due to technological and market maturation as well as economies of scale, they are expected to eventually fall below CO_2 mitigation costs, so enabling self-sustaining operation. Specifically, focus on this cost gap, it has been proposed that the benchmark price be defined as the sum (per CO_2 ton) of (1) CO_2 capture costs (including CAPEX and OPEX for capture) and (2) transportation and storage fees (including CAPEX and OPEX for transportation and storage), while the reference price is set as the carbon price. Support measures focusing on the gap between the benchmark price and the reference price would then be provided, in proportion to the volume of CO_2, over a specified support period. Further consideration will proceed in this direction.



[Benchmark price]
The price calculated as the sum of the CO_2 capture cost, which is assessed for appropriateness based on domestic and international technology trends, and the transport and storage fee determined through an auction
[Reference price]
The carbon price used in the previous fiscal year under carbon pricing-related schemes, referenced on an annual basis

Figure 3 Conceptual Illustration of Support Based on the Cost Gap

Source: Working Group on Support Measures for CCS Projects, Carbon Management Subcommittee, Natural Resources and Fuel Committee, Advisory Committee for Natural Resources and Energy (5th meeting, Material 4, p.2)

2.3. Survey on the carbon footprint of CCS

Clarifying the value of CO_2 emission reductions achieved through CCS is important. In March 2026, discussions on the treatment of CCS were initiated within a study group on calculation methodologies under Greenhouse Gas Emissions Calculation, Reporting and Publication System (SHK system).[11)] This section introduces the treatment of CCS under the carbon footprint framework, examined as part of our research on support measures for CCS projects in Japan.

(1) Carbon footprint (CFP)

CFP[12] is an initiative undertaken by companies to calculate, aggregate, and disclose the unit amount of greenhouse gas (CO_2) emissions associated with a product or service across its entire lifecycle—from raw material procurement through manufacturing, distribution, use, and disposal. It serves as one of the foundational mechanisms for creating a market in which decarbonized and low-carbon products (green products) are preferentially selected. In general, CFP focuses on greenhouse gas emissions attributable to a company's own activities and is intended as an indicator for quantitatively evaluating its emission reduction efforts. Therefore, emission reductions achieved outside the defined system boundary of the CFP are typically not allowed to be offset through the purchase of external credits.

(2) Treatment of CCS under the carbon footprint framework

With regard to CCS, CO_2 generated during the manufacturing stage of a product lifecycle is captured and stored underground, thereby reducing CO_2 emissions. Accordingly, it is expected that the amount of CO_2 reduced through CCS will be deducted when calculating the CFP of the relevant product.

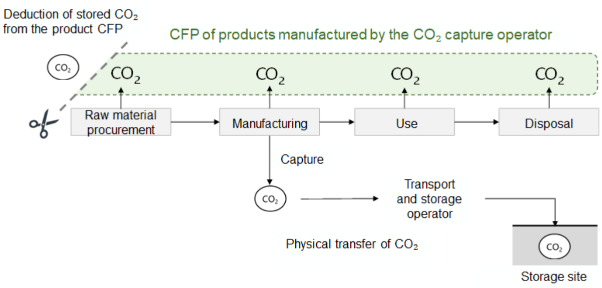


Figure 4 Relationship between CCS and CFP

Domestic and international frameworks related to the treatment of CO_2 emission reductions in CFP accounting were surveyed and organized.

1: Attribution of CO_2 emission reductions from CCS

According to the IPCC Guidelines for National Greenhouse Gas Inventories and National Greenhouse Gas Inventory Report of JAPAN, captured CO_2 is deducted from emissions in the source sector (i.e., the sector in which CO_2 is generated from fossil fuels) at the point when its permanent storage has been confirmed. In other words, the CO_2 emission reductions achieved through CCS are attributed to the CO_2 capture operator.

2: Relevant frameworks for product CFP and attribute claims

Under frameworks such as the International Organization for Standardization (ISO) 14067, the EU Carbon Border Adjustment Mechanism (CBAM), and the CFP guidelines of the Japan Automobile Manufacturers Association (JAMA), CO_2 emission reductions achieved through CCS may be included in a product's CFP. In this context, it is permissible to issue certificates representing the amount of CO_2 reduction and to make attribute claims in order to associate these reductions with the product. Such attribute claims involve allocating and attributing CO_2 emission reductions generated within the product's lifecycle boundary, and therefore different in nature from offsetting, which involves compensating for emissions by purchasing or transferring reductions achieved outside the lifecycle boundary.

3: Need for clarification under SHK system

Under current SHK system, it is already possible to deduct the amount of CO_2 captured. However, in order to achieve the self-sustaining development of CCS projects, it is necessary to ensure business predictability. In this context, discussions have started within the study group on calculation methodologies under SHK system to establish clear accounting rules for CCS, with the aim of promptly clarifying the value of CO_2 emission reductions achieved through CCS.

3. Promotion of international partnership

3.1. IPCC (Intergovernmental Panel on Climate Change)

The IPCC has been established in 1988 with a view to conducting a comprehensive assessment from scientific, technical, and socio-economic perspectives on climate change, impact, adaptation and mitigation measures by anthropogenic sources, jointly by the United Nations Environment Program (UNEP) and by the World Meteorological Organization (WMO). The IPCC examines scientific knowledge on global warming and makes the reports prepared by three WGs, - Physical Science Basis (WG1), Impacts and Adaptation, and Vulnerability (WG2), and Mitigation Measures (WG3).

In the IPCC, the experts chosen among each country make the reports, based on the literature or the scientific observation data and evaluate / examine the scientific analysis, social economic influence and countermeasures to control climate change. This outcome is to have a high influence on international negotiations since the scientific basis is also given to the policies of each country.

RITE serve as the domestic supporting office for the Mitigation Working Group (Working Group III), playing a role in connecting research and development and analytical studies with policymaking (Figure 5). Within the IPCC, activities for the Seventh Assessment Cycle (AR7) commenced in July 2023. Work is currently underway on the Special Report on Cli-mate Change and Cities, the Methodology Report on Short-Lived Climate Forcers (SLCFs), and the assessment reports of each Working Group.

In addition, an outline for the Methodology Report on Carbon Dioxide Removal (CDR) technologies and Carbon Capture, Utilization and Storage (CCUS) was approved at the IPCC Plenary in October 2025. Authors were selected in January 2026, and the report is now being drafted. RITE is providing support in this area as well, through activities such as information gathering, analysis, reporting, and policy-relevant advice.

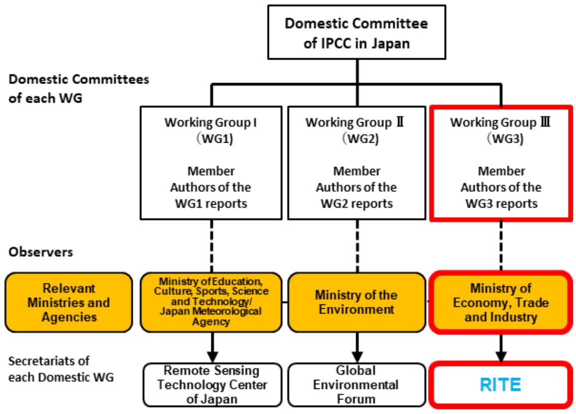


Figure 5 Committee structure and RITE

3.2. ISO

ISO (International Standard Organization) is an organization composed of 176 standardization bodies of various countries that gives the common standards and promotes global trade. It can provide safe, reliable, and high-quality products/service by utilizing ISO standards.

In the world, a number of CCS verification projects on a commercial scale are implemented, and inter-national collaboration is under way. International standardization of CCS can contribute to the wide-spread of safe and appropriate CCS as it can ensure internationally agreed knowledge on safety and environmental aspects.

RITE is a domestic deliberation organization on ISO / TC 265 (Carbon dioxide capture, transportation, and geological storage) and is in charge of a secretariat of WG 1 (capture). Through these activities, we are actively involved in the international standardization on design, construction, operation, environmental planning and management, risk management, quantification, monitoring and verification, and related activities in the CCS field (Figure 6).

As of the end of March, 2026, seventeen standards related to the CCS have been published from ISO / TC265 and nine documents are currently under development.

In addition to these efforts, proposals for new topics have been put forward and are now under consideration, indicating that overall activities within TC265 are becoming increasingly active. Revisions of standards published more than five years ago are also progressing, and a revised edition of ISO 27914, which addresses CO_2 storage as a whole, was published at the end of March. This standard was developed through a detailed review, conducted with the cooperation of relevant domestic companies, to verify that the overall revisions and the newly introduced CO_2 quantification for storage would not hinder practical implementation. The revised standard is expected to be utilized in future discussions toward the development of domestic rules for CO_2 storage.

This activity is conducted as a commissioned project of the New Energy and Industrial Technology Development Organization (NEDO).

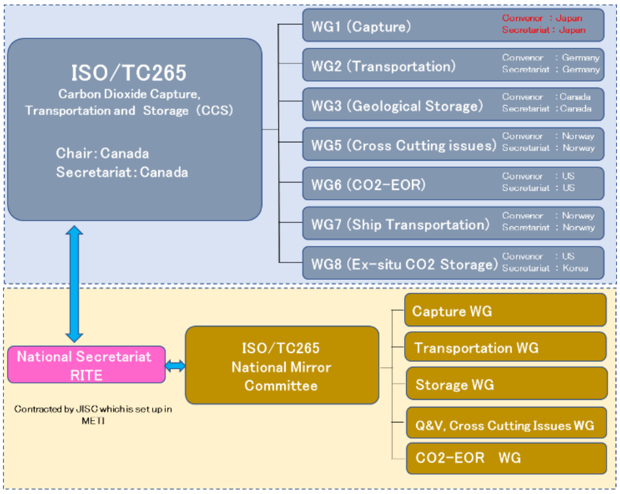


Figure 6 ISO/TC265 structure

4. Public awareness promotion / Human resources development and industry collaboration

4.1. Public awareness promotion / Human resources development

RITE is conducting various activities to promote public awareness and develop human resources with the aim of nurturing the next generation of researchers. Here, we will explain our activities separately for elementary, junior high, and high school students and university/graduate students.

<Elementary, junior high, and high school students>

Believing that educating the next generation about global warming issues is important, RITE accepts elementary, junior high, and high school students for field trips to its laboratories and visits schools to give lectures. In fiscal 2025, RITE focused on CCS technology from among its research projects and explained to 128 students from seven schools the mechanism of global warming and that even if CO_2, a major greenhouse gas, is stored underground, there is a low possibility of leakage due to the clay layer (shielding layer). Based on our learning cycle, we then deepened their understanding through reflection and exchange of opinions.(Figure 7).

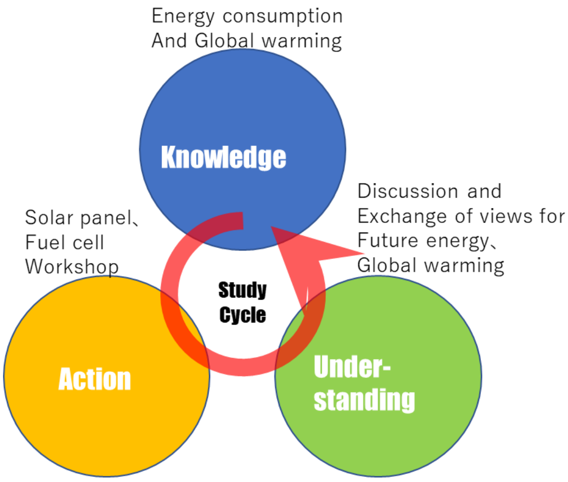


Figure 7 Human resource development by RITE (Elementary, Junior and high school students)

<University & Postgraduate student>

As part of efforts to develop human resources who will support next-generation research and technology, RITE promotes educational partner-ships with universities and graduate schools. We are developing education at universities and re-search guidance at research institutes (Figure 8). For example, Nara Institute of Science and Technology (NAIST) has set up a university-collaborated laboratory in the bio-science field at RITE. We are promoting research and education aimed at realizing are cycling-oriented and low-carbon society using renewable resources. In addition, we have established a collaborative laboratory with the materials creation science area of the NAIST, and are promoting research and education on CO_2 separation and recovery technology.

In addition, we believe that it is important to foster literacy related to climate change mitigation not only among researchers but also among students in the humanities. Accordingly, RITE provides lectures for first- and second-year humanities students at Kansai University, covering climate change mitigation in general as well as RITE's initiatives.

In this way, through a multifaceted approach targeting both science and humanities students, we aim to contribute to the development of individuals who will shoulder the future of research and development and who can also feel a sense of familiarity with it.

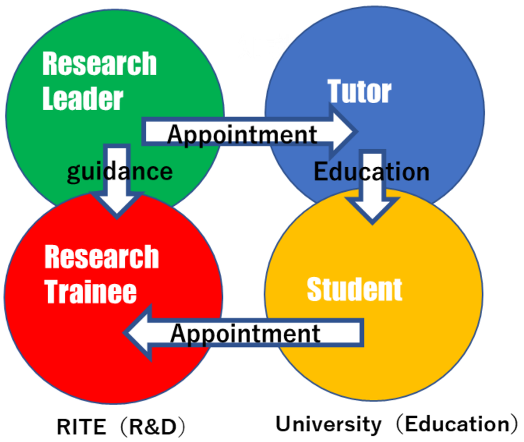


Figure 8 Human resource development by RITE (University & Post graduate students)

4.2. Intellectual property and industry collaboration

RITE strategically and efficiently acquires and manages intellectual property rights such as pa-tents and know-how regarding the results of re-search and development, etc., and actively utilizes them for the public interest. The aim is to advance and improve industrial technology that contributes to the conservation of the global environment.

The acquisition of such research results as intellectual property creates opportunities for industrial collaboration with companies, etc., and through joint research and joint applications, further intellectual property is generated through a virtuous cycle that contributes to society. At RITE, we focus on the di-verse functions of intellectual property rights and strategically promote intellectual property activities while taking into consideration the market and other research and development trends.

As part of the promotion of intellectual property strategies, the "Patent Deliberation Committee" was established with RITE executives as members and the public relations and industry collaboration team as the secretariat. The main agenda is the acquisition and management of intellectual property such as patent applications and examination requests, patent right maintenance, and intellectual property strategies such as approval of license agreements.

As of the end of March 2026, of the patents for which RITE is the sole or joint applicant, 22 domestic applications and 15 foreign applications are pending patent applications, and the registered rights are maintained. It holds 59 domestic patents (including 3 under license to companies) and 33 foreign patents (2 of which are licensed to companies).

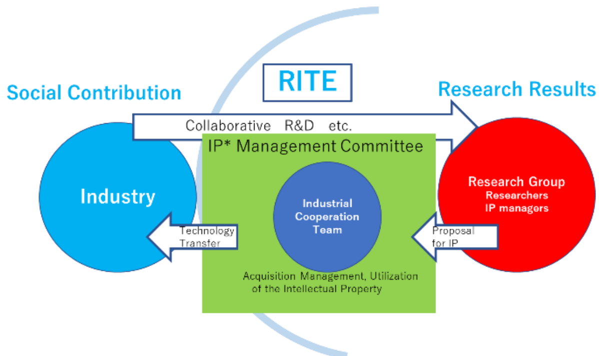


Figure 9 Strategic IP management and industrial collaboration

5. Conclusion

Since its establishment, RITE has promoted research and development of innovative energy and environmental technologies aimed at achieving substantial reductions in CO_2 emissions, while also developing climate change mitigation scenarios and translating them into policy recommendations.

Based on the domestic and international trends outlined above, RITE will continue to advance research and development in a timely and integrated manner, bringing these efforts to fruition as innovation, and striving to enable a lasting friendship between people and the earth.

In doing so, it is essential to foster social acceptance for the practical implementation of research and development achievements. RITE will therefore place emphasis on effective communication through various outreach tools, providing clear and convincing explanations, and further promoting awareness and understanding of climate change across diverse segments of society.

Reference

1) RITE, "The Role of RITE"
https://www.rite.or.jp/en/about/
2) METI
https://www.enecho.meti.go.jp/category/resources_and_fuel/carbondioxidecaptureandstorage/CCS_business.html (in Japanese)
3) METI: Carbon Management Subcommittee
https://www.meti.go.jp/shingikai/enecho/shigen_nenryo/carbon_management/index.html (in Japanese)
4) METI: News Release
https://www.meti.go.jp/english/press/2025/0221_003.html
5) METI: News Release
https://www.meti.go.jp/press/2025/09/20250917003/20250917003.html (in Japanese)
6) METI: News Release
https://www.meti.go.jp/press/2025/09/20250917002/20250917002.html (in Japanese)
7) METI: News Release
https://www.meti.go.jp/press/2026/04/20260415001/20260415001.html (in Japanese)
8) METI: News Release
https://www.meti.go.jp/shingikai/enecho/shigen_nenryo/carbon_management/ccs_wg/index.html (in Japanese)
9) METI: CCS Long-Term Roadmap Study Group
https://www.meti.go.jp/shingikai/energy_environment/ccs_choki_roadmap/index.html (in Japanese)
10) Seventh Strategic Energy Plan
https://www.enecho.meti.go.jp/category/others/basic_plan/
11) Study group on calculation methodologies under Greenhouse Gas Emission Calculation, Reporting and Publication System
https://policies.env.go.jp/earth/ghg-santeikohyo/study.html (in Japanese)
12) METI: Carbon Management Subcommittee
https://www.meti.go.jp/shingikai/enecho/shigen_nenryo/carbon_management/pdf/010_03_00.pdf (in Japanese)

Systems Analysis Group

Members (As of Apr. 2026)

Group Leader, Principal Research Scientist	**Keigo Akimoto**
Deputy Leader, Vice Principal Research Scientist	**Takahiro Nagata**
Principal Research Scientist	**Naoki Oda** (concurrent)
Vice Principal Research Scientist	**Wataru Fujisaki**
Senior Research Scientist	**Kenichi Wada**
Senior Research Scientist	**Miyuki Nagashima**
Senior Research Scientist	**Takashi Homma**
Senior Research Scientist	**Fuminori Sano**
Senior Research Scientist	**Ayami Hayashi**
Senior Research Scientist	**Atsuko Fushimi**
Senior Research Scientist	**Hiroshi Harada**
Senior Research Scientist	**Yuko Nakano**
Senior Research Scientist	**Naoko Onishi**
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Research Scientist	**Hitotsugu Masuda**
Research Scientist	**Teruhisa Ando**
Staff	**Kiyomi Yamamoto**
Staff	**Misako Saito**
Staff	**Sachiko Kudo**
Staff	**Ryoko Minamimura**

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 systematic approaches and analyses at both national and international levels.

The Government of Japan formulated the 7th Strategic Energy Plan[1)], the Plan for Global Warming Countermeasures[2)], and the GX2040 Vision[3)], and these were approved by the Cabinet in February 2025. Greenhouse gas (GHG) emissions reduction targets as Nationally Determined Contributions (NDCs) for 2035 and 2040 were set at reductions of 60% and 73%, respectively, compared to FY2013 levels, and were submitted to the UNFCCC Secretariat as Japan's NDC on February 18. Globally, many countries submitted their NDC3.0, which outlines emissions reduction targets for 2035 and 2040 around the time of COP30 in November 2025. The Systems Analysis Group conducted scenario analyses for the formulation of the 7th Strategic Energy Plan in FY2024, and carried out further expanded analyses in this fiscal year. In addition, while reviewing the status of emissions reduction targets in the latest NDCs, analyses and evaluations of emissions reduction efforts were conducted using multiple indicators. This report explains these scenario analyses and evaluations.

1. Sensitivity analysis of energy supply and demand scenarios for the 7th Strategic Energy Plan

The Government of Japan revised the Plan for Global Warming Countermeasures in February 2025 and set GHG emissions reduction targets as NDCs for 2035 and 2040 at reductions of 60% and 73%, respectively, compared to FY2013 levels, and also submitted them to the UNFCCC Secretariat on February 18. These targets correspond to a linear reduction path from the already submitted 46% reduction by 2030 to net-zero emissions (100% reduction) by 2050. While keeping exiting reduction targets and advancing responses to climate change, a pathway was selected that also responds to increasingly complex international circumstances. Furthermore, in the outlook of energy supply and demand in the 7th Strategic Energy Plan, a scenario in which emissions are higher was also presented as a response to economic risks. Meanwhile, global emissions continue to rise, and international conditions are becoming increasingly chaotic. The Russia–Ukraine war has prolonged, and in February 2026, the United States and Israel attacked Iran, intensifying tensions in the Middle East. The US Trump administration formally withdrew from the Paris Agreement in January 2026, and further declared withdrawal from the UNFCCC itself. Also, in February, it announced repeal of the GHG "endangerment finding", which had served as the legal basis for various emissions reduction policies.

Global climate change countermeasures are becoming increasingly fragmented. In aiming to achieve global carbon neutrality (CN), increasing differences in ambition and policy strength among countries make mitigation efforts more difficult. Climate change countermeasures are an urgent issue. However, in a situation without international cooperation on emissions reduction, even if domestic emissions reduction efforts are strengthened, reductions may be realized not through progress in climate policy but through declines in production activity and industrial leakage overseas. In such a case, even if domestic emissions decrease, global emissions will not decrease.

RITE conducted scenario analysis in FY2024, which was used as a major reference for the energy supply and demand outlook of the 7th Strategic Energy Plan[4),5)]. In that analysis, the "Risk Strategy Scenario" (regarded as the "Technology Improvement Scenario" by the government) was also adopted as a risk response scenario. However, under such international conditions, the importance of conducting broader scenario analysis has increased. Therefore, further expanded analysis was conducted based on the "Risk Strategy Scenario" presented for the formulation of the 7th Strategic Energy Plan.

1.1. Methodology

As in the analysis for the 7th Strategic Energy Plan, analysis was basically conducted using the DNE21+ model[6),7),8)]. Figure 1 shows the analysis flow.

The DNE21+ model is a partial equilibrium energy supply and demand model in which production volumes of energy-intensive industries (such as crude steel) and transport service demand are assumed exogenously. However, it has been observed that overseas relocation of energy-intensive industries has been progressing, and in future CO_2 emissions reductions, it is highly possible that production activity levels of energy-intensive industries themselves will change (decline in Japan) due to relative price changes with overseas markets induced by international differences in CO_2 emissions reduction stringency. Therefore, analysis was conducted incorporating the effect of reduced production volumes in energy-intensive industries that may be induced by international differences in CO_2 emissions reduction stringency. In this analysis, the global energy-economic model DEARS[9),10)] was basically used. On the other hand, there is a possibility that price elasticity has increased especially in developed countries, and therefore, analysis assuming higher price elasticity was also conducted for the "Low Growth Scenario". The calculations were performed again using DNE21+ with the updated prerequisites based on the estimated results of production declines.

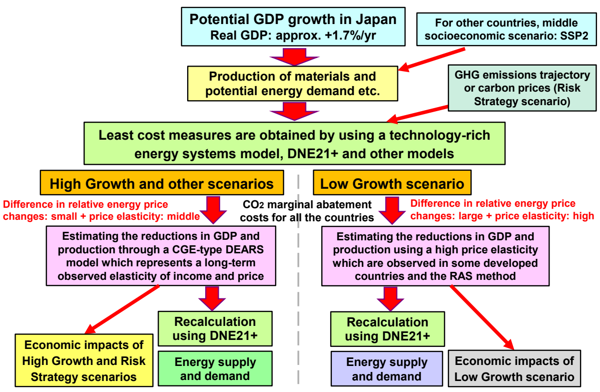

Figure 1 Estimation procedure for economic impacts and energy systems

1.2. Scenario assumption

Analysis was conducted for the seven scenarios shown in Table 1.

The "High Growth Scenario" assumes broad and significant technological progress. In contrast, scenarios in which only certain technologies progress successfully are the "Renewables," "Hydrogen," and "CCS" scenarios. All of these scenarios assume linear emissions reductions from a 46% reduction in 2030 to CN in 2050, and a 73% reduction in 2040. The targets of a 60% reduction in 2035 and a 73% reduction in 2040 (both compared to 2013 level) were submitted as Japan's NDC to the UNFCCC Secretariat in February 2025.

The "Low Growth Scenario" assumes that all technologies progress only along an extension of current trends. As can be understood from the analysis results described later, the impact on Japan's economy under this "Low Growth Scenario" is extremely large. Due to rising relative energy prices compared to overseas, energy-intensive industries may fall behind in international competition, and significant declines in production volumes may be expected. The government's GX policy aims to achieve a virtuous cycle between the environment and the economy, and a situation in which GHG emissions are significantly reduced but the economy is severely damaged must be avoided. Moreover, in such a case, even if domestic emissions are reduced, energy-intensive industries would increase their activities overseas, and global emissions would likely not decrease.

It should be noted that even in the "Low Growth Scenario," technological progress along the current trends is assumed, and given the recent economic downturn in Germany, for example, this scenario represents a sufficiently high risk of occurrence. Therefore, as a risk response strategy in the case where innovative technological progress does not occur, the "Risk Strategy Scenario" was also presented, in which strict achievement of domestic GHG emissions targets is not required so as to avoid excessively widen relative energy price differences. In this scenario, a carbon price level equivalent to that in a 1.5°C scenario is assumed, and Japan's emissions are calculated based on the model's economic calculation. As a result, in the "Risk Strategy Scenario," the targets of a 73% reduction in 2040 and CN in 2050 are not achieved; instead, emissions are reduced by 61% in 2040 and 79% in 2050.

Amid the increasing fragmentation of climate change countermeasures in recent years, relative energy price differences are more likely to widen further. Therefore, in FY2025, scenarios were analyzed assuming even lower carbon price levels than in the "Risk Strategy Scenario," namely the "High-risk Scenario" and the "Stated Policies Scenario." As will be described later in detail, the former adopts the carbon prices assumed in the International Energy Agency (IEA)'s Net Zero by 2050 (NZE) scenario, and the latter adopts the carbon prices assumed in the IEA's Stated Policies Scenario (STEPS).

The above scenarios are illustrated in Figure 2.

Table 1 Assumed scenarios

Emissions scenarios	Scenario name	Scenario descriptions
Emissions reduction scenarios: 2030: -46% 2040: -73% 2050: -100% [World] Below 1.5 °C	**High Growth** [Innovative technology expansion]	Broad mitigation technologies advance rapidly and expand internationally. Gaps between the relative prices of energy in Japan and other countries are moderate. A virtuous cycle between the economy and the environment.
	Renewables [Renewable expansion]	High social acceptance and rapid cost reduction of renewables
	Hydrogen [Hydrogen and new fuels deployment]	Rapid cost reductions in hydrogen, including ammonia, e-methane, and e-fuels
	CCS [CCS deployment]	Lower social barriers to geological CO_2 storage
	Low Growth [-]	Incremental technology improvements. The relative prices of energy in Japan will increase. Relocation of industries to abroad, an emerging risks for economic stagnation
Carbon price scenarios: Risk-responding scenario with a virtuous cycle between the economy and the environment under the uncertainties of technology improvements. -73% in 2040 and CN in 2050 as policy targets, but focused more on mitigation costs, leading to changes in the emissions under uncertainties	**Risk Strategy** [Technology Improvement]	Technology improvements are conservative, leading to the increase in relative energy prices in Japan. Restrictive carbon price policies are taken to maintain a virtuous cycle of the economy and the environment. Carbon prices are assumed based on the NGFS NZE2050 scenarios.
	High-risk Strategy [-]	Same as above, except for the assumption of the carbon price which refers to the IEA NZE
Carbon price scenario: Enhanced priority on the economy. Withdrawal from 1.5 °C and CN by 2050. Only pledged policies are implemented.	**Stated policies scenario** [-]	Same as above, except for the assumption of the carbon price which refers to the IEA STEPS

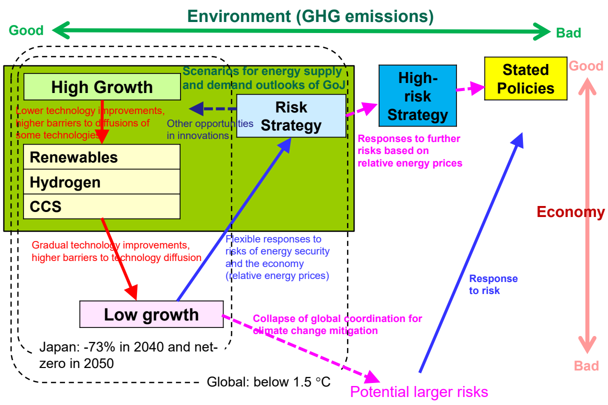

Figure 2 Map of the assumed scenarios

1.3. Assumption on technology scenarios and model preconditions

The assumptions for individual technologies in each scenario are as shown in Table 2, consistent with the scenario analysis conducted for the 7th Strategic Energy Plan. For details of the model preconditions and scenario assumptions, refer to References 4) and 11).

