RITE Today

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Annual Report

Research Institute of Innovative Technology for the Earth

Biotechnology Manufacturing Laboratory Building

RITE Carbon Capture Center

Feature

Starting with Twin Power
~Introduction to the RITE Carbon Capture Center and
Biotechnology Manufacturing Laboratory Building~

Topics

RITE Future Forest at World Expo 2025 Osaka, Kansai, Japan

RITE Today 2025 Vol.20

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Where Change Come from

Noriaki Hirota
Deputy Director - General,
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I am Hirota, who has been appointed as a director and deputy director of RITE.

Founded in 1990, RITE is celebrating its 35th anniversary this year. During this time, thanks to the guidance and efforts of many stakeholders and predecessors, we have become a research organization that plays a leading role in global warming countermeasures. We would like to ask for your continued support and cooperation in the future.

At the time RITE was established, the communication speed of wired lines that could be used in ordinary households in Japan was about 14.4 kbps. Today, it can reach 10 Gbps, which is about 5 million times faster. In addition, the communication speed of mobile phones has also become incomparably faster than it was back then due to the evolution from 2G to 5G. In terms of information processing capacity, CPU performance has improved by more than 10,000 times from tens of MIPS to hundreds of thousands of MIPS, and conversely, the unit price of memory has decreased from about $50/MB to about $0.1/GB for DRAM, which is 1/500,000. It can be said that it is an amazing change in both performance and cost, and with the benefit of this, we are bringing about major changes in services and lifestyles that were unimaginable 35 years ago.

On the other hand, if we think about it in the context of "the present that was unimaginable 35 years ago," we are surprised by the foresight and high perspective of the RITE founding concept. The concept included the following as an outline of the institute.

"In order to solve global environmental problems and to build an industrial technology system that integrates and harmonizes with the general circulation of nature, we will integrate a wide range of industrial technologies utilizing chemical engineering, biotechnology, system engineering, etc., have researchers on secondment from national laboratories, private companies, etc., conduct comprehensive and intensive research, and accumulate technical information, etc., thereby becoming a core research institute for international research exchange."

Today, the RITE Systems Analysis Group makes a significant contribution to national policy decisions, including the Basic Energy Plan and the Global Warming Countermeasures Plan, through detailed scenario analysis. The Chemical Research Group accelerated the development of CO_2 separation and capture technology, conducted a demonstration test of DAC (Direct Air Capture), which captures CO_2 directly from the atmosphere, at the Osaka-Kansai Expo site, and established the RITE Carbon Capture Center, which serves as a common platform for standard evaluation of separated materials. The CO_2 Storage Research Group is studying the practical application of injection and evaluation technologies and is accelerating support and collaboration for CCS projects in Japan in response to the enactment of the CCS Business Act. With the aim of contributing to the commercialization of bio-manufacturing that contributes to global warming countermeasures, the Molecular Microbiology and Biotechnology Group has begun to develop a strain development platform, including the construction of a dedicated research building, the Biotechnology Manufacturing Laboratory Building. After 35 years, I feel that tenacious and steady efforts to solve global environmental problems are moving forward.

When I look at RITE's efforts from a bird's-eye view, I am often reminded of what someone once taught me about **"where change come from."** He said: **"Change comes from three directions. One is politics, the other is social, and the other is technology."**

For example, the explosive spread of mobile phones in the 1990s due to the liberalization of mobile phones led to a combination of the politics of establishing and introducing systems, a society with a need to communicate anytime, anywhere, and technologies that made it smaller, lighter, and faster.

RITE has played a major role at the very intersection of politics, society and technology. We will continue to pursue results in a wide range of fields as an entity that creates innovative changes on the issue of global warming.

We will continue to work together in the future, and we look forward to your continued support.

Starting with Twin Power ~ Introduction to the RITE Carbon Capture Center and Biotechnology Manufacturing Laboratory Building ~

Chemical Research Group	Group Leader, Chief Researcher	**Katsunori Yogo**
	Deputy Leader, Chief Researcher	**Masahiko Mizuno**
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Japan has declared its aim to be carbon neutral by 2050 and is taking various energy and global warming countermeasures in order to achieve CO_2 emissions reduction as well as economic growth and strengthened industrial competitiveness. As part of the efforts, the following is promoted:

(1) R&D on materials that can separate and capture emitted CO_2 at low cost and with low energy for industrial sectors where significant CO_2 emissions reductions are difficult

(2) Bio-manufacturing that produces chemical materials, fuels, and medicines, using the cells of microorganisms through recombinant DNA technology.

RITE has been working on this type of R&D for some time. In fiscal 2024, in response to the demands of the times, it built two new adjacent buildings: (1) the RITE Carbon Capture Center, which will accept external samples and evaluate CO_2 separation materials, and (2) the Biotechnology Manufacturing Laboratory Building, which aims to bio-produce high-added-value chemicals. With these facilities used as twin power, new initiatives have just been launched to promote further acceleration of R&D. This special feature will introduce these two facilities.

2. RITE Carbon Capture Center

2.1. Background of establishment

RITE has, to date, conducted R&D on various CO_2 capture technologies, primarily chemical absorption, solid sorbent, and membrane separation, and has successfully achieved commercialization of some of these technologies. Now we are undertaking an initiative to "establish a common base for evaluating the standards of CO_2 separation materials" in order to support fundamental research and promote industry collaboration in the R&D of CO_2 capture and utilization technologies, with a new platform.

In May 2022, in collaboration with the National Institute of Advanced Industrial Science and Technology, RITE was commissioned by the New Energy and Industrial Technology Development Organization (NEDO) to undertake a project named "Green Innovation Fund Project / Establish a common base for evaluating the standards of CO2 separation materials" (hereinafter referred to as "this project"). As part of this project, we established Japan's first test center capable of evaluating CO_2 separation materials using real gas, the RITE Carbon Capture Center (RCCC).

In countries such as the United States, Norway, and Australia, real-gas test centers are third-party organizations operated by governments or other organizations. These centers formed the International Test Center Network (ITCN), which facilitates mutual information exchange among members. Since 2017, RITE has been a member of the ITCN, participating in discussions and information sharing while pursuing the establishment of Japan's first real-gas test center. This long-standing goal has now been realized with the successful establishment of RCCC.

2.2. Facility overview

RCCC consists of a dedicated small-scale city-gas boiler and CO_2 separation test unit. In order to further enhance Japan's advantages in materials development, the center is designed to enable real-gas testing at the early stages of CO_2 separation material R&D, thereby accelerating the practical application of such materials in Japan.

As shown in Figure 1, the flue gas from the boiler is directed through a cooler, blower and chiller, and supplied to the testing processes including absorption, adsorption, and membrane separation. The center is equipped with test systems capable of capturing up to 100 kg of CO_2 per day from boiler combustion flue gas with CO_2 concentrations below 10%, offering performance evaluation well-suited to various separation materials under real gas. In Japan, CO_2 emissions from boiler combustion are estimated to account for several percent of total emissions, making it an important sector where carbon capture solutions will be increasingly needed.

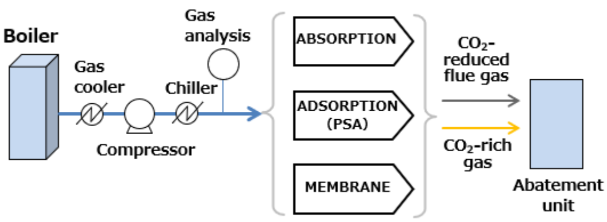

Fig.1 Scheme of RITE Carbon Capture Center

Figure 2 shows the layout of RCCC: (1) the Evaluation Building houses the absorption unit, the Pressure Swing Adsorption (PSA) unit, and the membrane module unit; (2) the outdoor Utility Yard contains the boiler and utility unit. In addition, there are plans to install a Temperature Swing Adsorption (TSA) unit in the currently unused space within the Evaluation Building.

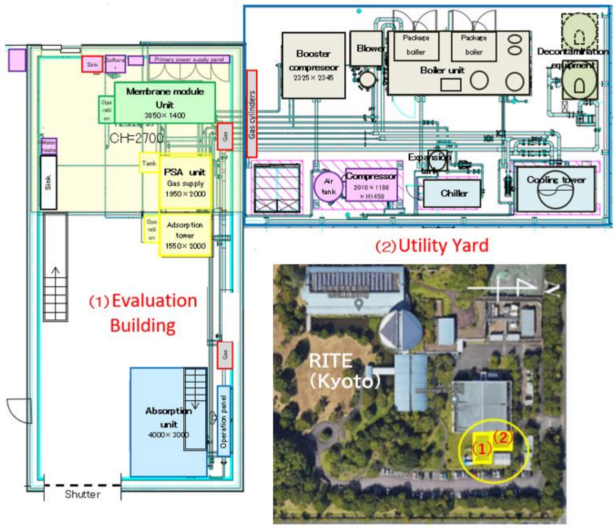

Fig.2 Layout of RITE Carbon Capture Center

The specifications of each test unit were determined by members of the Project Steering Committee.

The boiler unit is equipped with two city gas boilers, each equivalent to a steam output of 250 kg/h, enabling uninterrupted supply of combustion flue gas to the test systems even during mandatory inspections. The absorption unit consists of an absorption tower (packed section: 2 m in height × 0.2 m in diameter), and a regeneration tower (packed section: 2 m in height × 0.1 m in diameter), and approximately 70 liters of absorbent will be needed for testing. The PSA unit is equipped with three adsorption towers (each 250 A × 1800 L) and allows for testing with a dry flue gas at a dew point of −60 °C, under adsorption pressures ranging from 101 to 900 kPa and desorption pressures down to 10 kPa. The membrane separation system has space to install modules approximately 1 meter in length and is capable of testing with a flue gas controlled at a dew point between −15 to 80 °C, under the following conditions: temperature range of 30–85 °C; feed pressure of 101–900 kPa; permeate pressure of 10–101 kPa.

Fig. 3 Each Unit of RITE Carbon Capture Center

2.3. Future development

RCCC aims to be an actively utilized center capable of providing reliable, fair and neutral real-gas test data through the use of standardized evaluation methods established via testing with reference materials. In addition, by accommodating user-specified testing conditions with flexibility, we will conduct evaluations of externally provided samples. We hope that many users will apply for real-gas tests at this Center.

Through the evaluation of both standard reference materials and external samples, we are promoting the development of domestic CO_2 separation materials and to building and expanding a comprehensive database that supports international standardization of CO_2 capture technologies. We would be honored if our efforts contribute to accelerating the advancement of CO_2 separation material development in Japan.

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3. Biotechnology Manufacturing Laboratory Building

3.1. Background of establishment

Since March 2023, RITE has been implementing the NEDO-commissioned project “Green Innovation Fund Project: Promotion of Carbon Recycling Using CO_2 as Direct Raw Material through Biomanufacturing Technology”[*1] in collaboration with Sekisui Chemical Co. This project focuses on developing a producer strain capable of bioconverting waste gas (CO_2) emitted from waste incineration facilities into high-value-added chemicals. By fully utilizing the smart cell creation technology, enzyme modification technology through genetic recombination, microbial resistance technology against fermentation inhibitors, and bioproduction technology that have been developed so far, we have initiated the development of a production strain capable of bioconverting waste gas (CO_2) emitted from waste incineration facilities into high value-added chemicals, as well as the development of a bioprocess using this strain (Fig. 4).

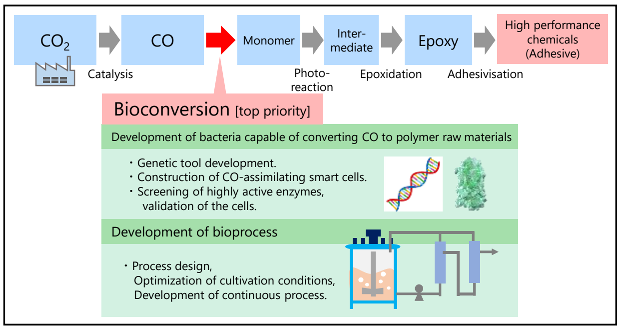

Fig. 4 Conceptual Diagram of the Project

CO_2 is an exceptionally stable compound that composes the end products of organic matter combustion. While we can harness plants to use CO_2 for biomass production as a raw material for biomanufacturing, it requires large facilities and a large site in order to uniformly provide light energy to microorganisms.

Thus, the RITE Molecular Microbiology and Biotechnology Research Group has shifted its attention on CO rather than CO_2. We utilize the power of CO-assimilating bacteria and flexibly tailor its metabolic pathway to confer its bioproduction ability. As a result, we have come up with the idea of bioproducing high-value-added chemicals from CO.

Meanwhile, Sekisui Chemical has succeeded in developing a technology that can convert CO_2 to CO with a high efficiency (>90%) using chemical catalysts. Thus, our final goal is to use RITE's bio-manufacturing technology to produce polymer materials for the company's high-performance chemicals (adhesives) from CO, thereby realizing a carbon-recycling society.

3. 2. Facility overview

RITE had previously developed bioconversion technology using gas components as raw materials, but now we established a dedicated experimental building (Bio-manufacturing Experimental Building) for full-scale operations (Fig. 5).

Fig.5 Newly constructed bio-manufacturing experimental building

On the first floor, the culture facilities necessary for gas fermentation are built. A dedicated anaerobic chamber is installed for the genetic manipulation of oxygen-phobic CO-assimilating bacteria, which require an experimental environment with special gas components (Fig. 6).

Fig.6 Anaerobic chamber for genetic manipulation

The anaerobic chamber is a workstation for cultivating microorganisms in a varying gas composition environment. Since the equipment necessary for genetic modifications is stored in the chamber in advance, researchers can conduct various genetic modification and anaerobic cultivation (gas fermentation) experiments using the autotrophic bacteria through the glove.

Bioprocess development using the developed producer strains is conducted in cultivation facilities dedicated to gas fermentation (e.g., jar culture equipment installed in a local exhaust system). In this process, the composition of both feed gas and the fermentation exhaust gas can be quantified on-site, allowing timely evaluation of the CO utilization efficiency (Fig. 7). Using these state-of-the-art facilities, we are optimizing the fermentation conditions of the newly developed CO-assimilating strain and studying continuous process production method.

Fig.7 Research scene using a dedicated gas fermentation system

The second floor houses the essential equipment for extensive biofunctional analysis, smart cell strains improvement, by-products analysis, and bioprocess evaluation. In particular, an integrated HPLC analysis system has been updated to analyze various metabolites throughout cultivation process (Fig. 8).

The Biomanufacturing Experimental Building is equipped with a safety and sanitation environment that complies with various laws and regulations so that researchers can safely conduct research and development centered on gas fermentation.

Fig.8 HPLC for metabolite analysis

3. 3. Future development

The bioproduction method has many excellent features, including the ability to selectively synthesize high-value-added compounds that are difficult to produce by chemical methods due to isomeric byproducts, utilizing the continuous catalytic action of enzymes under mild conditions near room temperature and pressure. Accordingly, this method is expected to be implemented in a variety of fields. If this technological development enables biomanufacturing of various chemicals and fuels necessary for industrial activities using CO_2 captured and collected at DAC facilities and CO_2 emitted from waste incineration facilities, steel mills, thermal power plants, and various factories in the future, it will greatly contribute to the realization of carbon neutrality, which RITE aims to achieve. RITE believes that this will make a significant contribution to attaining our carbon neutrality target.

In order to meet the expectations of companies wishing to enter the bio-manufacturing industry, RITE will continue to develop new technologies, develop producer strains best suited for commercialization, and expand its research activities to supply production technologies.

*[1] This article is based on results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

We will establish a manufacturing method to produce high value-added chemicals using CO_2 as a raw material, and we welcome all those interested in the effective CO_2 utilization.

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Deputy Leader	**Tatsuro Ide**	Planning Manager	**Sou Kuranaka**
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Associate Chief Researcher	**Yoshinori Aoki**	Senior Researcher	**Natsuko Yasumoto**
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Associate Chief Researcher	**Kin-ichiro Kusunose**	Senior Researcher	**Yuji Yamashita** (concurrent)
Associate Chief Researcher	**Takayuki Higashii**	Vice Manager	**Yuka Matsugu**
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			Michiyo Kubo
Manager	**Minehiro Takahashi**		**Mizuki Nagata**

Toward a Carbon-Neutral Society
~ For people and the earth to live in harmony ~

1. Introduction

RITE is conducting R&D into global warming while keeping in mind the trends of the times and ensuring that people and the earth can live in harmony for many years to come.

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 IPCC (Intergovernmental Panel on Climate Change) and facilitate collaboration with international organizations, such as ISO (International Organization for Standardization); 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].

Here, we would like to first provide an overview of the Japanese government's actions taken toward carbon neutrality in fiscal year 2024 and then touch on the specific R&D being carried out by this group.

1.1. Trends surrounding Japan's global warming countermeasures in FY2024

Although fiscal 2024 saw events such as the U.S. withdrawing from the Paris Agreement, it can be said to have been a turning point for Japan's efforts to combat global warming.

Specifically, the Act on Carbon Dioxide Storage Businesses (CCS Business Act)[2] was enacted in May 2024, marking a major step forward toward the social implementation of CCS in Japan. In addition, the comprehensive 7th Strategic Energy Plan, the GX2040 Vision, and the Plan for Global Warming Countermeasures were approved by the Cabinet on February 18, 2025, providing momentum toward achieving carbon neutrality in the future.

Also on the same day, Japan submitted a new version of Japan's NDC (Nationally Determined Contribution) to the Secretariat of the United Nations Framework Convention on Climate Change. This aims to reduce greenhouse gas emissions by 60% and 73% in fiscal 2035 and 2040, respectively, from fiscal 2013 levels, as ambitious targets that are consistent with the global 1.5°C target and are on a direct path toward achieving net zero CO_2 emissions by 2050.

Here, we would like to explain the 7th Strategic Energy Plan, the GX2040 Vision, and the developments surrounding the CCS Business Act.

1.2. The 7th Strategic Energy Plan

The government has formulated the Strategic Energy Plan based on the Basic Act on Energy Policy in order to indicate the basic direction of its energy policy. The current 7th Strategic Energy Plan was first reviewed by the General Resources and Energy Research Committee of the Ministry of Economy, Trade and Industry (METI) in May 2024, with a draft presented on December 17 of the same year. After receiving public comments and other information, the plan was approved by the Cabinet in February 2025.

Specifically, taking into account changes in domestic and international circumstances, including the energy situation, since the formulation of the 6th Strategic Energy Plan in October 2021, the government has formulated the 7th Strategic Energy Plan in a manner consistent with the government's newly established target of a 73% reduction in greenhouse gas emissions by fiscal 2040. The government will implement this plan in conjunction with the GX2040 Vision and the Plan for Global Warming Countermeasures and will work to simultaneously achieve a stable energy supply, economic growth, and decarbonization.