As mentioned earlier, except for the "Low Growth Scenario," reductions in production volumes of energy-intensive industries were, in principle, estimated using the global energy-economic model DEARS and then fed back into the DNE21+ model for calculation. On the other hand, for the "Low Growth Scenario," analysis was conducted assuming a relatively high long-term price elasticity value of −1.0.

Table 2 Scenario assumption for technologies

Scenarios	Potential economic growth	GHG emissions	Nuclear	Renewables		CCS／CDR	Hydrogen/ammonia	e-fuels/e-methane	IT electricity demands	Automobiles	Iron and steel	
	Income, population, and baseline industrial structure changes	Carbon prices due to emissions reduction	[Upper bound] Low: Existing 60 yrs operation reators only/ Mid: 20% in 2040; 10% in 2050/ High: 20%	[Upper potential considering social acceptance] Low: double of the current deployment level of solar PV, and three times for onshore wind power/ High: four times as the current deployment levels both of PV and onshore wind power	[Cost] Mid./ Rapid cost red.	[Upper bound] Annual potentials of geological storage (2050) Low: 0.12 Gt/ High: 0.24 Gt	[Cost] Mid./ Rapid cost red.	[Cost] Mid./ Rapid cost red.	Exogenous outlook	[EV cost] Mid./ Rapid cost red.	Diffusion constraints of hydrogen DRI	EITE and car production reductions due to energy price increase including relative prices
High growth	The official ambitious target by the GoJ	[World] 1.5℃ target [Japan] 2030: -46% 2040: -73% 2050: -100%	High	High (Economical potential: Mid)	Rapid cost red.	High	Rapid cost red.	Rapid cost red.	High	Rapid cost red.	High	Low (mid. price elasticity (CGE model: DEARS))
Renewables			Mid	High (Economical potential: Mid)	Rapid cost red.	Low	Mid	Mid	High	Rapid cost red.	High	
Hydrogen			Mid	High	Mid	Low	Rapid cost red.	Rapid cost red.	High	Mid	High	
CCS			Mid	High	Mid	High	Mid	Mid	High	Mid	High	
Low growth (Ref.)			Low	Low	Mid	Low	Mid	Mid	Mid	Mid	Mid	High (high price elasticity +RAS)
Risk strategy		Carbon price: NGFS NZ2050	Mid	High	Mid	Low	Mid	Mid	High	Mid	Mid	Low

1.4. Results of scenario analysis

(1) Global emissions and temperature rise

This section presents the model analysis results for the assumed scenarios.

First, Table 3 summarizes the emission reduction rates of global emissions in 2040, the timing of achieving net-zero CO_2 emissions globally, and temperature increases for the analyzed scenarios. The scenarios with a 73% reduction in 2040, including the "High Growth Scenario" adopted in the government's Strategic Energy Plan, as well as the "Risk Strategy Scenario," show a peak temperature increase of 1.7°C, which correspond to 1.5°C scenarios with temperature overshoot, and are consistent with the current recognition, such as statements by the UN Secretary-General António Guterres that temperature overshoot is unavoidable.

In the "High-risk Strategy Scenario," the temperature increase in 2100 is 2.4°C, while in the "Stated Policies Scenario," it is 3.2°C. Global emissions do not achieve net zero by 2100 in both scenarios. These levels are close to the UNEP estimate of 2.6°C (range: 1.9-3.6°C) under current policy continuation.

Table 3 Global emissions and temperature rise

		GHG emissions reduction in 2040 (relative to 2019)	Net-zero timing of CO2 emissions	Temperature rise compared with the pre-industrial level	
				Peak	2100
IPCC C1：1.5℃ with no or limited overshoot		69 [58–90] %	2050–55	1.6℃ [1.4–1.6]	1.3℃ [1.1–1.5]
IPCC C2：1.5℃ with high overshoot		55 [40–71] %	2055–60	1.7℃ [1.5–1.8]	1.4℃ [1.2–1.5]
Scenarios in this analysis	**-73% in 2040 and net-zero in 2050**	62 % (energy CO2：71–72%)	2050–55	1.7℃	1.4℃
	Carbon price scenario (Risk strategy)	52 % (energy CO2：54%)	2050–55	1.7℃	1.5℃
	Carbon price scenario (High-risk strategy)	24% (Energy CO2：8%)	— (2100-)	2.4℃	2.4℃
	Stated policies scenario	1% (Energy CO2：-28%)	— (2100-)	3.2℃	3.2℃

(2) Costs and economic impacts

Table 4 shows the marginal abatement costs of CO_2, and Table 5 shows the marginal costs of electricity.

Looking at the marginal abatement costs of CO_2, even under the "High Growth Scenario," it is analyzed that achieving a 73% reduction by 2040 and CN by 2050 would require considerably high costs. It is also considered that further innovation beyond what was assumed in this analysis would be necessary for realization.

In the "Low Growth Scenario," even greater increases in CO_2 marginal abatement costs and electricity costs are estimated. In addition, in comparison with other countries, it is confirmed that the electricity price gap widens in relative price terms. It should be noted that this analysis assumes achieving less than 1.5°C globally;

however, in reality, the world is heterogeneous, and some countries may implement only measures close to baseline levels. In such cases, the electricity price gaps between Japan and other countries under the “Low Growth Scenario” could widen even further. Therefore, it is important to consider flexible responses in emissions reductions to some extent.

The “Risk Strategy Scenario” is designed to respond to such situations. In this scenario, as described earlier, a carbon price equivalent to that in a 1.5°C scenario is assumed globally, resulting in uniform CO_2 marginal abatement costs (carbon prices) worldwide, which are slightly lower than those in the “High Growth Scenario.” In the “Risk Strategy Scenario,” which assumes continuing the current pace of technological progress, because the scenario assumes carbon prices rather than emission constraints, energy costs and electricity costs remain at levels comparable to the “High Growth Scenario.” In comparison with other countries, although electricity prices increase compared to current levels in all scenarios due to emissions reduction measures, the relative price gap with overseas does not widen significantly.

The “High-risk Strategy Scenario” and the “Stated Policies Scenario” refer to the carbon prices in IEA scenarios. Japan’s carbon prices in 2040 are estimated at 116 USD/tCO_2 and 41 USD/tCO_2, respectively (equivalent to 12,800 yen/tCO_2 and 4,500 yen/tCO_2 assuming an exchange rate of 1 USD = 110 yen). The upper and lower bounds of the GX-ETS carbon prices in 2026 are set at 1,700-4,300 yen/tCO_2 (with an annual increase of 3% in real terms), and the assumed carbon prices in these scenarios are considered to be close to these levels. The marginal electricity costs in 2040 is estimated to remain almost unchanged compared to 2020 in the “High-risk Strategy Scenario”, while they slightly decrease due to reductions in renewable energy costs in the “Stated Policies Scenario.”

Table 4 Marginal abatement costs of CO_2 emissions

		Emissions reduction scenario (-73% in 2040)					Carbon prices scenario		
		High growth	Renewables	Hydrogen	CCS	Low growth	Risk strategy	High risk strategy	Stated policies
Japan	2040	301	369	467	396	538	257	116	41
	2050	578	716	742	892	951	500	141	50
US	2040	294	350	409	362	410	257	116	0
	2050	262	348	454	350	467	500	141	0
UK	2040	294	350	419	369	428	257	116	84
	2050	317	387	558	452	579	500	141	89
EU	2040	298	350	409	362	410	257	116	84
	2050	413	516	648	541	664	500	141	89
Others	2040	294	350	409	362	410	257	20～116	0～84
	2050	262	348	454	350	467	500	31～141	0～89

Unit: USD/tCO_2 (in 2000 price)

Table 5 Marginal costs of electricity in 2040

	2020	Base line	Emissions reduction scenario (-73% in 2040)					Carbon prices scenario		
			High growth	Renewables	Hydro gen	CCS	Low growth	Risk strategy	High risk strategy	Stated policies
Japan	166	127	212	224	251	242	311	213	168	141
US	40	38	98	118	125	116	126	127	86	43
UK	114	135	180	195	223	203	222	201	168	158
Germany	114	119	175	191	202	198	204	194	158	148
France	114	113	171	165	172	173	173	174	170	160
Korea	103	103	174	173	194	195	194	184	145	123
China	61	66	143	152	213	192	213	173	103	71
India	105	121	187	190	236	239	237	223	165	121

Unit: USD/MWh (in 2000 price)
Note) The prices are the generation output terminal prices but including the grid integration costs.
The 2020 prices are also estimated using the model.

Table 6 shows the estimates of production volumes and GDP declines calculated using the global energy-economic model DEARS for the “High Growth Scenario,” “Low Growth Scenario,” and “Risk Strategy Scenario.” It also presents economic growth projections including the effects of overseas diffusions of mitigation technologies and products.

In the “High Growth Scenario,” rapid technological progress is assumed; however, due to the stringent emissions reduction targets of a 73% reduction by 2040 and CN by 2050, GDP is projected to decline by 4.1% in 2040 and 5.6% in 2050. In the iron and steel sector, production declines by 3.9% in 2040 and 11% in 2050 (for example, the potential crude steel production in 2050 is estimated at 90 million tons per year, but declines by 11% to 80 million tons per year). However, if the world moves toward the 1.5°C target, there is also the potential to capture overseas markets. Although there is significant uncertainty in the estimates, an increase of about 5 percentage points per year is projected. Therefore, this scenario could achieve economic growth roughly at the level of potential growth (slightly positive in 2040; the economic growth rate for 2023–2040 is estimated at 1.5% per year, incorporating population decline effects).

In the "Low Growth Scenario," where technological progress remains gradual, it is possible that Japan is placed in a situation where access to relatively low-cost decarbonized energy is even more limited compared to overseas, resulting in wider relative energy price gaps with other countries and large-scale industrial relocation overseas. In the iron and steel and chemical industries, extremely large declines in production volumes of around 40% compared to the baseline are estimated. Similarly, in the automobile industry (transport equipment), similar level of production decline is estimated. Overall GDP is also projected to decline significantly by around 13–14%. If emissions reductions are pursued linearly toward CN by 2050 without substantial technological progress, a situation similar to that shown in the "Low Growth Scenario" could plausibly occur.

In the "Risk Strategy Scenario," technological progress is assumed to be similar to that in the "Low Growth Scenario" rather than rapid as in the "High Growth Scenario," and the economic impact is estimated to be not significantly different from that of the "High Growth Scenario" while emissions increase relative to targets. Avoiding major declines in economic activity and industrial relocation due to carbon constraints is important, and this scenario represents one that can respond to such risks.

In the "High-risk Strategy Scenario," because carbon prices are low, negative impacts on the economy can be significantly suppressed compared to other scenarios. On the other hand, since emissions reductions abroad also do not progress, the effect of the international advantages of mitigation technologies in Japan is smaller than in other scenarios. As a result, when including overseas market acquisition effects, the overall economic impact will be at a level similar to that of the "Risk Strategy Scenario" and the "High Growth Scenario."

Table 6 GDP and major manufacturing industries in Japan

Reduction ratios in productions/value added	High Growth (DEARS)		Low Growth (price elasticity: -1.0, income elasticity: +1.0, and RAS)		Risk Strategy (DEARS)		High-Risk Strategy (DEARS)	
	2040	2050	2040	2050	2040	2050	2040	2050
Iron and steel	-3.9%	-11.0%	-41%	-46%	-3.6%	-11.0%	-2.8%	-2.1%
(production [million ton/yr])	(0.86)	(0.80)	(0.53)	(0.49)	(0.86)	(0.80)	(0.87)	(0.88)
Chemical	-3.7%	-11.2%	-35%	-40%	-3.3%	-10.7%	-2.1%	-1.7%
Non-metal materials	-2.1%	-2.7%	-30%	-34%	-1.7%	-3.8%	-0.9%	-0.6%
Non-ferrous metals	-1.4%	-2.7%	-35%	-39%	-1.2%	-5.0%	-0.8%	-0.2%
Paper and pulp	-3.5%	-6.3%	-33%	-37%	-3.1%	-7.2%	-1.5%	-1.7%
Transport machinery	-4.1%	-6.9%	-42%	-47%	-4.7%	-8.2%	-1.6%	-2.0%
GDP (excluding the overseas diffusion effects)	-4.1%	-5.6%	-13%	-14%	-3.6%	-5.9%	-1.8%	-2.1%
GDP/GNI (including the overseas diffusions particularly of mitigation technologies/ products)	Approximately same of the potential economic growth (oversea effects:+4% to +5%)		Less expectation on the overseas additional effects of economic increase		Approximately same of the potential economic growth (oversea effects:+3% to +4%)		Approximately same of the potential economic growth (overseas effects:+1%)	
Annual growth in GDP/GNI since 2023 (including future population decrease)	+1.5%/yr	+1.2%/yr	+0.6%/yr	+0.7%/yr	+1.4%/yr	+1.2%/yr	+1.4%/yr	+1.2%/yr

(3) Japan's emissions

Figure 3 shows GHG emissions by sector in Japan. As noted earlier, emissions are estimated to be reduced by 61% in 2040 and 79% in 2050 in the "Risk Strategy Scenario." The reductions are 52% in 2040 and 63% in 2050 in the "High-risk Strategy Scenario," while reductions remain at 41% in 2040 and 45% in 2050 in the "Stated Policies Scenario,".

In the "High-risk Strategy Scenario" and the "Stated Policies Scenario," hydrogen-based direct reduction steelmaking is not economically viable even in 2050, and the blast furnace–basic oxygen furnace method remains economically efficient. Consequently, a considerable amount of emissions remains in the iron and steel sector.

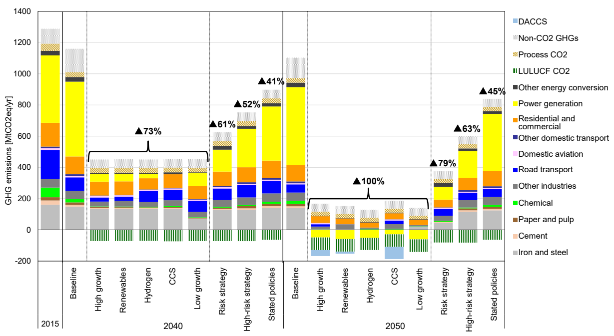

Figure 3 GHG emissions by sector

(4) Japan's energy supply and demand

Figure 4 shows electricity generation in Japan. Electricity generation increases in all scenarios except for the "Low Growth Scenario." Under the 73% reduction scenario for 2040, since non-CO_2 GHGs and other hard-to-abate industrial sectors remain, achieving near-zero emissions in the power generation sector is economical. A combination of renewable energy, nuclear power, and CCS is found to be economically optimal. The share of renewable energy in 2040 is estimated to be around 40–50%, and it is slightly lower at around 35% in the "Risk Strategy Scenario." In 2050, a notable increase in floating offshore wind power is observed.

Electricity demand is expected to essentially increase due to factors such as IT demand. However, if energy prices become relatively high, it becomes necessary to suppress energy consumption while production volumes decline, including through industrial relocation overseas. Investment in economically efficient power sources often requires long lead times. Therefore, in order to avoid tight electricity supply-demand conditions, it can be said that highly predictable energy and climate policies that prevent the realization of the "Low Growth Scenario" are important.

In the "Risk Strategy Scenario," the share of LNG-based power generation (including cogeneration and CCS-equipped systems) remains at approximately the current level until 2050 as an economically efficient outcome. In the "Stated Policies Scenario," coal-fired power generation remains economically viable, while the economic potential of renewable energy is significantly constrained.

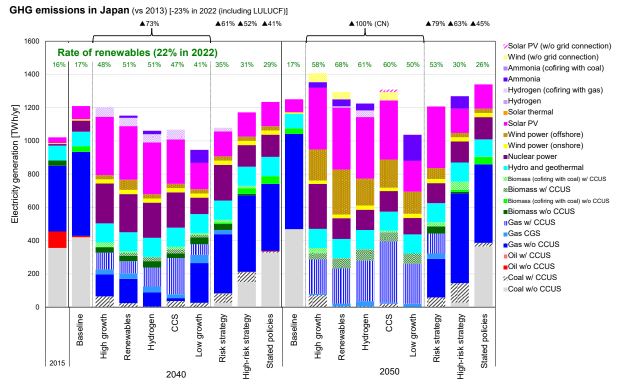

Figure 4 Electricity supply

Figure 5 shows final electricity consumption by sector. In the "High Growth Scenario," final electricity consumption is 1,081 TWh/year in 2040 and 1,210 TWh/year in 2050. The demand is expected to be significantly suppressed due to high energy prices in the "Low Growth Scenario." In the "High-risk Strategy Scenario" and the "Stated Policies Scenario," electrification is somewhat suppressed due to low level of carbon prices, however, energy-saving effects are also weaker, resulting in relatively high levels of final electricity consumption.

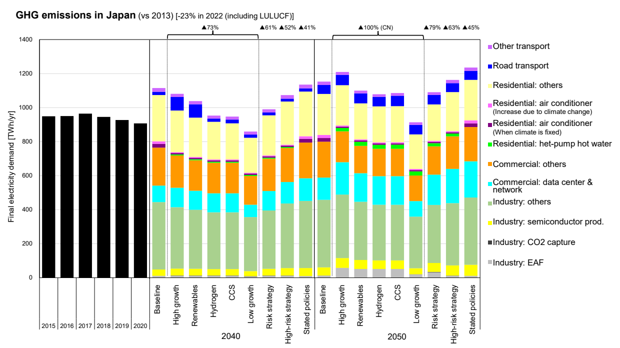

Figure 5 Final electricity demand by sector

Figure 6 shows total final energy consumption. Increasing the electrification rate is an economically efficient measure. However, complete electrification is not economical in any sector, and a combination of hydrogen, ammonia, synthetic methane (e-methane), synthetic fuels (e-fuels), and biofuels is considered economically optimal.

For total final energy consumption, the electrification rate in 2040 is estimated to be 38–44% under the 73% reduction scenarios, and 54–57% under CN in 2050. Total final energy consumption in 2040 is estimated to decrease by 26–28% compared to 2015 under the 73% reduction scenarios, and by 36–41% in 2050 under CN.

In the “High-risk Strategy Scenario” and the “Stated Policies Scenario,” relatively high total final energy consumption is estimated as carbon price level is low.

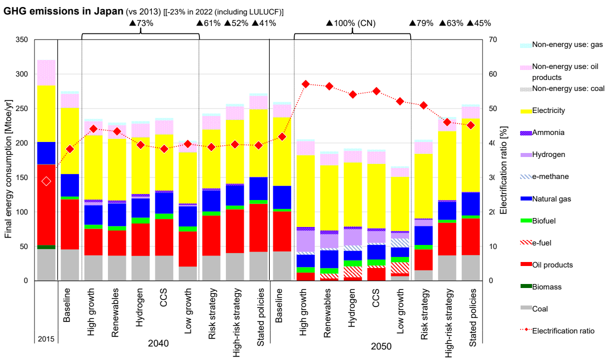

Figure 6 Final energy consumption by fuel type

2. Analysis and evaluation of 2035 emissions reduction targets (NDCs)

2.1. Status of emissions reduction targets in NDCs

A pledge-and-review mechanism was adopted in the Paris Agreement in order to encourage participation from many countries, which established a framework in which nearly all countries undertake emissions reduction efforts. Under the Paris Agreement, all countries determine their own targets and methods for achievement and submit them as Nationally Determined Contributions (NDCs) every five years (Article 4, paragraphs 2 and 9). When revising targets, countries are required to make progression beyond their previous targets (Article 4, paragraph 3). In addition, to promote effective implementation, all countries are required to report their implementation status and undergo review in a transparent manner using common and flexible methods (Article 13). For the Paris Agreement to effectively achieve emissions reductions, it is considered important how appropriately the review process can be implemented. However, as the appropriateness or inadequacy of each country’s NDC is not subject to review under the review procedures decided at COP24, evaluation outside the UNFCCC framework is considered important.

RITE previously analyzed emissions reduction efforts using various indicators for the Intended Nationally Determined Contributions (INDCs) submitted before the Paris Agreement in FY2015. Furthermore, in FY2021, a similar analysis was conducted for the NDCs submitted to the UN by November 11. Subsequently, around COP30 in November 2025, many countries submitted NDC3.0, including emissions reduction targets for 2035 (and for some countries and regions, including Japan, also for 2040). Based on this, in FY2025, analysis and evaluation of emissions reduction efforts focusing on NDC3.0 were conducted.

Table 7 shows the emissions reduction targets of NDC3.0 submitted to the UN by December 31, 2025, as well as the status of published NDCs and CN declarations (only selected countries are shown).

Developed countries, including Japan, present enhanced emissions reduction targets compared to their 2030 targets in NDC3.0. Meanwhile, China, which had previously set CO_2 intensity targets, has expanded the scope to GHGs and presented an absolute emissions reduction target of 7–10% below peak level.

Table 7 Emissions reduction targets in major countries' NDCs

	2030 NDC	2035 NDC	2040 NDC	2050 -
Japan	-46% (vs 2013)	-60%	-73%	CN by 2050
US※1	-50% to -52% (vs 2005)	-61% to -66%	—	CN by 2050
EU27	-55% (vs 1990)	-66.25% to -72.5%	-90%	CN by 2050
UK	-68% (vs 1990)	-81%	—	CN by 2050
Switzerland	-50% (vs 1990)	At least -65%	At least -75%	CN by 2050
Norway	-55% (vs 1990)	-70% to -75%	—	Low emission society by 2050
Australia	-43% (vs 2005)	-62% to -70%	—	CN by 2050
New Zealand	-50% (vs 2005)	-51% to -55%	—	CN by 2050 (w/o methane)
Canada	-40% to -45% (vs 2005)	-45% to -50%	—	CN by 2050
Russia	-30% (vs 1990)	-65% to -67%	—	CN by 2060
Korea	-40% (vs 2018)	-53% to -61%	—	CN by 2050
China※2	-65% CO_2 emissions per GDP (vs 2005)	-7% to -10% vs GHG emissions peak (peaking before 2030)	—	CN by 2060
India	-45% GHG emissions per GDP (vs 2005)	—	—	CN by 2070

※1 Submitted by the Biden administration. Withdrawn from the Paris agreement on Jan. 26, 2026.
※2 Evaluated with the 2030 baseline emission estimated by the DNE21+ as the peak.

2.2. Evaluation of emissions reduction efforts in NDCs

(1) Indicator and methodology for evaluation

It is important to properly review emissions reduction targets pledged by each country in their NDCs. Given differences in national circumstances, it is important to evaluate emissions reduction efforts in a way that ensures comparability while taking these differences into account, and therefore, it is necessary to select appropriate indicators and measure emissions reduction efforts accordingly. In this study, evaluation was conducted using the indicators described below based on previous research[12)].

Measuring emissions reduction efforts is considered important for establishing a PDCA (Plan–Do–Check–Act) cycle. The principles for comparability metrics are described in Reference 13) as below.

- Comprehensive: capturing efforts comprehensively
- Measurable: capable of being measured
- Replicable: reproducible and transparent
- Universal: applicable to as many countries as possible

Furthermore, since no single indicator can uniquely determine fairness or equity, it is necessary to conduct a multifaceted evaluation using multiple indicators.

In this study, the evaluation of "emissions reduction effort" in NDC targets adopts the same methodology as used in the 2015 evaluation, selecting indicators summarized in Table 8 so that efforts can be appropriately assessed despite differences in national capabilities and mitigation potentials. The methodology described here has also been adopted as a peer-reviewed literature in Reference 14), and in addition, indicators not explicitly included in that study (such as per capita emissions) are also adopted and evaluated here.

Table 8 Evaluation indexes adopted in this study

Indicators for emissions reduction efforts		Overview	Notes
Emissions reduction ratio from the base year	Relative to 1990, 2005, 2013, etc.	When baseline emissions are expected to stagnate, it is more relevant to simply compare the projected reduction rates, which makes it possible to avoid uncertainties in the estimation for baseline emissions.	Comparison based on each country's base year should be conducted.
	Relative to latest possible year, such as 2019		It is good as a measure for evaluating future reduction efforts since reduction ratios based on the most recent results are shown.
Emissions per capita	Absolute level	To show the level of GHG emissions per capita.	As this is highly dependent on the country's level of economic activity and situation in general, assessing emissions reduction efforts through this indicator can be difficult.
GHG emissions per unit of GDP (CO_2 intensity)	Absolute level	To show the level of GHG emissions considering a scale of economic activities.	Values tend to be higher for low-GDP countries, and highly dependent on industrial structure.
	Improvement rate (e.g. compared to 2019, etc.	Using the rate of change might be assessed as an aspect of the emissions reduction efforts, as the differences of economic growth rate can be removed.	Countries with low-GD tend to show better improvement rate of intensity due to high GDP growth rates.
Emissions reduction ratio compared to baseline emissions		Differences in economic growth can be taken into account.	It excludes past efforts in energy saving and the abatement potential of renewables.
CO_2 marginal abatement cost (carbon price)		This is highly relevant for assessing reduction efforts, as it reflects national differences in terms of economic growth, energy savings efforts and the abatement potential of renewables.	Existing measures such as energy taxes are considered out of scope (however, if energy saving effects have already been achieved, they may be taken into consideration as the MAC is estimated to be high).
Emission reduction costs per GDP		While marginal abatement costs do not take into account the economy's ability to bear the necessary burden, this indicator is sensitive to that.	Uncertainties are high as this is a model-based estimation.

Below are several points to note in evaluating emissions reduction efforts in NDCs.

- There is significant uncertainty in emissions projections and reductions related to Land Use, Land-Use Change, and Forestry (LULUCF), making evaluation difficult; therefore, this study basically does not address them.
- For countries that have submitted emissions reduction targets relative to a base year, the emissions for the target year are calculated based on actual emissions in the base year (excluding LULUCF).
- For countries that have submitted GDP intensity improvement targets, evaluation is conducted based on RITE's assumptions for future GDP.
- For countries that have submitted reduction targets relative to BAU (Business-As-Usual), when BAU emissions are specified in the NDC, total emissions for the

evaluation year are calculated based on those values.

(2) Results of analysis and evaluation of emissions reduction efforts

Figure 7 shows a comparison of the emissions reduction ratio in 2035 compared to the base year of 2013. Table 9 summarizes emissions reduction ratio in 2035 compared to 1990, 2005, 2013, and 2021 for major countries.

In terms of reductions relative to 2013, Norway shows the highest reduction rate, followed by the United Kingdom and Australia. On the other hand, countries expected to experience significant economic growth in the future may appear disadvantaged when evaluated based on reductions relative to a base year. Thus, while this indicator is very simple, it is considered inappropriate for evaluating emissions reduction efforts, especially when including developing countries.

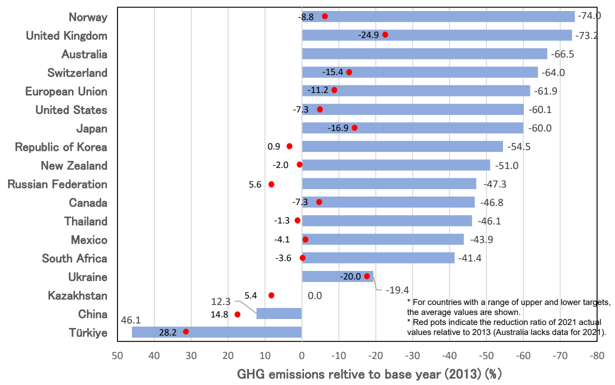

Figure 7 GHG emissions reduction ratio in 2035 relative to the base year of 2013

Table 9 GHG emissions reduction ratio in 2035 relative to the base year

	Emissions reduction ratio from the base year			
	1990	2005	2013	2021
Japan: -60% vs 2013 (-73% vs 2013 in 2040) *1	-56% (-70%)	-59% (-73%)	-60% (-73%)	-52% (-68%)
US: -61% to -66% vs 2005	-55% to -61%	-61% to -66%	-57% to -63%	-54% to -60%
EU27: -66.25% to -72.5% vs 1990 (-90% vs 1990 in 2040) *1	-66.25% to -72.5% (-90%)	-64% to -71% (-89%)	-58% to -66% (-88%)	-53% to -61% (-86%)
UK: -81% vs 1990	-81%	-78%	-73%	-64%
Switzerland: -65% vs 1990 (-75% vs 1990 in 2040) *1	-65% (-75%)	-66% (-76%)	-64% (-74%)	-57% (-70%)
Norway: -70% to -75% vs 1990	-70% to -75%	-72% to -77%	-72% to -76%	-69% to -74%
Australia: -62% to -70% vs 2005	-53% to -63%	-62% to -70%	-63% to -70%	n/a *2
New Zealand: -51% to -55% vs 2005	-38% to -43%	-51% to -55%	-49% to -53%	-48% to -52%
Canada: -45% to -50% vs 2005	-32% to -38%	-45% to -50%	-44% to -49%	-40% to -45%
Russia: -65% to -67% vs 1990	-65% to -67%	-44% to -47%	-46% to -49%	-49% to -52%
China: -7% to -10% vs GHG emissions peak *3	+298% to +285%	+85% to +79%	+14% to +10%	-1% to -4%
Korea: -53% to -61% vs 2018	+14% to -6%	-38% to -49%	-50% to -59%	-51% to -59%

*1 The values in parentheses are targets for 2040.
*2 Actual value for 2021 is lacking.
*3 Evaluated regarding the 2030 baseline emission estimated by DNE21+ as a peak.

Figure 8 shows GHG emissions per capita in 2035. The United Kingdom, Switzerland, and Norway have relatively low levels, while Turkey, Ukraine, and China are projected to have incremental per capita emissions.

Figure 9 shows GHG emissions per unit of GDP in 2035. Switzerland, Norway, and the United Kingdom are estimated to have low emissions per GDP. However, it should be noted that emissions per GDP are influenced by industrial structure - for example, countries with a larger tertiary sector tend to show better values, while those with a larger secondary sector tend to show worse values - independent of actual emissions reduction efforts.

Figure 10 shows emissions relative to baseline in 2035. In addition to Norway, which has a high reduction rate relative to its base year, Thailand is also evaluated as having a high reduction rate due to expected future economic growth.

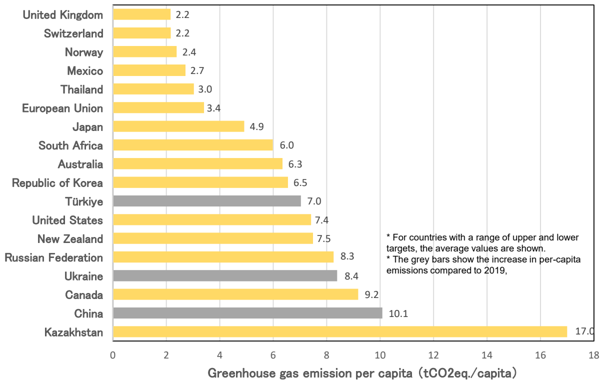

Figure 8 Per-capita GHG Emissions in 2035 for NDCs

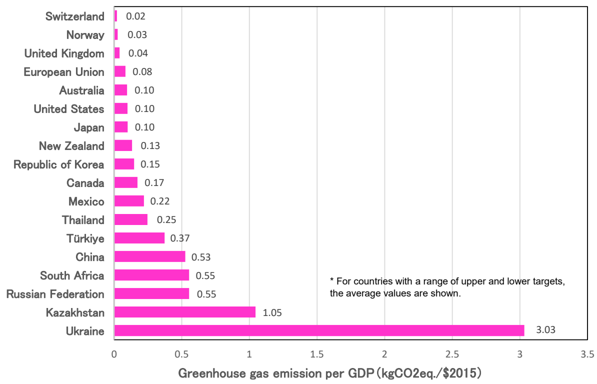

Figure 9 Per-GDP(MER) GHG Emissions in 2035 for NDCs

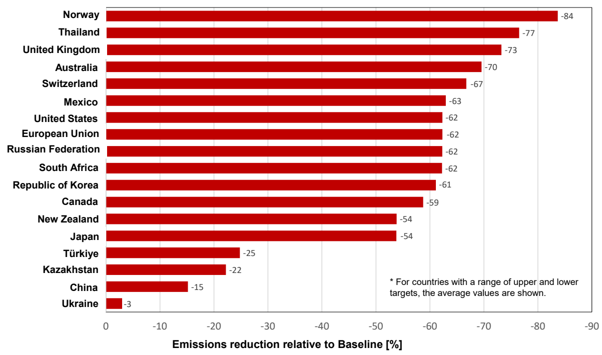

Figure 10 Emissions reduction ratio relative to baseline in 2035

Figure 11 shows marginal abatement costs of CO_2 in 2035. Thailand, the United Kingdom, and Russia are evaluated as having high marginal abatement costs. For countries and regions such as the EU27, Switzerland, and Japan, which also present 2040 targets, marginal abatement costs in 2040 are estimated to be 387, 318, and 368 USD/tCO_2, respectively. For China, since the timing and level of its emission peak are not clearly specified, the 2030 baseline emission estimated by the DNE21+ model was treated as the peak for evaluation, resulting in a marginal abatement cost of 38 USD/tCO_2.

Including non-Annex I countries, many submitted targets imply marginal abatement costs reaching hundreds of USD per tCO_2. While these are considered ambitious targets on one hand, their feasibility raises more questions than previous NDCs.

Figure 12 shows emissions reduction costs relative to GDP in 2035. Russia, Thailand, and Ukraine are evaluated as having high costs relative to GDP. These costs include the effect of net cost increases due to decrease in exports of oil and gas associated with emissions reductions. For example, Russia is evaluated as having a 16% increase in reduction cost relative to GDP due to decreased fossil fuel exports compared to baseline. Therefore, caution is required in interpretation.

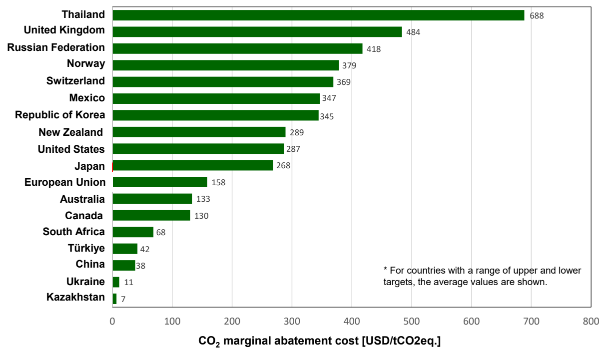

Figure 11 Marginal abatement costs of CO_2 in 2035

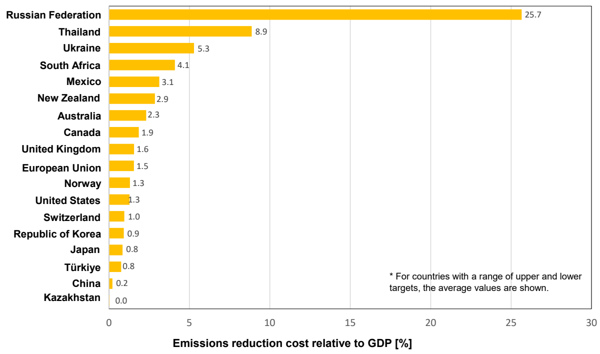

Figure 12 Per-GDP emissions reduction cost in 2035

2.3. Summary

Emissions reduction targets for 2035 NDCs of various countries were evaluated using multiple indicators for emissions reduction effort. Among these, emissions reduction costs were analyzed using the global energy and climate policy assessment model DNE21+.

Including non-Annex I countries, many submitted emissions reduction targets imply marginal abatement costs reaching hundreds of USD per tCO_2. While these indicate ambitious targets, their feasibility is even more questionable than previous NDCs. As noted earlier, this evaluation basically does not include LULUCF due to its high uncertainty. Some countries with high marginal abatement costs may be assuming significant reductions through LULUCF; however, even in such cases, their targets may deviate from actual emission reductions.

For China, since the emission peak is not clearly specified in its NDC, the 2030 baseline emission estimated by DNE21+ was treated as the peak, resulting in a marginal abatement cost of 38 USD/tCO_2.

The Paris Agreement's NDC framework is based on a pledge-and-review approach. Although differences exist among countries, striving for equitable emissions reduction efforts is important for maintaining the system and achieving global emissions reductions. However, the United States has withdrawn from the Paris Agreement, and some major emitting countries have not submitted NDC3.0, suggesting that significant disparities in emissions reduction efforts among major countries may remain.

Reference

1) The Government of Japan, The 7th Strategic Energy Plan (2025) https://www.meti.go.jp/english/press/2025/0218_001.html

2) The Government of Japan, The Plan for Global Warming Countermeasures (2025) [in Japanese] https://www.env.go.jp/earth/ondanka/keikaku/250218.html

3) The Government of Japan, GX2040 Vision (2025) [in Japanese]. https://www.meti.go.jp/press/2024/02/20250218004/20250218004.html

4) K. Akimoto, F. Sano, and T. Homma, The Energy demand and supply analyses for Japan toward the 2050 CN target (updated version of the analyses presented on Dec. 3, 2025) (2024) [in Japanese]. https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2024/068/068_008.pdf

5) METI, Specification for scenario analyses (2024) [in Japanese]. https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2024/066/066_005.pdf

6) K. Akimoto, M. Nagashima, F. Sano, T. Ando, Gaps between costs and potentials estimated by bottom-up assessments versus integrated assessment models, Energy Strategy Reviews, 55, 101521, 2024.

7) K. Akimoto, F. Sano, J. Oda, H. Kanaboshi, Y. Nakano, Climate change mitigation measures for global net-zero emissions and the roles of CO_2 capture and utilization and direct air capture, Energy and Climate Change, 2, 100057, .2021.

8) K. Akimoto, F. Sano, T. Homma, J. Oda, M. Nagashima, M. Kii, Estimates of GHG emission reduction

potential by country, sector, and cost, Energy Policy, Vol. 38,(7), 3384-3393, 2010.

9) T. Homma, K. Akimoto, Analysis of Japan's energy and environment strategy after the Fukushima nuclear plant accident, Energy Policy 62, 1216-1225 (2013).

10) T. Homma, et al., An analysis of international competitiveness in country contributions to the Paris Agreement, taking into account current climate and energy policies, Energy and Resources, 41-5 (2020)

11) RITE, The overview of RITE models including DNE21+ for the analyses on the scenarios (2024) [in Japanese] https://www.rite.or.jp/system/global-warming-ouyou/download-data/DNE21plusmodeloverview.pdf

12) RITE, FY2015 Report for project for international c ooperation on the analysis and assessment of tec hnologies for climate change mitigation (2016).

13) J. Aldy, B. Pizer, Comparability of effort in international climate policy. Harvard Project on Climate Agreements Discussion Paper 14-62, 2014.

14) J. Aldy, B. Pizer, K. Akimoto, Comparing emission mitigation efforts across the countries, Climate Policy, Vol.17, Issue 4, pp. 501-515, 2017.

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Members (As of Apr. 2026)

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Vice Principal Research Scientist	**Haruhiko Teramoto**
Vice Principal Research Scientist	**Kazumi Hiraga**
Vice Principal Research Scientist	**Masato Miyamoto**
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Staff	**Junko Nishi**
Staff	**Aya Okada**
Staff	**Yukiko Yanagida**

Development of Biomanufacturing Technologies for the Realization of Sustainable Society

1. Introduction

Sustainability refers to a term that combines “sustain” and “ability,” and indicates the state in which the systems of the Earth and society maintain their functions and continue to operate into the future. Moreover, in order to realize a sustainable society, it is considered important to build systems and processes in which the three pillars of “environmental protection,” “social development,” and “economic growth” develop in a balanced way while mutually influencing each other.

Biomanufacturing technology is attracting attention as one of the approaches to realize this sustainable society. In principle, biomanufacturing is a cutting-edge technological innovation that combines biotechnology, such as synthetic biology and genome editing, with rapidly developing digital technologies like IoT and AI. It utilizes technologies that enable more efficient genetic modification to produce useful substances from the cells of microorganisms, animals, and plants. This technology is fundamentally based on the biological mechanisms found in nature. However, in addition to the substances that microorganisms originally produce within their cells for their own purposes, it employs techniques such as conferring additional substance-producing capabilities upon microorganisms using genome editing, enhancing or disabling the functions of microbial enzymes, and other similar methods. These approaches enable the efficient mass production of target substances from raw materials. In other words, it is a new approach that applies biological operations to industrial manufacturing processes and has the following characteristics and advantages.

Biological manufacturing has the advantage of enabling high-yield synthesis of compounds that are difficult to produce through chemical processes, by using highly specific bioprocesses with microbial enzymes, thereby reducing the generation of byproducts. Various enzymes in microbial cells collaborate to facilitate multi-step synthesis reactions, making them ideal for synthesizing substances with complex structures and high carbon numbers. Biomanufacturing has been primarily used in the biopharmaceuticals and food industries. However, as biotechnology advances rapidly, its application in a variety of industrial fields, including fuels, chemicals, and textile materials, is on the rise.

The greatest advantage of biomanufacturing is that it not only drives innovation in industrial activities, such as the development of new products and the transformation of manufacturing processes, but also makes it possible to simultaneously address global social challenges like climate change, food shortages, resource scarcity, and marine pollution. In chemical manufacturing, which is at the center of current industrial activities, it often requires reactions at high temperatures and high pressures that have a significant environmental impact. In contrast, in biomanufacturing reactions can be carried out at room temperature and pressure, which is expected to reduce CO_2 emissions compared to chemical processes. Biomanufacturing can also utilize bio-based resources as raw materials, such as biomass, which absorb CO_2 during its growth process. Unlike chemical processes that depend on fossil resources like petroleum, this method considerably reduces new emission of CO_2 that affects climate change. Furthermore, in cutting-edge biomanufacturing, it is becoming increasingly possible to recycle waste derived from chemical products—which previously could only be disposed of through environmentally burdensome methods such as landfilling or incineration—and the CO_2 generated from incinerating these wastes, into resources needed for industrial activities, such as fuels (biofuels), new chemicals (green chemicals), or as starting materials for these products.

In this way, biomanufacturing is important as a technology for achieving carbon neutrality by moving away from petroleum resources and using manufacturing methods that do not put a burden on the environment. In addition, biomanufacturing is important as a technology for addressing social issues such as marine pollution and for building a circular economy through the effective use of unused resources derived from waste, thereby preserving the global environment for the future. Furthermore, the technological innovations in biomanufacturing will enhance brand strength and international recognition, supporting the next generation of industrial infrastructure, attracting investment, and becoming the economic foundation that sustains the future. It is not an exaggeration to say that this technology should be developed to promote a balanced advancement of “environmental protection” and “economic development,” which are essential for realizing a sustainable society. RITE has long focused on biotechnology manufacturing and has actively worked on developing core technologies and other elements to lay the foundation for industrial applications.

This overview will first introduce RITE's core technologies, including the "RITE Bioprocess"[*1] and

"Smart Cell Creation Technology." Next, it will introduce the status of technological development efforts in various national projects involving RITE, particularly the initiatives in foundational technology development in the "bio × digital" technology field at "RITE Biomanufacturing Center," which was completed in November 2025. Finally, it will discuss efforts toward commercialization aimed at social implementation and future prospects.

2. The Core Technologies of RITE

2.1. "RITE Bioprocess"

RITE has been focusing on the value of Corynebacterium, which are representative industrial microorganisms with unparalleled high production capabilities, and has been engaging in developing core technologies for their use. As part of RITE's research, it was discovered that "Corynebacteria exhibit the phenomenon where their growth is inhibited under anaerobic conditions, while the metabolic functions necessary for substance production are maintained, allowing them to efficiently produce organic acids and other compounds from sugars." Based on this phenomenon, RITE established the RITE- proprietary technology, growth-independent bioprocess known as the "RITE Bioprocess." "RITE Bioprocess" is one of the most crucial core technologies for promoting the social implementation of biomanufacturing. (Fig. 1). Below are its three main features.

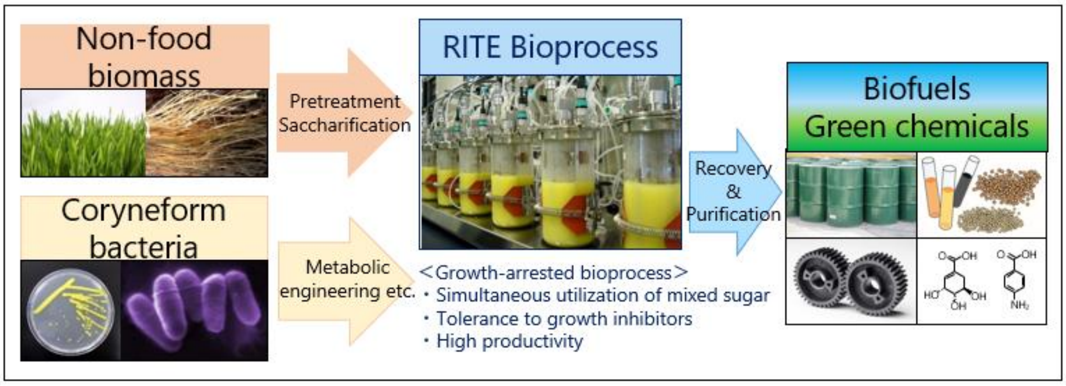

Fig. 1 Biomanufacturing using the "RITE Bioprocess"

Feature 1: Growth-arrested bioprocess

In nature, fermentation typically requires microorganisms to grow while producing substances. However, RITE has established a " growth-arrested bioprocess," in which cell growth stops under certain anaerobic conditions or aerobic conditions with essential growth factors removed, while the production of the desired substance continues (Fig. 2). " Growth-arrested bioprocess" are technologies that achieve productivity equal to or greater than chemical processes, because all the nutrients and energy that are conventionally consumed for microbial growth are used solely for the production of the target substance.

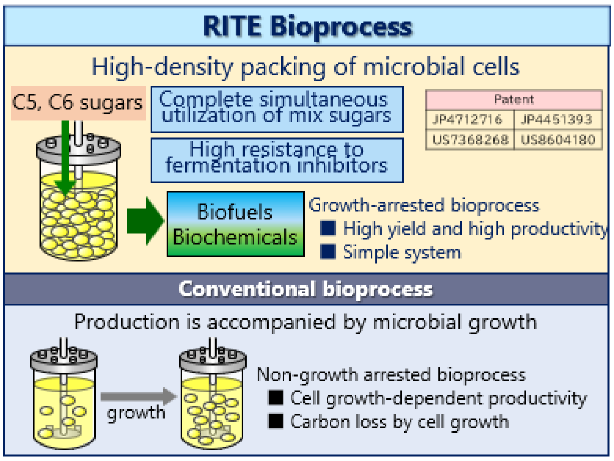

Fig. 2 Feature 1 of the "RITE Bioprocess" (Growth-arrested bioprocess)

Feature 2: High tolerance to fermentation inhibitors

In biomanufacturing, raw materials such as biomass or waste-derived unused resources often contain chemicals that inhibit microbial growth. Also, the target substances produced by microorganisms can themselves inhibit growth or damage the microorganisms. It limits the types of substances that can be produced through fermentation. On the other hand, "RITE Bioprocess," is a production system that does not involve microbial growth, making it highly resistant to various fermentation inhibitors (Fig. 3).

This allows high productivity even with previously unusable raw materials and for various substances that were difficult to produce through fermentation.

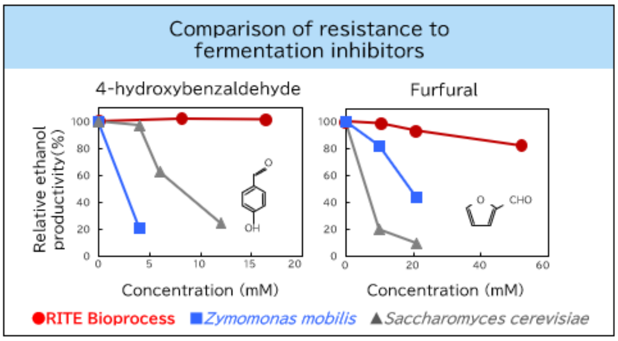

Fig. 3 Feature 2 of the “RITE Bioprocess” *1
(High tolerance to fermentation inhibitors)

Feature 3: Complete simultaneous use of mixed C5 and C6 sugars

Non-edible cellulose-based biomass is a common raw material in the biomanufacturing sector. This biomass contains a mixture of C6 sugars, such as glucose, and C5 sugars, such as xylose and arabinose. Microorganisms typically favor C6 sugars utilization for substance production, which reduces C5 sugar utilization efficiency. At RITE, new C5 sugar metabolic and transporter genes were introduced into microorganisms to increase the utilization rate of C5 sugars to the same level as C6 sugars (Fig. 4). The complete simultaneous utilization technology of C5 and C6 sugars is an essential core technology in biomanufacturing, enabling maximum production efficiency while minimizing waste of non-edible biomass raw materials.

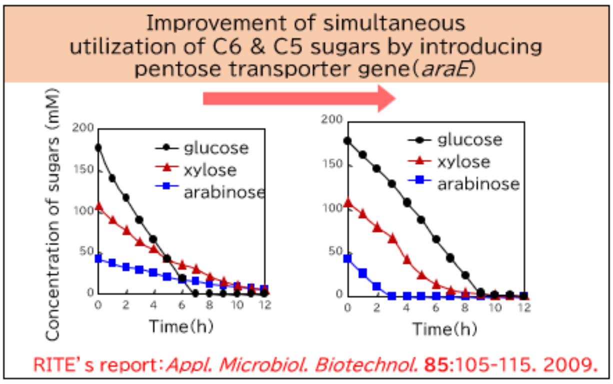

Fig. 4 Feature 3 of the “RITE Bioprocess” *1
(Simultaneous usage of mixed sugars)

2.2. Smart Cell Creation Technologies

Smart cells are biological cells whose functions and metabolism have been precisely designed and controlled through genetic modification to maximize its capacity for substance production. The collective set of digital technologies used to analyze biological information and design ideal cells, together with the biotechnologies that implement these designs in actual production strains, are referred to as Smart Cell Creation Technologies. These technologies enable the efficient breeding and development of smart cells.

Through proof-of-concept studies in which target compounds were defined, RITE has successfully developed a suite of smart cell creation technologies and demonstrated their effectiveness (Fig. 5). Going forward, RITE aims to apply these technologies to a wide range of fields, including biofuels and green chemicals, while continuing to improve and refine the technologies.

In addition, a project is currently underway to develop Industrial Smart Cell Creation Technologies with the objective of addressing the challenges associated with practical implementation, thereby linking smart cell creation technologies and the smart cells generated by them to industrial applications. Details of this project are explained in Section 3.5, Research and development of industrial smart cell.

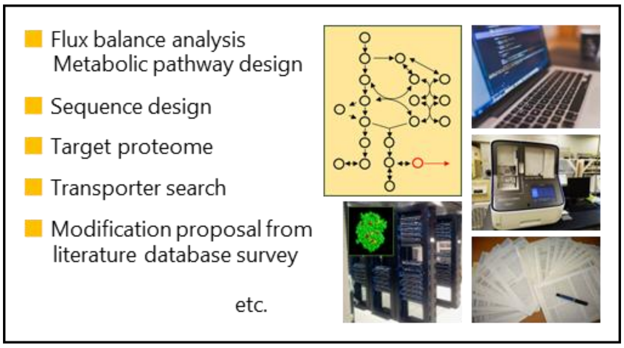

Fig. 5 Smart Cell Creation Technologies

2.3. Substances Produced by the "RITE Bioprocess"

RITE has achieved high production levels for various substances, as shown in Fig. 6. Many of these compounds have reached exceptional productivity levels. In the biofuel domain, RITE has expanded its lineup to include not only ethanol and biohydrogen but also butanol and high-performance bio-jet fuels. Meanwhile, our green chemicals focus has broadened to include L-lactic acid, D-lactic acid, amino acids, and high-functional chemicals such as aromatic compounds.

Aromatic compounds, which are key industrial chemicals important as raw materials for polymers and other products, are also valuable high-added-value compounds used as raw materials for pharmaceuticals, functional nutritional ingredients, fragrances, cosmetics, and more. Currently, aromatic compounds are primarily manufactured from petroleum, with only a small fraction derived from natural plants.

However, from reducing petroleum dependency, environmental conservation, and ensuring productivity perspectives, biomanufacturing is eagerly anticipated. In nature, microbes biosynthesize a variety of aromatic compounds, such as phenylalanine, tyrosine, tryptophan, folic acid (vitamin B9), and coenzyme Q. All these compounds are derived from a metabolic pathway known as the shikimate pathway, which is present in microorganisms.

By employing biomanufacturing technology to the fullest extent, designing the metabolic pathway of Corynebacteria at will, and utilizing non-edible biomass, RITE has established a high-performance bioprocess capable of producing shikimic acid (the raw material for influenza medicine Tamiflu), 4-aminobenzoic acid (promising raw material for high-performance polymers), and other raw materials for polymers, pharmaceuticals, cosmetics, and fragrances (vanillin).

Biofuels	Green chemicals
■ Gasoline additives ・Ethanol * ■ Bio-jet fuels ・Isobutanol * ・n-Butanol * ・C9-C15 Saturated hydrocarbon + Aromatics ■ Biohydrogen	■ Aromatics ・Shikimic acid (Anti-influenza drug; Tamiflu raw materials) ・Phenol * (Phenolic resins, Polycarbonates) ・4-Hydroxybenzoic acid * (Polymer raw materials) ・Aniline * (Natural resource tire (Age resistor)) ・4-Aminobenzoic acid * (Pharmaceutical raw materials) ・Protocatechuic acid * (Cosmetic raw materials) ■ Organic acids ・D-Lactate *, L-Lactate * (Stereo-complex PLA) ・Succinate * ■ Amino acids ・Alanine (Chelators) ・Valine (Next-generation feed-use amino acids) ・Tryptophan (Next-generation feed-use amino acids) ■ Alcohols ・Isopropanol (Propylene raw materials) ・Xylitol (Sweetener)

* : Polymer raw materials Red character : World's highest productivity achieved

Fig. 6 Substances produced using the "RITE Bioprocess"

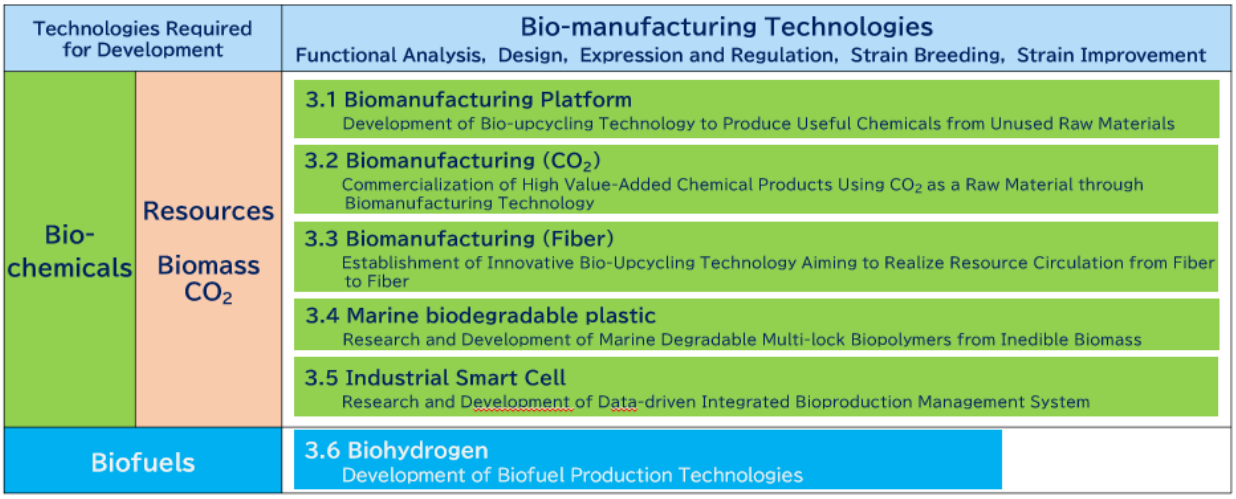

Fig. 7 Overview of participating national projects and new technologies required for development

3. Fundamental Technology Development (National Projects)

The Japanese government is currently providing substantial support for biomanufacturing, aiming to achieve sustainable manufacturing through economic growth and resource self-sufficiency, while simultaneously pursuing innovation that addresses social challenges. Fig. 7 summarizes the national projects in which RITE participates, as well as the biomanufacturing technologies that RITE is responsible for developing.