<Overview>

With electricity demand expected to increase due to DX and GX, it is recognized that whether Japan can secure an appropriate amount of decarbonized power sources at a price that is internationally competitive will have a direct impact on its industrial competitiveness.

In order to achieve both a stable energy supply and decarbonization, the government will promote thorough energy conservation and fuel conversion in manufacturing while making maximum use of power sources that contribute to energy security and have a high decarbonization effect, such as renewable energy and nuclear power.

The plan also states the following about CCS and CDR (Carbon Dioxide Removal), which are closely related to RITE.

- Consider support systems to encourage investment in CCS projects, develop technologies to reduce CCS costs, and develop carbon storage sites.
- For CDR, work to improve the environment, create markets, and accelerate technological development since CDR is necessary as a means to offset residual emissions.

1.3. GX2040 Vision

Amid growing uncertainty about the future outlook, including the tense overseas situation and increased demand for electricity due to digital transformation and electrification, the above-mentioned vision has been formulated to indicate a longer-term direction in order to improve the predictability of investment for achieving GX.

Specifically, in order to realize a GX industrial structure, the vision aims to promote the social implementation of innovation and to leverage GX to promote the establishment of new industrial locations and the development of decarbonized power sources, leading to regional revitalization and economic growth.

<Growth-oriented carbon pricing initiative>

Based on the above-mentioned initiative to provide institutional support for these efforts, a bill to amend the GX Promotion Act was submitted to the 2025 ordinary session of the Diet.

Specifically, the bill calls for the full-scale operation of an emissions trading scheme (from fiscal year 2026 onwards), which will require all companies with emissions above a certain level (direct emissions of 100,000 tons) to participate, regardless of industry, and for a fossil fuel surcharge to be introduced (from fiscal year 2028 onwards). Necessary measures will be put in place to ensure the smooth and reliable introduction and implementation of the initiative.

1.4. CCS Business Act

This act regarding CCS was enacted in May 2024, providing momentum toward the commercialization of CCS. We will go into more detail on this, including the latest trends, in Section 2.

2. Research activities

2.1. Introduction

The CCS business environment is gradually improving, with the selection of “Advanced CCS Projects”[3] in June 2023 and the promulgation of the CCS Business Act in May 2024. Additionally, detailed discussions have been underway since January 2025 regarding support measures for CCS projects[4]. The basis for these efforts is the final summary on the CCS Long-Term Roadmap[5] published in March 2023. This article introduces the results of a survey on the status of consideration for the development of the domestic CCS business environment, which was conducted as part of the research activities of the Research & Coordination Group.

2.2. CCS Long-Term Roadmap[5]

The final summary on the CCS Long-Term Roadmap, which serves as the basis for promoting the development of the CCS business environment in Japan, was published in March 2023. Its basic philosophy is to promote the sound development of CCS projects in our country while minimizing social costs by implementing CCS systematically and rationally, thereby contributing to economic and industrial development of our country, securing a stable energy supply, and achieving carbon neutrality.

This long-term roadmap aims to achieve an annual CO2 storage amount of approximately 120 to 240 million tons as of 2050 and, with a final investment decision (FID) of 2026 as a milestone, to establish a business environment (construct a business model, etc.) and launch CSS projects by around 2030 with a view to commencing full-fledged operations from 2030 and onwards.

The specific actions set out in the CCS Long-Term Roadmap to achieve this goal include (1) government support for CCS projects (advanced CCS projects, etc.), (2) initiatives to reduce CCS costs, (3) promotion of public understanding of CCS projects, (4) promotion of overseas CCS projects, (5) examination for the development of the CCS Business Act, and (6) development and review of the CCS Action Plan. The CCS Business Act, which was promulgated in May 2024, and the selection of Advanced CCS Projects, which began in fiscal year 2023, fall under (5) and (1) of the specific actions in the roadmap.

2.3. Status of consideration for the development of the CCS business environment and the development structure

(1) CCS Long-Term Roadmap Study Group[5]

CCS is a key technology for achieving carbon neutrality by 2050. Meanwhile, in order to implement CCS in society, creating an environment conducive to commercialization remains an issue. For this reason, the 6th Strategic Energy Plan (October 2021) called for the formulation of a CCS long-term roadmap and for the public and private sectors to work together to address the issue. To make this a reality, the CCS Long-Term Roadmap Study Group (hereinafter referred to as the "Long-Term RM Study Group") was established in January 2022.

The Long-Term RM Study Group held a total of five discussions between January and May 2022 and published an interim summary in May. Subsequently, in September 2022, two working groups, the CCS Business Domestic Law Review Working Group and the CCS Business Cost and Implementation Scheme Review Working Group, were established to delve deeper into issues such as "issues for establishing domestic legislation for CCS projects" and "current costs and future cost targets across the entire CCS value chain and the form of government support." Four meetings were held in each working group to discuss the issues by December 2022. Based on the results of discussions at these working groups, the 6th Long-Term RM Study Group meeting was held in January 2023, and the final summary on the CCS Long-Term Roadmap was compiled.

(2) Carbon Management Subcommittee[6)]

Based on the content of the final summary on the CCS Long-Term Roadmap, the Carbon Management Subcommittee (hereinafter referred to as the "CM Subcommittee") was established in September 2023 under the General Resources and Energy Research Committee and the Resources and Fuel Subcommittee to more specifically consider the form of government support and the development of the CCS Business Act toward the commercialization of CCS and to promote carbon management using CCUS technology by companies.

Regarding the form of institutional measures related to CCS, the CM Subcommittee held a total of four discussions between September and December 2023 in collaboration with the Industrial Structure Council, the Security and Consumer Product Safety Subcommittee, and the Basic Industrial Security System Subcommittee, and it published an interim summary (on the form of institutional measures related to CCS) in January 2024.

In addition, discussions to consider a support framework for CCS projects have resumed since September 2024. Four discussions were held by December, and the Discussion on the Draft of the CCS Support System, presented at the eighth CM Subcommittee meeting (December 2024), stated that an interim summary on the CCS support system would be compiled by mid-2025.

(3) Carbon Dioxide Storage Business Safety Subcommittee[7)]

Discussions on the form of institutional measures related to CCS had been held jointly with the Basic Industrial Security System Subcommittee. However, following the promulgation of the CCS Business Act (May 2024), the Carbon Dioxide Storage Business Safety Subcommittee was established in August 2024 under the Industrial Structure Council and the Security and Consumer Product Safety Subcommittee as a forum for discussing and examining the drafting of safety regulations for CCS projects and their enforcement status. Three discussions have been held so far, and deliberations are underway on laws and regulations related to exploratory drilling, pipeline transportation, and storage.

(4) Working Group on Support Measures for CCS Projects[4)]

As mentioned above, the eighth CM Subcommittee meeting presented a draft of a support system for CCS projects. Going forward, the detailed design of the support system for CCS projects will be considered at the working level, with an interim summary scheduled to be compiled by mid-2025. Accordingly, in February 2025, the Working Group on Support Measures for CCS Projects (hereinafter referred to as the "Support Measures WG") was established under the CM Subcommittee. The Support Measures WG is expected to meet approximately once a month until May 2025.

(5) Others[8) 9)]

The LCO_2 Shipping Value Chain Standardization

Council was established in September 2024 to standardize specifications for CO_2 shipping and reduce associated shipping costs. Moreover, the Carbon Dioxide Geological Storage Assessment Committee was established in December 2024 to provide the technical advice necessary to properly advance exploratory drilling and storage projects in accordance with the Act on Carbon Dioxide Storage Businesses.

An organizational chart of the councils and other bodies described in (2) to (5) is shown below.

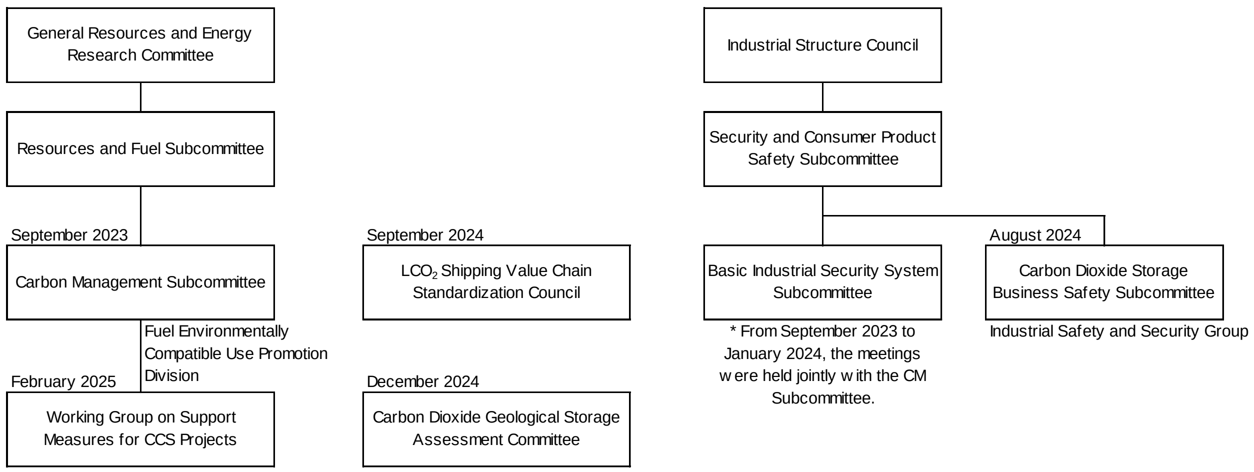


Figure 1 Organizational chart of the councils and other bodies

2.4. CCS Business Act and related government and ministerial ordinances[10)]

The CCS Business Act was enacted on May 17, 2024 and promulgated on May 24. Of the provisions of this act, the provisions regarding exploration came into effect on August 5, within a period not exceeding three months from the date of promulgation of the act, and the provisions regarding exploratory drilling came into effect on November 18, within a period not exceeding six months. The provisions regarding storage and pipeline transportation projects will be in effect for no more than two years (by May 23, 2026). Other related government and ministerial ordinances are also being enacted one after another.

The CCS Business Act is a regulatory law that creates a business environment for CCS in Japan, based on which the following systems have been established.

i. A licensing system for exploratory drilling and storage projects has been established, under which the Minister of Economy, Trade and Industry would designate specific areas and grant licenses to businesses, and under which specific implementation plans for exploratory drilling and storage projects would be subject to approval by the Minister of Economy, Trade and Industry.

ii. Regarding the development of business and safety regulations related to CO_2 pipeline transportation projects, a notification system to the Minister of Economy, Trade and Industry has been established.

For more details, please see the METI website (Policies > Resources and Fuels > CCS Policy > CCS Business Act) (in Japanese).

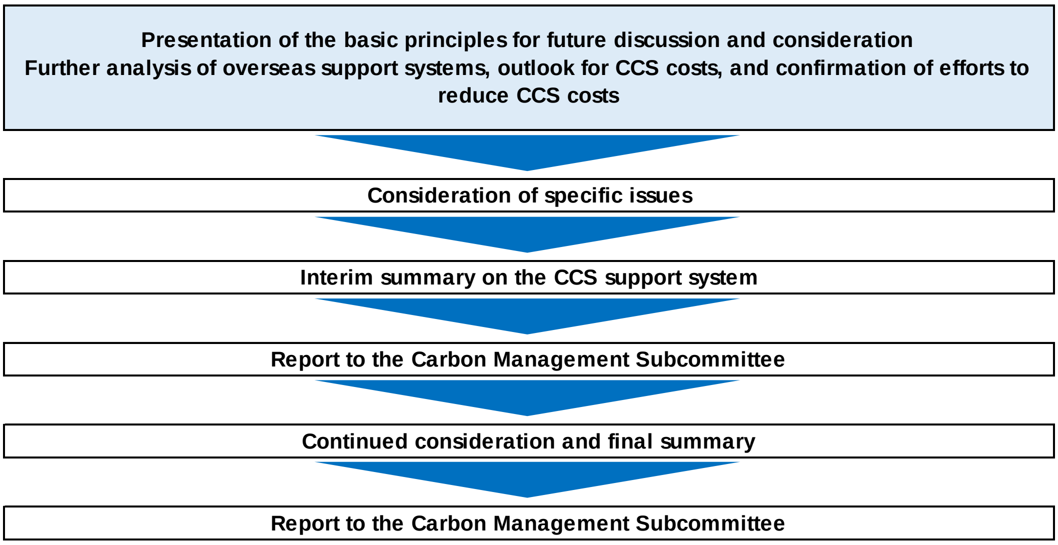
2.5. Trends in support for CCS projects[4)]

CCS projects as a measure against global warming are not necessarily highly predictable because financial mechanisms for generating business revenues have not been established. For this reason, Europe and the U.S.

are taking measures to provide support that focuses on the cost difference between the costs required for CCS and the costs of CO_2 countermeasures and to offer relatively high subsidy rates. In Japan, by commercializing CCS projects ahead of other projects with government support, it will be possible to make the CCS business self-sufficient and build a cost-competitive CCS value chain. To this end, as described in 2.3.(4), the Support Measures WG has been established under the CM Subcommittee, and discussions are underway to compile an interim summary on the CCS support system, scheduled for around summer 2025 (the results of which will be reported to the parent committee, the Carbon Management Subcommittee).

Since the establishment of the Support Measures WG, three discussions had been held by the end of March 2025. Meetings are scheduled to be held once a month from April onwards. The main direction is for support to focus on the cost difference between the costs required for CCS and the costs of CO_2 countermeasures. In addition, a direction has also been indicated that will promote making the CCS business self-sufficient.

For the time being, priority will be given to support measures for the domestic pipeline case. For the ship transport case, an interim summary is scheduled to be issued, after which a review will be conducted and a final summary will be reported.



Source: 1st Working Group on Support Measures for CCS Pro-jects (February 5, 2025)
https://www.meti.go.jp/shingikai/enecho/shigen_nenryo/carbon_management/ccs_wg/pdf/001_06_00.pdf (in Japanese)

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 counter-measures 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 plays the central role of domestic support secretariat of mitigation measures (WG 3) (Figure 2). The IPCC began its Seventh Assessment Cycle (AR7) in July 2023, and is currently preparing a Special Report on Climate Change and Cities and a Methodology Report on Short-Lived Climate Forcers (SLCF). The outlines of each Working Group report were adopted at the 62nd Session of the IPCC in February 2025, and after the selection of authors, the writing process starts. It has also been decided to produce a Methodology Report on Carbon Dioxide Removal Technologies (CDR) and Carbon Capture Utilization and Storage (CCUS). RITE has also been supporting METI through information gathering, analysis, report, advise, etc.

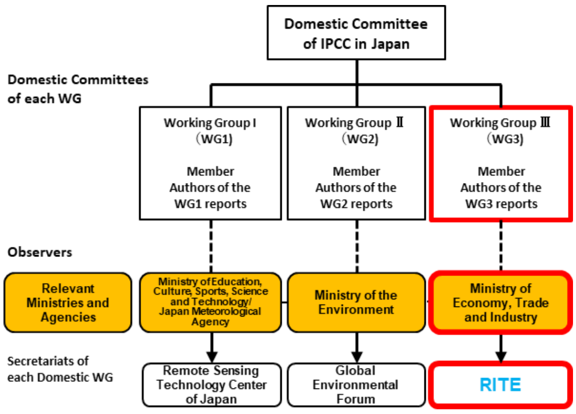


Figure 2 Committee structure and RITE

3.2. ISO

ISO (International Standard Organization) is an organization composed of 173 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 3).

As of the end of March, 2025, fifteen standards related to the CCS have been published from ISO / TC265 and five documents are currently under development. The launch of a new project is also being considered, and TC265 has become more active in recent years. In particular, CO_2 ship transportation is attracting attention as a powerful means of transportation from emission sources to CO_2 storage site and technical report related to CO_2 ship transportation was published in 2024. Currently, a new technical report on the interface between ships and onshore facilities is being proposed by Japan.

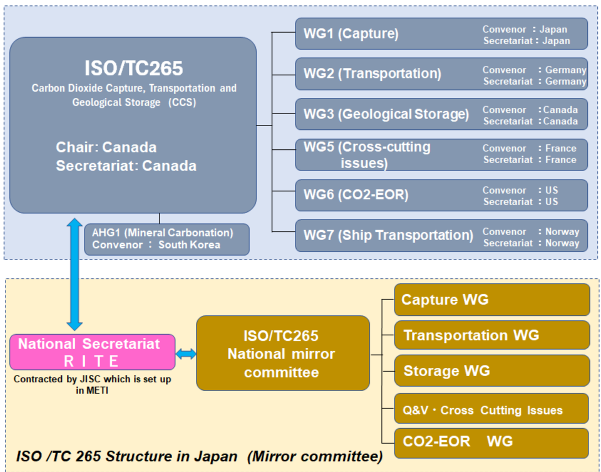


Figure 3 ISO/TC265 structure

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 2024, RITE focused on CCS technology from among its research projects and explained to 227 students from seven schools the mechanism of global warming and that even if CO2, 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 4).

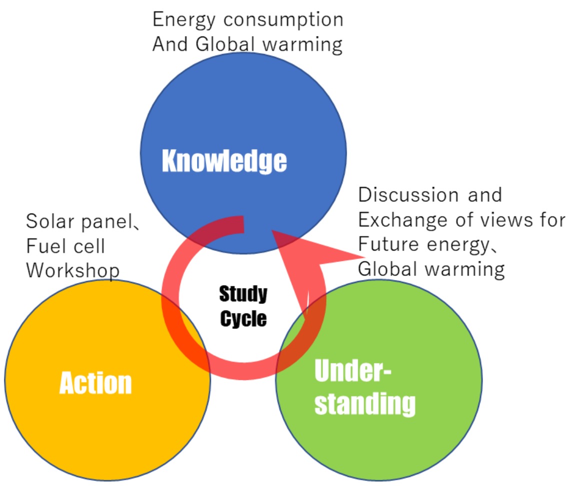


Figure 4 Human resource development by RITE
(Elementary, Junior and high school students)

<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 5). 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.

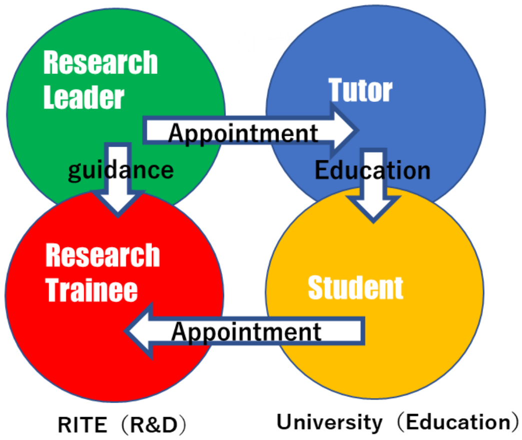


Figure 5 Human resource development by RITE
(University & Post graduate students)

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 2025, of the patents for which RITE is the sole or joint applicant, 21 domestic applications and 12 foreign applications are pending patent applications, and the registered rights are maintained. It holds 63 domestic patents (including 3 under license to companies) and 40 foreign patents (3 of which are licensed to companies).