We are involved in the NEDO Biomanufacturing Revolution Promotion Fund Project and the NEDO Green Innovation Fund Project and , which is bio-upcycling technologies to produce useful chemicals from unused resources (Biomanufacturing Platform; Sections 3.1) and to develop biomanufacturing technologies for high-performance adhesive raw materials from CO_2 (Biomanufacturing (CO_2); Sections 3.2), and also, development of biotechnology for Recycling Waste Fibers (Biomanufacturing (Fiber); Sections 3.3).

Furthermore, as a participant in the Moonshot R&D Program, we are also pursuing the research and development of Multi-Lock Marine Biodegradable Plastics (Section 3.4) made from non-edible biomass as a raw material. In addition, we participate in JST's COI-NEXT (Carbon Farming Hub Challenging the Limits of Carbon Negativity) Project, and engage in research and development related to “Biohydrogen (Section 3.6). Below, we describe the status of RITE's involvement in national projects for the fiscal year 2026.

3.1. Biomanufacturing platform “Development of bio-upcycling technology to produce useful chemicals from unused raw materials”

NEDO “Biomanufacturing Revolution Promotion Project” Phase 1, launched in FY2023[*2]

This project aims to build a value chain for bio-based manufacturing that utilizes a diverse range of feedstocks to produce a wide variety of products. In this initiative, RITE, together with Takasago International Corporation and Teijin Limited, has identified key challenges and has launched research and development activities to address them.

As part of the technology development, RITE is creating a metabolism model specifically designed for Corynebacterium species, along with computational methods for metabolic simulation based on the model. By incorporating detailed culture data, these simulations can more closely approximate actual production conditions than conventional approaches. Although metabolome analysis, which comprehensively measures and analyzes small-molecule metabolites present in cells, can yield extremely valuable information, it is also a technique in which obtaining high-quality data is often difficult. By improving this analytical method and tailoring it specifically to Corynebacterium strains used at RITE - while also semi-automating the workflow - we succeeded in enabling more accurate metabolome analysis. This advancement now allows the entire process, from sampling to data analysis, to be completed within RITE.

In addition, following the efforts made last year, RITE has continued to develop a database containing information on the composition of underutilized resources and the production-inhibiting effects of products (cytotoxicity caused by compounds).

Using the collected data, we have implemented enhanced functions such as applying machine learning to identify components that are important for cell growth and product formation. By integrating these strain engineering technologies, RITE aims to strengthen its competitiveness in microbial breeding and to serve as a “microbial development platform” that provides production strains and manufacturing technologies to companies seeking to enter the biomanufacturing industry (Fig. 8). To serve as a hub for these efforts, RITE has established a new research facility, the “RITE Biomanufacturing Center.” The center integrates both Dry functions—computational design and information analysis—and Wet functions, including biological experiments, strain engineering, cultivation, and analysis. This integrated environment is being developed to enable more efficient strain development for biomanufacturing. Furthermore, in the future, to ensure that short-term visitors from partner companies can securely obtain cultivation data and other information needed for development, RITE plans to strengthen security measures and enhance its hosting environment. RITE and each company aim to strengthen Japan's industrial competitiveness and address social issues through the “RITE Bio Manufacturing Center.”

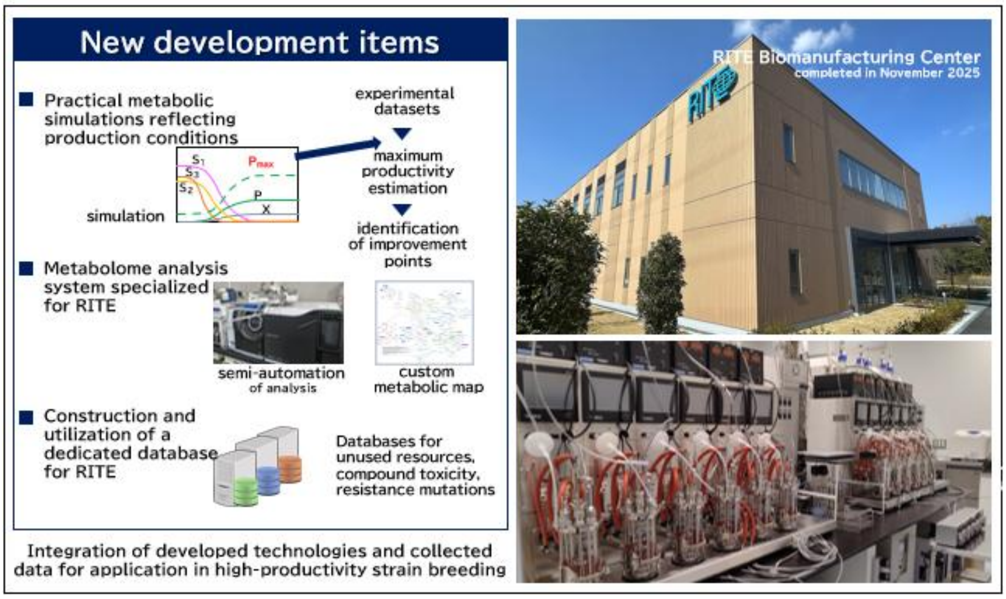

Fig. 8 A base functioning as a microbial development platform

3.2. Biomanufacturing (CO_2) "Productization of High Value-Added Chemicals Products Using CO_2 as a Raw Material through Biomanufacturing Technology" *2

This project aims to contribute to the realization of "carbon neutrality by 2050" by developing and deploying novel biomanufacturing products that use CO_2 as a raw material. This breakthrough also seeks to reform the industrial structure by embracing CO_2 as a resource.

In this respect, RITE, together with Sekisui Chemical Co., Ltd., started this project in FY2023 and are currently undertaking it (project period: 8 years from FY2023 to FY2030). Fig. 9 displays the research and development conducted in this collaboration. In this project, Sekisui Chemical utilized chemical catalysts to convert CO_2 efficiently into CO with high energy levels, making it easier to use by organisms. RITE then converts CO into polymer raw materials for epoxy resin by using a bioprocess using CO-utilizing bacteria. The resulting polymer raw materials are dimerized and epoxidized by Sekisui Chemical to produce high-value-added heat-resistant adhesives, which are used in the electronics field, including smartphones, aircraft, and automobiles, to bind special components that require heat resistance. After use, these adhesives can be combusted into CO_2, thus closing the resource recycling loop.

RITE is harnessing the smart cell technology and bioproduction technology it has cultivated to date to address the most important issues: (1) development of bacteria strains able to convert CO to polymer raw materials (such as developing genetic recombination tools for CO-utilizing bacteria and constructing producer strains of the intermediates and the polymer raw materials from CO), and (2) developing bioprocesses for the target polymer (including process design, optimization of culture conditions, and continuous process development) on a laboratory scale in general.

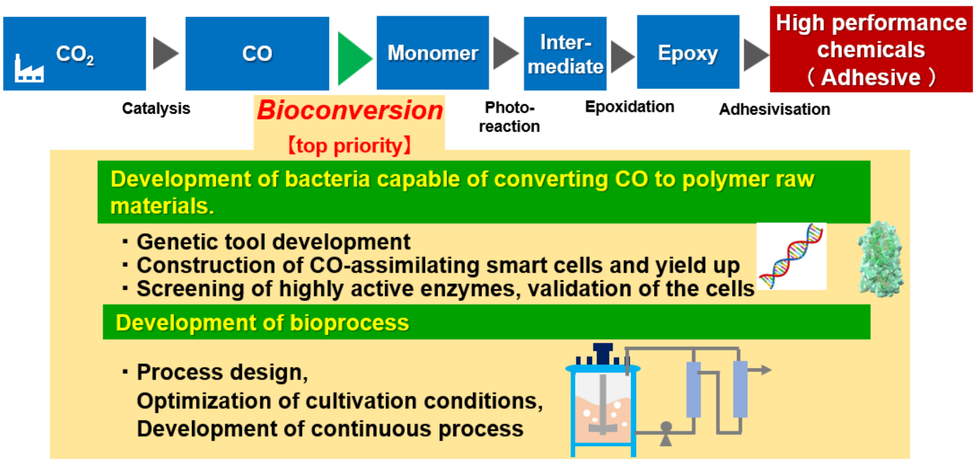

Fig. 9 High-value-added chemical products made from CO_2 by biomanufacturing technology

3.3. Biomanufacturing (Fiber) "Research, Development, and Demonstration for the Realization of Fiber-to-Fiber Resource Circulation /Development, Demonstration, and Advancement of Innovative Bio-upcycling Technologies Based on Bio-separation and Bio-conversion for the Realization of Fiber-to-Fiber Resource Circulation"

Commencing in FY2025, this project aims to establish the world's first "fiber-to-fiber resource circulation system" through a strategic partnership between RITE and five of Japan's leading textile companies: Teijin Frontier Co., Ltd., Kurabo Industries Ltd., Toray Industries, Inc., Nisshinbo Textile Inc., and The Japan Wool Textile Co., Ltd. By integrating mechanical, chemical, and biological technologies, this initiative addresses the recycling of composite fiber garments—which were previously incinerated or landfilled—by enabling the simultaneous reclamation of both synthetic and natural fibers.

Most clothing is made of composite materials consisting of synthetic and natural fibers. In order to recycle them, it is necessary to separate the composite materials into single materials. However, with conventional technology, some materials are damaged during the separation process, so recycling has been limited. Aiming to solve this issue, RITE is developing pretreatment technologies utilizing mechanical and chemical pretreatment methods, selective bio-separation using enzymes and microorganisms, and bioconversion techniques that transform materials into high-value-added textile precursors. By combining these technologies, RITE promotes the development of technologies to selectively separate synthetic fibers, such as polyethylene terephthalate (PET), from composite fiber materials and recover natural fibers (cotton, wool) as single fiber materials. In addition, for synthetic fibers such as PET, we aim to establish innovative technologies to reuse chemicals that become fiber raw materials, and for natural fibers, to reuse them as regenerated fibers (project period: 8 years from FY 2025 to FY 2032).

In collaboration with our industrial partners, RITE is focused on three primary technical pillars: the discovery and enhancement of high-performance enzymes and microbial strains capable of selectively degrading PET under mild conditions without compromising the physical properties of natural fibers; the engineering of strains to convert PET degradation products into value-added chemical raw materials; and the establishment of an integrated bioprocess that harmonizes these stages of degradation, separation, and production.

Looking ahead, RITE intends to accelerate these innovations by constructing a comprehensive database of enzymes for various synthetic fibers, implementing automated robotics to expedite enzyme screening and strain breeding, and establishing advanced analytical techniques for process evaluation and fiber property characterization. By equipping facilities for bench-scale testing and consolidating these core technologies, RITE aims to develop a sophisticated "Textile Resource Recovery Platform" that serves as a cornerstone for a sustainable textile industry.

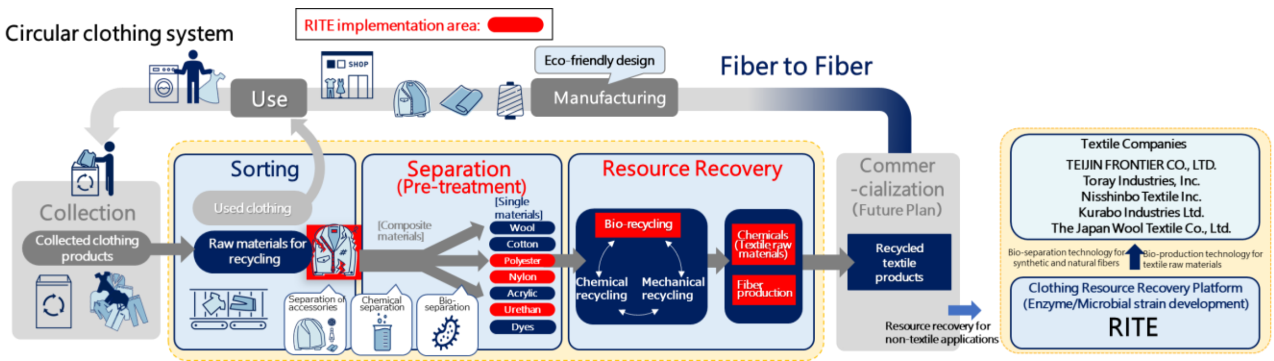

Fig. 10 RITE's role in establishing the fiber-to-fiber resource circulation system

(PET degradation, natural fiber separation, and upcycling of PET metabolites into textile raw materials)

3.4. Marine biodegradable plastic "Research and Development of Marine Degradable Multi-lock Biopolymer from Inedible Biomass" *2

In this project, research and development are being conducted to introduce a "multi-lock mechanism" in order to achieve both toughness and degradability in plastics (project period: 10 years from FY2020 to FY2029). Multi-lock mechanism is a mechanism that prevents degradation by maintaining the durability and toughness inherent in plastics during use, but when accidentally dispersed into the marine environment, the polymer bonds break only when multiple stimuli such as light, heat, oxygen, water, enzymes, microorganisms, and catalysts are applied simultaneously, triggering the decomposition process and enabling rapid, on-demand degradation.

The products targeted for commercialization in this project include tires and agricultural materials that generate fine particulate matter during use, as well as fishing nets and fishing gear that contribute to ghost fishing. Once released into the marine environment, these items are extremely difficult to recover, raising serious concerns regarding their potential adverse impacts on marine ecosystems and the broader environment (Fig. 11).

By FY2025, RITE developed technology that enables artificially control of the timing of multi-locked plastics degradation initiation. This includes development of new technology utilizing degradative enzymes. First, electrostatically binding the thermostable plastic-degrading enzyme to a biodegradable carrier notably improved its thermostability. We added the enzyme into plastic and thermally melt the mixture resulting in a test plastic film. Using the film, we were able to confirm the results reproducibly

that rapid enzymatic degradation (degradation on demand) occurs only when exposed to seawater, both on laboratory test and marine field tests (FY2024 and FY2025). Going forward, our efforts will focus on achieving even faster on-demand degradation through the functional enhancement of plastic-degrading enzymes and the optimization of blending conditions with plastics. In parallel, we will advance the exploration and functional improvement of enzymes capable of degrading multiple types of plastics with different bonding structures. Furthermore, we will continue to promote biomanufacturing approaches for producing monomers for marine-biodegradable plastics from non-edible resources.

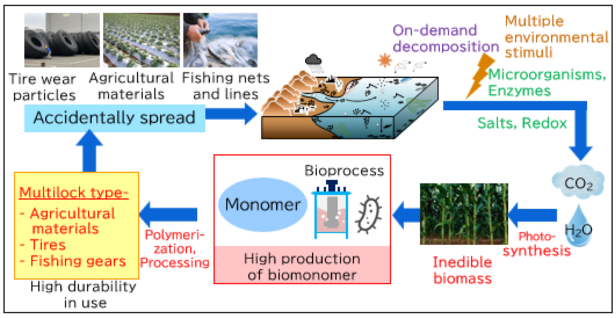

Fig. 11 Development of multi-lock biodegradable plastic and realization of resource recycling

3.5. Research and development of industrial smart cell "Data-driven Integrated BioProduction Management System (Data-driven iBMS)" *2

In the NEDO Project "Development of Production Technology for Bio-based Products to Accelerate the Realization of Carbon Recycling," technology development is being carried out to address challenges associated with practical implementation, with the aim of enabling smart cells optimized at the laboratory scale to demonstrate their capabilities in industrial processes as well. In FY2026, as the final year of the project, it is expected to present concrete examples demonstrating the effectiveness of the developed technologies, as well as a clear pathway toward social implementation. RITE has participated in "Research and Development of Data-driven Integrated Bioproduction Management System," one of the thematic components of this project, since its initial year, and is advancing the development of a set of novel technologies aimed at addressing challenges associated with the practical application of biomanufacturing technologies, specifically issues arising from reduced enzyme activity due to high product concentrations and from heterogeneity within large-scale fermenters (Fig. 12).

Utilizing a technology developed in collaboration with affiliated research institutions that can avoid enzyme activity reduction caused by the product by appropriately substituting the amino acid sequence of the enzyme, in the fiscal year 2025, we actually bred production strains and obtained results in studies using jar fermenters suggesting that this technology contributes to improved productivity. On the other hand, during scale-up, conditions such as temperature, pH, substrates, and dissolved oxygen concentration tend to become locally biased, resulting in heterogeneous environments. In response, we have aimed, in collaboration with partner research institutions, to develop design technologies for robust production strains capable of maintaining high productivity even under such conditions. In FY2025, verification was conducted on proposed genetic modifications expected to confer robustness. These proposals are based on detailed gene expression and metabolite data obtained by RITE under conditions that reproduce localized decreases in dissolved oxygen concentration. Production strains for verification were bred and their productivity was compared using jar fermenters, resulting in the identification of multiple modifications that enable the maintenance of yield even under conditions where dissolved oxygen concentration temporarily decreases. Through the development and validation of technologies that address issues likely to arise in actual production processes, this project aims to contribute to the realization of a carbon-circulating society and a biomanufacturing-based society that supports sustainable economic growth.

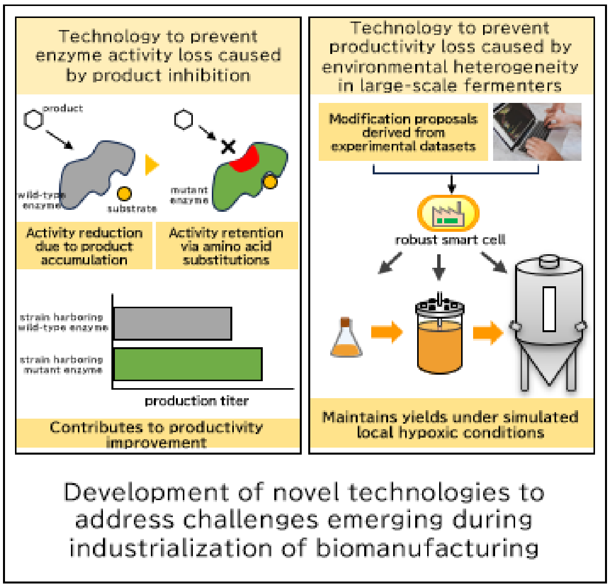

Fig. 12 Development of technologies to address issues that may arise during production

3.6. Biohydrogen "Development of Biofuel Production Technology"

RITE took part in the Japan Science and Technology Agency (JST)-commissioned program on open innovation platforms (COI-NEXT) themed "Carbon Cultivation Hub Challenging the Limits of Carbon Negativity." Started in 2023, we are working on developing biohydrogen production and liquid biofuel production technologies for establishing carbon-cultivation–based fuel-production technology. RITE develops biological conversion technologies for efficient fuel (hydrogen/liquid fuel) production based on various biomass feedstocks. Meanwhile, we collaborate with the participant organizations specialized in biomass cultivation technologies, thus enabling an increase in CO_2 fixation by photosynthesis (Fig. 13). Using these technologies, we target liquid-fuel production for our short- to medium-term goal. Yet since hydrogen is expected to be the ultimate clean energy and is key in realizing carbon neutrality/negativity, our medium- to long-term aim is to develop CO_2-free hydrogen production processes.

One of the key challenges for the social implementation of biomass fuel-production technology is lowering production costs. In addition, the components of biomass feedstock are diverse, and their composition considerably varies depending on the feedstock type. It is challenging to funnel this wide range of demands into a uniform technology. To solve these issues, this project will promote technology development in different fields, including various thermochemical and biological conversion technologies in an integrated manner to enable the construction and expansion of a flexible biomass-based fuel supply system tailored to each regional and feedstock needs.

Based on RITE success in developing a biohydrogen production process with high production rate, we are currently developing producer strain with improved hydrogen yield based on biomass-derived sugars. In order to construct a genetically engineered microorganism with a novel hydrogen production pathway, we examined effects of introduction of the heterologous enzyme complex and optimized its expression level to stably improve the microbial hydrogen-producing ability.

In liquid fuel, previously RITE has also established a bioprocess that efficiently converts C6 and C5 sugars mixture derived from non-edible biomass to ethanol. We improved the RITE bioprocess in this project and revealed that xylose, which is difficult for other organisms to consume, was consumed at a rate equal to or greater than that of glucose, and both sugars were completely consumed. Using this technology, we aim to develop an alcohol-to-jet (ATJ) process to produce a sustainable aviation fuel (SAF) using various biomass feedstocks, such as energy crops, rice with high CO_2 fixation capability, and microalgae with high sugar content.

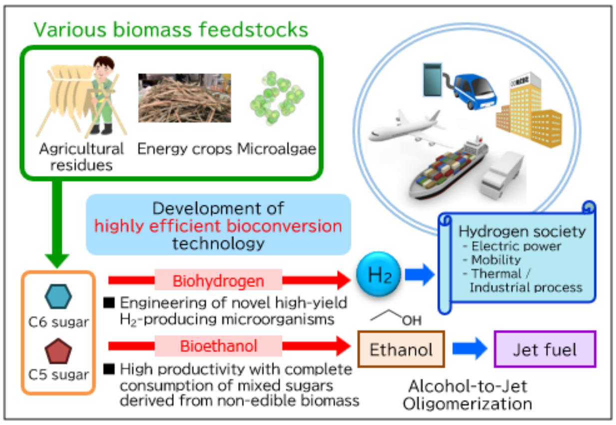

Fig. 13 Development of biohydrogen/bioethanol production technologies

4. Future Industrialization of Our Technologies

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

(Head Office・Laboratory: in Kyoto headquarters, RITE; Shizuoka Laboratory: in Shizuoka plant, Sumitomo Bakelite Co., Ltd.) (Here's a link for GCC website)

In February 2010, RITE established the "Green Phenol and High-Performance Phenolic Resin Production Technology Research Association" (GP Association) with Sumitomo Bakelite Co., Ltd. to develop fundamental technologies related to phenol production and phenolic resin production through the application of bioprocesses that use cellulosic raw materials (non-food biomass). The GP Association was reorganized in May 2014 as "Green Phenol Development Co., Ltd." (GPD), which became the first example of demutualization of a technology research association. Green Phenol Development Corporation's trade name was changed to Green Chemicals Co., Ltd. (GCC) in April 2018, in recognition of the fact that GPD technology is able to develop valuable compounds alongside phenol bioproduction. In 2024, GCC's trademarks "Green Chemicals" and "Green Phenol" were registered.

Leveraging the mass production technology and know-how cultivated for green phenol manufacturing, GCC has established mass production technologies for green chemicals such as aromatic compounds, which were previously considered difficult to produce in large quantities. Among them, we possess advanced mass-production technologies for high value-added chemicals such as 4-hydroxybenzoic acid (4-HBA), which is promising for applications like high value-added liquid crystal polymer raw materials, protocatechuic acid, which is promising for use as a raw material in cosmetics and fragrances (vanillin), and shikimic acid, which is a raw material for the anti-influenza drug Tamiflu. For all of these substances, we have obtained confirmation from the Minister of Economy, Trade and Industry (Ministerial Confirmation) for the second-class use of genetically modified organisms as production strains in industrial applications, and we are promoting the commercialization of green compounds and business development activities (Fig. 14).

At present, we are receiving inquiries from a considerable number of companies both domestically and internationally. In order to respond appropriately to these diverse needs, we intend to promote the social implementation of biomanufacturing by addressing various challenges, including the further reduction of production costs and the enhancement of product quality.

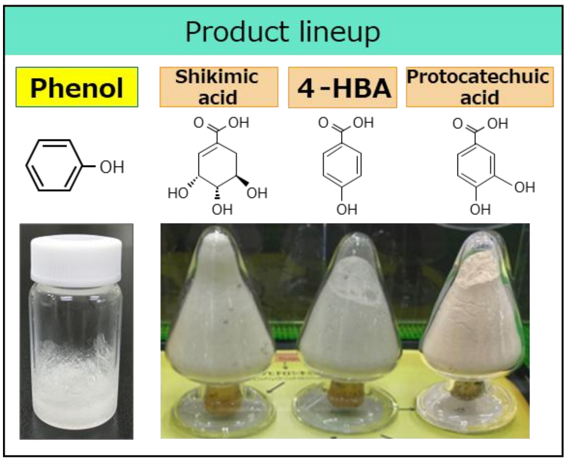

Fig. 14 Major product lineup of Green Chemicals Co., Ltd.

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

(Head office: 6F Q Plaza Shinjuku 3-chome, 3-5-6 Shinjuku, Shinjuku-ku, Tokyo, Laboratory: 2-5-9 Kazusa-kamatari, Kisarazu-shi, Chiba)

(Click here for the Green Earth Institute Inc. website)

In September 2011, RITE established Green Earth Institute Co., Ltd. (GEI), as a venture company originating from RITE in order to commercialize "RITE Bioprocess." *1 Due to successful business results, the company was listed on the Tokyo Stock Exchange (Mothers) in December 2021. By the following April, it moved to the Tokyo Growth Market due to market reorganization.

GEI is promoting research and development as well as commercialization with domestic and international partner companies through the Biofoundry project commissioned by NEDO, the Green Innovation Fund project, and the Biomanufacturing Revolution Promotion project, and is attempting to develop a "Vertically Integrated Biofoundry."

In addition, GEI established a joint venture, "Morizora Biorefinery LLC," in July 2025 to manufacture and sell bioethanol and other products using woody biomass as a raw material, and is working on the realization of sustainable aviation fuel (SAF).

4.3. Joint Research with Companies

Besides the main compound products introduced in this overview (Section 2.3), biomanufacturing is possible for numerous other substances, and RITE is developing collaborative research tailored to the needs of each individual companies. Since the Japanese government declared its goal of "carbon neutrality by 2050" in October 2020, inquiries and requests from companies aiming to expand their products overseas have surged, and the number of joint research projects has also increased. The requests vary, ranging from the desire to quickly convert fossil resource-derived products to bio-based production, to the goal of transitioning main products and key raw materials from fossil resources to bio-based sources over the mid- to long term, to manufacture high-value-added bio-products using waste generated from own production as raw materials. Leveraging its advanced expertise and extensive experience, RITE offers biomanufacturing solutions that are closely tailored to the specific needs of each company.

5. Closing remarks

RITE will continue to advance biomanufacturing technologies, including smart cell creation technology, by leveraging the national projects introduced in Chapter 3. At RITE Biomanufacturing Center, completed in November 2025 (Fig.15), it will be possible to provide services for the development of optimal biomanufacturing technologies for each product. This will be achieved by leveraging RITE's accumulated technological capabilities, including "RITE Bioprocess" and "Smart Cell Creation Technology," along with extensive knowledge and technologies for utilizing underused domestic resources as raw materials, highly advanced research facilities, and development technologies for production processes that require a certain scale, which are difficult for individual companies to implement due to considerations such as cost performance and maintaining competitiveness.

RITE will continue to undertake the development of microbial production strains required by numerous companies that wish to enter the biomanufacturing industry but hesitate to do so, and provide production technologies. By consolidating RITE's expertise in biotechnology, research facilities, technologies, and information into a "Microbial Development Platform," we aim to contribute to the promotion of Japan's smart cell industry and to the near future establishment of biomanufacturing in society, particularly in the energy and chemical industry sectors.

Compounds that were previously difficult to produce with microorganisms may now achieve high production with RITE's latest technologies. If you have compounds you would like to make with bioconversion, or if you consider the companies considering the high-value-added bio-development of waste resources, or if you are attracted to RITE's biomanufacturing, please contact us. We look forward to collaborating with you to drive innovation and sustainability in the biomanufacturing industry.

For more details about the "RITE Bio Manufacturing Center," please also refer to the topics article in this "RITE today."

*1 "RITE Bioprocess" is a registered trademark of RITE.

*2 This article is based on results obtained from a project commissioned or subsidized by NEDO (New Energy and Industrial Technology Development Organization).

Fig. 15 "RITE Biomanufacturing Center"

Chemical Research Group

Members (as of June 2026)

Group Leader, Principal Research Scientist	**Katsunori Yogo**	Research Assistant	**Hanako Araki**
Deputy Leader, Principal Research Scientist	**Masahiko Mizuno**	Research Assistant	**Kozue Kataoka**
Principal Research Scientist	**Hidetoshi Kita**	Research Assistant	**Rie Sugimoto**
Principal Research Scientist	**Firoz Alam Chowdhury**	Research Assistant	**Junko Yonezawa**
Deputy Leader, Vice Principal Research Scientist	**Naoki Kikuchi**	Research Assistant	**Naomi Yoshino**
Deputy Leader, Vice Principal Research Scientist	**Hideki Yamaguchi**	Research Assistant	**Keiko Mori**
Vice Principal Research Scientist	**Narutoshi Hayashi**	Research Assistant	**Yoichi Fujiwara**
Senior Research Scientist	**Kazuya Goto**	Research Assistant	**Takashi Teshima**
Senior Research Scientist	**Teruhiko Kai**	Research Assistant	**Hidenori Ogata**
Senior Research Scientist	**Makoto Ryoji**	Research Assistant	**Yozo Narutaki**
Senior Research Scientist	**Toshinori Muraoka**	Research Assistant	**Atsushi Yasuno**
Senior Research Scientist	**Masahiro Seshimo**	Research Assistant	**Hiromi Urai**
Senior Research Scientist	**Tomohiro Kinoshita**	Research Assistant	**Akiyoshi Fujii**
Senior Research Scientist	**Noriyuki Taniyama**	Research Assistant	**Takahiro Yoshii**
Chief	**Keiko Komono**	Research Assistant	**Makoto Asano**
Research Scientist	**Shuhong Duan**	Research Assistant	**Kazuhiko Tsuda**
Research Scientist	**Takayasu Kiyokawa**	Research Assistant	**Satoshi Nakajima**
Research Scientist	**Lie Meng**	Research Assistant	**Tsukasa Mizobuchi**
Research Scientist	**Aoi Torigoe**	Staff	**Noriko Onishi**
Research Scientist	**Hiroaki Maeda**	Staff	**Yuko Nara**
Research Scientist	**Go Kato**	Staff	**Yuko Miyaji**
Research Scientist	**Kiminori Sato**		

Challenges Associated with Advancing the Industrialization of CO_2 Capture and Utilization Technologies

1. Introduction

RITE is working towards achieving the technical breakthroughs needed for the practical application and industrialization of various technologies related to CO_2 capture and utilization (CCU) at an early stage. The research topics that RITE is currently working on are described below.

2. Technologies for CO_2 capture and utilization

In October 2020, Japan declared that it aims to achieve carbon neutrality by 2050, and in December 2020 (with detailed planning in June 2021), it formulated the Green Growth Strategy through Achieving Carbon Neutrality in 2050, and various initiatives to combat global warming are being promoted in multiple sectors. In May 2024, the Act on Carbon Dioxide Storage Business (CCS Business Act) was enacted, marking a significant step toward realizing the CCS roadmap, which sets ambitious targets for annual CO_2 storage of 6 to 12 million tons per year by 2030 and 120 to 240 million tons per year by 2050. Under this legislation, nine domestic advanced CCS projects have been selected to spearhead the development of business models encompassing the entire CCS value chain—from CO_2 capture and transportation to storage.

To achieve carbon neutrality, it is essential to implement technologies that can reduce the atmospheric CO_2 concentration—known as negative emission technologies. Of these technologies, Direct Air Capture (DAC), which directly captures CO_2 from the atmosphere, is garnering significant attention. In July 2021, Japan's Ministry of Economy, Trade and Industry revised the Carbon Recycling Technology Roadmap to include DAC as a newly advancing technological field. Efforts in carbon management—encompassing Carbon Dioxide Removal (CDR) and Carbon Capture, Utilization, and Storage (CCUS)—are intensifying, with a focus on the recycling and reduction of CO_2. As large-scale DAC projects are progressing overseas, Japan has been conducting various R&D initiatives for DAC technologies since 2020 under the Moonshot R&D Program. Some of these DAC technologies were showcased at Expo 2025 Osaka, Kansai.

At the 2025 Expo Osaka, Kansai, RITE conducted a demonstration test of Japan's largest-scale DAC system equipped with its proprietary solid sorbent, showcasing domestic DAC technical expertise to the world. Furthermore, in June 2025, RITE held the opening ceremony for the RITE Carbon Capture Center (RCCC), Japan's first facility capable of testing with actual flue gas (boiler combustion exhaust). During this event, the center's significance and the commencement of external sample acceptance were promoted to both CO_2 separation material developers and CO_2 capture process developers. RITE continues to generate world-leading R&D carbon capture results towards practical application, with a primary focus on chemical absorption, solid sorbent, and membrane separation technologies.

For chemical absorption, high-performance chemical solvent was developed and have been commercialized under the COURSE50 project (Environmentally Harmonized Steelmaking Process Technology Development) commissioned by NEDO. The application of chemical absorption is expected to broaden within advanced CCS initiatives. Concurrently, R&D efforts are underway to develop new absorbents based on a mixed solvent system.

For solid sorbent, a pilot-scale CO_2 capture demonstration test using solid sorbents with excellent CO_2 desorption performance at low temperatures, was conducted under a NEDO funded project in collaboration with private companies and using actual flue gas from a coal-fired power plant. Efforts are also underway to apply solid sorbents to flue gas from natural gas-fired power plants, which contain lower concentrations of CO_2. R&D is ongoing for solid sorbents that not only allow low-temperature regeneration but also exhibit high resistance to oxidative degradation.

Membrane separation was advanced for processes including high-pressure gas separation (CO_2/H_2), the Integrated Coal Gasification Combined Cycle (IGCC) process and H_2 production plants. Beginning in 2024, a new NEDO-funded project was launched to support a demonstration trial of a compact, medium-pressure hydrogen production system equipped with a membrane-based CO_2 capture process.

Also, RITE is engaged in the R&D of CO_2 utilization technology, for example, using membrane reactors equipped with dehydration membranes to convert CO_2 into methanol. Since 2021, we have been conducting a NEDO-funded project named Development of Optimum Systems for Methanol Synthesis Using CO_2 in collaboration with private companies to synthesize methanol by reacting CO_2 from steel plants with hydrogen.

Furthermore, efforts for CO_2 fixation that utilizes the calcium and magnesium contained in industrial waste and similar materials to convert CO_2 from flue gas into high-purity calcium carbonate are underway in collaboration with private companies.

3. Technology for capturing CO_2 from the atmosphere

NEDO's Moonshot R&D Program was launched in FY 2020 as one of the systems to support the action plan of the Environment Innovation Strategy, which aims to establish technologies that enable Beyond Zero by 2050.

RITE is working to develop technologies for high-efficiency CO_2 capture from the atmosphere and carbon circulation in cooperation with Kanazawa University and Mitsubishi Heavy Industries, Ltd., as part of (1) Development of technologies to capture, convert, and detoxify greenhouse gases in Moonshot Goal 4: realization of sustainable resource circulation to recover the global environment by 2050 (Fig. 1).

The technology for capturing CO_2 directly from the atmosphere is called Direct Air Capture (DAC), and in combination with storage, it is expected to be one of the negative emission technologies. Seven other industrial DAC projects are also underway.

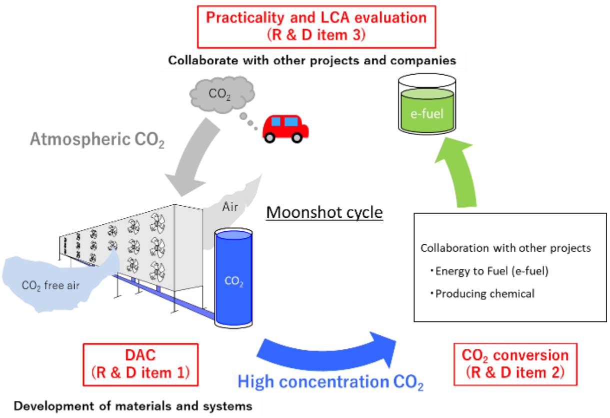

Fig. 1. Development of highly efficient DAC and carbon recycling technologies

RITE is developing new amines suitable for DAC and structured solid sorbents that show low-pressure drops at a high flow rate and low energy consumption in CO_2 desorption. The fundamental properties of both amines and structured sorbents are collected using lab testing equipment, the CO_2 capture performance of real-sized sorbents is evaluated using DAC system evaluation equipment, and improved sorbent structure and optimized operation conditions are predicted by process simulation (Fig. 2).

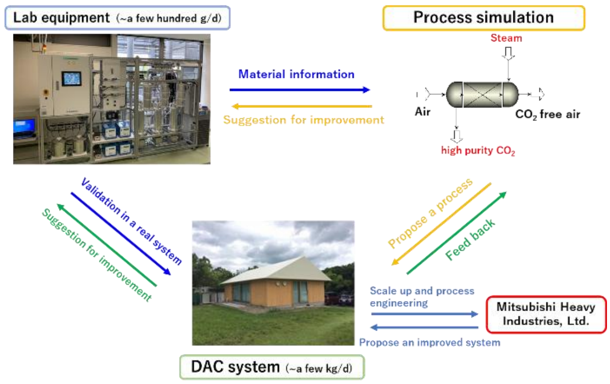

Fig. 2. Development of DAC technology: integration of simulation and laboratory systems

At RITE Future Forest in the Carbon Recycling Factory area of the venue of the Osaka–Kansai Expo held from April to October 2025, a pilot demonstration test was conducted with the cooperation of Mitsubishi Heavy Industries Group, with the aim of capturing up to 0.3 t/day of CO_2 (Fig. 3).

Fig. 3. Pilot-scale demonstration test equipment installed at the Osaka-Kansai Expo site

In the pilot demonstration test, the effects of temperature, humidity, and various operational parameters on the amount of CO_2 captured and the energy required for capture were clarified, and a methodology was established to evaluate their impacts in scaling up. The captured CO_2 was temporarily stored in tanks (Fig. 4) and then supplied to Osaka Gas Co., Ltd. and Air Water Inc., which were also conducting demonstration tests within the Carbon Recycling Factory area, where it was used for methane synthesis (methanation) and dry ice production, respectively.

Fig. 4. CO_2 store tanks

The two tanks on the left store the recovered CO_2 with a purity of 95% or higher at atmospheric pressure, while the two tanks on the right store CO_2 compressed to approximately 0.6 MPa for CCU collaboration.

The synthesized methane was utilized in facilities such as the kitchens of the state guesthouse, and the dry ice was used at various locations within the venue. Although the methane and dry ice used at the venue were ultimately converted back into CO_2 and released into the atmosphere, the DAC system was able to re-capture CO_2 from the air, enabling repeated production of methane and dry ice. In this way, a large-scale carbon circulation (carbon recycling) system based on DAC was demonstrated for the first time in Japan and presented to many visitors and successfully showed how the future envisioned by the Moonshot Research and Development Program can be realized.

In addition, a portion of the produced dry ice was taken by RITE and utilized by Fukujuen Co., Ltd. to promote the growth of green tea leaves. Mitsubishi Gas Chemical Company, Inc. transported CO_2 outside the venue to investigate the feasibility of geological storage and its use for methanol production. Through these activities, carbon recycling demonstrations were also carried out beyond the Expo site.

4. Common evaluation standard for CO_2 capture materials

Since 2022, RITE has been conducting the NEDO Green Innovation Fund Project for the establishment of a common evaluation standard for CO_2 capture materials in collaboration with the National Institute of Advanced Industrial Science and Technology (AIST). In February 2025, RITE established a test center (RCCC), where CO_2 capture materials are evaluated under the flue gas conditions of power plants and boilers. We have already conducted evaluations of standard samples and have opened a service to accept evaluation requests from external material developers. We provide fair and neutral testing of CO_2 capture materials, and RCCC is the only center in Japan that accepts evaluations of new materials being developed domestically.

Figure 5 gives an overview of the test facilities at the RCCC. A city gas-fired steam boiler is used as the CO_2 emission source, and its flue gas is supplied to test facilities for various CO_2 capture technologies. The RCCC consists of absorption, adsorption (PSA*, TSA**), and membrane test facilities with a CO_2 processing capacity of 0.1 t/d, as well as a small-scale testing device for CO_2 capture materials of membrane and adsorption.

*PSA: Pressure Swing Adsorption

**TSA: Temperature Swing Adsorption

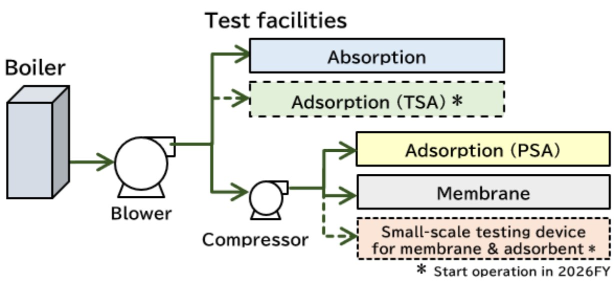

Fig. 5. Overview of RCCC test facilities
(Capacity of each unit: –100 kg-CO_2/day)

Table 1 Flue gas composition
(e.g. measurement at the inlet of the PSA test facility)

	Flue gas	Mixture of flue gas and air (ratio 1:1)
CO_2	9.3%	4.1%
O_2	4.9%	14.1%
NOx	55.1 ppm	25.9 ppm

Considering that the project targets low-pressure, low-concentration CO_2 gas with a CO_2 concentration of 10% or less, the flue gas supplied to each test facility can have its CO_2 concentration controlled by mixing with air. Table 1 shows an example of the analysis results of the gas at the inlet of the PSA test facility. The flue gas from the boiler has a CO_2 concentration of approximately 9%, but by mixing it with air at a 1:1 ratio, the CO_2 concentration becomes approximately 4%. It is possible to control it to a level as low as that of NGCC (gas-fired combined cycle).

In 2025, the test facilities were operated using standard materials (absorption solvent: 30 wt% MEA aqueous solution, adsorption: zeolite 13X, membrane: polyimide-based hollow fiber module) to trace known performance and to collect and accumulate comprehensive evaluation data. In addition, the standard evaluation method established by 2024 was improved for practical use.

Regarding the acceptance of external samples, we have actively promoted our services externally through academic conferences, symposiums, and newspaper articles. As a result, we have received numerous inquiries about testing and requests for facility tours from private domestic companies. We are currently in discussions with several companies regarding testing at the test facilities of the RCCC.

Regarding outreach to overseas, we participated in the PCCC-8 meeting (Post-Combustion Capture Conference, France, Sep. 2025) and the ITCN (International Test Center Network), both hosted by IEAGHG, where we introduced the progress of RCCC to overseas experts and exchanged opinions. We are making even greater progress in building strong collaborative relationships with overseas organizations.

Through the activities of the RCCC, RITE will support the activities of companies and organizations involved in the development CO_2 capture materials in Japan, and contribute to promoting the development of CO_2 capture materials so that Japan can remain a world leader in CO_2 capture technology.

5. Solid sorbent method for CO_2 capture

Unlike a chemical absorbent where amines are dissolved in a solvent, such as water, a solid sorbent is one where the amines are supported on a porous material, such as silica or activated carbon (Fig. 6). In the process of using a solid sorbent, a reduction of the CO_2 capture energy can be expected because the heat of vaporization and sensible heat caused by the solvent can be suppressed.

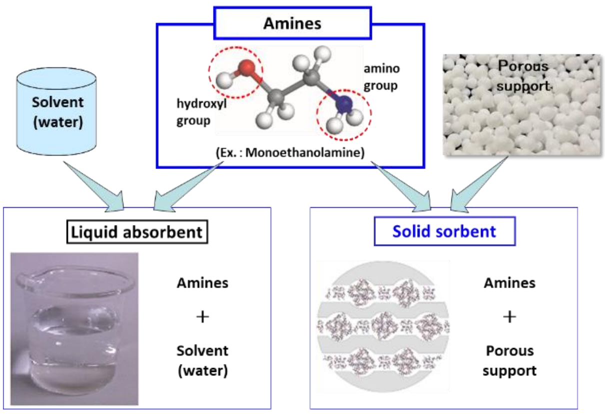

Fig. 6. Liquid absorbent and solid sorbent

1) For coal-fired power plants

RITE has been developing solid sorbent materials since 2010, mainly for CO_2 capture from the combustion exhaust gas of coal-fired power plants.

In the fundamental research phase (FY2010-FY2014), we developed an innovative solid absorbent that can utilize low-temperature exhaust heat of 60°C, and in the practical application research phase (FY2015-FY2019) in which we partnered with Kawasaki Heavy Industries, Ltd. (KHI), scale-up synthesis of solid absorbent (>10 m^3), bench scale testing (>5 t-CO_2/day), and real-gas exposure testing at a coal-fired power plant were conducted.

In the NEDO-commissioned project that began in 2020, KHI constructed a pilot scale test facility (40 t-CO_2/day scale) at the Maizuru Power Plant in cooperation with Kansai Electric Power Co., Inc. From the second half of 2023, we started CO_2 capture tests from the flue gas of the combustion exhaust gas from coal-fired power plants using solid sorbent supplied by RITE (Fig. 7).

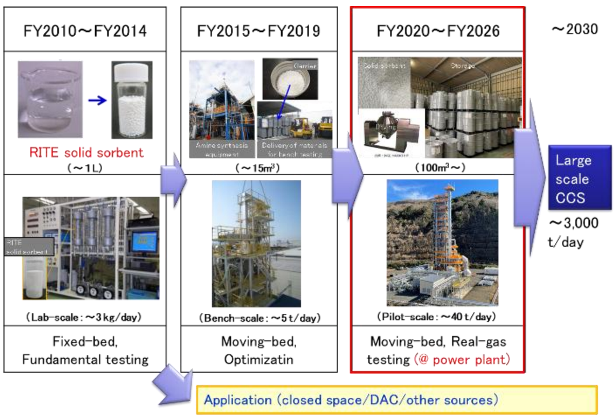

Fig. 7. Development roadmap of the solid sorbent method for CO_2 capture

We are working on elucidating the mechanism of material degradation and developing technologies to prevent degradation, as well as developing technologies to reuse the materials used, and examining handling methods through long-term storage tests.

In the long-term storage tests, materials stored in a warehouse for up to four years from the date of manufacture were periodically checked, and it was confirmed that there was no change in CO_2 equilibrium adsorption amount and that the performance had not deteriorated (Fig. 8). We also conducted storage tests under various storage conditions to establish a method for storing the materials.

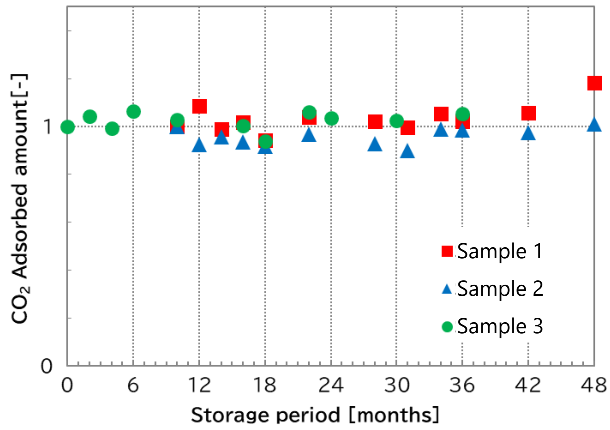

Fig. 8. Long-term storage test results

Furthermore, we are also working on examining efficient operating conditions using process simulation technology, and have developed a simulator that can predict the amount of CO_2 captured and the energy required for separation and capture with high accuracy in KHI's moving bed system (Fig. 9).

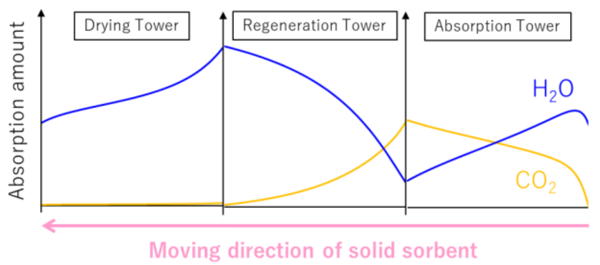

Fig. 9 Absorption/desorption behavior in moving bed system using simulation

In the pilot test, we plan to use this simulation technology to examine optimal operating conditions. Simulations are also useful for understanding the absorption and desorption behavior inside the equipment, which is difficult to observe in reality, and the calculation results are also being used in material development.

2) For natural gas-fired power plants

In 2022, the Technology Development Project of CO_2 Separation and Capture in the Green Innovation Fund project was started jointly with Chiyoda Corporation (organizer company) and JERA in order to commercialize low-cost separation and capture processes for CO_2 from natural gas combustion exhaust gas (Fig. 10).

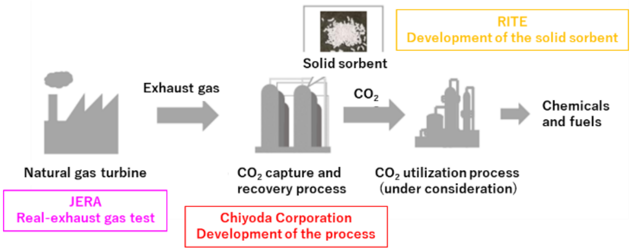

Fig. 10. Project overview

The CO_2 concentration contained in natural gas combustion exhaust gas is around 4%, which is lower than the CO_2 concentration in coal combustion exhaust gas (around 13%), and the oxygen concentration is as high as about 10%. Therefore, solid sorbent materials with high CO_2 absorption performance even at low CO_2 concentrations and high durability against oxidation are required. RITE is in charge of the development of amines based on the knowledge and technology accumulated in the R&D histories in this field, in addition to the development of solid sorbent materials composed of developed amines and optimal support. The developed solid sorbent exhibits the following characteristics:
(1) A significant change in CO_2 adsorption capacity can be achieved with only a slight temperature change. (2) Superior oxidative degradation resistance with respect to natural gas combustion exhaust gas. This year, the solid sorbent was further improved, resulting in enhanced absorption/desorption kinetics (Fig. 11).

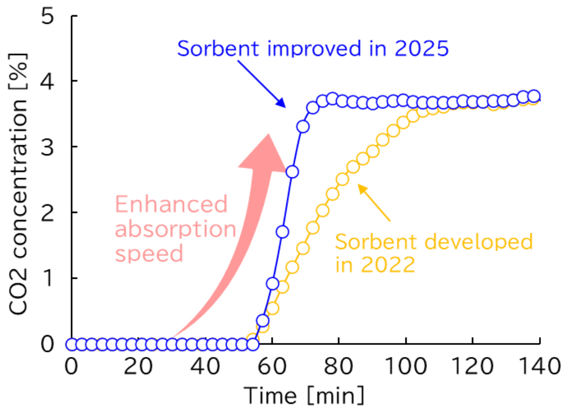

Fig. 11. Marked Improvement in absorption kinetics

When the improved solid sorbent was applied to a process in which the CO_2 capture rate was approximately 70% using the sorbent prior to modification, the capture rate was confirmed to increase to approximately 90% (Fig. 12).

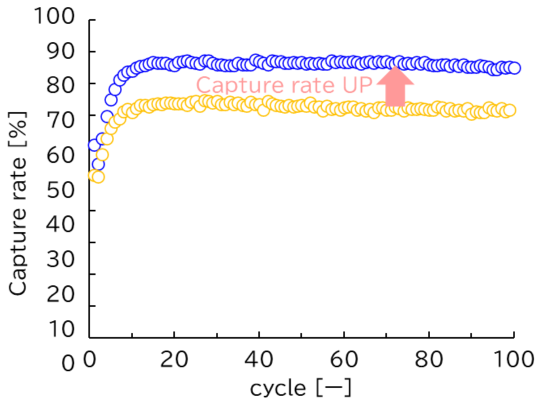

Fig. 12. Effect of absorption rate on CO_2 capture rate

In addition, a long-term continuous cycle test was conducted using simulated gas containing NOx and O_2 at concentrations equivalent to those of exhaust gas from a natural gas–fired power plant. The results demonstrated that the material performance exhibited almost no degradation even after 4,500 hours of operation.

It has been estimated that the combination of the solid sorbent and process developed in this project offers superior competitiveness compared with competing technologies in terms of both required energy and equipment size. This advantage will be verified through bench-scale testing in the next year.

6. Chemical absorption method for CO_2 capture

The chemical absorption method based on the chemical reaction between amine and CO_2 in a solvent is applied to gases with a relatively low CO_2 concentration, such as combustion exhaust gas, and the method is one of the most mature CO_2 capture technologies developed. In the COCS project (METI's Subsidy Project), the COURSE50 project (NEDO consignment project), and the GREINS project (NEDO consignment project), RITE has been working to develop high-performance solvents that reduce the cost of CO_2 capture. The chemical absorbent and process created by the COURSE50 project were adopted by the energy-saving CO_2 capture facility ESCAP® of Nippon Steel Engineering Co., Ltd.

In the GREINS, we tried to develop a new technology, *mixed solvent* (Fig. 13), to be a crucial breakthrough in further reducing energy consumption, and we achieved novel mixed solvents with better energy performance. In the first half of 2024, bench-scale plant tests were conducted at the Kimitsu Steelworks of Nippon Steel Corporation, and in 2025 a pilot-scale test was carried out. The new high-performance mixed solvents developed by RITE successfully performed CO_2 capture from actual blast furnace gas, and the results demonstrated that tCO_2 capture using the mixed solvents was economically rational technology suitable for practical use. Figure 14 shows the energy performance of the developed mixed solvents tested at the bench-scale plant. We continuously contribute to further carbon neutrality by expanding the applications of the new mixed solvents technology.

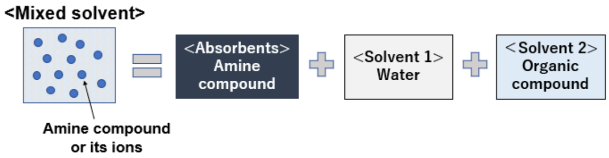

Fig. 13. Concept of a mixed solvent

A mixed solvent is a solvent in which some of the water is replaced with an organic compound, to control the reaction mechanism of CO_2 absorption and the effect of polarization.

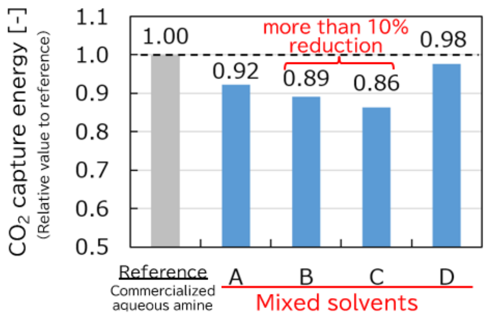

Fig. 14. Bench plant test results

RITE research activity for solvent development has attracted international attention. At the PCCC-8 international conference in September 2025, Principal Research Scientist Chowdhury presented results on mixed solvents, which were included in the conference report compiled by IEAGHG. The published experimental results are shown in Table 2.

Table 2. Water-lean solvent performance (mixed solvent)

Selected Water-lean Solvent	Absorption[a]/ Desorption[b] Rate (g/kg/min.)	CO_2 Loading[c] @ 40 °C (g/kg)	Cyclic Capacity[d] @ (40-90) °C (g/kg)	CO_2 Recovery[e] (%)	Heat of Absorption[f] (kJ/mol-CO_2)	Specific Heat[g] (J/gK)
Water-lean solvent_22	1.35/10.8	125	114	91	63.1	3.1
Water-lean solvent_19	1.40/10.8	124	120	97	64.9	3.0
Water-lean solvent_9	1.32/10.6	123	110	89	66.1	2.9
Aq. MEA_30wt% (Ref.)	2.38/2.38	119	35	29	86.9	3.75

https://publications.ieaghg.org/technicalreports/2026-TR02%20PCCC-8%20Summary%20Report.pdf

In order to accelerate CCUS, we still have to overcome the technological issues of cost reduction and practical implementation. In particular, R&D to decrease the energy consumption in the solvent regeneration process and the enhancement of amine durability for stable long-term operation are required. RITE will also actively work to support such R&D in order to implement and expand the use of the developed chemical absorption solvents.

7. Membrane separation

CO_2 separation by membranes involves the selective permeation of CO_2 from the pressure difference between the feed side and the permeate side of the membrane. Membranes used for separation are classified into inorganic and organic membranes, with organic membranes further classified into facilitated transport membranes and solution-diffusion membranes. Facilitated transport membranes have carriers that transport CO_2, and therefore selectively permeate CO_2 regardless of its molecular size.