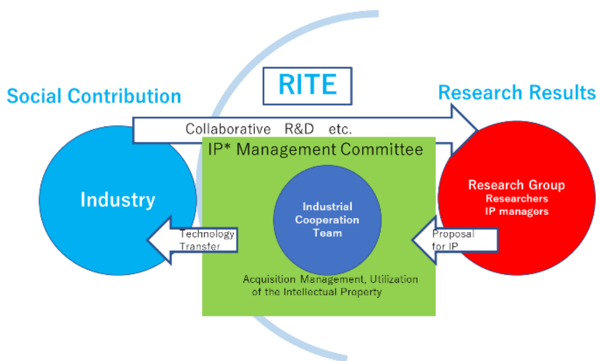


Figure 6 Strategic IP management and industrial collaboration

5. Conclusion

Toward the realization of carbon neutrality by 2050, the government has started the issuance of GX economy transition bonds and various GX promotion measures. With the enactment of the CCS Business Act, in addition, efforts have just been commenced to develop a business environment in which private companies are able to launch CCS business by around 2030. However, it is never easy to achieve carbon neutrality. To achieve this, RITE is required to play an active role in the social implementation of innovative environmental technologies. For practical application of CCS and other new technologies, it is essential to enhance public understanding. Taking advantage of the opportunity to display its DACCS (Direct Air Capture and Storage) technology at Expo 2025 Osaka, Kansai, Japan, RITE will make active efforts to enhance public understanding of the need to achieve carbon neutrality and the importance of CCS.

We at the Research & Coordination Group will also actively collect information on domestic and overseas policies and technology trends. With an eye toward realizing carbon neutrality by 2050, we, together with research groups, will actively implement and promote technology development and PR activities as well as industry-university cooperation activities. We believe that through RITE's concerted efforts to promote the social implementation of innovative environmental technologies, we will be able to contribute to carrying out RITE's mission: “to achieve the balance between the global environmental protection and economic growth.”

Reference

1) RITE, “The Role of RITE”
https://www.rite.or.jp/en/about/

2) METI: Policies > Resources and Fuels > CCS Policy > CCS Business Act
https://www.enecho.meti.go.jp/category/resources_and_fuel/carbondioxidecaptureandstorage/CCS_business.html (in Japanese) (accessed in

March 2025)

3) METI: News Release “Advanced Efforts for Commercialization of CCS” https://www.meti.go.jp/press/2024/06/20240628011/20240628011.html (accessed in March 2025)

4) METI: Councils and Study Groups > Working Group on Support Measures for CCS Projects https://www.meti.go.jp/shingikai/enecho/shigen_nenryo/carbon_management/ccs_wg/index.html (in Japanese) (accessed in March 2025)

5) METI: Councils and Study Groups > CCS Long-Term Roadmap Study Group https://www.meti.go.jp/shingikai/energy_environment/ccs_choki_roadmap/index.html (in Japanese) (accessed in March 2025)

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7) METI: Councils and Study Groups > Carbon Dioxide Storage Business Safety Subcommittee https://www.meti.go.jp/shingikai/sankoshin/hoan_shohi/carbon_dioxide/index.html (in Japanese) (accessed in March 2025)

8) Japan Organization for Metals and Energy Security (JOGMEC): LCO2 Shipping Value Chain Standardization Council https://www.jogmec.go.jp/ccs/advancedsupport_003.html (in Japanese) (accessed in March 2025)

9) METI: Councils and Study Groups > Carbon Dioxide Geological Storage Assessment Committee https://www.meti.go.jp/shingikai/energy_environment/carbon_dioxide/index.html (in Japanese) (accessed in March 2025)

10) METI: Policies > Resources and Fuels > CCS Policy > CCS Business Act https://www.enecho.meti.go.jp/category/resources_and_fuel/carbondioxidecaptureandstorage/CCS_business.html (in Japanese) (accessed in March 2025)

Systems Analysis Group

Members (As of Apr. 2025)

Group Leader, Chief Researcher	**Keigo Akimoto**	Senior Researcher	**Hiroshi Harada**
Deputy Leader, Associate Chief Researcher	**Takahiro Nagata**	Senior Researcher	**Yuko Nakano**
Chief Researcher	**Naoki Oda** (concurrent)	Senior Researcher	**Naoko Onishi**
Associate Chief Researcher	**Wataru Fujisaki**	Senior Researcher	**Teruko Hashimoto**
Senior Researcher	**Kenichi Wada**	Researcher	**Hitotsugu Masuda**
Senior Researcher	**Miyuki Nagashima**	Researcher	**Teruhisa Ando**
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Research Activities in Systems Analysis Group

The Systems Analysis Group aims to provide valuable information about response measures to global warming and energy issues through systematic approaches and analyses at both national and international levels.

In February 2025, the 7th Strategic Energy Plan[1], the Plan for Global Warming Countermeasures[2], and the Green Transformation (GX) 2040 Vision[3] were formulated and approved by the Cabinet. RITE presented quantitative scenario analyses using energy systems models and provided supporting information to formulate these plans during each of the discussions. This report explains the scenario analyses presented in the discussion for formulating the Strategic Energy Plan.

1. Background of scenario analyses regarding Strategic Energy Plans

The “Paris Agreement[4],” which was adopted at the 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) at the end of 2015, came into effect in November 2016. Under the Paris Agreement, it was agreed to keep the global mean temperature rise well below 2°C above pre industrial levels and to pursue efforts to limit it to below 1.5°C. Subsequently, in November 2021, the 26th Conference of the Parties (COP26) was held in Glasgow, UK, where they agreed to pursue efforts to limit global temperature rise to 1.5°C. On the other hand, progress has been limited in deepening the Nationally Determined Contributions (NDCs), emission reduction targets pledged voluntarily by each country stipulated in the Paris Agreement. Even if all current NDCs were achieved, there would still be significant gaps not only with the 1.5°C but also with the 2°C emissions pathways[5]. Moreover, based on the recent emission trends, it seems becoming difficult for many countries to meet their NDCs targets. While the international community mostly agrees on the need to strengthen climate change measures, there are differing views on specific approaches. In order to achieve global carbon neutrality (CN), it is essential to address competitive imbalances due to the differences in national ambition levels and policy strength, preventing carbon leakage.

In June 2019, the Government of Japan formulated the "Long-term Strategy under the Paris Agreement[6]," which stated Japan’s commitment to reaching net zero emissions as early as possible in the second half of the

21st century. Then, in October 2020, the then Prime Minister Suga declared the goal of achieving CN and a decarbonized society by 2050 in his policy speech. Furthermore, the Plan for Global Warming Countermeasures[7] was revised in 2021, and the greenhouse gas (GHG) emissions reduction target as the 2030 NDC was raised from a 26% reduction compared to FY2013 levels to a 46% reduction, with further striving for a 50% reduction.

On the other hand, in 2022, issues surrounding energy security and stable supply became more apparent. The surge in fossil fuel prices due to the Russia-Ukraine situation and the electricity supply-demand crisis in March 2022 led to a renewed awareness of the importance of energy security. In response, under then Prime Minister Kishida, the "Basic Policy for the Realization of Green Transformation (GX)[8]" was approved by the Cabinet in February 2023.

Against this background, the 7th Strategic Energy Plan[1], the Plan for Global Warming Countermeasures[2], and the GX 2040 Vision[3] were formulated in December 2024, and approved by the Cabinet in February 2025. The GHG emissions reduction targets of 60% by 2035 and 73% by 2040 (both compared to FY2013 levels) were decided in the plans and submitted to the UNFCCC as Japan's updated NDC in February 2025. These plans respond to the increasing need for enhanced climate change measures both domestically and internationally, while also addressing emerging risks related to energy security and stable supply, climate actions, and trade relationship. They also intend to implement industrial policies and energy and climate measures in a comprehensive manner.

2. Overview of countermeasures toward Carbon Neutrality

For the analyses of the 7th Strategic Energy Plan and related policies, it was requested to be based, in principle, on the assumption of achieving CN by 2050, in line with the Japanese government's policies to date. Therefore, before explaining the model analyses, this section aims to provide an overview of the measures for achieving CN.

Figure 1 illustrates the realization of CN from the perspective of primary energy supply. Decarbonization of energy is essential for achieving CN, however, each energy source that can contribute to decarbonization has technical, social, and economic constraints. Therefore, from the perspective of minimizing total costs, energy saving remains crucial for achieving CN. Social innovations including sharing and circular economy associated with digital transformation (DX) will be increasingly important as well as energy savings of each technology.

On top of that, it is necessary, in principle, to build a supply structure consisting of renewable energy (RE), nuclear power, and fossil fuels with carbon capture and storage (CCS) or carbon dioxide removal (CDR) technologies, and proceeding electrification will be important for achieving CN on the final energy side. While electricity can be directly decarbonized through nuclear power and renewable energy, non-electric energy needs to be converted to other forms such as hydrogen-based energy, which tends to be more costly. Thus, promoting electrification, by means of heat pump water heaters, electric vehicles, and so on, is important. On the other hand, there are many high-temperature demand applications unsuitable for electrification, and diverse individual consumers make uniform electrification physically and economically difficult. Therefore, it is important to appropriately combine various energy types.

Moreover, variable renewable energy (VRE) sources, such as solar and wind power, often result in surplus energy at certain times when introduced on a large scale, therefore, converting them into hydrogen energy, in addition to storage in batteries, can serve as a key countermeasure. However, solar and wind power generated in Japan generally have huge constraints in terms of cost and volume compared to overseas, so from an economic efficiency perspective, it may be necessary to consider importing renewable energies or fossil fuels with CCS from abroad and converting them into hydrogen. Also, for further convenience, it could be highly important to combine hydrogen with nitrogen or captured CO_2 to produce ammonia, synthetic methane (e-methane), or synthetic fuels (e-fuels). Although the production of e-methane and e-fuels requires an additional process of synthesizing hydrogen with CO_2, they can be transported more cheaply than directly transporting hydrogen, which needs to be converted to liquid or other forms. Furthermore, it is advantageous that existing gas and oil infrastructure, as well as current gas appliances and internal combustion engine vehicles, can be utilized while possibly realizing CN. In any case, hydrogen and hydrogen-based energy sources, similar to electricity as secondary energy, can be produced from a variety of primary energy sources, have a wide range of applications, and contribute to achieving net-zero emissions. According to the economic calculations using the models described later, the supply of hydrogen and hydrogen-based energy is expected to be predominantly imported from overseas.

In the model analyses, optimal cost-minimizing energy systems are derived, including the transition process toward CN, under various assumptions about the costs and potentials of various energy sources, considering both domestic and import circumstances.

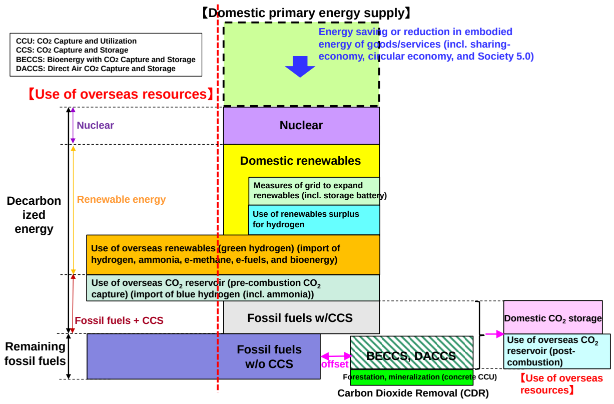

Figure 1 Image of primary energy for net-zero emissions

3. Scenario assumptions and analysis method

3.1. Scenario assumptions

Before explaining the scenario analysis methodology and the model outline, this section describes the scenarios presented to the government advisory council. Table 1 shows the assumed scenarios (in addition to those listed, a "Zero Nuclear Scenario" was also presented to the council, but it is omitted here due to space limitations). Figure 2 illustrates the map of these scenarios. It should be noted that as the Strategic Energy Plans present goals for the desired future, the "Low Growth Scenario," which RITE presented to the council as a scenario reflecting potential risks, is not included in the 7th Strategic Energy Plan.

In principle, the analyses assume existing government targets, the 1.5°C goal, CN by 2050, and a 46% emissions reduction by 2030. For 2040, a 73% reduction target (based on a linear reduction trajectory) presented by the government was assumed. The "High Growth Scenario" assumes that technological advancements progress rapidly and broadly in an innovative manner, with minimal barriers to technology diffusion, while the "Low Growth Scenario" assumes that technological progress remains gradual. As a case to avoid the associated economic risks, the "Risk Strategy Scenario" slightly relaxes emission constraints and applies carbon pricing in the analysis. In this scenario, the average values of carbon prices projected in the Net Zero 2050, the 2050 CN scenario, developed in the NGFS's three models are adopted.

3.2. Analysis method and overview of DNE21+

This section outlines the method and the models used for the analyses. For more detailed information on the models and the future technological assumptions in each scenario, please refer to Reference 9) and 10), and others. Figure 3 illustrates the procedure of the scenario analyses.

Table 1 Assumed scenarios

Emissions scenarios	Scenario name	Scenario descriptions
Emissions reduction scenarios: [World] Below 1.5 °C (2030: NDCs) [Japan] 2030: -46% 2040: -73% 2050: -100% [Other major developed countries] 2050: -100%	**High Growth**	Broad technologies contributing to deep emissions reduction and net-zero emissions are rapidly improved. Social barriers of nuclear power, renewables, and CCS are also small. In this case, the relative prices of energy will keep also in the future.
	Renewables	High social acceptance of solar PV and onshore wind power, and rapid cost reductions in solar PV and wind power including offshore wind power
	Hydrogen	Rapid cost reductions in hydrogen including ammonia, e-methane and e-fuels
	CCS	Lower social barriers of CO_2 geological storage
	[Extreme risk] **Low Growth**	Incremental technology improvements. In this case, the relative prices of energy in Japan will increase due to limited potentials of net-zero emission technologies.
Carbon price scenario: The price targets consistent with 1.5 °C (based on the NGFS NZE2050 scenarios: 257 $/t$CO_2$ in 2040, 500 $/t$CO_2$ in 2050)	**Risk Strategy**	Technology improvements are conservative, and the energy and climate policies will have a carbon price target not to realize high relative prices of energy compared to those of overseas. The resulting GHG emissions will be higher than those in other scenarios which achieve net-zero emissions by 2050.

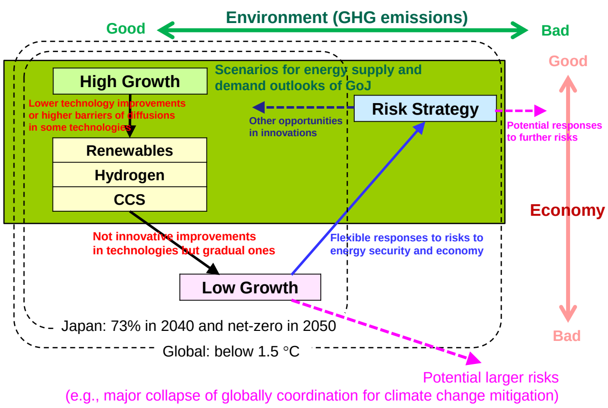

Figure 2 Map of the assumed scenarios

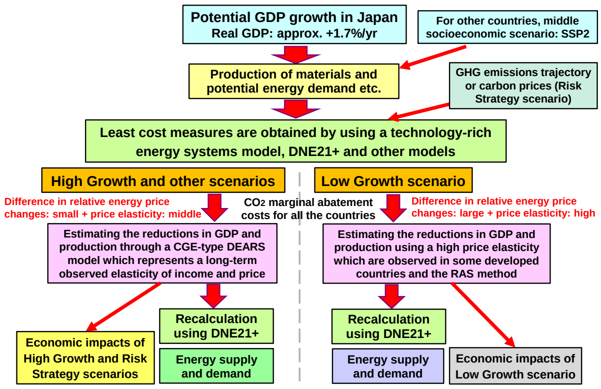

Figure 3 Estimation procedure for economic impacts and energy systems

The analyses of the energy system were conducted using the global energy and climate change mitigation model, DNE21+. The DNE21+ divides the world into 54 regions and makes evaluation dynamically from the year 2000 to 2100. It is a bottom-up, technology-based model that includes not only the energy supply side but also a wide range of technologies on the demand side covering energy-intensive industries, residentials, transportation, and so on, which enables to present concrete policy measures.

DNE21+ is a partial equilibrium model that evaluates only the energy system and cannot assess the overall impacts on the macroeconomy. Currently, due to the differences in relative energy costs across countries, there is a trend that some industries, energy-intensive sectors in particular, relocate from developed to developing countries. However, since the DNE21+ exogenously assumes production volume scenarios for industries such as iron and steel and chemicals, it cannot evaluate the relocation of production volumes endogenously. Therefore, as shown in Figure 3, DEARS, a general equilibrium global energy-economic model, was also employed for the scenario analyses. The DEARS model is based on the international input-output tables of Global Trade Analysis Project (GTAP). Recently, an increasing price elasticity for electricity and energy is observed in some developed countries, especially in EU, and companies may be responding more swiftly to relative energy price differences in a globalized world. However, since the GTAP database has a large time lag in updates, it may not be able to reflect recent conditions accurately. Thus, in the "Low Growth Scenario," a high price elasticity for energy of –1.0 was adopted for the analysis. Based on the results of these estimates, the projected production volumes for energy-intensive industries and the transport machinery sector in the DNE21+ model were revised and calculated, and energy scenarios were presented.

4. Analysis results

This section presents the results of the scenario analyses.

4.1. Costs and economic impacts

Table 2 shows the marginal abatement costs of CO_2.

Even in the "High Growth Scenario," it is analyzed that achieving a 73% reduction by 2040 and CN by 2050 will require quite high costs. It is also considered that further innovations beyond what was assumed in this analysis will be needed to achieve these goals.

Under the "Low Growth Scenario," the marginal abatement cost of CO_2 is estimated to increase even more. Additionally, the relative costs compared to other countries will become larger, resulting in wider gaps of relative energy costs. Although this analysis assumes global emissions reduction pathways for the below 1.5°C target, in reality, global efforts may be uneven, with some countries implementing only baseline-level measures. In such cases, the gaps between Japan's electricity costs and those in other countries could widen even further in the "Low Growth Scenario." Therefore, it is important to consider a certain level of flexibility in emissions reduction strategies.

The "Risk Strategy Scenario" is designed to address such situations. Under this scenario, carbon prices equivalent to achieving CN by 2050 (below 1.5°C) are assumed globally, and therefore, the marginal abatement costs (carbon prices) are uniform worldwide and slightly lower than those in the "High Growth Scenario." Although the "Risk Strategy Scenario" assumes that technological progress remains at the current pace, it does not assume emissions constraints but fixed carbon prices. Consequently, energy and electricity costs remain at levels similar to those in the "High Growth Scenario."

Table 2 Marginal abatement costs of CO_2 emissions

	High growth		Renewables		Hydrogen		CCS		Low growth		Risk strategy	
	2040	2050	2040	2050	2040	2050	2040	2050	2040	2050	2040	2050
Japan	301	578	369	716	467	742	396	892	538	951	257	500
US	294	262	350	348	409	454	362	350	410	467	257	500
UK	294	317	350	387	419	558	369	452	428	579	257	500
EU	298	413	350	516	409	648	362	541	410	664	257	500
Others	294	262	350	348	409	454	362	350	410	467	257	500

Unit: USD/tCO_2 (in 2000 price)
Note) Some selected countries are shown.

Table 3 shows the economic impact on Japan. Even in the "High Growth Scenario," which assumes rapid technological advancement, GDP losses are expected to be 4.1% in 2040 and 5.6% in 2050 because of high carbon prices shown in Table 2. The projected declines in the iron and steel sector are -3.9% in 2040 and -11% in 2050 (for example, crude steel production, estimated at 90 million tons/year in 2050, would fall to 80 million tons/year with an 11% decrease). However, if the world works toward the 1.5°C target, there is the possibility of acquiring overseas markets particularly of emissions reduction products, and around 5% growth is expected, although the estimates include large uncertainty. Therefore, this scenario could achieve the same level of economic growth (slightly higher in 2040) as the potential growth projection (estimated at 1.5%/year from 2023 to 2040, considering population decline).

In the "Low Growth Scenario," where technological improvement is incremental, Japan's access to low-cost decarbonized energy is more limited compared to other countries. Consequently, the relative energy price gaps would be widened, which would possibly accelerate the relocation of industries abroad. In the iron and steel and the chemical industries, production is projected to hugely decline by around 40% compared to the baseline. A similar level of decline is also estimated in the automobile (transport machinery) sector. Overall GDP is expected to fall significantly, by around 13–14%. If emissions reduction toward 2050 CN is pursued in a linear manner without major technological improvements, the world of "Low Growth Scenario" shown in the analysis results is quite plausible. To avoid this, the "Risk Strategy Scenario" has been proposed.

Table 3 Changes in production and GDP

Reduction ratios in productions/value added	High growth (DEARS)		Low growth (price elasticity: -1.0, income elasticity: +1.0, and RAS)		Risk strategy (DEARS)	
	2040	2050	2040	2050	2040	2050
Iron and steel	-3.9%	-11.0%	-41%	-46%	-3.6%	-11.0%
(production [million ton/yr])	(86)	(80)	(53)	(49)	—	—
Chemical	-3.7%	-11.2%	-35%	-40%	-3.3%	-10.7%
Non-metal materials	-2.1%	-2.7%	-30%	-34%	-1.7%	-3.8%
Non-steel metals	-1.4%	-2.7%	-35%	-39%	-1.2%	-5.0%
Paper and pulp	-3.5%	-6.3%	-33%	-37%	-3.1%	-7.2%
Transport machinery	-4.1%	-6.9%	-42%	-47%	-4.7%	-8.2%
GDP (excluding the overseas diffusion effects)	-4.1%	-5.6%	-13%	-14%	-3.6%	-5.9%
GDP/GNI (including the oversea diffusions particularly of emission reduction 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%)	
Annual growth in GDP/GNI since 2023 (note: +1.4% and +1.3%/yr by 2040 and 2040-50, respectively, in baseline)	+1.5%/yr	+1.2%/yr	+0.6%/yr	+0.7%/yr	+1.4%/yr	+1.2%/yr

In the "Risk Strategy Scenario," technological progress is assumed to be not rapid like in the "High Growth Scenario," but as modest as in the "Low Growth Scenario." As a result, although emissions are higher (a 61% reduction in 2040 and 79% in 2050), the economic impacts are estimated to be around the same as in the "High Growth Scenario." A sharp decline in economic activities and the relocation of industries due to carbon constraints should be avoided, and this scenario is for addressing such risks.

4.2. Energy demand and supply

Figure 4 shows Japan's primary energy supply. In all the scenarios, a substantial reduction is observed in 2040 and 2050. The expansion of renewables and the use of CCS are considered economically efficient. The import of hydrogen, ammonia, e-methane, and e-fuels is also evaluated as cost-effective. Both primary energy supply and electricity generation are significantly constrained in the "Low Growth Scenario." On the other hand, in the "Risk Strategy Scenario," the import of hydrogen-based energy is reduced, and maintaining the current level of LNG use will be economically efficient.

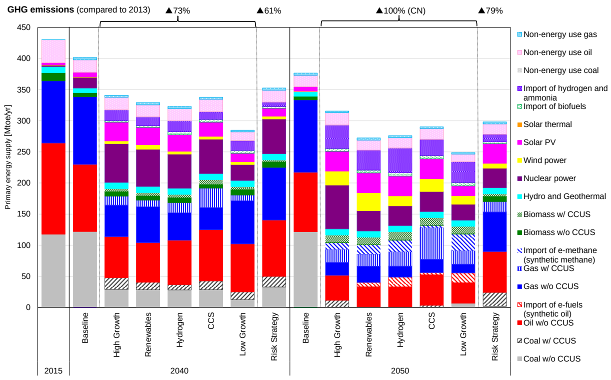

Figure 4 Primary energy supply in Japan

Figure 5 shows final energy consumption in Japan. Raising the electrification ratio is an economically reasonable measure, and a significant reduction in final energy consumption will be required. On the other hand, in the industry, residential, and transport sectors, full electrification will not be economically efficient, and measures combining with hydrogen, ammonia, e-methane, e-fuels, and bio fuels will be cost-efficient. The electrification ratio in the total of final energy consumption is estimated to be 38-44% in the 73% reduction by 2040 scenario, and 54-57% at the point of CN in 2050.

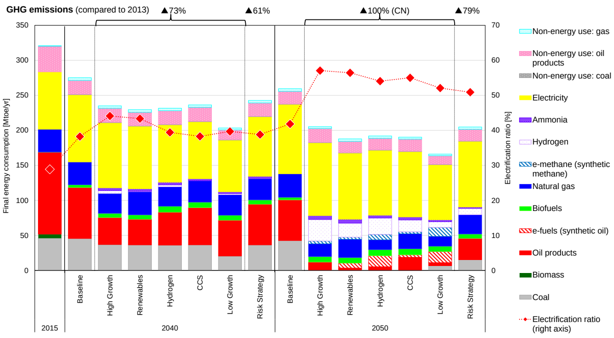

Figure 5 Final energy consumption in Japan

Electricity demand is projected to be 1,081 TWh/year in 2040 and 1,210 TWh/year in 2050 under the "High Growth Scenario." For 2040, relatively higher CO_2 marginal abatement costs in the "Hydrogen Scenario" and the "CCS Scenario than those in other scenarios will lead to lower electricity demands. In the "Low Growth Scenario," high energy prices are expected to significantly suppress electricity demand.

Electricity supply (Figure 6) is expected to potentially increase due to IT demand and others, however, if relative energy prices remain high, energy consumption may need to be suppressed along with production decrease caused by industry shift overseas. Since economically viable power generation investments often require long lead times, it is critical to implement energy and climate policies with high predictability to avoid electricity shortages and prevent the realization of the "Low Growth Scenario."

Regarding LNG-based power generation (including cogeneration and facilities with CCS) in the "Risk Strategy Scenario," the result shows that sustaining them at about current level through 2050 will be cost-efficient.

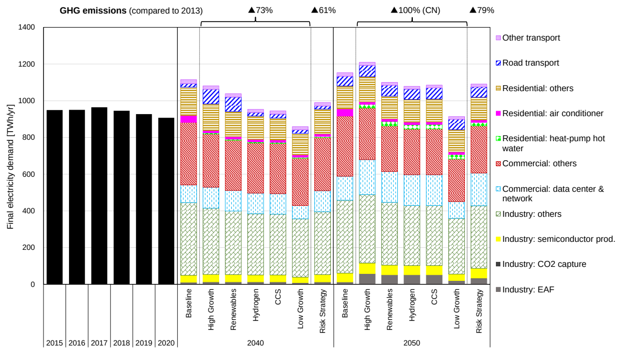

Figure 7 Final electricity consumption in Japan

Figures 8 and 9 show the CO_2 and hydrogen balances in Japan, respectively. In 2050, Direct Air Carbon Capture and Storage (DACCS) is regarded as an economically viable measure in many scenarios. Hydrogen imports are evaluated as cost-effective, with diverse applications projected in the power generation, the iron and steel, and other sectors. In addition to direct hydrogen use, the import and use of ammonia, e-methane, and e-fuels are also evaluated as economically efficient, as mentioned earlier.

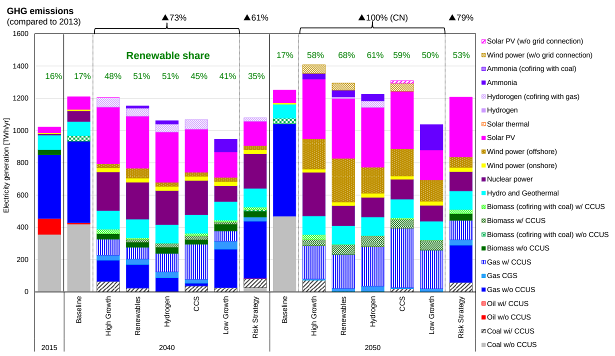

Figure 6 Electricity supply in Japan

Figure 7 shows final electricity consumption by sector. In all the scenarios, electricity demand is expected to increase toward 2040, and grow even further toward 2050 due to increasing IT and electrification demands.

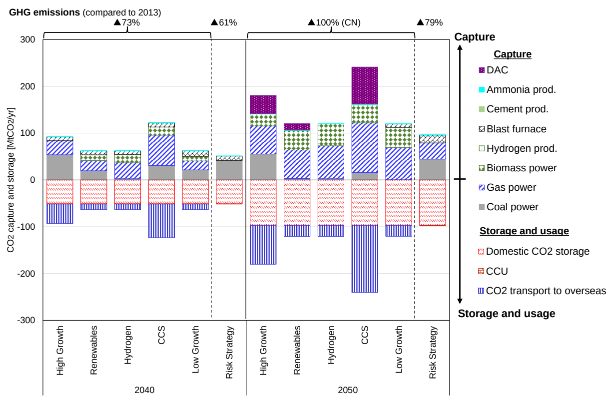

Figure 8 CO_2 balance in Japan

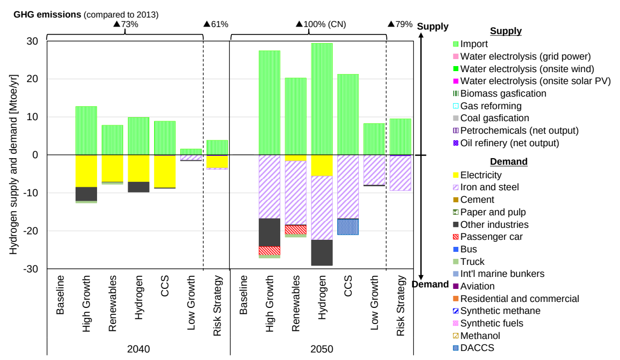

Figure 9 H_2 balance in Japan

5. Summary and policy implications

RITE conducted energy system analyses for Japan toward the 2050 CN target assuming multiple scenarios, using global models such as DNE21+ and DEARS, which provide results balancing energy supply and demand and costs. To achieve a virtuous cycle between the economic growth and the environment, it is crucial to focus on the relative energy prices gaps with other countries, and the analyses were conducted considering that.

While the world has been taking actions toward ambitious goals such as 1.5°C and 2050 CN, significant gaps with current emissions are observed. Even in countries including Japan, where emissions reduction has progressed considerably, there are the cases that the emissions reduction is mainly attributed to the decline in production in energy-intensive industries and the relocation of manufacturing abroad. The "High Growth Scenario" is the optimum situation, however, climate change requires global actions, and effective solutions cannot be achieved without international cooperation. It is also important to recognize that the "High Growth Scenario" represents a narrow pathway and to prepare energy strategies that account for the potential emerging risks of the "Low Growth Scenario."

These analyses conducted by RITE were a major source of reference for formulating the energy demand and supply outlook in the 7th Strategic Energy Plan. It can be said that the 7th Strategy Energy Plan provides a strategy for achieving CN while also considering energy supply stability and economic viability, by presenting multiple scenarios, including the "Risk Strategy Scenario" for risk management.

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Development of Bio-manufacturing Technologies that Contribute to Carbon Neutrality

1. Introduction

Bio-manufacturing technology is a key field that utilizes advanced genetic modification techniques to enhance microorganisms' fermentation capabilities or to confer the ability to produce desired substances on them. It also includes ways to effectively obtain target breakdown products from raw materials by enhancing microbial enzyme functions. Bio-manufacturing uses these approaches to replicate biological mechanisms in nature and apply them to industrial manufacturing processes. Its features and advantages are as detailed below.

Bio-manufacturing utilizes microbial cells' inherent bio-processes and enzymes in production. This allows the synthesis of compounds that are difficult to produce through chemical processes, using highly precise bio-processes involving microbial enzymes, resulting in high yields with few by-products. 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. Bio-manufacturing 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, in on the rise.

The greatest advantage of bio-manufacturing is its ability to drive innovation in industrial activities, such as new product development and manufacturing process transformation. It also addresses social issues such as reducing environmental impact and utilizing sustainable resources. For example, conventional chemical-based manufacturing processes are often high-temperature and high-pressure reactions. In contrast, bio-manufacturing can carry out reactions at room temperature and pressure, which is expected to reduce CO_2 emissions compared to chemical processes. Bio-manufacturing 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 the emission of new CO_2 that affects climate change. Meanwhile, advanced bio-manufacturing technologies are making it possible to recycle waste derived from chemical products. While previously such waste could only be disposed of by landfill or incineration, now it can be converted into fuels (biofuels) and new chemicals (green chemicals) or their starting materials necessary for industrial activities.

In short, bio-manufacturing is vital to achieving carbon neutrality. Sustainable bio-manufacturing also provides a competitive edge in various industrial sectors, laying the groundwork for a resource-circulating next-generation industry. Recognizing its potential early on, RITE has been actively focused on developing core technologies 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 highlight the progress in developing fundamental technology in the fast-evolving "Bio × Digital" field through Japan's national projects involving RITE. Finally, it will discuss efforts towards commercialization and future prospects.

2. The Core Technologies of RITE

2.1. "RITE Bioprocess"

RITE has focused on developing core technologies for the industrial use of Corynebacterium, which possesses unparalleled substance production capabilities among microorganisms. As part of RITE's research, it was discovered that while its growth is suppressed under anaerobic conditions, Corynebacterium is able to maintain metabolic functions necessary for substance production, efficiently converting sugars into organic acids. Based on this phenomenon, RITE established the growth-independent bioprocess known as the "RITE Bioprocess." This highly productive method is unique to RITE and is considered as one of the most important core technologies for promoting the social implementation of bio-manufacturing (Fig. 1). Below are its three main features.

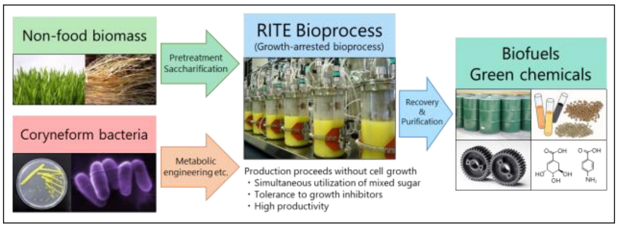


Fig. 1 Bio-manufacturing using the "RITE Bioprocess"

Feature 1: Growth-arrested bioprocess

In nature, fermentation typically requires microorganisms to grow while producing substances. However, RITE has established a bioprocess in which cell growth is inhibited under certain anaerobic conditions or by removing key growth factors under aerobic conditions suited for growth, yet target substance production continues (Fig. 2). In the "RITE Bioprocess," nutrients and energy that would normally be consumed for microbial growth are instead used solely for the production of the target substance, achieving productivity equal to or greater than chemical processes.

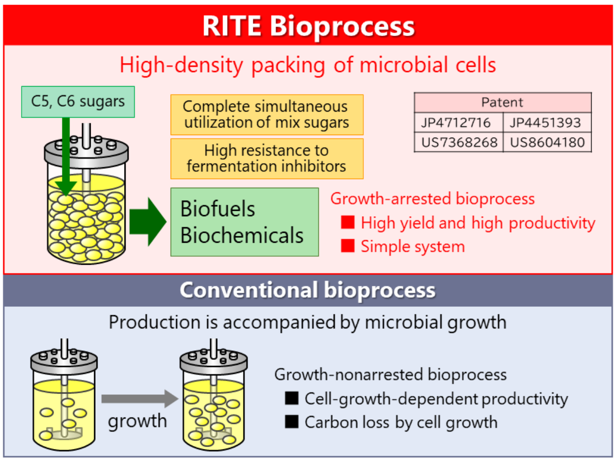


Fig. 2 Feature 1 of the "RITE Bioprocess"
(Growth-arrested bioprocess)

Feature 2: High tolerance to fermentation inhibitors

In bio-manufacturing, 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. Since "RITE Bioprocess," is a production system that does not involve microbial growth, it is 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.

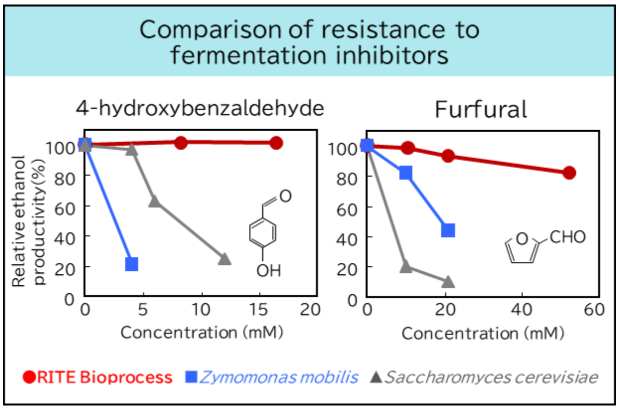


Fig. 3 Feature 2 of the "RITE Bioprocess"[*1]
(High tolerance to fermentation inhibitors)

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

Non-edible cellulose-based biomass is a common raw material in the bio-manufacturing 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 bio-manufacturing, enabling maximum production efficiency while minimizing waste of non-edible biomass raw materials.