RITE, in collaboration with Sumitomo Chemical Co., Ltd. has formed the Molecular Gate Membrane Module Technology Research Association (MGMTRA) and has been developing a facilitated transport membrane called a molecular gate membrane (MGM) for use in the integrated gasification combined cycle (IGCC) and hydrogen production equipment. A schematic illustration of the working principles of the molecular gate membrane is shown in Figure 15. It is a composite membrane made of a poly (amidoamine) dendrimer which has a high density of amino groups and cross-linked polymer materials. 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. A poly (vinyl alcohol) (PVA) polymer matrix is used for pressure durability and to immobilize the dendrimers.

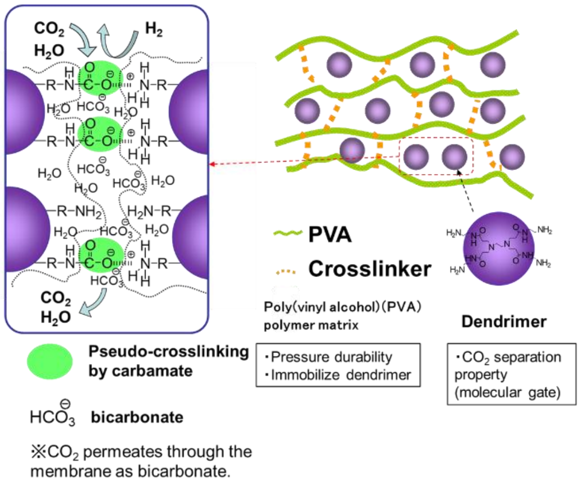

Fig. 15. Schematic illustration of the working principles of the molecular gate membrane

The greatest feature of the molecular gate membranes, as shown in Figure 16, is their world-leading CO_2/H_2 separation performance. Their performance has been further improved, significantly outperforming competing membranes, and they can be applied not only to high-pressure but also to medium-pressure applications.

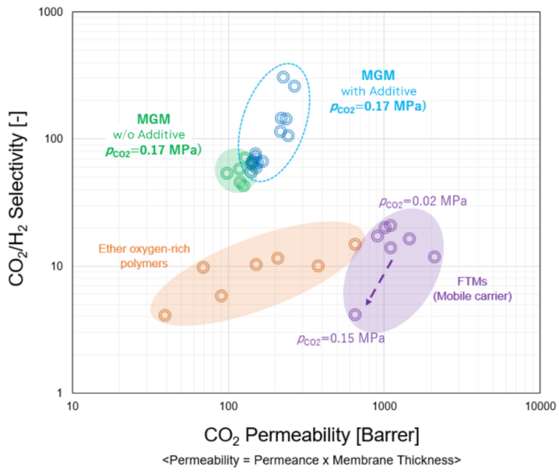

Fig. 16. CO_2/H_2 separation performance of molecular gate membranes

Operating conditions of molecular gate membranes: temperature 85°C, total pressure 0.85 MPa, feed gas composition CO_2/N_2 = 20/80.

Currently, MGMTRA, in collaboration with Mitsubishi Kakoki Kaisha, Ltd., a hydrogen production system manufacturer, is conducting research and development for a demonstration test of a hydrogen production system with CO_2 capture, under a NEDO-funded project named Development of Technologies for Carbon Recycling and Next-Generation Thermal Power Generation / R&D of CO_2 separation/capture technologies / R&D for Practical Application of CO_2 Separation Membrane Systems / Study on the Applicability of High-Performance CO_2 Separation Membranes to Hydrogen Production Systems (Fig. 17).

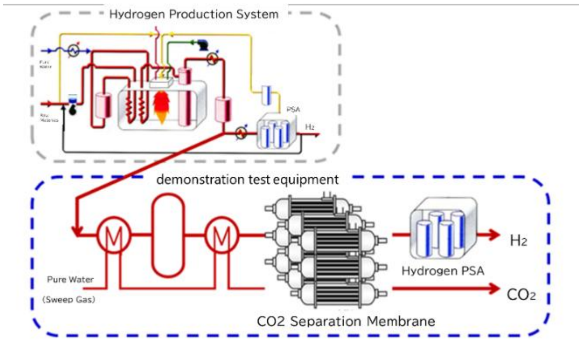

Fig. 17. Schematic illustration of the demonstration test of the hydrogen production system with CO_2 capture

In this project, MGMTRA has been working on long-length membrane manufacturing toward the practical use of the separation membrane. As a result, we have established technology for high-volume preparation of a coating solution that forms separation membranes with high separation performance, and for wide-width long-length membrane manufacturing using that coating solution (Fig. 18).

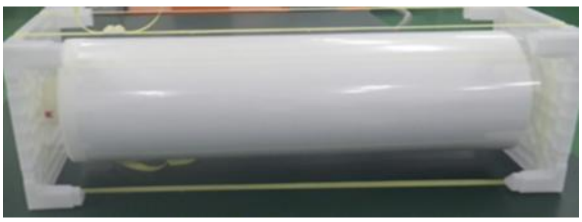

Fig. 18. CO_2 separation membrane roll products

Furthermore, MGMTRA has successfully developed commercial-size membrane elements (ϕ = 20 cm, L = 60 cm) (Fig. 19).

Membrane element
(ϕ = 20cm; L = 60cm)

Membrane module
(ϕ = 20cm; L = 60cm)

Fig. 19. CO_2 selective membrane, membrane element, and membrane module

Membrane element: Structure with a large membrane area composed of a membrane, support, and spacer

Membrane module: Structure in which the membrane element is placed

8. Effective methanol synthesis from CO_2 hydrogenation

CO_2 hydrogenation is one of the utilization technologies that produces water, causing deactivation of the catalyst and decreasing the reaction rate. In order to solve this problem, we shed light on methanol synthesis using CO_2 as the raw material using a membrane reactor that combines the membrane and the catalyst.

RITE has successfully developed a dehydration membrane (Si-rich LTA membrane) with high hydrothermal stability and permeation separation performance, and has experimentally demonstrated that a laboratory-scale methanol synthesis membrane reactor using the new dehydration membrane has a CO_2 conversion rate three times higher than that of a conventional catalytic packed bed reactor. Currently, we are studying the possibility of extending the length of the developed dehydration membrane under the NEDO project named Development of Technologies for Carbon Recycling and

Next Generation Thermal Power Generation / Development of Technologies for CO_2 Emission Reduction and Effective Utilization / Development of Technologies for CO_2 Utilization in Chemical Products / Development of Optimal Systems for Methanol Synthesis Using CO_2. In this study, we have succeeded in synthesizing a practical-length dehydration membrane with relatively high permeation separation performance and achieved the target values (H_2O permeability: 1 x 10^{-6} mol m^{-2} s^{-1} Pa^{-1}, H_2O/MeOH selectivity: >1,050) in the reaction temperature range for methanol synthesis. In addition, the synthesis conditions for long-length dehydration membranes were able to identify conditions that allow for synthesis without any variation in water permselective performance along the length.

With a view to mass-produced dehydration membranes of a practical length in FY2025, we conducted a detailed examination of coating conditions to evaluate the dip coating method for coating zeolite seed crystals onto the porous support. The dip coating method involves preparing a slurry in which seed crystals are dispersed in a solution, and then immersing a porous support in the solution to coat the seed crystals onto the support. Therefore, it is anticipated that the amount of seed crystals dispersed (slurry concentration) will significantly affect the permselective performance of the dehydration membrane. Figure 20 shows the permselective performance (H_2O/MeOH vapor permselective performance) of the dehydration membranes synthesized by hydrothermal synthesis after coating with varying slurry concentrations. These results suggest that, when applying seed crystals using the dip coating method, neither too dilute nor too concentrated a slurry yields sufficient separation performance, indicating that is the optimal concentration. Furthermore, since the dehydration membrane obtained at the appropriate slurry concentration exhibited permselective performance comparable to that achieved using the conventional rubbing method, it can be said that relatively suitable coating conditions were identified.

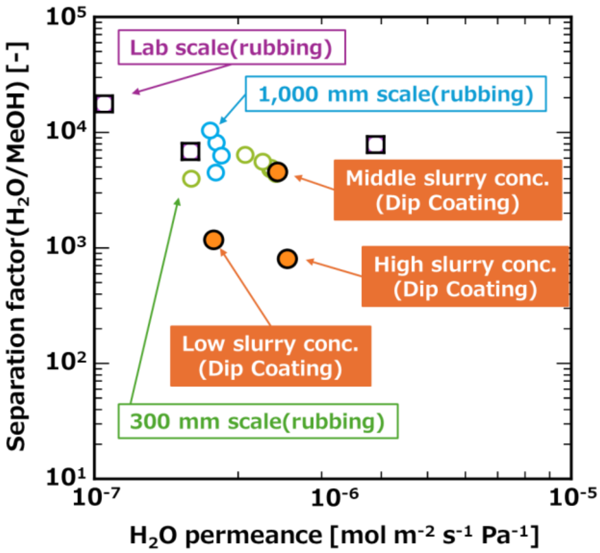

Fig. 20. The effect of changes in seed crystal coating method on permselective performance

Going forward, with the aim of commercializing the dehydration membranes we have developed in practical lengths, we will collaborate with membrane manufacturers to investigate manufacturing conditions and methods for these membranes, while also seeking to expand their application to other dehydration uses.

9. He recovery membrane

RITE has been developing silica membranes for hydrogen separation and has succeeded in producing various silica membranes that can permeate hydrogen produced from a variety of different reactions, including dehydrogenation of methylcyclohexane (MCH), one of the hydrogen carriers. The silica membrane was formed using the counter diffusion chemical vapor deposition (CVD) method (Fig. 21). Oxygen was supplied from inside of the porous support, and a silica source was fed to outside of that. When the pores are filled with silica, the reaction occurs preferentially in the unfilled areas, allowing for the reproducible formation of silica membrane with relatively high performance.

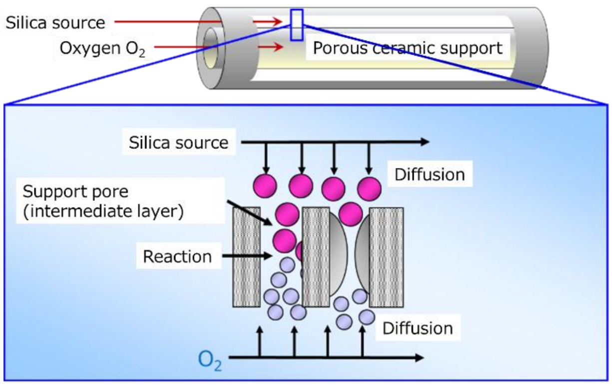

Fig. 21. Schematic diagram of counter-diffusion CVD method

Recently, the global helium crisis has become an issue, and it is important to find a way to secure sources of helium. Considering energy conservation, a method of recovering helium using a membrane separation method that does not involve a phase change is considered the best option. The smallest molecular size of helium is 0.26 nm, and other small molecules are H_2: 0.29 nm, CO_2: 0. 33 nm, N_2: 0.36 nm, and CH_4: 0.38 nm. The silica membranes for hydrogen separation developed at RITE are considered to be sufficiently applicable to helium separation. Currently, we are studying the development of longer silica membranes for helium separation under the NEDO Leading Research Program / Leading Research Program for the Creation of New Industry and Innovative Technology / Development of Highly Efficient Helium Membrane Separation and Recovery Technology in Nonflammable Gas Fields entrusted by the Japan Fine Ceramics Center (JFCC). We investigated the production of longer silica membranes for Helium separation and successfully fabricated membranes with relatively high performance. Computational results indicate that these membranes can efficiently recover Helium for non-flammable gas fields, and this project was successfully completed.

10. CO_2 fixation

CO_2 mineralization is a negative emission technology in which CO_2 is reacted with alkaline earth metals and immobilized as chemically stable carbonates. Research and development are underway both domestically and internationally to realize a carbon-neutral society

RITE has a proprietary process that has been developed over many years to immobilize CO_2 as carbonate, and since 2020, in collaboration with private companies, RITE has been developing technology to extract alkaline earth metals from steel slag, concrete waste, etc. in a wet process to recover CO_2 emitted from factories, etc. as stable compounds of carbonate (Fig. 22).

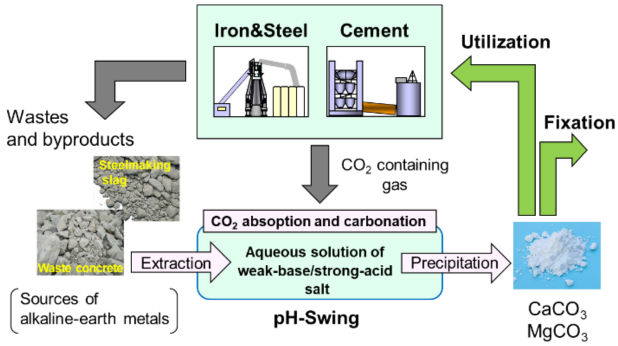

Fig. 22. CO_2 fixation as carbonates

Presently, we are working on process optimization of reaction temperature, reaction time, etc., and are currently studying the commercialization of this process and effective uses of the immobilized carbonates.

11. Activities and efforts toward commercialization and industrialization

The core of the Industrial Collaboration Division is the Industrialization Strategy Council, which includes a total of 46 private companies (as of April 2026) and the Fine Ceramics Center, Inc., as a special member.

From FY 2023, activities were expanded to promote the following projects with the aim of establishing technologies for CO_2 separation and effective utilization that will contribute to innovative environmental and energy technologies. We are promoting a variety of activities, which include the following:

【General Activities】

(1) Sponsorship of research meetings

(2) Free seminars for members only

(3) Dissemination of information on needs and seeds and hot topics to members

(4) Sponsorship of symposiums

【Individual Activities】

(1) Plans for joint implementation projects funded by the government and NEDO

(2) Acceptance of Research Scientists from council members to the Research Section of the RITE

(3) Offers for technical guidance from the RITE Advisory Board and Research Section

(4) Mediating the matching of council member's needs and seeds.

In FY 2025, to expand the scope of the research groups, a new research group called the CO_2 Separation, Recovery and Utilization Research Group was launched. In the workshop, technological tours of RITE's RCCC and eSep Inc., Ltd.'s membrane separation testing equipment were held. Furthermore, RITE presented the latest trends in CO_2 separation mainly from overseas conferences, and a survey on practical application and demonstration trends focusing particularly on CO_2 utilization.

The members-only free seminars were held three times at a venue and online. Research Scientists from universities and private companies gave lectures on the latest R&D trends and case studies on CO_2 capture and effective utilization, and active Q&A sessions took place.

In addition, we conducted patent and literature searches related to the information presented at the lectures and sent out *needs and seeds information* once with comments from RITE Research Scientists, and *hot topics* three times with academic conferences and overseas visits by RITE members, thus contributing to the promotion of technological development and improvement of knowledge of the members.

Member companies participated in poster presentations at the Symposium on Innovative CO_2 Capture and Effective Utilization held in February 2026.

12. Conclusion

RITE will continue to advance the R&D of CO_2 capture and utilization technologies targeting various emission sources. We will actively address the challenges within each process/application, and for those technologies that are closer to the commercialization stage, we will focus on scaling up and conducting real-gas tests to demonstrate these technologies at an early stage and facilitate their societal implementation. There is a need to further develop technologies that can also address low-concentration CO_2 emission sources. We will also dedicate efforts to negative emission technologies, such as Direct Air Capture with Carbon Storage (DACCS), which are expected to make significant contributions to sustainable development scenarios aimed at decarbonization. As CO_2 concentrations decrease, the volume of gas that needs to be processed increases, and since the oxygen concentration is higher, the development of low-cost, durable materials and corresponding system designs will become increasingly important. We will accelerate these developments to enable the early societal implementation of CO_2 capture technologies that are more energy-efficient and cost-effective. In addition, RITE conducted R&D for the effective utilization of captured CO_2, advancing technologies such as methanol synthesis and CO_2 immobilization as carbonate.

RCCC is operated as a facility capable of acquiring reliable, fair and neutral real-gas testing data. Starting within the duration of the Green Innovation Fund project, the center will begin accepting external materials/samples and providing fair and neutral test data to domestic CO_2 capture material developers. Additionally, to ensure the continuation of the center's operations after the project, the acceptance of external samples will help cultivate the management of RCCC. Meanwhile, through presentations at ITCN and international conferences, RITE will share the test data with international audiences to promote the global recognition of the standard evaluation methods established by RCCC.

Through these activities, we are committed to contributing to the further advancement of domestic CO_2 capture and utilization technologies.

CO_2 Storage Research Group

Member (As of Apr. 2026)

Group Leader, Principal Research Scientist	**Ziqiu Xue**
Deputy Leader, Principal Research Scientist	**Nobuo Umeda**
Principal Research Scientist	**Satoru Yokoi**
Principal Research Scientist	**Takahiro Nakajima**
Principal Research Scientist	**Yasuhide Nakagami**
Principal Research Scientist	**Makoto Nomura**
Vice Principal Research Scientist	**Nobuo Takasu**
Vice Principal Research Scientist	**Tsutomu Hashimoto**
Vice Principal Research Scientist	**Saeko Mito**
Senior Research Scientist	**Tetsuma Toshioka**
Senior Research Scientist	**Hyuck Park**
Senior Research Scientist	**Keisuke Uchimoto**
Senior Research Scientist	**Hironobu Komaki**
Senior Research Scientist	**Atsushi Ibusuki**
Senior Research Scientist	**Yuji Watanabe**
Senior Research Scientist	**Osamu Takano**
Senior Research Scientist	**Jiro Suekuni**
Senior Research Scientist	**Ken Asajima**
Senior Research Scientist	**Tetsumi Imamura**
Chief	**Kimiko Nakanishi**
Chief	**Akemi Nishide**
Chief	**Megumi Okumichi**
Research Scientist	**Takayuki Miyoshi**
Research Scientist	**Takeya Nagata**
Research Scientist	**Rasha Amer**
Research Scientist	**Jinrong Cao**
Research Scientist	**Masafumi Kotani**
Research Scientist	**Hiraku Miyasaka**
Research Scientist	**Wataru Ouchi**
Research Scientist	**Barry Majeed Hartono**
Research Assistant	**Junko Hirai**
Research Assistant	**Yuko Himi**
Research Assistant	**Megumi Sasaki**
Research Assistant	**Asato Murai**
Research Assistant	**Asuka Nakamura**
Staff	**Nae Hidaka**
Staff	**Mari Okuda**

Technology Demonstration, Commercialization Support, and International Collaboration for Practical CO_2 Geological Storage

1. Introduction

The CCS Business Act was promulgated in May 2024. While the provisions for exploration and exploratory drilling have already been enacted, the necessary government ordinances and ministerial regulations are currently being finalized to implement transportation and storage operations. Simultaneously, nine advanced CCS projects are underway, led by Ministry of Economy, Trade and Industry (METI) and Japan Organization for Metals and Energy Security (JOGMEC). Among these, exploratory drilling has commenced offshore Tomakomai, Hokkaido. Following the drilling and evaluation of two exploratory wells, the Final Investment Decision (FID) is scheduled for fiscal year 2026. Furthermore, efforts toward operational launch are progressing, with procedures for exploratory drilling underway offshore Kujukuri, Chiba Prefecture.

RITE has been advancing the development of technologies essential for practical-scale geological CO_2 storage, specifically tailored for application in these CCS projects. Through Research Institute of Innovative Technology for the Earth (RITE), we have organized Geological Carbon Dioxide Storage Technology Research Association. In collaboration with private companies poised to become CCS operators, and as part of a project commissioned by New Energy and Industrial Technology Development Organization (NEDO), we are engaged in a wide range of initiatives to enhance the safety and cost-efficiency of CCS operations.

Our core research focuses on the technical demonstration of CO_2 injection and storage monitoring using optical fiber sensing, the development of methodologies to evaluate fault safety and integrity surrounding CO_2 storage sites, and the construction of resources such as a "CO_2 Emission Source Database" and a "CCS Project Cost Estimation Tool," both of which are critical for evaluating value chains and business models. Additionally, we are conducting international surveys on policy and technical trends through partnerships with global CCUS organizations, also under the auspices of NEDO. The results of these activities are presented below.

2. Main research topics and results

2.1. Development and Field Demonstration of Multi-Sensing Technology Using Optical Fibers

To ensure the safety of CO_2 geological storage, continuous monitoring is essential to verify that injected CO_2 remains confined within the storage reservoir and that the resulting increase in pore pressure does not compromise the integrity of the caprock or the wellbore. Monitoring systems must be both long-term stable and cost-effective. Distributed Fiber-Optic Sensing (DFOS) is a highly promising technology that meets these requirements. RITE has been advancing the research and development of this technology through laboratory experiments and field trials, and is currently conducting long-term demonstration tests at various sites in Japan and abroad. This measurement technology is expected to play a critical role in the safety management of CO_2 geological storage throughout the entire project lifecycle, from initiation to completion.

2.1.1. Principle of distributed optical fiber multi-sensing

Distributed Fiber-Optic Sensing (DFOS) is increasingly adopted across various sectors because it allows for spatially continuous measurements by utilizing the entire length of the optical fiber as a sensor. The measurement principle is illustrated in Figure 1. When a laser pulse is transmitted through the fiber, backscattered light is reflected from various points along the fiber. The interrogator analyzes the backscattered light and calculates shifts in temperature or strain by comparing the signal against a baseline (initial state). By measuring the round-trip time of the scattered light, the precise location of the disturbance can be determined. Furthermore, the characteristics of the scattering vary based on the wavelength of the light, corresponding to different measurement parameters (Figure 1, bottom).

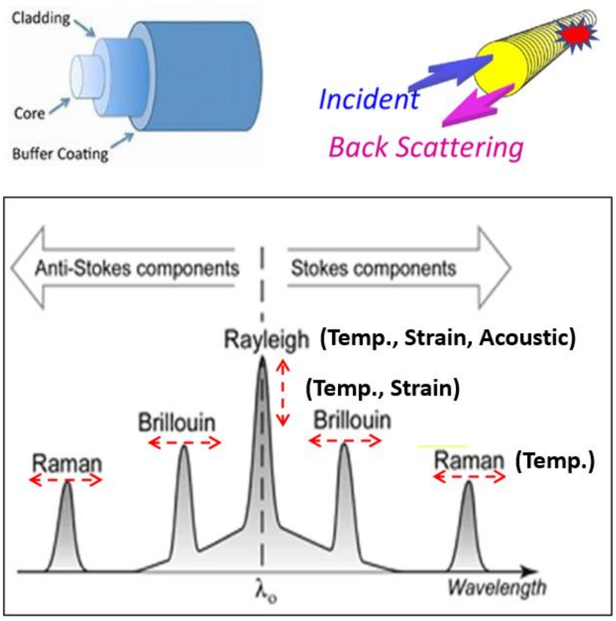

Figure 1: Principles of Distributed Fiber-Optic Sensing (DFOS) illustrating Rayleigh, Brillouin, and Raman backscattering components for multi-sensing applications.

Different scattering phenomena are utilized for specific sensing applications: Raman scattering is used for Distributed Temperature Sensing (DTS), while Brillouin scattering is employed for both temperature and strain sensing (Distributed Strain Sensing, DSS). Rayleigh scattering is widely used for Distributed Acoustic Sensing (DAS), though it is also utilized for high-precision temperature and strain measurements. While these scattering components must typically be measured individually, a multi-core or multi-strand fiber cable allows for the simultaneous monitoring of temperature, strain, and acoustics along the entire length of the cable.

The primary advantage of DFOS is that the sensing cable contains no electrical or mechanical components; it is entirely passive. This enables deployment in the harsh, high-pressure, and high-temperature environments typical of deep underground geological formations. Additionally, the fiber's small diameter allows for installation in confined spaces. Compared to conventional monitoring systems (e.g., discrete electronic thermometers and pressure gauges), DFOS provides superior long-term reliability with negligible degradation and immunity to electromagnetic interference.

Table 1 summarizes the potential measurement parameters and applications for geological CO_2 storage. Temperature (DTS) and strain (DSS) data, obtained from optical fibers installed on the exterior of the casing in injection and observation wells, facilitate:

-Identification of the active CO_2 injection zones within the reservoir.

-Assessment of injection efficiency and formation permeability.

-Real-time monitoring of caprock deformation and detection of potential fluid migration along the wellbore annulus.

Meanwhile, acoustic sensing (DAS) acts as a high-density seismic array, enabling the monitoring of underground CO_2 plume at any point during operations. Consequently, DFOS is expected to significantly contribute to the overall cost-efficiency of CCS projects. The following section presents specific field demonstration results conducted by RITE.

Table 1 Application examples of DFOS

Measurement element	Monitoring targets
Temperature (DTS)	・The injection intervals in the reservoir ・Quality assurance of well cementing CO_2 leakage from pipelines and injection wells
Strain (DSS)	・Characterization of CO_2 plume intrusion into the reservoir ・Detection of potential CO_2 leakage from the storage formation ・Monitoring of caprock integrity
Acoustics (DAS)	・Mapping of CO_2 plume and plume migration within the reservoir

2.1.2. North Dakota CCS Site, USA

The North Dakota CCS project is a commercial-scale operation managed by Gevo North Dakota (formerly Red Trail Energy). The project involves the sequestration of approximately 180,000 tons of CO_2 annually—captured from a corn-based ethanol production process—into a deep saline aquifer located at a depth of approximately 2,000 meters. Injection operations commenced in June 2022, and as of the end of March 2026, cumulative CO_2 storage has reached approximately 640,000 tons. The injection and observation wells are certified as Class VI wells under U.S. regulatory frameworks, providing a robust platform for real-world demonstration of mandatory monitoring protocols.

RITE has deployed fiber-optic cables along the wellbores and CO_2 pipelines (Figure 2) to demonstrate multi-sensing technology through the simultaneous acquisition of DAS, DTS, and DSS data. This long-term monitoring campaign is critical for identifying operational challenges and developing technical countermeasures that will serve as a foundation for future domestic CCS projects. Representative results from the DAS and DTS measurements are detailed below.

Seismic Monitoring with Surface Orbital Vibrators (SOVs)

Distributed Acoustic Sensing (DAS) utilizing well-installed fiber cables provides a high-resolution window into subsurface CO_2 plume migration. In particular, Vertical Seismic Profiling (VSP)—a technique widely employed in CO_2 storage and geothermal sites—is highly effective for high-precision monitoring near the wellbore. At the North Dakota site, we have introduced an innovative seismic source technology: the Surface Orbital Vibrator (SOV).

SOVs generate seismic waves by rotating an eccentric mass, transmitting vibrations into the subsurface. Four SOV units have been installed at the site (Figure 2) to capture the gradual spatial evolution of the CO_2 plume as injection progresses. The system is fully automated and programmable, allowing for remote activation at any time. Furthermore, DAS data processing is performed in real-time via on-site computing, which significantly reduces the data transfer requirements between the site and the research office.

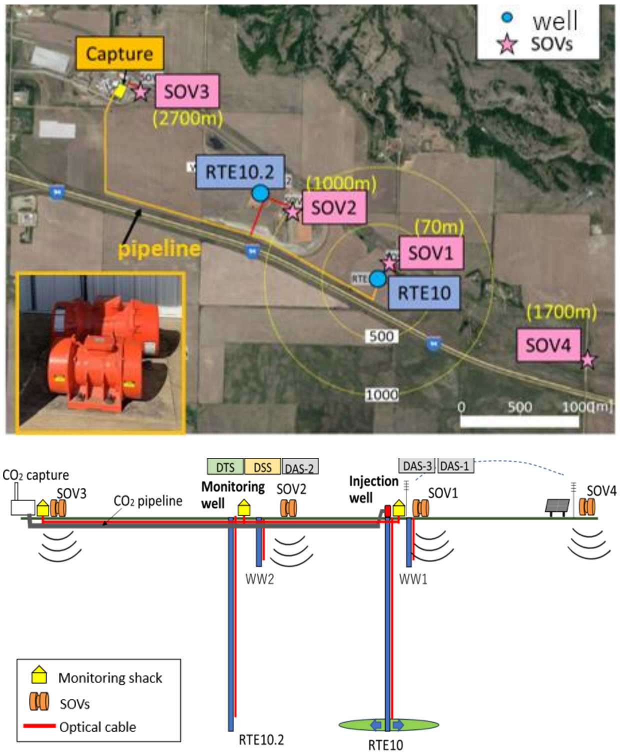

Figure 2: Layout of the integrated monitoring infrastructure at the North Dakota site, showing the alignment of optical fiber cables, CO_2 pipelines, injection/observation wells, and Surface Orbital Vibrators (SOVs).