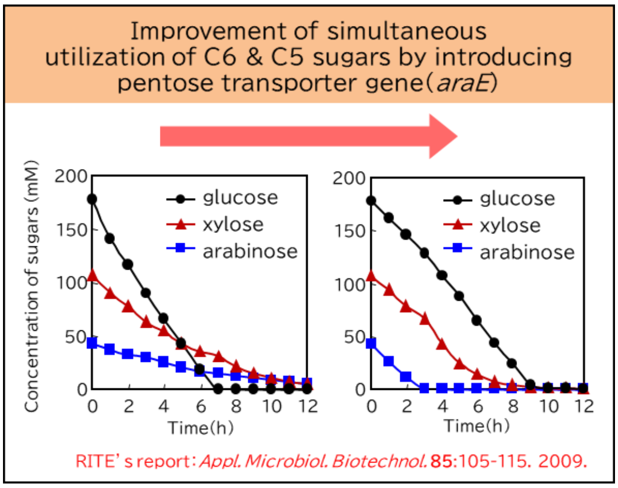


Fig. 4 Feature 3 of the "RITE Bioprocess" (Simultaneous usage of mixed sugars)

2.2. Smart Cell Creation Technologies

RITE has participated in the Smart Cell Project (NEDO "Project for Development of Production Techniques for Highly Functional Biomaterials Using Smart Cells of Plants and Other Organisms", 2016-2020) and has been involved in the development of technology sets to create smart cells. Smart cells are biological cells whose functions have been highly designed and whose gene expression has been controlled through genetic modification. More specifically, they are cells that combine cutting-edge biotechnology and digital technology to maximize the biological cells capacities and optimize its chemical production. This enables us to set specific a target compound and fine-tune its smart producer strains efficiently by developing and incorporating metabolic pathway design technology, breeding technology, and fermentation production technology (Fig. 5). This method can also be applied to develop producer strains for various other biofuels and bio-based chemicals. We will continue to brush up on these technologies and aim to make effective use of smart cell creation technologies.

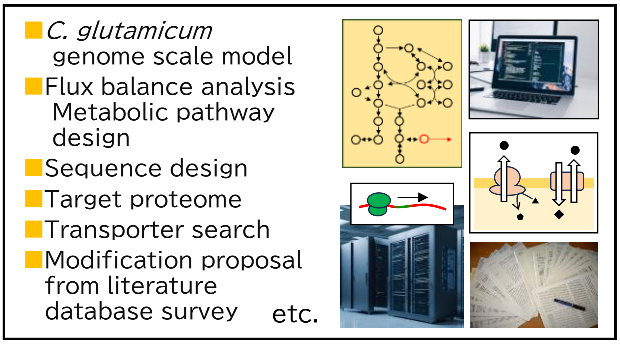


Fig. 5 Smart Cell Creation Technologies

2.3. Cytotoxicity Control Production System

RITE has developed biotechnological processes to produce various compounds. In this development activity, we have faced the problem that several target compounds exhibited profound antibacterial properties that halted production due to their accumulation during the process. For example, the production of catechol, a type of aromatic compound, has been limited to a certain concentration in the conventional batch method. To avoid cytotoxicity and achieve high production, we constructed a cytotoxicity control production system that selectively removes the target compound from the reaction solution and recovers it altogether. Fig. 6 illustrates our catechol continuous reaction method that combines membrane separation and resin adsorption. The catechol produced in the reaction solution is continuously collected in the adsorption resin, allowing production while maintaining a low concentration of catechol in the reaction solution. This enables exceptionally efficient catechol production compared to the conventional batch method. In other words, by avoiding the strong catechol cytotoxicity, the producer strain's true productivity was demonstrated, resulting in enormously higher catechol production.

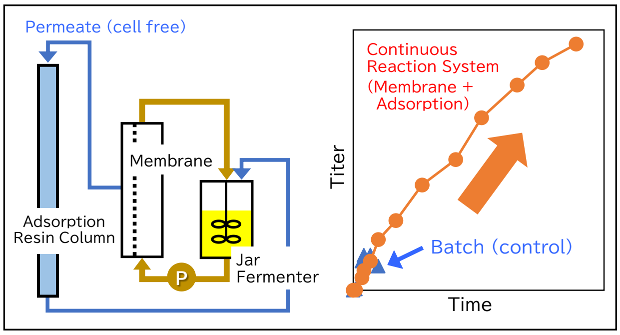


Fig. 6 A continuous reaction system using membrane separation and resin adsorption

2.4. Substances Produced by the "RITE Bioprocess"

RITE has achieved high production levels for various substances, as shown in Fig. 7. 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.

Biofuels	Green chemicals
■ Gasoline additives ・Ethanol * ■ Bio-jet fuels ・Isobutanol * ・n-butanol * ・C9-C15 Saturated hydrocarbon + Aromatics ■ Biohydrogen * : Polymer raw materials Red character : World's highest productivity achieved	■ 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)

Fig. 7 Substances produced using the "RITE Bioprocess"

Aromatic compounds, in particular, are essential basic industrial chemicals that serve as raw materials for polymers and other products. Among these are numerous high-value compounds that are used as ingredients in pharmaceuticals, functional dietary supplements, fragrances, and cosmetic products. 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, bio-manufacturing is eagerly anticipated. 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. By utilizing advanced bio-manufacturing technologies, RITE has successfully established non-edible biomass-based high-production bioprocesses for shikimic acid (a raw material for the influenza drug Tamiflu), 4-aminobenzoic acid (a promising raw material for functional polymers), and aromatic hydroxy acids, which are favorable raw materials for polymers, pharmaceuticals, cosmetics, adhesives, and fragrances (vanillin).

3. Fundamental Technology Development (National Projects)

The Japanese government is currently providing substantial support for bio-manufacturing as an innovation that simultaneously pursues economic growth and address social issues. Fig. 8 summarizes the national projects in which RITE participates, as well as the bio-manufacturing technologies that RITE is responsible for developing. We are involved in the NEDO Green Innovation Fund Project and the NEDO Bio-manufacturing Revolution Promotion Fund Project, which is to develop bio- manufacturing technologies for high-performance adhesive raw materials from CO_2 and bio-upcycling technologies to produce useful chemicals from unused resources (Sections 3.1 and 3.2). RITE also participates in the NEDO "Moonshot" Project, where we conduct research and development on multi-

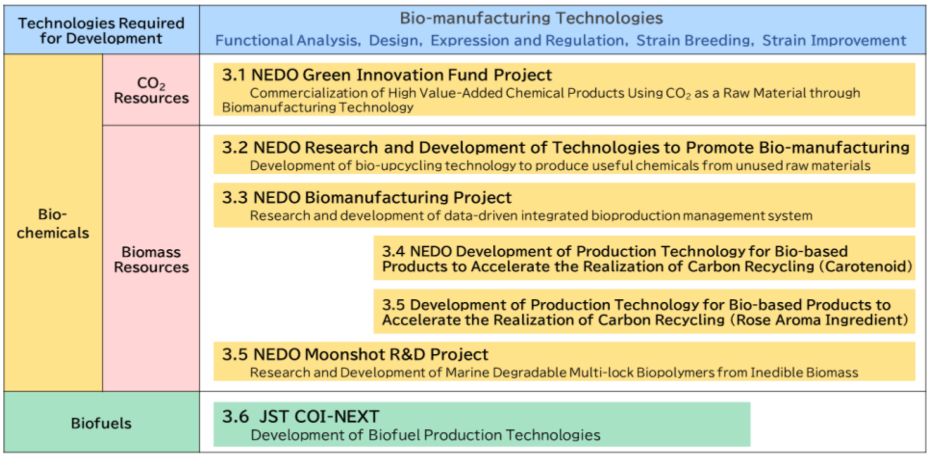


Fig. 8 Overview of participating national projects and new technologies required for development

lock type biodegradable biopolymers made from non-edible biomass (Section 3.6).

Furthermore, RITE is involved in the NEDO "Bio-manufacturing Demonstration" Project, in which we collaborate with private companies to commercialize the bio-production of carotenoids and fragrance compounds (Sections 3.4 and 3.5). RITE also promotes the transformation of manufacturing processes and the social implementation of products by developing and demonstrating the necessary technologies to build a bio-manufacturing value chain with diverse raw materials and products. Below are the details of RITE's initiatives.

3.1. NEDO Green Innovation Fund Project: "Commercialization of High Value-Added Chemical Products Using CO_2 as a Raw Material through Biomanufacturing Technology"[*2]

This project aims to contribute to "carbon neutrality realization by 2050" by developing and implementing 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 is currently implementing it (project period: 8 years from FY2023 to FY2030). For more details, see the "Special Feature" on the recently constructed "Biomanufacturing Experimental Facility."

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 to bind special components that require heat resistance, such as smartphones, aircraft, and automobiles. 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.

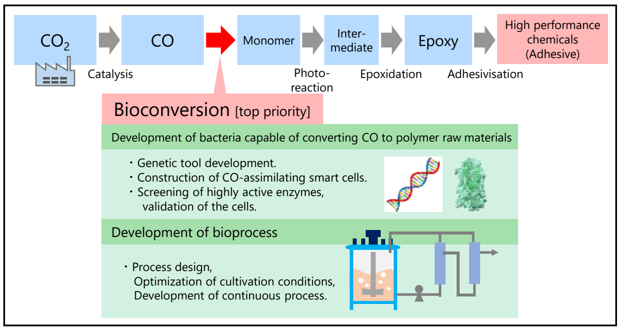


Fig. 9 High-value-added chemical products made from CO_2 by bio-manufacturing technology

3.2. NEDO Research and Development of Technologies to Promote Bio-manufacturing: "Development of bio-upcycling technology to produce useful chemicals from unused raw materials"*2

The shift to sustainable manufacturing and the promotion of social implementation of bio-based products are important issues that must be addressed in order to foster the next generation of industrial infrastructure. In addition, there is a need to develop biomanufacturing technologies that use domestic unused resources as raw materials rather than relying on imported biomass. In response to these circumstances, NEDO launched a project "Research and Development of Technologies to Promote Biomanufacturing" in 2023. This project aims to strengthen Japan's industrial competitiveness and solve social issues by aiming to build a value chain for biomanufacturing that uses a variety of raw materials and produces a variety of products. In this project, RITE raised issues with Takasago International Corporation and Teijin Limited and began research and development to solve them (more information here in our Japanese press release). We are developing new high-efficiency production strain breeding technologies from both the Dry (computer-based information analysis) and Wet (biological experiments) perspectives. As an example of the development technology, we are building a database to improve the efficiency of metabolic design and production condition determination. We will store the vast amount of production strain information we have accumulated, as well as newly acquired information on unused resources and production inhibition effects (cytotoxicity by compounds) of products in our own database, thereby strengthen our breeding competitiveness (Fig. 10).

Based on RITE experience in developing various production strains so far, such strain development requires advanced biotechnology. Consequently, companies without prior experience might face substantial hurdles in terms of initial investment, specialists' training, and know-how acquisition. These factors reasonably wary many companies that want to enter the biomanufacturing industry. We aim to fulfill the role of a "microbial development platform" that undertakes the development of producing strains that these companies need and provides production technology. For this purpose, we develop research facilities that bring together bio-specialized personnel, research equipment, technology, information, etc. named the "RITE Biomanufacturing Center" (Fig. 10). The construction began in December 2024 and is scheduled to be completed in November 2025, with preparations underway to start operations in fiscal year 2025.

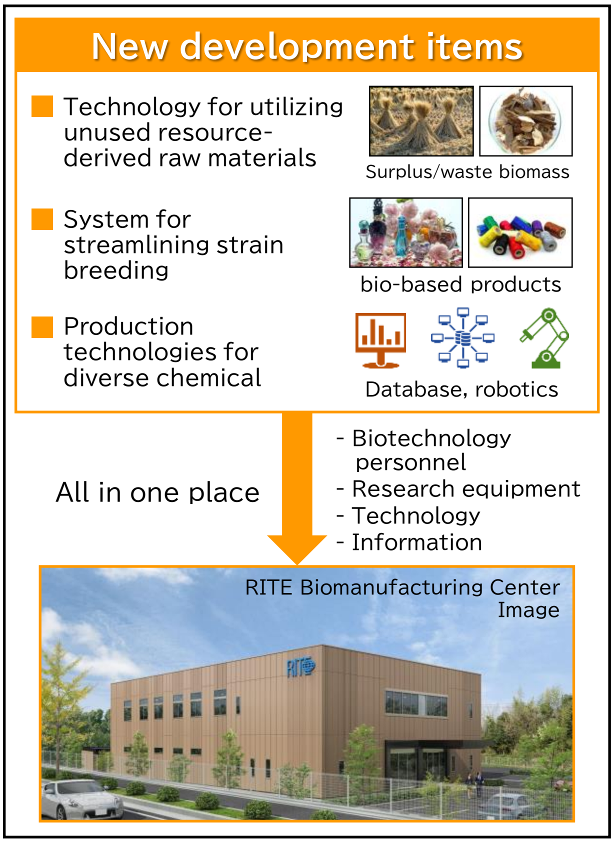


Fig. 10 RITE Biomanufacturing Center

3.3. NEDO Biomanufacturing Project "Research and development of data-driven integrated bioproduction management system"[*2]

"Development of Production Technology for Bio-based Products to Accelerate the Realization of Carbon Recycling" was launched in FY2020. This initiative, which is commonly known as the NEDO Biomanufacturing Project, is creating technology to address practical application challenges so that laboratory-optimized smart cells can demonstrate their capabilities in industrial processes. RITE has been involved right from the start, where we developed a group of new technologies to resolve issues associated with the practical application of biomanufacturing technology, including product inhibitory properties and scale-up issues (Fig. 11).

Our research has shown that there are several cases in which the target chemical itself is responsible for limiting the activity of enzymes necessary for production. To resolve this issue, we developed new technology with collaborating research institutions in FY2024. The resulting experimental data has identified the mechanism behind the reduction in activity. In addition, we discovered that the decrease in enzyme activity could be avoided by estimating the mechanism and substituting appropriate amino acids.

On the other hand, we observed that various parameters, including the temperature, pH, nutrients, and dissolved oxygen, are likely to become spatially biased and uneven in the larger-scale bioproduction. Research and development were conducted with collaborating research institutes with the aim of developing design technology for robust producer strains that can maintain high productivity even in such circumstances. In 2024, RITE identified conditions that reproduced the environmental fluctuations. The detailed gene expression and metabolite data we obtained contributed to constructing and verifying a simulation model for the fermentation production.

By researching and delivering solutions to problems that may arise during actual production, we aim to eliminate the need for rework in the producer strains' development, thus accelerating the social implementation of bio-derived products.

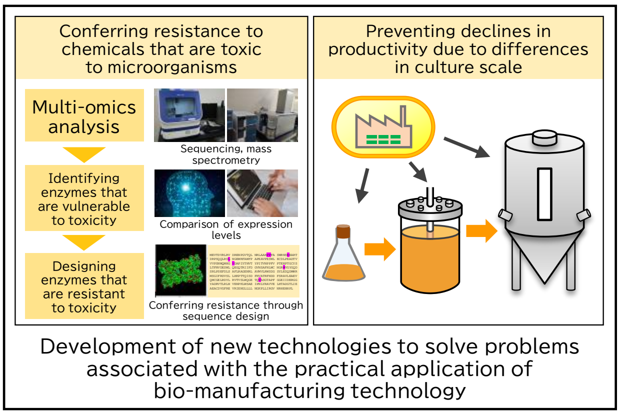


Fig. 11 Technology development in the Biomanufacturing project

3.4. NEDO Development of Production Technology for Bio-based Products to Accelerate the Realization of Carbon Recycling (Carotenoid)*2

Carotenoids are functional ingredients with high antioxidant activity. However, the bioavailability of most carotenoids on the market is notably poor due to their all-*trans* chemical configuration.

Since 2022, RITE has worked with Harima Chemicals, Inc., on the NEDO "Industrial Material Production System Demonstration" project, which aims to socially implement a biobased mass production system for highly bioavailable carotenoids (Fig. 12). In 2024, we have developed genetically modified enzymes that synthesize *cis*-configured carotenoids more efficiently and established a novel cultivation condition that uses saccharification liquor as a carbon source. We are currently expanding our cultivation scale for social implementation of bio-based functional ingredients.

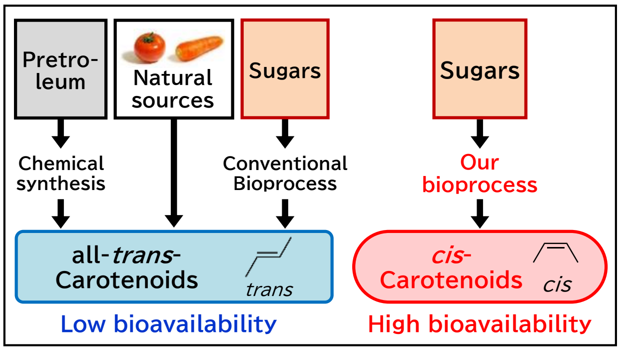


Fig. 12 Outline of our project for bio-based production of highly bioavailable carotenoids

3.5. Development of Production Technology for Bio-based Products to Accelerate the Realization of Carbon Recycling (Rose Aroma Ingredient)*2

Since 2022, RITE has been participating in the NEDO Demonstration Project for Industrial Substance Production Systems, titled "Demonstration of a Rose Fragrance Production System Using a Flow-Continuous Isolation Method and a Growth-Independent Bioprocess" (representative organization: Takasago International Corporation). In addition to developing industrial smart cells, RITE is advancing the development of a bioproduction system that avoids microbial fermentation inhibition caused by fragrance materials (Fig. 13). In FY2024, we increased productivity using the aforementioned production system by establishing production strains and improving production conditions, obtaining the productivity required for practical application in the laboratory. We also successfully scaled up the aroma ingredients bioproduction to a 90 L fermenter. Moving forward, we will continue to study and expand the scale-up production for practical application, aiming for the social implementation of the first domestically produced fragrance material manufactured through synthetic biology.

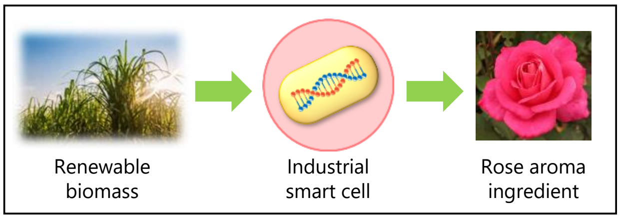


Fig. 13 Production of a rose aroma ingredient

3.6. NEDO Moonshot R&D Project: "Research and Development of Marine Degradable Multi-lock Biopolymers from Inedible Biomass"*2

This project focuses on research and development to introduce a "multi-lock mechanism" for plastic degradation (Fig. 14). The degradation in this mechanism specifically requires simultaneous multiple stimuli, including light, heat, oxygen, water, enzymes, microorganisms, and catalysts. As a result, the plastic would not degrade throughout typical use, ensuring its durability and toughness. However, unintentional dispersal of our target plastic in the marine environment will trigger the multi-lock mechanism, resulting in high-speed on-demand degradation.

There have been strong concerns that various plastic-based products discharge into the oceans expose adverse effects on marine organisms and its environment. Accordingly, various practical products are targeted in this project, including tires, that generate secondary fine plastic particles when used; agricultural equipment; also fishing nets and fishing gear which waste continue to harm marine life.

By FY2024, RITE developed technology that enables artificially control 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 that rapid enzymatic degradation (degradation on demand) occurs only when exposed to seawater, both on laboratory test and marine field tests. In the future, we aim to increase degradation speed by improving the plastic-degrading enzyme functionality, reducing the carrier size, and optimizing the plastic manufacturing process.

On the other hand, we started a new international joint research project with the U.S. Department of Energy's ARPA-E to develop biomanufacturing from marine-derived inedible resources, thereby closing the plastic cycle in the marine environment.

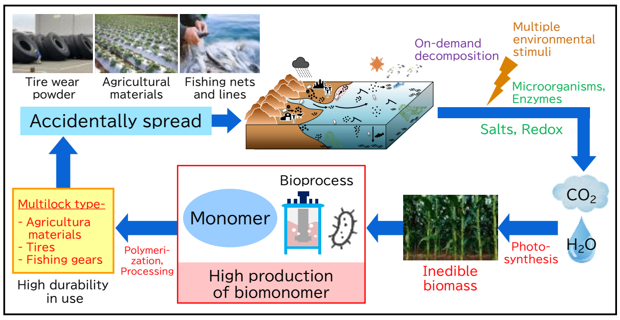


Fig. 14 Development of multi-lock biodegradable plastic and realization of resource recycling

3.7. Japan Science and Technology Agency (JST) the Program on Open Innovation Platforms for Industry-academia Co-creation (COI-NEXT): "Development of Biofuel Production Technologies"

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. 15). 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 examine two different hydrogen-producing enzyme recombinants, each with its reaction mechanisms and hydrogen productivity.

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 applied the RITE bioprocess in this project and demonstrated ethanol production from various non-edible biomass-based sugar, with comparable high titer and yield to reagent sugar mixture-based production. Using this technology, we aim to develop an alcohol to jet (ATJ) process to produce a sustainable aviation fuel using various biomass feedstocks, such as energy crops, rice with high CO_2 fixation capability, and microalgae with high sugar content.

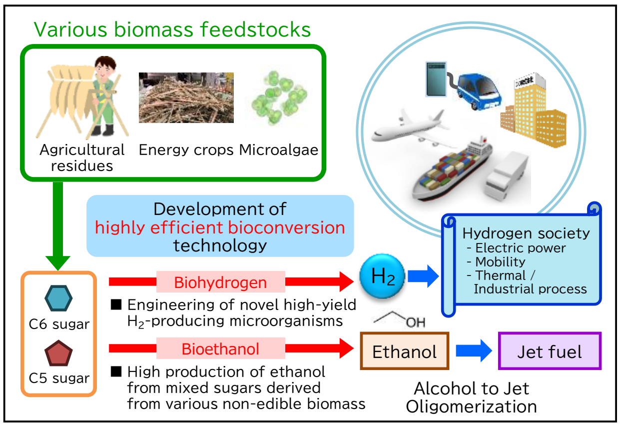


Fig. 15 Development of biohydrogen/bioethanol production technologies

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.

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. We have pioneered mass production technologies for high-value-added 4-hydroxybenzoic acid (4-HBA), protocatechuic acid, and shikimic acid (Fig. 16). Furthermore, regarding the secondary use of genetically modified organisms, etc., for the industrial application of their production strains, we have obtained confirmation from the Minister of Economy, Trade and Industry (Ministerial Confirmation) for all of these substances and are promoting the commercialization and business development of these green compounds.

We are currently receiving numerous inquiries from companies both domestically and internationally, and commercialization negotiations are underway. To meet various needs, we will further accelerate our efforts toward the practical application of bio-manufacturing, including further reducing production costs and improving product quality.

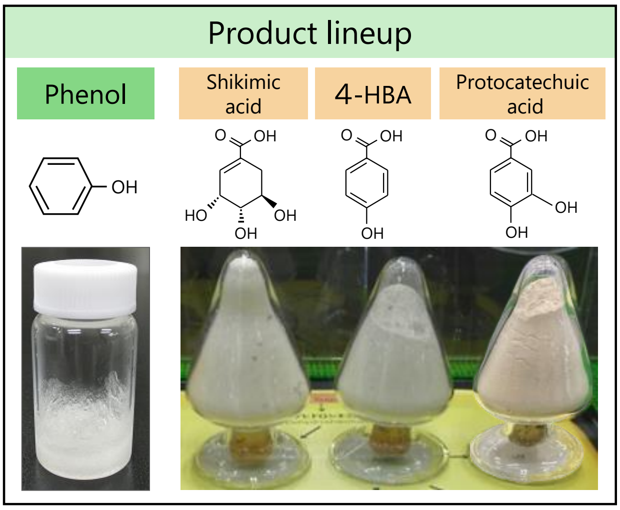


Fig. 16 Major product lineup of Green Chemicals Co., Ltd.

4.2. Green Earth Institute Co., Ltd.

(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 the Green Earth Institute Inc. 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.

In February 2025, the company announced that it would establish a joint venture for the production and sale of "Bioethanol" and other products from "Wood Biomass".

Currently, the company is promoting research and development with domestic and overseas partner companies, including "Biofoundry Base" (based on the government's "Biostrategy 2020), NEDO's "Green Innovation Fund Project," and NEDO's "Bio-manufacturing Revolution Promotion Project."

4.3. Joint Research with Companies

In addition to Harima Chemicals, Inc. and Takasago International Corporation, which are part of the NEDO Bio-manufacturing Demonstration Project, RITE is conducting collaborative research in response to requests from many other companies. Besides the main compound products introduced in this overview (Section 2.4), bio-manufacturing is possible for numerous other substances, and RITE is developing collaborative research tailored to the needs of each individual companies. 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. Leveraging its advanced expertise and extensive experience, RITE offers bio-manufacturing solutions that are closely tailored to the specific needs of each company.

5. Closing remarks

RITE will continue to advance bio-manufacturing technologies, including smart cell creation technology, by leveraging the national projects introduced in Chapter 3. Technological innovations in the "Bio × Digital" field are progressing rapidly, with smart cell development expected to make significant strides in the future. However, the creation of industrial smart cells, which require advanced bio-manufacturing technologies, is becoming increasingly difficult for individual companies to undertake on their own due to factors such as technical complexity, cutting-edge research facilities, cost performance, and maintaining competitiveness. Additionally, process development requires a certain level of production as well as a specialized platform, which demands capital investment and securing specialists experienced with bioprocesses. In the near future, the promotion of the smart cell industry by bio-platformers is expected to lead to the bio-manufacturing establishment in the energy and chemical industries (Fig. 17).

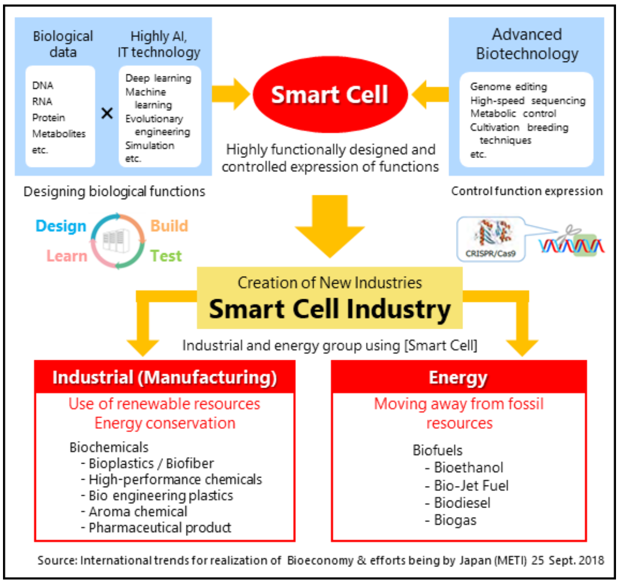


Fig. 17 Fusion of industrial / energy fields impacted by new bio and digital technologies

RITE will continue to develop the RITE Bio-platform, which provides optimal bio-manufacturing technology development services for each product, based on "RITE Bioprocess" and "Smart Cell Creation Technology." We encourage you to actively utilize these services. Since Japan's "2050 Carbon Neutral" declaration in October 2020, inquiries and requests from companies have surged, and the number of collaborative research projects with companies has increased.

We are also recruiting personnel to develop bio-manufacturing technologies together. We are looking for individuals who are interested in designing and developing bioprocesses using microorganisms and enzymes along those who are eager to create new products and processes using the latest biotechnology and digital technologies.

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 are attracted to RITE's bio-manufacturing, please contact us. We look forward to collaborating with you to drive innovation and sustainability in the bio-manufacturing industry.

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

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

Chemical Research Group

Members (as of April 2025)

Group Leader, Chief Researcher	**Katsunori Yogo**	Research Assistant	**Makoto Asano**
Deputy Leader, Chief Researcher	**Masahiko Mizuno**	Research Assistant	**Hanako Araki**
Chief Researcher	**Hidetoshi Kita**	Research Assistant	**Hiromi Urai**
Deputy Leader, Associate Chief Researcher	**Naoki Kikuchi**	Research Assistant	**Noriko Onishi**
Deputy Leader, Associate Chief Researcher	**Hideki Yamaguchi**	Research Assistant	**Hidenori Ogata**
Associate Chief Researcher	**Narutoshi Hayashi**	Research Assistant	**Kumiko Ogura**
Associate Chief Researcher	**Firoz Alam Chowdhury**	Research Assistant	**Kozue Kataoka**
Senior Researcher	**Teruhiko Kai**	Research Assistant	**Keiko Komono**
Senior Researcher	**Tomohiro Kinoshita**	Research Assistant	**Rie Sugimoto**
Senior Researcher	**Junichiro Kugai**	Research Assistant	**Kazuhiko Tsuda**
Senior Researcher	**Kazuya Goto**	Research Assistant	**Takashi Teshima**
Senior Researcher	**Masahiro Seshimo**	Research Assistant	**Yuko Nara**
Senior Researcher	**Toshinori Muraoka**	Research Assistant	**Yozo Narutaki**
Senior Researcher	**Makoto Ryoji**	Research Assistant	**Akiyoshi Fujii**
Researcher	**Fuminori Ito**	Research Assistant	**Yoichi Fujiwara**
Researcher	**Takayasu Kiyokawa**	Research Assistant	**Yuko Miyaji**
Researcher	**Shuhong Duan**	Research Assistant	**Keiko Mori**
Researcher	**Lie Meng**	Research Assistant	**Atsushi Yasuno**
Researcher	**Soji Yamaguchi**	Research Assistant	**Takahiro Yoshii**
Researcher	**Yoshiyuki Kubota**	Research Assistant	**Naomi Yoshino**
Researcher	**Aoi Torigoe**	Research Assistant	**Junko Yonezawa**
Researcher	**Hiroaki Maeda**		
Researcher	**Go Kato**		

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 current research topics of RITE 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: 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 are being showcased at Expo 2025 Osaka, Kansai.

In 2024, RITE made a significant move in the demonstration of DAC technology at Expo 2025 Osaka, Kansai. Developed under the "Moonshot R&D Program" by the New Energy and Industrial Technology Development Organization (NEDO), a DAC demonstration unit equipped with advanced solid absorbents is actively capturing CO_2 from the atmosphere at Expo 2025 Osaka, Kansai. This exhibition showcases RITE's cutting-edge DAC technology to visitors from Japan and around the world.

Funded by NEDO's program "Establish a common base for evaluating the standards of CO_2 separation materials," RITE Carbon Capture Center (RCCC) was established in February 2025. RCCC is Japan's first actual real gas test center for carbon capture, and it aims to support the acceleration of the development and commercialization of domestic CO_2 capture materials. Furthermore, RITE is the only Japanese member of the International Test Center Network (ITCN), a global coalition dedicated to advancing carbon capture technologies. Through its participation in ITCN, RITE actively works on the construction of an international network and announces to the global Carbon Capture community the activities of the RITE Carbon Capture Center that is contributing to the standardization of CO_2 capture technologies.

RITE is dedicated to developing and commercializing CO_2 capture technologies and providing world-leading R&D results with a special focus on chemical absorption, solid sorbent, and membrane separation. For chemical absorption, high-performance chemical solvent was developed and 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 the solid sorbents to flue gas from natural gas-fired power plants, which contain lower concentrations of CO_2. The 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 Goal 4 "Realization of sustainable resource circulation to recover the global environment by 2050."

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

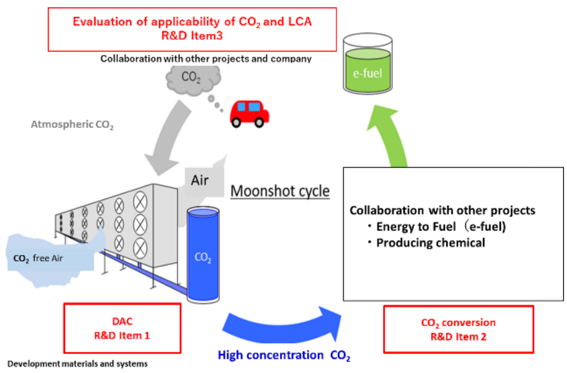


Fig. 1. Development of highly efficient DAC and carbon recycling technologies

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 (Fig. 2), the CO_2 capture performance of real-sized sorbents is evaluated using DAC system evaluation equipment (Fig. 3, designed by Mitsubishi Heavy Industry Co., Ltd., and built on the RITE premises), and improved sorbent structure and optimized operation conditions are predicted by process simulation. In FY2024, a pilot-scale demonstration test on a scale of up to 0.5 t-CO_2/day was conducted at the Osaka-Kansai Expo site, which opened in April 2025, with the cooperation of Mitsubishi Heavy Industries, Ltd. (Fig. 4).

Fig. 2. Lab test equipment for DAC

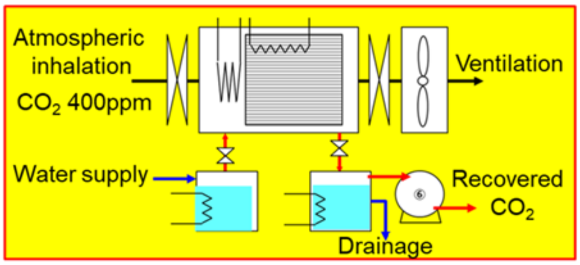


Fig. 3. DAC system evaluation equipment schematic image (upper) and DAC experimental laboratory on the RITE premises (lower)

Fig. 4. Pilot-scale demonstration test equipment installed at the Osaka-Kansai Expo site

The recovered CO_2 will be fed to the methanation facility of Osaka Gas Co. The synthesized methane will be used in the kitchen of guest house. This is the first attempt in Japan to demonstrate effective utilization on such a scale.

4. Common evaluation standard for CO_2 capture materials

In order to move toward decarbonization, fuel and energy sources in both the power and industrial sectors are shifting to renewable energy sources, but a certain amount of fossil-fuel-based thermal power generation remains to meet electricity demand, and CO_2 emissions are inevitable. Therefore, it is necessary to develop low-energy-consumption and low-cost technologies for CO_2 capture from low-pressure and low-concentration mixed gas, for example, a natural gas combustion gas of 10% or less with relatively low CO_2 concentrations.

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). Along with the vision of realizing a carbon neutral society, a common base for CO_2 capture materials will be established, and it will support the enhancement of the global share of domestic companies in the expanded CO_2 capture market.

The project is scheduled for the nine years from 2022 to 2030 (the first stage: 2022–2024) and will carry out the following R&D objectives: (a) formulation of standard evaluation methods using actual gas (installation and operation of RCCC), (b) establishment of standard evaluation methods for the development of innovative capture materials, (c) development of durability evaluation methods, and (d) database construction and popularization of the standard evaluation methods.

RITE formulated standard performance evaluation methods using actual gas and developed a test center (RCCC) in the first stage up to FY 2024 in order to evaluate CO_2 capture materials under the flue gas conditions of power plants and boilers. RCCC was constructed at the RITE headquarters site in Kyoto. Three different test facilities for absorption, adsorption, and membrane processes are installed there, and a natural gas combustion boiler is the source of the actual flue gas (Fig. 5). The test facilities for adsorption (PSA) and membrane processes were installed and preparation for evaluating CO_2 capture materials was completed in FY 2024.

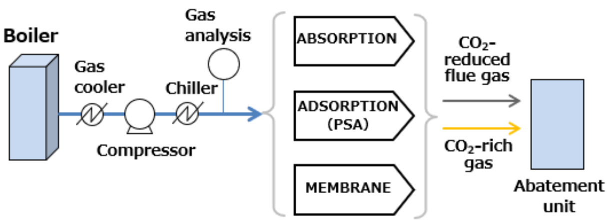


Fig. 5. Overview of RCCC test facilities (Each unit capacity: –100 kg-CO_2/day)

The second phase that will continue until FY2028 was approved upon recognizing the successful achievements of the previous three years based on the results of the stage gate review in January 2025. The test facility for the absorption process will be installed by June 2025 after which operation will start, and another adsorption process (TSA) and single-membrane test facilities will be planned in the first half of the 2nd phase of the project.

In recent years, in the development of CO_2 capture materials for carbon neutrality, test centers for CO_2 capture technologies have been established throughout the world, but such a test center was not organized in Japan. Through the activities at RCCC, we exchange opinions on a CO_2 capture test center with domestic companies in the project and built cooperative relationships with overseas organizations, especially with the International Test Center Network (ITCN) members. RITE provided the first real gas test center in Japan, and it is used by companies and institutions involved in the development of CO_2 capture materials. The test center will contribute to the promotion of domestic CO_2 capture materials development so that Japan will continue to be the world's top operator of CO_2 capture technologies.

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.

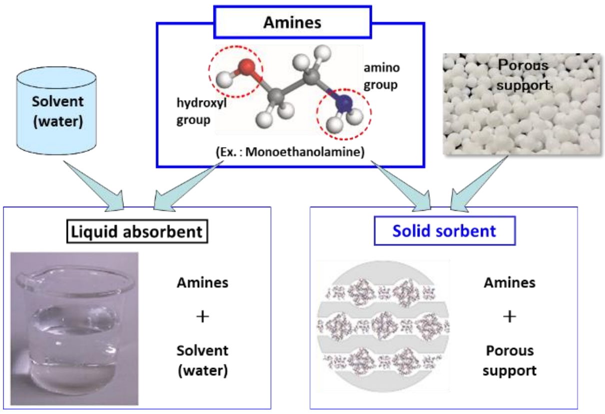


Fig. 6. Liquid absorbent and solid sorbent

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 the pilot scale test facility (40t-CO2/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).