Strategic Advantages of Continuous Monitoring

Figure 3 illustrates the conceptual distinction between conventional time-lapse (4D) seismic surveys and continuous monitoring using SOVs. Routine 3D seismic surveys are typically conducted at five-year intervals due to high costs. The primary advantage of the SOV system is its ability to provide high-frequency data acquisition, effectively "filling the gap" between conventional survey cycles. By capturing short-term, high-resolution snapshots of the CO_2 plume migration, the frequency of expensive, large-scale seismic surveys may be reduced. Additionally, the remote operation capability of the SOV system eliminates the need for on-site personnel, offering a safer, more autonomous, and cost-effective monitoring solution for long-term storage projects.

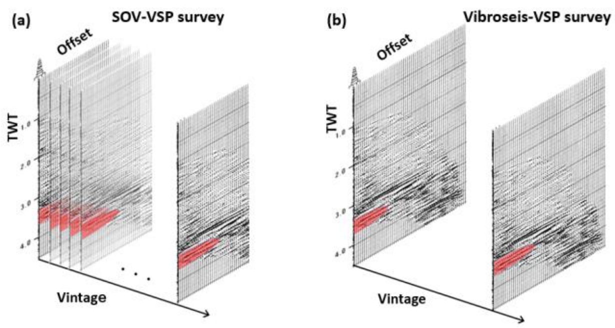

Figure 3: Conceptual comparison between high-frequency continuous monitoring using SOVs and discrete conventional 4D seismic surveys.

Data Analysis: Seismic Waveform Processing

For the data analysis derived from SOV excitation and DAS measurements, the seismic signal is first processed to separate direct down-going waves from the reflected up-going waves; the latter contain essential information regarding the target reservoir (Figure 4a). Next, the reflected waves from stratigraphic boundaries are converted into the Two-Way Travel Time (TWT) domain. Finally, by mapping the data chronologically against the cumulative CO_2 injection volume, we can characterize the impact of CO_2 plume migration on seismic reflections.

Figure 4b illustrates the monitoring results from the SOV located closest to the injection well (approximately 70m offset). Data indicate that once the cumulative injected CO_2 volume exceeds approximately 5,000 tons, distinct changes in the reflected waves occur within both the reservoir and its underlying layers. Specifically, in the later phase, the red and blue bands exhibit a downward curvature, indicating an increase in the travel time of the reflected waves (time-delay). This phenomenon demonstrates a reduction in P-wave propagation velocity caused by the substitution of pore water with CO_2. This observation is consistent with the velocity changes predicted by Gassmann's relationship, which has been validated through independent rock physical property testing.

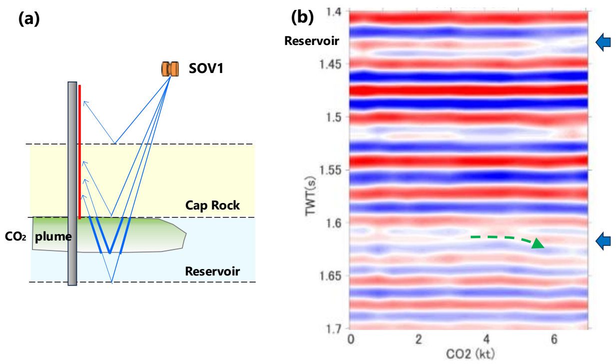

Figure 4: (a) Schematic of CO_2 plume imaging via SOV-DAS; (b) Processed seismic waveform showing time-delay characteristics correlating with cumulative CO_2 injection.

Integration of Monitoring Data and Reservoir Simulation

To validate the observed seismic changes, we compared the monitoring results with numerical simulations of CO_2 behavior. Given the early stage of injection, a horizontal multi-layer model was adopted. Formation flow properties were characterized using porosity and permeability profiles derived from well-log data, with the model discretized into 2-meter layers. The simulation also accounted for wellbore hydraulics, using actual injection rates as boundary conditions at the grid block corresponding to the reservoir top. Numerical simulations were performed using the TOUGH2 code.

Figure 5 presents cross-sectional snapshots of the CO_2 saturation at various cumulative injection stages. The vertical axis represents depth (1,950m to 2,040m, covering the 90m-thick reservoir), while the horizontal axis represents radial distance from the injection well. The simulation results indicate that CO_2 is sequestered primarily within the upper 40 meters of the reservoir. This localized injection interval was subsequently validated by pulsed neutron logging data acquired approximately one year after the commencement of injection.

Synthesis and Implications

The interpretation of the monitoring data indicates that the seismic phase delay observed via SOV monitoring directly correlates with the vertical thickness of the CO_2 plume. A key advantage of the SOV system is its high-frequency acquisition capability, which enabled the detection of subtle seismic changes even during the early stages of injection, with cumulative volumes as low as several thousand tons.

The ability to delineate the CO_2 plume during the initial injection phase provides critical data for assessing reservoir performance. Specifically, this confirms whether the reservoir possesses the requisite injection capacity and containment integrity for the long-term operational lifecycle of the CCS project.

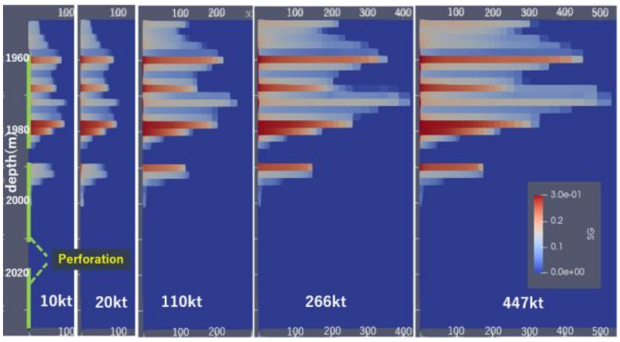

Figure 5: Numerical simulation of CO_2 saturation and plume migration across various injection stages, showing vertical distribution within the reservoir.

DTS Monitoring Results: Thermal Profile Analysis

Finally, we present the Distributed Temperature Sensing (DTS) results obtained at the North Dakota site. Figure 6 illustrates the temperature profile over approximately one year for both the shallow CO_2 pipeline section and the deeper injection well section.

In the pipeline section, long-period cyclic temperature fluctuations are evident, which correlate directly with annual ambient temperature variations at the surface. In contrast, the injection well section exhibits a standard geothermal gradient prior to the commencement of CO_2 injection—characterized by a steady temperature increase with depth. Upon injection, a significant temperature drop is observed, corresponding to the movement of CO_2 (at approximately 15°C) through the wellbore. During intermittent injection pauses (indicated by the brief red segments in Figure 6), the wellbore temperature gradually recovers toward the ambient formation temperature, only to drop again immediately upon the resumption of injection.

Operational Implications

These results demonstrate that DTS provides an effective means for the continuous, real-time monitoring of thermal fluctuations across the entire length of the pipeline and injection well infrastructure. Beyond routine monitoring, this capability serves as a critical diagnostic tool; in the event of an operational malfunction—such as a leak or integrity failure—along the fiber-equipped wells or pipelines, DTS enables the precise, real-time localization of the incident. This spatial accuracy is essential for minimizing response times and ensuring the long-term containment integrity of the CCS project.

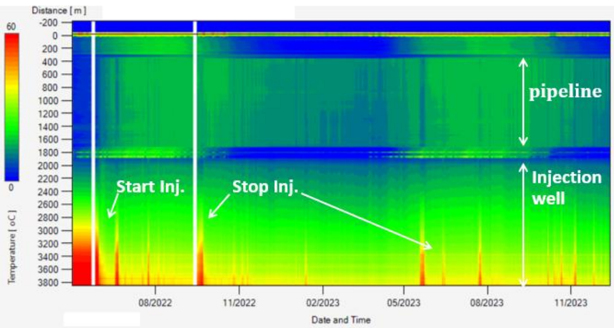

Figure 6: DTS temperature profiles over one year, illustrating seasonal temperature cycles in the pipeline and the localized cooling effect during CO_2 injection within the wellbore.

2.1.3. Field Demonstrations at Australian Sites

In Australia, we are conducting field trials to develop technologies for assessing fault stability during fluid injection and evaluating potential leakage from fault zones. Because geological faults and fractures represent critical leakage risks for CO_2 storage, fiber-optic multi-sensing is being deployed as a primary monitoring tool. Since 2021, we have collaborated with Australian research institutions—specifically those with access to well-characterized fault sites—to establish robust methodologies for fault integrity and stability assessment.

Otway Site (Victoria): Shallow Fault Leakage Detection

At the Otway site, managed by the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), we are conducting tests to detect CO_2 leakage from shallow faults. The experiment involved injecting CO_2 at a depth of approximately 100 meters to simulate leakage from a fault zone. RITE installed high-sensitivity Distributed Strain Sensing (DSS) fibers in newly drilled wells to monitor the subsurface strain during these leakage tests.

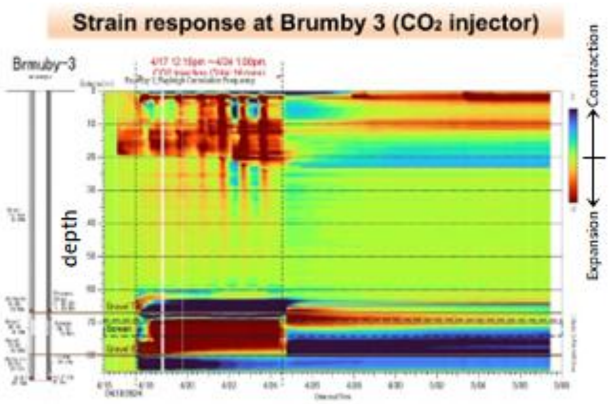

Figure 7: High-sensitivity DSS monitoring results during the shallow leakage test, confirming the absence of CO_2 migration toward the observation well via the fault zone.

Figure 7 indicates the absence of strain anomalies between the 60m and 20m depth intervals, demonstrating that the injected CO_2 did not migrate into the vicinity of the observation well. Given that our established empirical data from domestic sites confirm that fiber-optic sensors can detect minute pressure variations (or fluid movement) within a 15-meter radius, we conclude that the fault fracture zone is not currently acting as a leakage pathway. Future work will involve a comparative analysis with seismic survey data obtained by partner institutions.

Perth South Site (Western Australia): Deep Fault Stability Assessment

In collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), we are conducting field tests south of Perth to assess the stability of deep-seated faults. This site features a significant fault zone with a fracture width of several hundred meters, through which two research boreholes have been drilled (Figure 8).

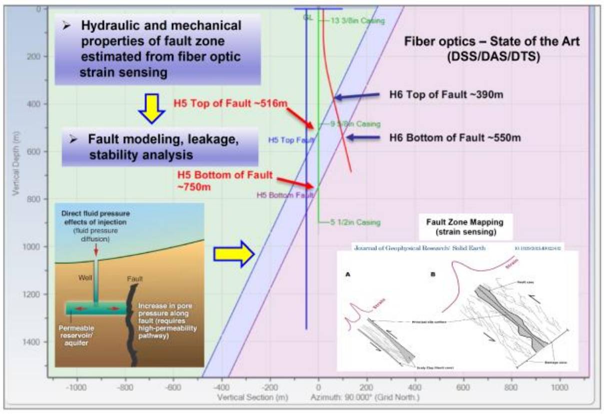

Figure 8: Geological cross-section of the Perth site, showing the intersection of injection and observation wells with a large-scale deep fault zone targeted for stability assessment.

As illustrated in Figure 8, the target fault is identified as the light purple band. Based on core analysis and well-logging data, multiple injection zones (orange triangles) were strategically positioned where the injection wells (green lines) intersect the fault. Observation wells (red lines) are equipped with fiber-optic strain sensors. Four seismometers have also been deployed; observational data over the past four years indicate no seismic activity associated with natural fault movement. Our future objectives include:

-Simultaneous Monitoring: Executing continuous, integrated strain measurements and seismic monitoring during fluid injection.

-Fluid Behavior Mapping: Using fiber-optic strain data to track fluid movement within the fracture zone.

-Technique Validation: Establishing definitive methodologies for assessing both fault stability (mitigating induced seismicity) and fault integrity (preventing CO_2 leakage through fracture zones).

2.2. Development of a CCS Scenario Generator: Analyzing Long-term Shifts in Major CO_2 Emission Sources

Effective deployment of CCS operations relies heavily on the optimal matching of industrial CO_2 emission sources with suitable geological storage reservoirs. To support this strategic alignment, RITE has been spearheading the development of a comprehensive CO_2 Emission Source Database.

Given that CCS deployment is a multi-decadal endeavor, it is essential to forecast the time-series evolution of emission sources. To address this, we have initiated the development of a "Scenario Generator," a modeling tool designed to analyze the long-term impact and deployment pathways of CCS technologies as part of broader CO_2 reduction strategies.

The following section outlines the current status and utilization of the CO_2 Emission Source Database, followed by an overview of the development progress and future roadmap for the CCS Scenario Generator.

2.2.1. Overview of the CO_2 Emission Source Database

The CO_2 Emission Source Database (hereinafter "Emission Source DB") is designed to facilitate the optimal matching of CO_2 emission sources with suitable geological storage reservoirs. This section outlines the database's data structure, functional capabilities, and current applications.

① **Data Structure**

The database leverages public data from the Ministry of the Environment's "Mandatory Greenhouse Gas Accounting, Reporting, and Publication System (SHK system)" (based on the Act on Promotion of Global Warming Countermeasures). While the system contains approximately 16,000 entries in total, the Emission Source

DB specifically utilizes a refined set of approximately 10,000 thermal power plants and industrial facilities. This data has been processed to support CCS-specific decarbonization analysis as follows:

-Estimation of Direct CO_2 Emissions: Emissions reported under the Act include indirect emissions from electricity and heat supplied by third parties. As CCS technology captures direct emissions at the source, we have derived "direct emission factors" for various industrial sectors through statistical processing. These factors are applied to the reported data to isolate and calculate direct CO_2 emissions for each facility.

-Integration of Biomass-Derived CO_2: Since the original Act-based data focuses on fossil fuel emissions, it excludes biomass sources. To account for Bioenergy with CCS (BECCS)-a key component for achieving negative emissions-we have incorporated estimated CO_2 emissions from biomass fuels, sourced from the Agency for Natural Resources and Energy's electricity survey statistics.

-Storage Potential Integration: The database incorporates the storage potential map from RITE's nationwide survey, "CO_2 Storage Potential Assessment in Japan" (RITE, 2006).

② Mapping and Screening Functions

Emission Source and Reservoir Mapping: Visualizing the spatial relationship between emission sources and storage reservoirs is critical for project planning. The database includes a mapping function that allows for immediate identification of regional disparities—such as the concentration of emission sources along the Pacific coast versus the prevalence of potential storage sites on the Sea of Japan side.

Information Screening: The interface supports dynamic map manipulation, including panning and zooming. Users can select specific regions to extract clustered emission source data, which is highly beneficial for hub-and-spoke infrastructure planning.

Flexible Emission Visualization: CO_2 emissions can be filtered by three categories: fossil fuel, biomass, and total emissions. Figure 9 displays a map of total emissions, while Figure 10 enables a shift to biomass-only visualization, facilitating the strategic evaluation of BECCS-based carbon offset strategies.

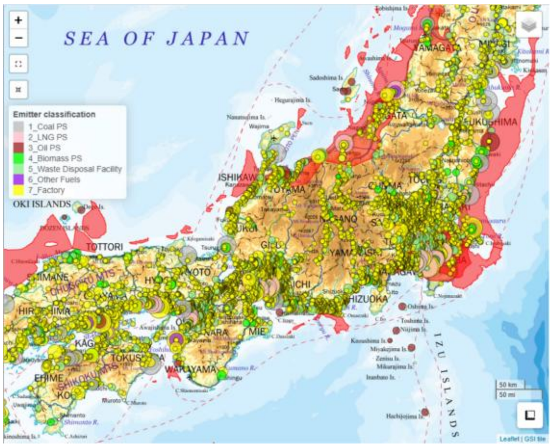

Figure 9: Spatial mapping of major CO_2 emission sources and potential geological storage sites across Japan, integrated into the CO_2 Emission Source Database.

Figure 10: Filtered database visualization focusing on biomass-derived CO_2 sources for the evaluation of negative emission strategies through BECCS.

③ Utilization Status of the CO_2 Emission Source DB

Since November 2024, the CO_2 Emission Source Database has been made available to authorized trial users (for further details, please visit: https://www.co2choryu-kumiai.or.jp/research-theme/post-1140/).

As of March 31, 2026, the database has been adopted by over 100 companies and research institutions. We maintain a proactive engagement strategy with these stakeholders, actively soliciting feedback to iteratively refine and enhance the database's functionality. The widespread adoption and valuable user insights have underscored the strategic importance of this tool, with significant interest and anticipation currently directed toward the development of the "CCS Scenario Generator" introduced in the following section.

2.2.2. Development of a CCS Scenario Generator

Achieving carbon neutrality by 2050 requires rigorous decarbonization strategies across all industrial levels-from entire sectors to individual business sites. CCS is a vital component of this transition; however, its scale and implementation pathway depend on numerous external variables, including energy demand forecasts and the deployment rates of alternative technologies such as electrification and hydrogen-based manufacturing. Given the long development lead times and substantial capital requirements inherent in CCS infrastructure, long-term strategic planning is essential. To support these complex decision-making processes, RITE has initiated the development of a "Scenario Generator" by extending the existing Emission Source DB. This section details an example of scenario setting and the underlying conceptual framework of the generator.

① **Scenario Setting and Long-term Dynamic Estimation)**

a) Analysis Period: The Scenario Generator covers the transition period toward the 2050 carbon neutrality goal, with specific data snapshots modeled for the intermediate milestones of 2030 and 2040.

b) Filtering Criteria for CO_2 Emission Sources: The comprehensive Emission Source DB includes approximately 10,000 data points. To maintain analytical efficiency without sacrificing accuracy, we have restricted the scope of our long-term modeling to thermal power plants and industrial facilities with annual CO_2 emissions exceeding 100,000 tons. This filter narrows the focus to approximately 250 key emitters, which collectively account for over 90% of total industrial CO_2 emissions, allowing for a precise and manageable projection of long-term emission dynamics.

c) Methodology for Emission and CCS Processing Estimation: Projections for 2030, 2040, and 2050 were calculated based on the following framework:

1) Target Achievement: All facilities with annual emissions ≥ 100,000 tons are assumed to reach carbon neutrality by 2050.
2) Facility Lifecycle Integration: Incorporates publicly announced data on the construction, suspension, and decommissioning of power plants and industrial facilities.
3) Industry Alignment: Estimates are grounded in the decarbonization roadmaps published by various industrial associations.
4) Data Interpolation: Where time-series information is unavailable, data is supplemented through RITE's proprietary assumptions and models.

d) Visualization of Projections: Figure 11 displays the estimated 2050 CO_2 emission and CCS processing volumes.

- Spatial Mapping: Light blue circles signify the locations of emission sources and their respective CO_2 capture volumes. Note that sources transitioning to alternative decarbonization pathways (e.g., fuel switching) are excluded from these plots. Dark blue dots represent smaller emitters (< 100,000 t/year), whose spatial distribution remains a critical focus for future decarbonization policy planning.

-Sectoral Breakdown: The graph at the bottom of Figure 11 illustrates the projected CO_2 capture volume by industry. For instance, in the blast furnace steelmaking sector (yellow band in Figure 11), while baseline emissions in FY2022 were approximately 130 million tons, the model projects that 50 million tons per year will remain to be managed via CCS by 2050, accounting for the adoption of electrification, hydrogen-reduction processes, and facility decommissioning.

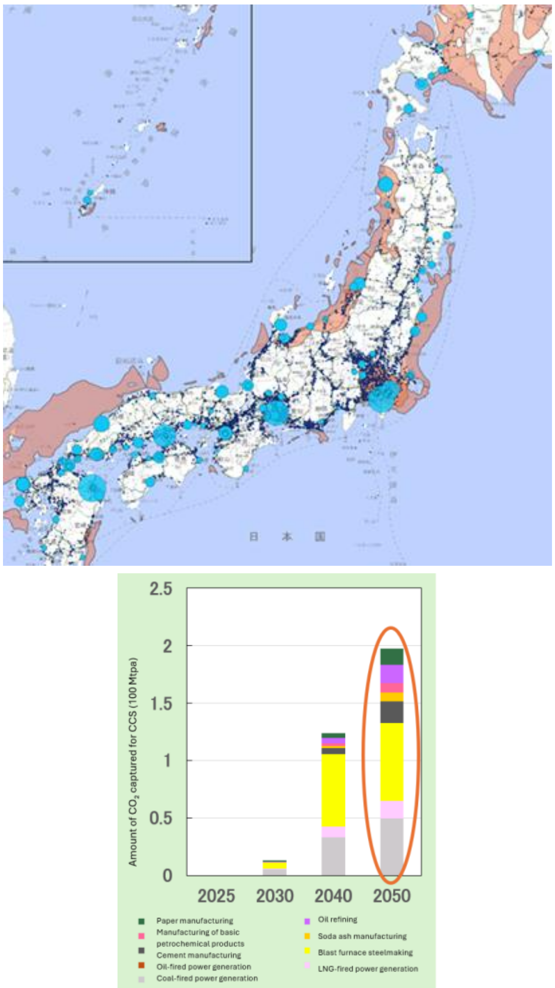

Figure 11: Future projection of CO_2 capture and CCS volumes by industrial sector for 2050, showing the spatial redistribution of emission clusters.

② Development Roadmap for the CCS Scenario Generator

As demonstrated, visualizing the spatial distribution and scale of 2050 CO_2 emission sources alongside potential storage sites (depicted in pale red) provides a robust foundation for evaluating future CCS value chains. However, as this represents only a single hypothetical scenario, it is insufficient for comprehensive strategic planning. In practice, stakeholders must deliberate across a wide spectrum of scenarios-integrating feasibility assessments of competing decarbonization technologies-to identify and optimize CCS value chains.

The CCS Scenario Generator is designed to serve as an integrated decision-making platform to support this collaborative process. Its functional workflow is illustrated in Figure 12:

-Scenario Setter: Enables the definition of diverse, multi-variable scenarios. This module incorporates long-term projections for CCS implementation, fuel switching trends, storage site development progress, and the technological maturity of alternative decarbonization solutions.

-CCS Model Creator: Determines the optimal CCS value chain for each scenario. By integrating CO_2 capture data with geographic variables, this module selects the most efficient CO_2 transport and infrastructure configurations. CCS Model Creator could also be regarded as CCS Value Chain Creator.

-CCS Feasibility Assessment Simulator: Conducts economic and operational feasibility evaluations. This module considers configuration costs, infrastructure requirements, and the impact of economic incentives (e.g., carbon pricing or subsidies) on the overall project viability.

While the current framework remains at the conceptual stage, RITE intends to engage with a broad range of stakeholders to refine detailed technical specifications and accelerate the development of this platform.

<u>Concluding Remarks</u>

The widespread deployment of CCS is a long-term undertaking defined by significant uncertainties. It requires iterative analysis and consensus-building among industry, government, and technical stakeholders. We believe the CCS Scenario Generator will serve as a critical decision-making platform, providing the rapid, data-driven support necessary to navigate these complexities and ensure the successful planning and implementation of CCS initiatives.

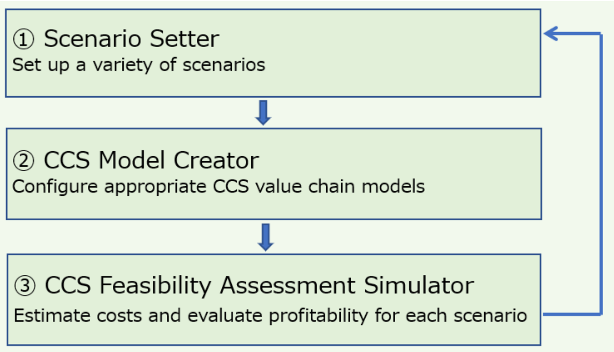

Figure 12: Integrated workflow of the CCS Scenario Generator, incorporating the Scenario Setter, CCS Model Creator, and Feasibility Assessment Simulator.

2.3. International CCS Trends

RITE is actively engaged in international cooperation to address the financial support scheme and technical challenges associated with the global deployment of CCS. By participating in international CCUS forums and forums of global organizations, we monitor emerging trends and actively disseminate information regarding Japan's initiatives. Furthermore, through interviewing in meetings with CCUS related organizations and rigorous literature reviews, RITE investigates and analyzes global CCS projects and governmental support frameworks, utilizing these insights to inform the development of Japan's domestic CCS regulatory and business environment.

This section highlights key trends in major regions, focusing on operational and planned projects in Europe, North America, and Australia, with particular emphasis on the recent rise of cross-border CO_2 transport.

2.3.1. Developments in Europe

European CCS deployment is underpinned by Directive 2009/31/EC (the CCS Directive), which has provided a unified legislative framework for member states since 2009. The North Sea region serves as the primary hub for large-scale storage resources, with projects advancing rapidly in the UK, Norway, Denmark, and the Netherlands. The European landscape is increasingly defined by cross-border transport projects and cost-effective "hub-and-cluster" industrial configurations. Beyond the North Sea, smaller-scale storage initiatives are currently under evaluation and prepared across the Mediterranean and various onshore locations.

Table 2 Projects that the CEF-E Foundation is considering as candidates for support

Project Name	Location of emission sources	Storage area (accumulation area)
CO_2 Transports	Netherlands, Belgium	North Sea off the coast of the Netherlands, etc.
Aramis	Netherlands, Germany, France, Belgium	North Sea off the coast of the Netherlands
Bifrost	Denmark, Germany, Poland	North Sea off the coast of Denmark
Callisto	France, Italy	Mediterranean Sea off the coast of Italy
CCS Baltic Consortium※	Latvia, Lithuania	(Lithuania, Baltic Sea coast)
Delta Rhine Corridor	The Ruhr region of Germany and the Rotterdam region of the Netherlands	North Sea off the coast of the Netherlands
EU2NSEA	Belgium, Germany, Denmark, France, Latvia, Netherlands, Poland, Sweden, and others	North Sea off the coast of Norway
Norne	Denmark, Sweden, Belgium, UK	Danish land area, North Sea off the coast of Denmark
Prinos-Apollo CO_2	Greece, Bulgaria, Croatia, Cyprus, Italy, Slovenia	Mediterranean Sea off the coast of Greece
Pycasso	France, Spain	Southwestern France
BaltiCO$_2$Net	Denmark, Germany, Latvia, Poland, Sweden	Danish land area
ECO$_2$CEE※	Poland, Lithuania	(Poland (Ports along the Baltic Sea)
Northern Lights	Belgium, Germany, Ireland, France, Sweden, and others	North Sea off the coast of Norway
Nautilus CCS	France, Germany, Norway	(English Channel coastal ports, North Sea coastal ports)
Atlas	Within the EU	North Sea off the coast of Norway
Ship Connect	Belgium (Zeebrugge)	North Sea off the coast of UK
German Carbon Transport Grid	Germany	Northern Europe

※Projects that do not include CO_2 storage.

(1) European Union (EU) Policy and Funding

-Cross-Border Infrastructure: To accelerate the deployment of transboundary CO_2 transport infrastructure, the European Commission announced candidate projects for funding under the Connecting Europe Facility for Energy (CEF-E) in December 2025 (Table 2).

-Innovation Fund: Projects involving high technical complexity receive support from the EU Innovation Fund, which is financed by revenue generated from the EU Emissions Trading System (EU-ETS). In the November 2025 funding round, selected projects included decarbonization initiatives in the cement industry, maritime CO_2 capture, and the production of sustainable fuels (e.g., Sustainable Aviation Fuel (SAF) and ethanol), as well as the development of strategic CO_2 hubs in Greece and Poland.