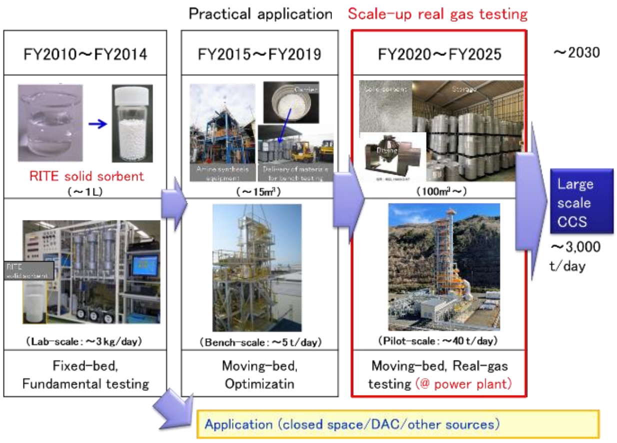


Fig. 7. Development roadmap of the solid sorbent method for CO_2 capture

We are working on elucidating the mechanism of material degradation and developing technologies to prevent degradation, developing technologies to reuse the materials used, and examining handling methods through long-term storage tests, in which we checked the materials periodically for three years after their manufacture and found no abnormalities. 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. 8).

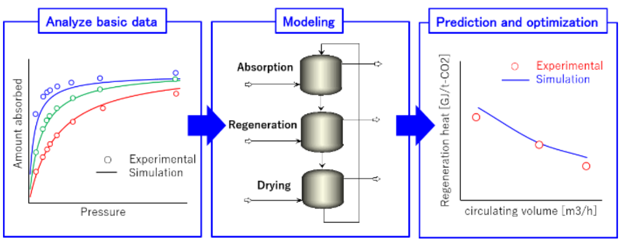


Fig. 8. RITE's simulation technology

In the pilot test, we plan to use this simulation technology to examine optimal operating conditions. Simulations are also useful for understanding the adsorption 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 started jointly with Chiyoda Corporation (organizer company) and JERA in order to commercialize low-cost CO_2 separation and capture processes from natural gas combustion exhaust gas.

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 during the R&D histories in this field, in addition to the development of solid sorbent materials composed of developed amines and optimal support.

RITE passed the stage-gate review in the 3Q of FY2024 by developing a new solid sorbent (Fig. 9), which can change the CO_2 absorption amount significantly with slight temperature changes. As a result, our project was going to move forward from the basic research phase to the bench testing phase.

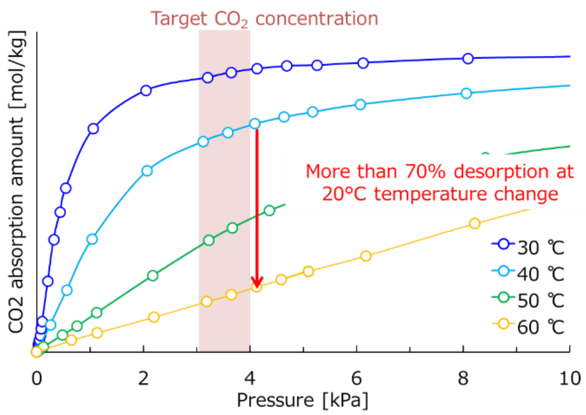


Fig. 9. Absorption isotherms of the developed solid sorbent

The developed new solid sorbent is characterized not only by its ability to be regenerated at low temperatures, but also by its extremely high resistance to oxidative degradation, which makes it applicable to natural gas-fired power plant exhaust gases with relatively high oxygen concentrations. In addition, large scale productivity was confirmed with the aid of chemical manufacturers this year. Further improvements of the solid sorbent will be conducted for bench testing.

6. Chemical absorption method for CO_2 capture

In the absorption method, CO_2 is separated by using the selective dissolution of CO_2 from a mixed gas into a solvent. In particular, the chemical absorption method based on the chemical reaction between amine and CO_2 in a solvent can be 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) and the COURSE50 project (NEDO consignment project), RITE has been working to develop a high-performance amine solvent that reduces 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. (Fig. 10).

Fig. 10. Equipment of energy-saving CO_2 absorption process ESCAP® at Niihama Nishi Power Station, Sumitomo Joint Electric Power Co., Ltd.
(This is the second commercial plant and it produces CO_2 for chemical production.)

Although the chemical absorption method for CO_2 capture is mature, 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.

In COURSE50, we also demonstrated a new technological concept with the possibility of further reducing energy consumption by using the absorption solvent with an organic compound instead of water (Fig. 11). We call the new technology *mixed solvent*, and it can control the reaction mechanism of CO_2 absorption and the effect of polarization.

Since 2022, we have been working to develop novel compounds and optimal formulations of the mixed solvents for practical use under the NEDO Green Innovation Fund Project for the development of hydrogen reduction technology using blast furnaces. In the first half of 2024, bench-scale plant tests were conducted at the

Kimitsu Steelworks of Nippon Steel Corporation. The new high-performance mixed solvents developed by RITE successfully performed CO_2 capture from actual blast furnace gas.

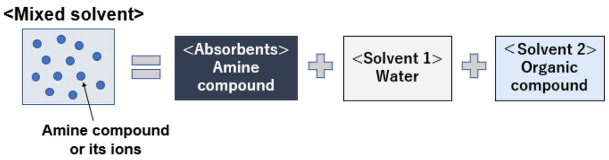
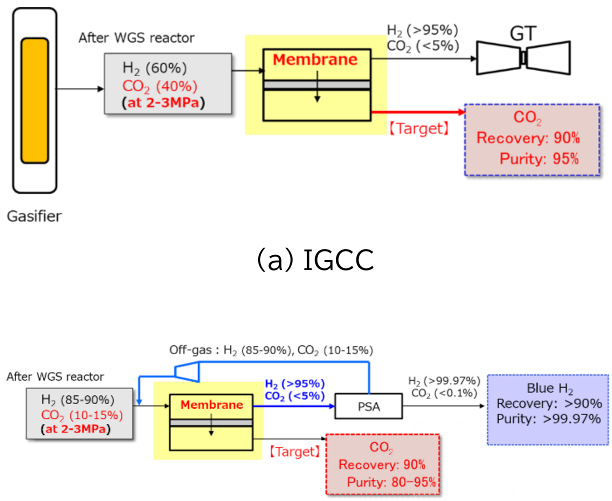


Fig. 11. Concept of mixed solvent

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. As such, CO_2 capture at low cost and low energy is expected by applying the membrane processes to pre-combustion (Fig. 12). For this reason, we are currently developing novel CO_2 selective membrane modules that effectively separate CO_2 for precombustion.



(a) IGCC

(b) Hydrogen production plant

Fig. 12. Schematic of the IGCC and hydrogen production plant with CO_2 capture by CO_2 selective membrane modules

We found that novel polymeric membranes composed of dendrimer/polymer hybrid materials (termed molecular gate membranes) exhibited excellent CO_2/H_2 separation performance. Fig. 13 presents a schematic that summarizes the working principles of a molecular gate membrane.

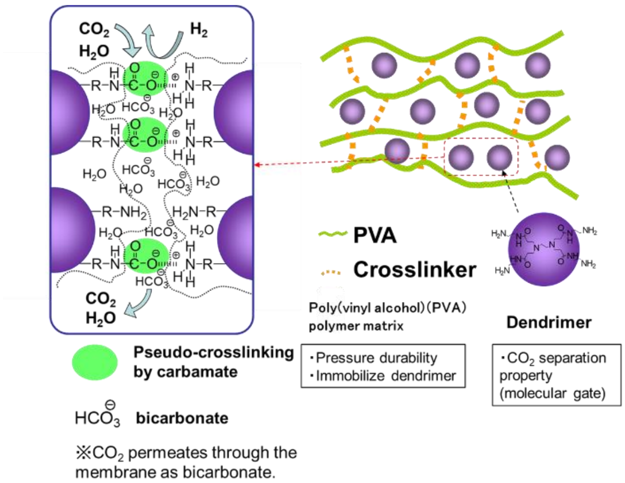


Fig. 13. Schematic illustration of the working principles of the molecular gate membrane

Under humidified conditions, CO_2 reacts with the amino groups in the membrane to form either carbamate or bicarbonate, which then blocks the passage of H_2. Consequently, the amount of H_2 diffusing to the other side of the membrane is greatly reduced, and high concentrations of CO_2 can be obtained. A poly (vinyl alcohol) (PVA) polymer matrix is used for pressure durability and to immobilize the dendrimers.

We developed new types of molecular gate membranes that provide superior separation of the CO_2/H_2 gas mixtures. Based on this work, the Molecular Gate Membrane Module Technology Research Association (MGMTRA consists of the Research Institute of Innovative Technology for the Earth [RITE] and Sumitomo Chemical Co., Ltd.) is conducting research in new membranes, membrane elements, and membrane separation systems.

As for the development of membrane materials, we modified the membrane materials for a new application (small-scale, medium pressure hydrogen production equipment). As a result, separation performance under medium pressure was improved as shown in Fig. 14.

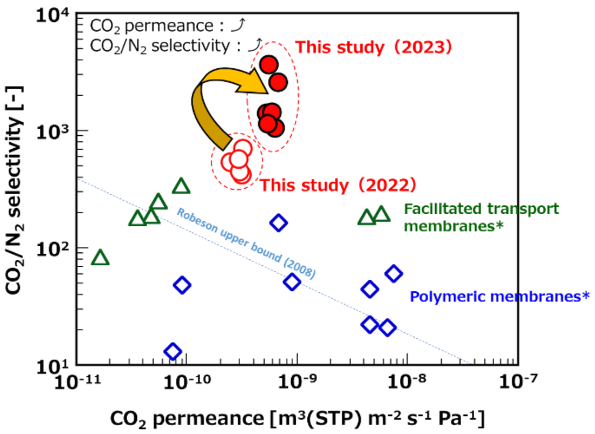


Fig. 14. CO_2/N_2 Separation performance of MGM membranes

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

*Reference: Kamio et al., *J Chem Eng Jpn* 56 (2023) 2222000.

By modifying membrane materials, both CO_2 permeance and CO_2/N_2 selectivity increased compared with our previous modified membranes (in 2022). The separation performance required to apply the membranes for use with hydrogen production equipment was obtained.

As for the development of the membrane elements, we succeeded in developing commercial-size membrane elements (ϕ = 20 cm, L = 60 cm) (Fig. 15).

As of FY 2024, we have started a project in collaboration with Mitsubishi Kakoki Kaisha, Ltd., a hydrogen production system manufacturer, which aimed to conduct demonstration testing of a hydrogen production system with CO_2 capture, under the NEDO-funded project "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."

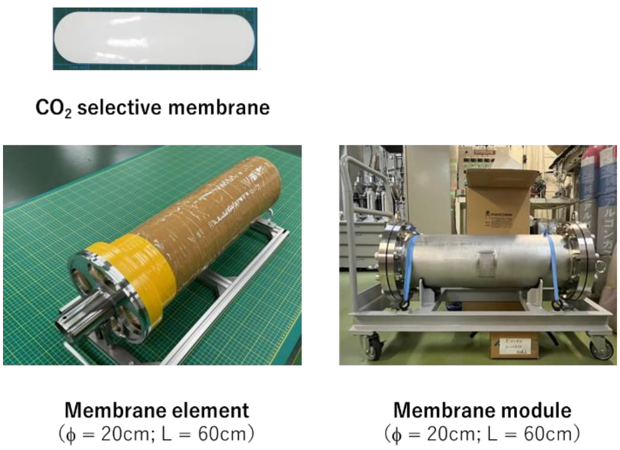


Fig. 15. CO_2 selective membrane, membrane element, and membrane module

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

Carbon dioxide (CO_2) is one of the causes of global warming; therefore, significantly reducing it is a critical global challenge and special importance is attached to Carbon Capture and Utilization (CCU) technologies. However, CO_2 hydrogenation as one of the utilization technologies produces water that causes deactivation of the catalyst and decreases 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 catalyst packed bed reactor. We have been experimentally demonstrating that the CO_2 conversion rate of a laboratory-scale methanol synthesis membrane reactor using the new dehydration membrane is three times higher than that of a conventional catalyst-packed layer reactor. Currently, we are studying the possibility of extending the length of the developed dehydration membrane under the NEDO project "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 FY2024, we focused on improving the reproducibility, confirming hydrothermal stability (durability), and further improving the permeation separation performance of dehydration membranes of practical length (1,000 mm), which show high permeation separation performance. In improving reproducibility, we have succeeded in increasing the yield by improving the synthesis method. In addition, the improved synthesis method resulted in a smaller performance distribution in the longitudinal direction, and we were able to establish a high-performance and highly reproducible method for synthesizing long dehydrated membranes. Fig. 16 summarizes the performance distribution of the long-dehydrated membrane in the longitudinal direction. The coefficient of variation on the vertical axis is calculated from the standard deviation and mean of the permeation separation performance of a sample of 1,000 mm long dehydrated membrane cut into 100 mm pieces, and is smaller as the performance distribution is smaller. Durability tests using cut samples (100 mm) of the obtained long dehydration membranes were conducted to confirm the hydrothermal stability of the dehydration membranes before and after the synthesis method improvement. The results showed that the improved membrane maintained its crystallinity for 500 h, suggesting that it has hydrothermal stability. As mentioned above, the synthesis conditions of the dehydration membrane with high performance have been established in a reproducible manner, and the membrane is steadily progressing toward practical application step by step.

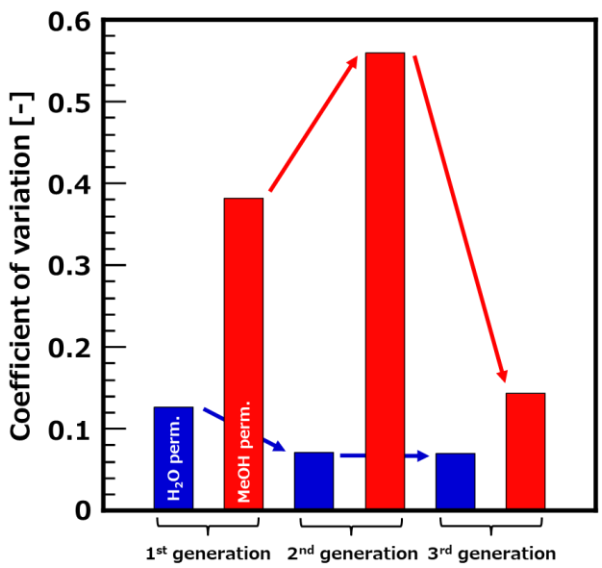


Fig. 16. Performance distribution of long-scale membranes with respect to the longitudinal direction

In the future, we aim to commercialize the developed dehydration membrane with a practical length, and to further improve the permeation separation performance (especially improvement of Si/Al), we will investigate the conditions for synthesizing dehydration membranes on various types of supports.

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. 17). 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.

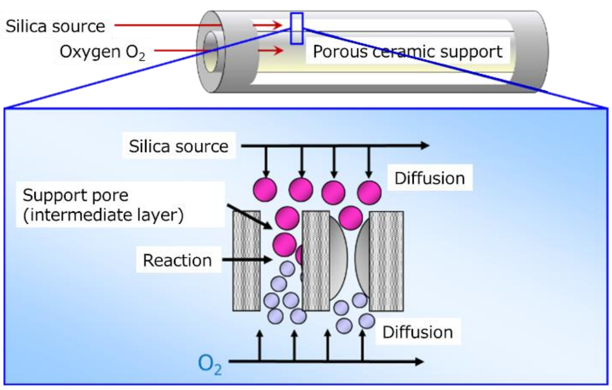


Fig. 17. Schematic diagram of counter-diffusion CVD method

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).

10. CO_2 fixation

CO_2 mineralization is an elemental technology of ‘enhanced weathering’, a negative emission technology in which CO_2 is reacted with alkaline earth metals and immobilized as chemically stable carbonates.

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. 18).

Presently, we are working on process optimization of reaction temperature, reaction time, etc., and are currently studying the commercialization of this process, including scaling up.

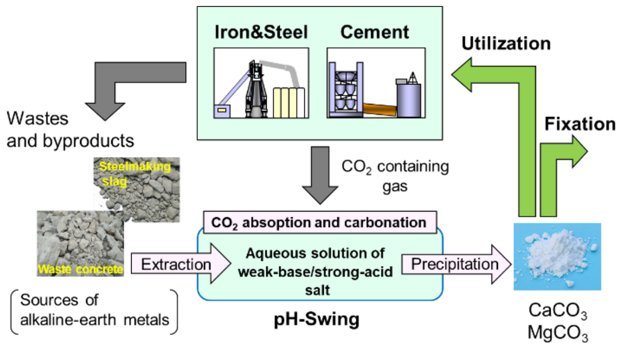


Fig. 18. CO_2 fixation as carbonates

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 43 private companies (as of April 2025) 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 researchers from council members to the Research Section of the RITE and the implementation of training workshops
(3) Offers for technical guidance from the RITE Advisory Board and Research Section
(4) Hosting of exclusive technology seminars for council members

In FY 2024, two research group activities were launched: the CO_2 Separation and Recovery Research Group and the Membrane Reactor Research Group.

In the CO_2 Separation Study Group, RITE presented the latest trends in CO_2 separation mainly from overseas conferences and survey visits, as well as information on RCCC.

In the Membrane Reactor Group, RITE provided information on effective CO2 utilization using membrane reactors and on supports for separation membranes, and one of the private companies of the research group presented the manufacturing supports for separation membranes. The above two research groups ended in FY 2024, and a new research group has been launched in FY 2025 to broaden the scope to CO2 separation and effective utilization.

The members-only free seminars were held three times at a venue and online. Researchers 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 researchers, and *hot topics* once with academic conferences and overseas visits by RITE members, thus contributing to the promotion of technological development and improvement of knowledge of the members.

Two member companies participated in poster presentations at the Symposium on Innovative CO_2 Capture and Effective Utilization held in February 2025.

12. Conclusion

RITE will continue to advance the R&D of CO_2 capture 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.

The RITE Carbon Capture Center (RCCC) will be 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, promoting 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 technologies.

CO_2 Storage Research Group

Member (As of Apr. 2025)

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

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

1. Introduction

In the “GX Promotion Strategy” approved by the Cabinet in July 2023, the government announced its policy to support exemplary and advanced projects in order to create a business environment for the start of CCS projects by 2030. In response, Ministry of Economy, Trade and Industry (METI) and Japan Organization for Metals and Energy Security (JOGMEC) are supporting exemplary projects to establish business models that can be deployed across the nation as “advanced CCS projects” that provide integrated support for the entire value chain from CO_2 separation and capture to transportation and storage. Currently, a total of nine projects are underway that utilize domestic and international storage sites.

RITE is promoting the development of practical CO_2 geological storage technology for use in these CCS projects. RITE has organized the Carbon Dioxide Geological Storage Technology Research Association to collaborate with private companies and other organizations that are CCS providers, and is handling a wide range of technologies that contribute to improving safety and reducing costs in CCS projects, as commissioned by the New Energy and Industrial Technology Development Organization (NEDO), a national research and development agency.