(2) United Kingdom (UK)

The UK government is aggressively promoting CCS as a cornerstone of its "Net-Zero" strategy, with a strategic focus on job creation and economic growth. The national target is to achieve an annual storage capacity of 20–30 million tons by 2030. To reach this, the government identified four industrial clusters for operational deployment by 2030, announcing a £22 billion support package in the autumn of 2024 allocated to the first two primary clusters. This funding milestone catalyzed a wave of Final Investment Decisions (FID) across transport, storage, and capture projects throughout late 2024 and 2025.

Financial Mechanism: The UK's CCS business model is designed to bridge the gap between the cost of CO_2 reduction and its market value, with the latter pegged to the EU/UK Emissions Trading System (ETS) price. Transportation and storage (T&S) segments operate under a regulated framework where the government reviews and approves necessary capital and operational costs. Capture projects are then reimbursed through a differential model, where the government covers the gap between the project's total costs (including T&S fees) and the market price of carbon.

-Project Spotlight: HyNet Cluster

HyNet cluster is one of the flagship initiatives driving the UK's CCS agenda.

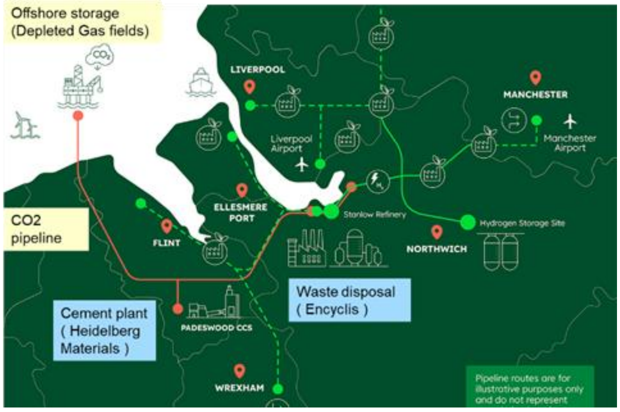

Figure 13: Hynet cluster.

Source: added to padeswoodccs: https://www.mol.co.jp/pr/2026/26013.html

① HyNet cluster T&S Project:

-Operator: Eni (Italian energy major).

-Storage Site: Offshore depleted gas fields (Eni-operated).

-Capacity: 4.5 Mtpa (Phase 1); scaling to 10 Mtpa by the 2030s.Infrastructure: 184 km pipeline network (incorporating 149 km of repurposed existing infrastructure).

-CO_2 Purity Requirements: ≥ 95%.

② HyNet cluster Capture Project:

-Phase 1 (FID Completed): Includes Cement (800 ktpa) and Waste-to-Energy (370 ktpa).

-2030s Expansion Pipeline: Targeting oil refining, hydrogen production, additional waste-to-energy facilities, and Direct Air Capture (DAC) integration.

(3) Norway

Norway occupies a strategic position in the European CCS landscape, leveraging its extensive North Sea oil and gas infrastructure and abundant offshore saline aquifer capacity. With the long-term vision of becoming a primary European storage hub, Norway launched the Longship project to develop a full-scale CCS value chain, which includes the flagship Northern Lights project (Transportation & Storage). This project, supported by significant direct government subsidies, officially commenced operations in August 2025.

① Northern Lights Project

Northern Lights represents a groundbreaking shift toward maritime CO_2 transport, facilitating the injection of CO_2 captured from diverse industrial sources—including the domestic Heidelberg Materials cement plant-into subsea saline aquifers.

- -Operators: A Joint Venture (JV) between Equinor, Shell, and TotalEnergies.
- -Capture Sources: Multi-national sources across Norway, the Netherlands, Denmark, and Sweden.
- -Storage Site: Offshore North Sea saline aquifers.
- -Capacity: 1.5 Mtpa (Phase 1); expanding to > 5 Mtpa (Phase 2). CO_2 Purity: ≥99.81 mol% (strict specification for maritime transport safety).
- -Funding Structure:
- -Phase 1: Direct government subsidy (approx. 14 billion NOK / €1.3 billion) covering both CAPEX and OPEX.
- -Phase 2: Backed by the EU's Connecting Europe Facility (CEF-E) fund (€4M for Front-End Engineering Design FEED, €131M for construction).
- -Maritime CO_2 Transport Infrastructure Northern Lights pioneered the world's first medium-temperature, medium-pressure (MTMP) liquefied CO_2 carriers for CCS.
- -Phase 1 Fleet: Four 7,500 m^3 capacity carriers. K-Line (Kawasaki Kisen Kaisha) has been contracted to operate three of these vessels.
- -Phase 2 Expansion: Four additional 12,000 m^3 capacity carriers will be commissioned, with deliveries scheduled to begin in late 2028. These vessels will be owned and operated through a consortium involving K-Line, Malaysian shipping interests, and MOL (Mitsui O.S.K. Lines).
- -Manufacturing Profile: Reflecting a strategic global supply chain, six of the total eight vessels are being constructed in China, with the remaining two manufactured in South Korea.

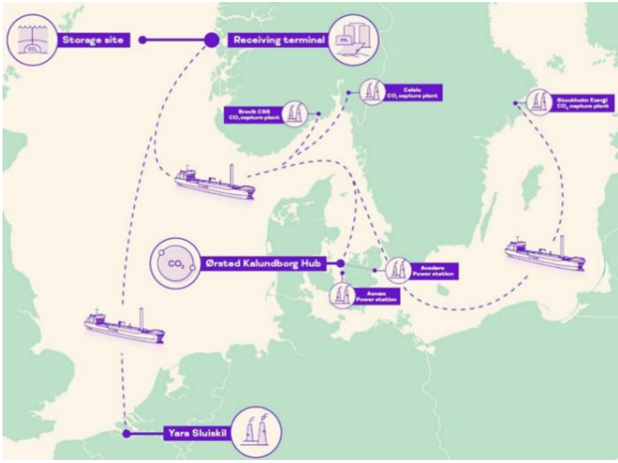

Figure 14: Northen lights project (including transboundary shipping.)

(Source: Added to article on signing a long-term charter contract for two new liquefied CO_2 carriers for Northern Lights)
https://www.mol.co.jp/pr/2026/26013.html

(4) Netherlands

The Netherlands has established a climate target of 49% CO_2 reduction by 2030 (relative to 2019 levels) under its 2019 Climate Act. The national strategy leverages North Sea storage potential to mitigate approximately half of all industrial emissions. Government support is channeled through the SDE++ program, which, similar to the UK model, employs a "Contract for Difference" (CfD) mechanism to bridge the gap between decarbonization costs and the market price of carbon.

① Porthos Project

Porthos represents the EU's first integrated transport and storage hub, with construction initiated in 2024 and operations targeted for 2026.

- -Operators: A consortium including the Port of Rotterdam Authority, EBN (state-owned oil & gas), and

Gasunie (state-owned gas grid).

-Storage: Depleted North Sea gas fields; capacity of 2.5 -Mtpa over 15 years.

-Infrastructure: 30 km onshore pipeline + 20 km offshore pipeline. The system is designed for an ultimate capacity of 10 Mtpa, allowing for future integration with the Aramis transport and storage corridor.

-Funding: Secured €100M from the CEF-E fund. Notably, the Port of Rotterdam issued €50M in dedicated "CCS Bonds," with Dai-ichi Life Insurance (Japan) investing €26M.

Figure 15: Infrastructure layout of the Porthos project in the Port of Rotterdam, the EU's first multi-user CO_2 transport and storage hub.
Source: Porthos, Project, https://www.porthosco2.nl/en/project/

② **Capture Project**

Operators: Shell, ExxonMobil, Air Liquide, and Air Products. Shell's refinery is scheduled for pipeline integration by March 2026, with all capture projects supported by the SDE++ framework.

(5) Denmark

Denmark's 2020 Climate Act targets a 70% GHG reduction by 2030 and full carbon neutrality by 2050. The Danish government actively supports CCS via a cost-value differential subsidy model. While exploration rights for both offshore (2023) and onshore (2024/25) sites have been granted, domestic storage is still transitioning from demonstration to commercial-scale.

① **Biomass CCS (BECCS)**

This project focuses on CO_2 capture from biomass power plants, with planned maritime export to Norway's Northern Lights storage hub.

Operator: Ørsted.

-Scope: Two biomass plants capturing 430 ktpa.

-Transport: Truck-based transport initially, with plans for future pipeline integration.

-Funding: Commercially bolstered by a carbon removal credit agreement with Microsoft.

② **Greensand (Future) Project**

Greensand achieved a global milestone in 2023 by completing the first successful cross-border maritime CO_2 transport and offshore injection. The "Greensand Future" commercial phase reached FID in December 2024.

-Operator: INEOS Energy.

-Transport & Storage: Maritime transport of liquefied CO_2 (5,500 m^3 capacity) to North Sea offshore sites. A unique technical feature involves using seawater to reheat the liquefied CO_2 within the vessel prior to injection.

-Funding: Backed by the EU Innovation Fund.

2.3.2. Trends in North America

North America is a global leader in CCS, leveraging abundant fossil fuel resources and a mature industrial base. The region currently operates over 20 active CCS projects, setting the standard for large-scale carbon management.

(1) United States

The U.S. CCS landscape has evolved significantly, built upon a foundation of 4,000 miles of CO_2 pipelines and numerous Enhanced Oil Recovery (EOR) sites developed since the 1970s. The introduction of the 45Q tax credit in 2008 and its subsequent expansions have been the primary catalyst for commercialization, particularly in low-cost capture sectors like ethanol production.

- Policy Update: Following the 2025 administration transition, the scale of tax credits for CCUS was bolstered.

The credit remains at $85 per ton for dedicated geological storage (CCS), while credits for CCU and EOR/EGR have been increased from $60 to $85 per ton. Concurrently, the Department of Energy has initiated rigorous financial audits of existing government-supported projects to ensure fiscal viability, resulting in the termination of support for projects failing to demonstrate expected returns on investment. But information regarding individual projects has not been made public.

① Net-Zero North Project

-Operator: Gevo (Biofuel producer; acquired Red Trail Energy’s CCS/ethanol assets in 2025).

-Capture: Ethanol production (biomass-derived), 180 ktpa.

-Storage: Saline aquifer, with RITE collaborating on advanced fiber-optic monitoring trials.

-Funding: A hybrid model utilizing government 45Q tax credits and private sector revenue from the sale of Puro.earth-certified CO_2 removal credits on the voluntary carbon market.

(2) Canada

Canada utilizes a robust mix of carbon pricing (carbon tax) and targeted investment incentives to pursue its carbon-neutrality goals. Large-scale activities are concentrated in Alberta and Saskatchewan.

-Quest Project (Success Story): Since beginning operation in 2015, this project has successfully injected over 9 Mt of CO_2, demonstrating the viability of long-term storage in Western Canada.

-CO_2 Storage Hub Development: The region is pivoting toward storage hubs, with 6 candidate projects near the Edmonton industrial center and 19 others identified across the province.

① Deep Sky Alpha Project (DAC) & Meadowbrook Storage Hub

Representing North America's first fully integrated Direct Air Capture and Storage (DACCS) operation (operational since 2025).

-Operator: Deep Sky (Canadian carbon removal developer).

-Capture: Currently 3 ktpa; modular expansion plans target 30 ktpa using 10 diverse DAC systems.

-Storage: Meadowbrook CO_2 Storage Hub (saline aquifer), with a target capacity of 3 Mtpa.

-Funding Structure: * Government Incentives: A 72% aggregate investment tax credit (60% federal CCUS ITC + 12% provincial add-on) and a $5M CAD provincial grant.

-Private Capital: Strategic funding including $40M USD from Bill Gates-backed funds, alongside long-term carbon removal credit purchase agreements with corporate off-takers like Microsoft and the Royal Bank of Canada (RBC).

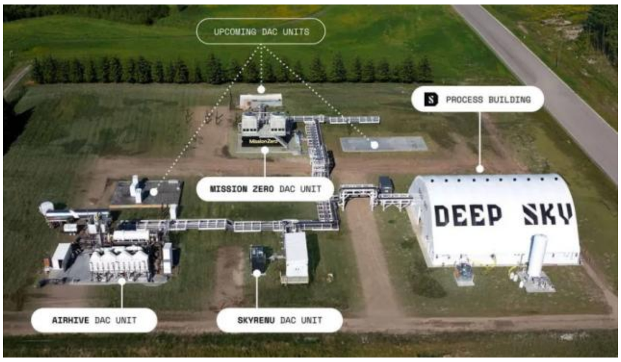

Figure 16: Conceptual framework of the Deep Sky project in Canada, showcasing the integration of multiple Direct Air Capture (DAC) and Ocean Carbon Capture technologies into a unified storage infrastructure.

Source: Deep Sky Alpha: Now Operational
https://www.deepskyclimate.com/alpha

2.3.3. Trends in North Australia

Australia, a global powerhouse in LNG and coal exports, has committed to achieving carbon neutrality by 2050 and a 43% emissions reduction by 2030 (relative to 2005 levels). The government is driving decarbonization across all sectors, including the oil and gas industry, primarily through the "Safeguard Mechanism." This regulatory framework mandates that large-scale emitters (>100,000$ t-CO_2/year) reduce their emission baselines by approximately 5% annually until 2030. Notably, new natural gas facilities are now subject to mandatory zero-emission requirements, rendering CCS an essential operational necessity. Currently, active projects include Gorgon (injecting into terrestrial saline aquifers) and Moomba (injecting into depleted gas fields). Several large-scale hubs are also in the pipeline, including CarbonNet, Bayu-Undan and Angel.

① Bayu-Undan CCS Project

This project focuses on utilizing depleted gas fields as a regional CO_2 storage hub for both domestic and international emitters.

-Operator: Santos.

- Capture: CO_2 from natural gas processing and overseas sources (e.g., South Korea).

-Storage: Depleted gas fields within East Timorese waters; potential capacity of 10 Mtpa.

-Transportation: Darwin LNG terminal serves as the primary hub, utilizing existing pipelines for offshore transport.

-Regulatory/Financial: Discussions are underway between the Australian and East Timorese governments regarding bilateral agreements for cross-border transport under the London Protocol. Currently, the primary driver is compliance with the Safeguard Mechanism rather than direct government subsidies.

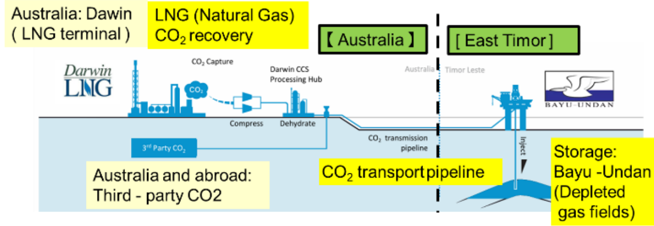

Figure 17: Conceptual model of the Bayu-Undan cross-border CCS project, linking Darwin’s industrial hub with offshore storage in East Timorese waters.

Source: Added to Santos - CCUS Project updates.
https://www.env.go.jp/earth/ccs/3rd_speech14.pdf

② CarbonNet Project

A flagship hub initiative spearheaded by the Victoria State government to support the state’s 2045 net-zero goal.

-Operator: Victoria State Government.

-Capture: Targeting high-emission industrial clusters, including hydrogen production, fertilizer manufacturing, and biomass processing.

-Storage: Two primary offshore sites:

- Pelican Site: 6 Mtpa for 30 years (saline aquifer).
- Kookaburra Site: 7.5 Mtpa for 20 years (future).

-Transportation: 80 km onshore and 20 km offshore pipeline network.

-Status & Funding:

-FEED phase completed. Total AUD 100M in feasibility funding (AUD 70M Federal, AUD 30M State).

-Fund for business model development, etc. （AUD 2.3M：Global CCS Institute (GCCSI))

-The project has garnered significant international interest, including an MOU between JOGMEC (Japan) and the Victoria State Government.

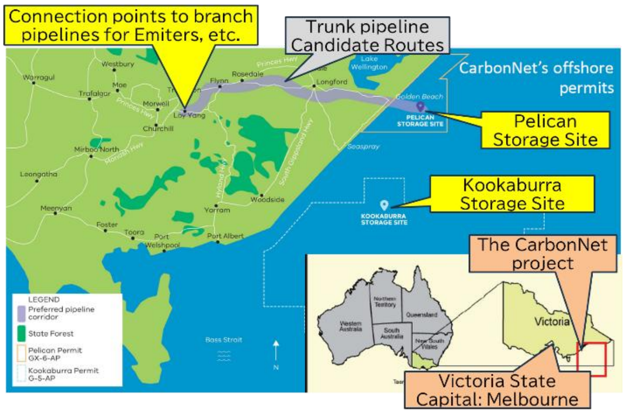

Figure 18: Strategic map of the CarbonNet project, illustrating the connection between industrial sources and offshore saline aquifer storage sites (Pelican and Kookaburra).

Source: Added to the CarbonNet Project
https://gccc.beg.utexas.edu/files/gccc/research/goi/2024/2.02_Bailey_VictoriaGovt_Australia_CarbonNet.pdf
https://hgeo.energy.gov/archives/cslf/sites/default/files/documents/perth2012/Clifford-CarbonNetProject-PIRT-Perth1012.pdf

Launch of the RITE Biomanufacturing Center

Molecular Microbiology and Biotechnology Group
Group Leader / Principal Research Scientist **Masayuki Inui**
Vice Principal Research Scientist **Nobutake Fugono**
Senior Research Scientist **Takeshi Kubota**

1. Background of Establishment

In recent years, expectations for the utilization of biotechnology have continued to grow, with investments amounting to several trillion yen being made worldwide. In Japan as well, under the national vision of "realizing a world-leading bioeconomy society by 2030," there is a strong demand for a transition toward Biomanufacturing that utilizes underused resources in order to simultaneously address environmental challenges and achieve economic growth.

As a key national initiative, the **Biomanufacturing Revolution Promotion Program** has been launched with a total budget of 300 billion yen, and RITE was among the earliest organizations to be commissioned under this program. The **RITE Biomanufacturing Center** was constructed as one of its core hubs to establish a strain development platform and to promote intensive R&D and demonstration activities.

RITE Biomanufacturing Center

- **Total floor area:** 1,353 m^2
- **Completion:** November 2025
- **Full-scale operation:** Starting April 2026

2. Facility Overview

2.1. Experimental Facilities

1. Strain Engineering Laboratory

The strain engineering laboratory consolidates equipment required for highly efficient development of production strains through genetic modification. Facilities include automated breeding robots (planned), automated nucleic acid extraction systems (planned), automated Western blot systems, PCR instruments, and sequencers. This integrated setup enables rapid and efficient strain development within short timeframes.

Genetic analysis system

2. Culture Laboratory

The culture laboratory is equipped with a wide variety of jar fermenter systems ranging from 1 mL to 10 L, enabling efficient evaluation of production strains and development of cultivation processes.

In addition to automated sugar feeding, online monitoring of growth behavior, and exhaust gas analysis, the facility supports detailed analysis of process dynamics. The laboratory also features an automated resistance development system based on RITE's proprietary *Mutator Method*, as well as plasma-based mutation induction equipment, allowing for advanced host strain enhancement.


100 mL Jar fermenter


1 L Jar fermenter


10 L Jar fermenter


Resistance strain automatic acquisition system

3. Analytical Laboratory

The analytical laboratory houses a diverse array of analytical instruments, including multi-cell spectrophotometers, fully automated sample preparation systems, six HPLC units, GC, GC-MS, automated derivatization GC-MS, and multiple LC-MS systems (single quadrupole, triple quadrupole, and Orbitrap).

By leveraging these resources, optimal analytical workflows can be established for a wide range of target compounds.

The laboratory has also introduced **metabolomics analysis**, which enables comprehensive measurement and analysis of metabolites using combined GC-MS and LC-MS approaches. Approximately 1,000 metabolites can be analyzed. Automated sample preparation systems and AI-based waveform processing and analysis software have been implemented, achieving semi-automation from sample pretreatment to data analysis.

Metabolomics data can be projected onto customized metabolite maps tailored for *Corynebacterium glutamicum*, enabling visualization of metabolic states during cultivation.

Metabolite analysis system

4. Bioinformatics and Data Analysis Room

This facility is responsible for the storage and analysis of large-scale datasets. It is equipped with storage systems, file servers, and backup NAS systems, enabling advanced analyses using databases of underutilized resources, compound toxicity, and resistance mutations.

The computational infrastructure supports metabolic simulations (e.g., flux balance analysis), strain engineering assistance, culture optimization, and metabolic pathway design, forming the foundation for the entire R&D pipeline.

Bioinformatics and data analysis room

5. Scale-Up Experimentation Laboratory

Centered on 30 and 90 L jar fermenters, this laboratory will be equipped with membrane separation systems, continuous centrifuges, crystallization units, and large-scale evaporators. These facilities enable integrated process demonstrations, from cultivation to target compound recovery.

5 L Jar fermenter - membrane separation system

The laboratory also supports evaluation of diverse feedstocks, including underutilized resources, as well as functions required for LCA (Life Cycle Assessment) and TEA (Techno-Economic Assessment), facilitating development with mass production in mind.

6. Purification Laboratory

This laboratory focuses on examining purification strategies for target products obtained from microbial cultivation. It is equipped with small-scale membrane separation systems, crystallization units, vacuum dryers, and freeze dryers, enabling evaluation of efficient separation, concentration, high-purity production, and recovery processes.

Additionally, detailed assessment of cultivation conditions and purification parameters is conducted through automated exhaust gas analysis using multi-jar fermenters directly connected to GC systems.

100 mL Jar fermenter-online GC system

7. Biomass Pretreatment Laboratory

The biomass pretreatment laboratory is equipped with biomass milling machines, hydrothermal reactors, and saccharification reactors, covering the entire pretreatment process for underutilized resources. A large refrigerated storage room is also provided, enabling efficient handling from raw material storage to processing.

Optimal pretreatment conditions can be studied for a wide variety of biomass feedstocks


Reactor


Cutting mill

2.2 Other Facilities

In addition to laboratories, the center includes office spaces and meeting rooms. The office, located on the second floor, adopts a free-address system. Meeting facilities include one large conference room formed by combining small and medium rooms, three web conference rooms, and multiple meeting spaces capable of accommodating simultaneous discussions of varying sizes.

The laboratories are arranged with functional optimization, with four rooms on the first floor and three on the second floor.


Office space


Web meeting room


Meeting space


Conference room

3. Summary and Future Outlook

For many years, RITE has continuously promoted strain development with industrial applications in mind. The Biomanufacturing Center, constructed as part of the Biomanufacturing Revolution Promotion Program, serves as a cutting-edge hub to accelerate the establishment and social implementation of next-generation Biomanufacturing technologies.

The center provides a comprehensive research environment capable of seamlessly integrating bio-process development using microorganisms, scale-up, feedstock evaluation, purification, and applied research.

High-throughput experimental systems, digital breeding technologies, automated robotics, and fermentation and cultivation evaluation equipment are consolidated in this facility, enabling researchers to collaborate closely with industry partners in a co-creation-driven R&D environment. In addition, a data-driven biomanufacturing platform has been established, integrating AI, robotics, and advanced measurement technologies to realize a highly innovative and practical research environment.

Looking ahead, the center will promote R&D aimed at developing new materials, reducing environmental impact, advancing carbon recycling, and upgrading production processes, thereby contributing to the growth of the bioeconomy. It will also function as a hub for nurturing the next generation of researchers. The RITE Biomanufacturing Center will continue to strengthen its role and value as one of Japan's leading research hubs driving the Biomanufacturing revolution.

We sincerely hope that many companies engaged in Biomanufacturing will actively utilize this center through collaborative research with us.

Overview of RITE Biomanufacturing Center

Note:
This work was conducted as part of projects commissioned and subsidized by the New Energy and Industrial Technology Development Organization (NEDO).

Contact:
RITE Biotechnology Research Group
mmg-lab@rite.or.jp

Fostering Group Synergy and Advancing Research Planning Capabilities — Design and Operation of Internal Seminar —

Internal Seminar Program Working Group (As of Apr. 2026)

Systems Analysis Group	Senior Research Scientist	**Miyuki Nagashima**
Molecular Microbiology and Biotechnology Group	Senior Research Scientist	**Takahisa Kogure**
Chemical Research Group	Research Scientist	**Takayasu Kiyokawa**
CO_2 Storage Research Group	Senior Research Scientist	**Keisuke Uchimoto**
Research & Coordination Group	Manager	**Minehiro Takahashi**

1. Introduction

At the Research Laboratory of Innovative Technology for the Earth (RITE) (hereinafter referred to as the "Research Laboratory"), an Internal Seminar Series has been conducted as an initiative proposed by Director-General Shimoda.

The series aims to foster a sense of unity within the Research Laboratory, promote group synergy, and enhance research planning capabilities by providing opportunities to engage with a broad range of knowledge.

In this article, we report on the five Internal Seminars held during the previous fiscal year.

2. Overview of the Internal Seminar Series

2.1. First Seminar — Introduction of the Molecular Microbiology and Biotechnology Group's Initiatives —

In April 2025, a seminar was held to introduce the initiatives of the Molecular Microbiology and Biotechnology Group, focusing on the theme "New initiatives undertaken by the Molecular Microbiology and Biotechnology Group" and "Activities under the Bio-manufacturing Revolution Promotion Program."

Following the seminar, guided tours were conducted at the Biotechnology Manufacturing Laboratory Building and the Molecular Microbiology and Biotechnology Group laboratories.

2.2. Second Seminar — Introduction of the Chemical Research Group's Initiatives —

In June 2025, a seminar was held to introduce the initiatives of the Chemical Research Group, focusing on the theme "RITE Carbon Capture Center (RCCC)."

Following the seminar, guided tours were conducted at the RITE Carbon Capture Center (RCCC) and the Direct Air Capture (DAC) experimental laboratory.

2.3. Third Seminar — Introduction of the CO_2 Storage Research Group's Initiatives —

In September 2025, a seminar was held to introduce the initiatives of the CO_2 Storage Research Group, focusing on the theme "The Evolution of Optical Fiber Measurement Technology Development in the CO_2 Storage Research Group."

During the seminar, actual casing equipped with optical fiber cables were displayed at the venue.

2.4. Fourth Seminar — Introduction of the Systems Analysis Group's Initiatives —

In December 2025, a seminar was held to introduce the initiatives of the Systems Analysis Group, focusing on the theme "Scenario analyses for the 7th Strategic Energy Plan's energy supply and demand outlook conducted by the Systems Analysis Group."

Following the seminar, a poster-based question-and-answer session was held, allowing participants to engage directly with seminar speakers.

2.5. Fifth Seminar — Sharing the Expo Legacy —

In March 2026, a seminar was held under the theme "The Legacy of Expo 2025 Osaka, Kansai," featuring a lecture by Director-General Shimoda (Chairperson of the Decarbonization Working Group, Japan Association for the 2025 World Exposition).

Following the lecture, a roundtable-style session was conducted with members involved in the RITE Future Forest.

3. Conclusion

The Internal Seminar Series is designed and operated by the Internal Seminar Program Working Group, which is composed of members selected from each research group within the Research Laboratory.

Seminar themes are examined through exchanges of views among the Working Group members.

Going forward, we will continue organizing the Internal Seminar on topics such as policies related to global environmental challenges and other issues.

Click the link to open the RITE website

Press Releases

Events

Paper, Presentation and Publication

- Systems Analysis Group
- Molecular Microbiology and Biotechnology Group
- Chemical Research Group
- CO_2 Storage Research Group

Other Activities

◆Environmental Education (Facility Visit Program)

Date	Participants	Number of participants
26 May 2025	Nara Prefectural KOKUSAI High School	17
25 Jul. 2025	Kyoto Prefectural Nishimaizuru High School	10
9 Oct. 2025	Izumo Senior High School	38
4 Nov. 2025	Ritsumeikan High School Japan Super Science Fair 2025	29
5 Dec. 2025	Seikanishi Junior High School	6
8 Dec. 2025	Nara Prefectural Narakita Senior High School	22
12 Mar. 2026	Kasagi Junior High School	6

◆Environmental Education (Workshop)

Date	Title	Number of participants
7 Aug. 2025	Craft and Science Experiment to Learn about Global Warming and Energy	33

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Research Institute of Innovative Technology for the Earth
Research Institute of Innovative Technology for the Earth

URL: www.rite.or.jp/en
Email: pub_rite@rite.or.jp

9-2 Kizugawadai,
Kizugawa-shi, Kyoto
619-0292 JAPAN
TEL.+81-774-75-2300