Major themes include: technical demonstration of multi-sensing using optical fiber at domestic and overseas sites, development of evaluation methods for fault safety and integrity around CO_2 storage sites and development of a “CO_2 emission source database” and “CCS project cost estimation tool” that will be useful in the study of basic plans such as value chains and business models for CCS projects. In addition to the above, RITE is also conducting a survey on international trends in policies and technologies through collaboration with international organizations in the CCUS field as a NEDO-commissioned project. The results of these activities are introduced below.

2. Main research topics and results

2.1. Development of multi-sensing technology using optical fibers and field demonstration tests

In order to safely proceed with CO_2 geological storage, it is necessary to confirm through monitoring that the CO_2 injected into the reservoir remains in the reservoir, and that the pore pressure increase caused by the injection does not affect the shielding layer or the wellbore. The monitoring system must operate stably for a long time, have sufficient sensitivity, and be cost-effective. The distributed fiber optic sensing (DFOS) is a promising technology that meets these requirements. RITE is conducting research and development of this technology through laboratory and field tests, and is currently conducting long-term demonstration tests at sites both in Japan and overseas. Below, we explain the principle of optical fiber multi-sensing technology and introduce examples of demonstration tests at sites both in Japan and overseas.

2.1.1. Principle of distributed optical fiber multi-sensing

DFOS is being used in various fields as a technology that can obtain spatially continuous records because the entire fiber can act as sensors. An overview of the measurement principle is shown in Figure 1 (above). When an optical pulse is sent from one end of the fiber connected to an interrogator (measuring instrument), the scattered light is returned from various points along the fiber. By analyzing the scattered light using the interrogator, not only can the data be converted into physical quantities such as temperature and strain, but the reflection point position can also be identified by the arrival time of the scattered light. In addition, the scattering characteristics and measurement target differ depending on the wavelength of the scattered light (Figure 1 (bottom)). Raman scattered light is used for temperature measurement (DTS: Distributed Temperature Sensing), and Brillouin scattered light is used for temperature and strain measurement (DSS: Distributed Strain Sensing). Rayleigh scattered light is widely used in acoustic (DAS: Distributed Acoustic Sensing) measurements, but it is also used for high-precision temperature and strain measurements. These scattered lights need to be measured separately, but by installing a single cable that bundles multiple optical fiber strands, it can be used as a multi-sensor that can simultaneously capture temperature, strain, and acoustics (vibration) along the optical cable. The DFOS has many advantages over conventional monitoring devices such as thermometers and pressure gauges, including the fact that it has no electrical or mechanical devices, can be used in harsh environments deep underground, does not require a power supply, degrades little over time, and is not affected by electromagnetic radiation. It is expected to contribute to the cost reduction of geological storage monitoring.

The application of DTS, DSS, and DAS are described below, and also the main targets of the monitoring for geological carbon storages are summarized in Table 1.

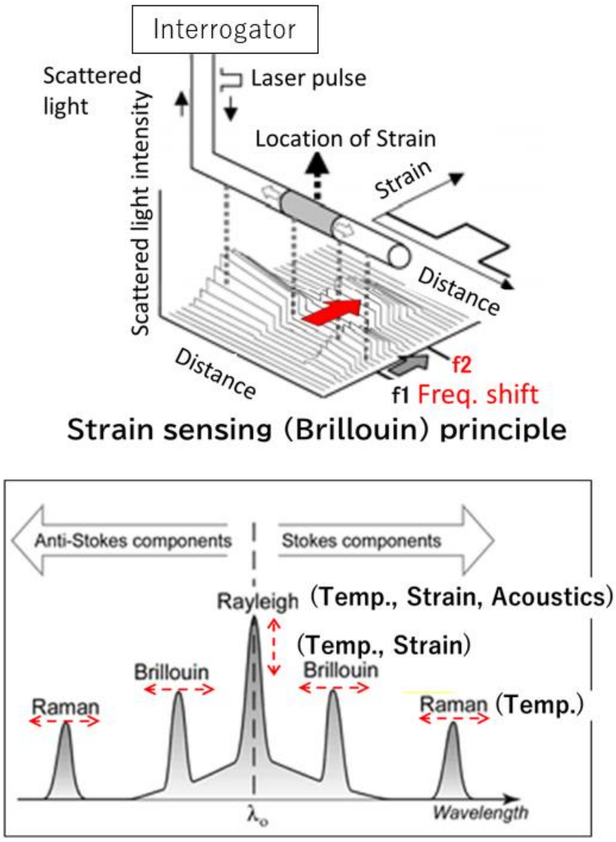


Figure 1 Principles of DFOS

Table 1 Application examples of DFOS

Measurement element	Monitoring targets
Temperature (DTS)	・The injection intervals in the reservoir ・Quality of well cementing ・CO_2 leakage from pipelines and injection wells
Strain (DSS)	・CO_2 intrusion into reservoir ・CO_2 leakage from reservoir ・Deformation of shielding layer during CO_2 injection
Acoustics (DAS)	・CO_2 distribution in the reservoir

2.1.2. Domestic Test Sites

At the test site in Mobara, Chiba Prefecture, field demonstration tests are being conducted for the purpose of developing technology for a CO_2 monitoring system using DFOS. To date, we have developed the fiber optic cables with high sensitivity for DSS that can be installed behind the well casing as well as improved installation operations for the newly designed cables in deep wells, and improved installation equipment. Through field tests at the site, we confirmed that optical cables can be installed behind the casing of wells over 900m deep without impairing the workability of the installation work, as long as the well walls are maintained during drilling (Figure 2). We are also using the installed optical fibers to develop a technology for evaluating the well integrity during cement laying. This technology evaluates the quality of cementing, which has a strong influence on fluid migration along the well, which is an artificial structure connecting the reservoir and the surface. Once the evaluation method identifies defective areas during cementing, it is expected that repairing the well before the start of injection will be possible.

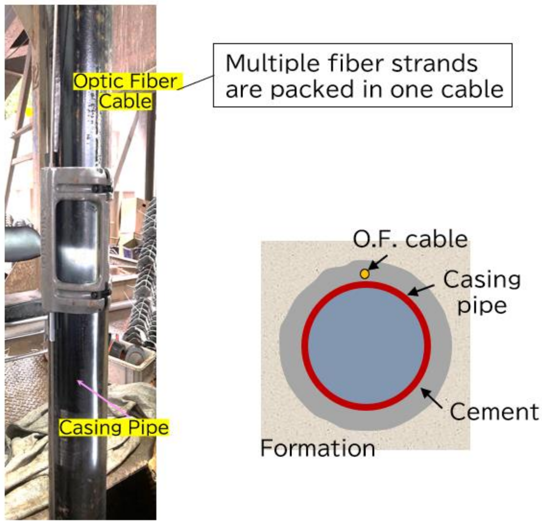


Figure 2 Fiber optic downhole installation

DSS measurements using Rayleigh scattered light were also carried out at the site (Figure 3). The results showed that strains of several tens of με due to fluid injection in nearby wells could be measured. Furthermore, differences in the geological layers and strains corresponding to fluid injection events were clearly confirmed. This result is an example of continuous in-situ acquisition of geological deformation due to fluid injection over time and space, and shows that it is a valuable measurement tool when considering CO_2

injection and ground deformation.

At present, long-term continuous DSS monitoring is being carried out at the site using optical fibers installed in the 900m well. The results of this monitoring are showing strain caused by groundwater pumping and injection around the site, and are expected to be used not only to evaluate the hydraulic properties of the surrounding area, but also to lead to evaluation technology for the effective placement of multiple wells, which will be essential for future geological carbon storages in Japan.

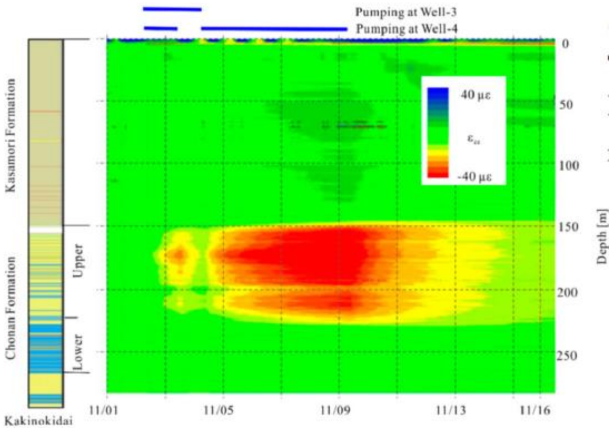


Figure 3 DSS measurement example at Mobara site

2.1.3. North Dakota CCS Site, USA

The North Dakota CCS project is a commercial project in which Red Trail Energy, Inc. is storing approximately 180,000 tons of CO_2 per year, which is recovered during the ethanol production process, in a saline aquifer approximately 2,000 meters deep. Injection begun in June 2022, and approximately 460,000 tons of CO_2 are stored as of the end of March 2025. In addition, the injection and observation wells at this site are wells approved as Class VI in the United States, and this is a demonstration test to be monitored under the US regulatory authorities.

In this project, optical fibers were installed along the wells and CO_2 pipelines (Figure 4), and simultaneous measurements of DAS, DTS, and DSS are ongoing to demonstrate multi-sensing technology. By continuing these measurements, knowledge is being collected on issues and countermeasures in the operation of the monitoring system that will contribute to domestic CCS projects. Below, we introduce examples of DAS and DTS results.

It is expected that the CO_2 plume subsurface is captured by DAS using fiber cables installed in the well. The VSP (Vertical Seismic Profiling), which is particularly suitable for monitoring CO_2 near the well with high accuracy, is a technology that is also used at various storage sites. The North Dakota site also adopts a new technology for the ground vibration sources.

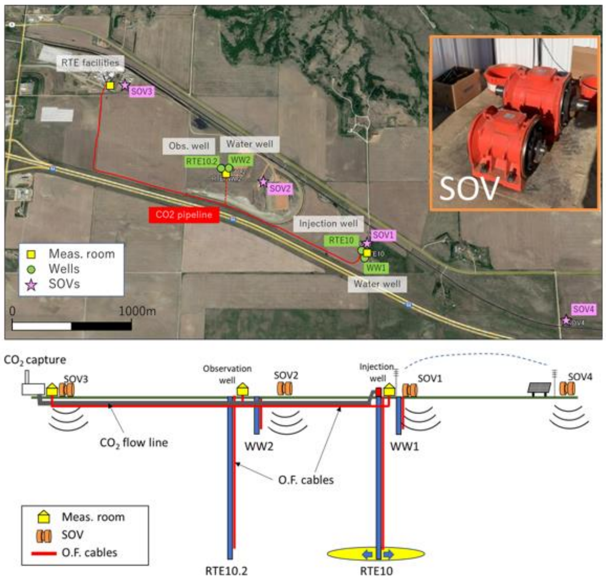


Figure 4 Overview of the optical fiber monitoring system at the North Dakota site and the location of the seismic seismometer

The repetitive seismic surveys are conducted every one to several years for cost considerations. To fill this gap between observations, permanently installed surface orbital vibrators (SOVs) were introduced to enable frequent data acquisition. SOVs transmit vibrations into the strata by rotating an eccentric weight. The control system of SOVs allows for scheduled oscillation by remote control and programming, so no on-site operator is required for SOVs operations. In addition, the data acquired from DAS can be automatically processed by an on-site PC, reducing the amount of data transferred to and from the site. At the North Dakota CCS site, SOVs are installed at four points at different distances from the injection well so that the gradual spread of CO_2 can be monitored immediately after the start of injection, and oscillation is performed every few days.

Figure 5 shows the DAS records of elastic waves emitted from an SOV installed near the injection well at a certain date and time, acquired by an optical fiber installed in the injection well, and the results of data processing. Figure 5a shows that the signal oscillated from the SOV is captured as a direct wave observed at the receiving point at each depth, and as a wave reflected and propagating upward at the formation boundary (reflected wave). In the VSP analysis, only the reflected waves from the received waves are extracted (Figure 5b) and converted to the same depth surface (Figure 5c), resulting in a nearly horizontal reflection surface. Furthermore, by adding multiple traces together, the image of the reflection surface near the wellbore is made clear (Figure 5d). Preliminary analysis confirms a trend toward slower elastic wave velocities in CO_2-infiltrated formations as the extent of CO_2 increases. In the future, it is expected that the spread of CO_2 will be imaged by comparing with the monitoring results of other SOVs and the injection history.

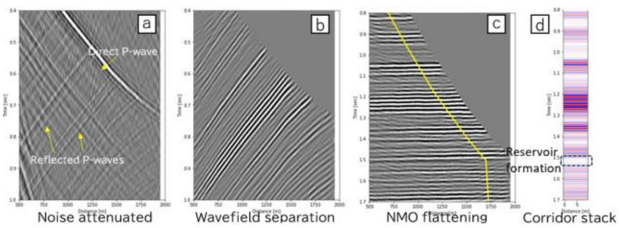


Figure 5 DAS/VSP recording and data processing examples

Next, we show an example of a DTS record obtained at the North Dakota site. Figure 6 shows the time and depth display of the DTS record in the injection well before and after the injection suspension period due to system maintenance, and the depth profile at a certain time section. The pre-injection period (baseline: left blue line in Figure 6) shows the geothermal gradient, whereas during the injection period, the injection well is cooled by CO_2, which is cooler than the ground temperature. Furthermore, during the injection shutdown period, the temperature of the injection well is captured as it returns to the surrounding formation temperature due to the cessation of CO_2 supply. As shown in these results, it was demonstrated that the temperature fluctuation of the entire injection well can be monitored in real time by DTS. Furthermore, if any trouble occurs along the well or pipeline equipped with optical fiber, it is expected that the location can be identified immediately.

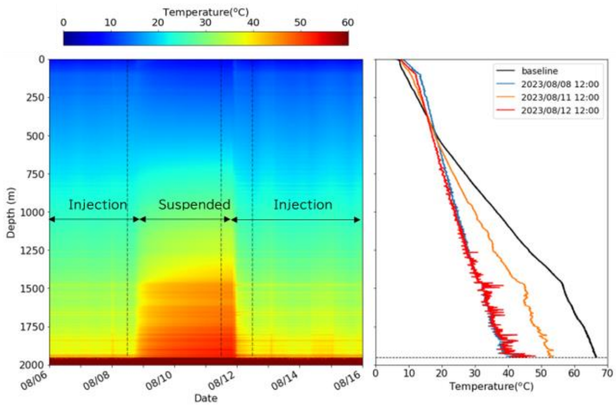


Figure 6 Example of injection monitoring using DTS

2.1.4. Australia Site

At the Australian site, we are conducting field demonstration tests with the DFOS technology to develop technology to evaluate the stability of faults against fluid injection and leakage from fault zones. Faults and cracks in geological strata are issues that must be considered as risks when advancing domestic CO_2 storage projects, and optical fiber multi-sensing technology is considered to be an effective means of monitoring them.

Therefore, in order to establish a technology for evaluating faults using optical fiber, a joint research project with an Australian research institute, which has a test site where known faults are distributed, was launched in FY2021, and field tests are being conducted.

At the Otway site in southwestern Victoria, Australia, testing is underway to detect CO_2 leakage from shallow faults, while the DFOS continues. The site is managed by the Australian research institute CO2CRC, and fluid injection tests were conducted from about the depth of 100 m of the well. RITE installed high-performance DSS fiber cables in newly drilled wells and measured strain during the tests. The depth distribution of the DSS results indicates the heterogeneity of the strata. We are currently examining the results of the seismic exploration to interpret the test results. In the future, we plan to conduct a leak detection performance evaluation test for small-scale CO_2 injection.

At the Perth South site in the southwest of Western Australia, field tests are being conducted to evaluate the stability of deep faults. The site is an existing test site (ISL: In-Situ Laboratory) managed in collaboration with the Australian research institute CSIRO, and the existence of a large fault zone several hundred meters deep is known (Figure 7). By the end of last year, the seismic survey was carried out to image the faults, observation wells were drilled, and optical fiber cables were installed in the well, and continuous DSS were performed. This year, a new well was drilled for fluid injection for the purpose of fault stability evaluation tests, and the geological properties were evaluated. In the future, a fluid injection test from this new well is planned to be carried out.

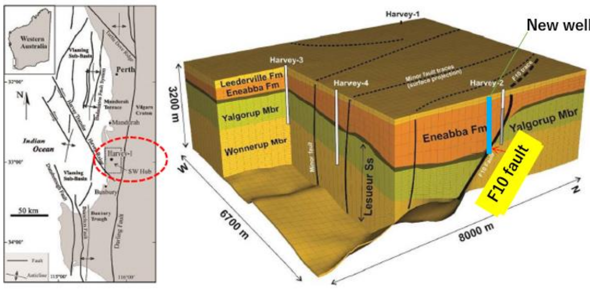


Figure 7 Faults and new well locations at the Perth South site

2.2. Support for CCS business plan development

The CCS Business Act was promulgated in May 2024, and the business environment for CCS is improving and CCS business development is progressing smoothly, with activities of advanced CCS support projects expanding.

RITE is also conducting research and development to support the development of large-scale CCS projects. Specifically, we are developing a CO_2 emission source database that will be useful in setting up a CCS project model and a CCS economic assessment tool that is necessary for evaluating the economic viability of CCS. Below, we will report on the details of each research and development project and introduce an example of a CCS project plan formulation support that combines them.

2.2.1. Development of a CO_2 emission source database

For the commercialization of CCS, it is important to appropriately match CO_2 emission sources with storage sites. Therefore, RITE is working on the development of a CO_2 emission source database (hereinafter referred to as emission source DB) to support this matching.

Below, we will introduce the data structure, functional overview, and future developments.

(1) Data structure of emission source DB

More than 10,000 pieces of CO_2 emission source information are registered in the public data based on the

Ministry of the Environment's "Greenhouse Gas Emissions Accounting, Reporting, and Publication System" (hereinafter referred to as "Global Warming Act Data"). The Emission Source DB uses this information as a base and takes the following steps a), b), and c) to suit the characteristics of decarbonization through CCS.

a) Estimation of direct CO_2 emissions and compilation of a database

The CO_2 emissions of each business site in the TOC data include CO_2 equivalent to electricity and heat supplied by others as a number.

CCS is intended to capture and store the direct CO_2 emissions actually emitted by the business site, so it is necessary to exclude CO_2 emissions equivalent to electricity and heat. Therefore, a "direct emission coefficient" is calculated for each business type using certain statistical processing, and this is multiplied by the CO_2 emissions under the Global Warming Act to calculate the direct CO_2 emissions from each business establishment, which are then entered into the database.

b) Incorporation of biomass fuel CO_2 emissions source information

The data in the Global Warming Law covers CO_2 emissions from fossil fuels, and CO_2 emissions from biomass fuels are not covered because they are carbon-neutral. On the other hand, biomass power plants also emit CO_2, which can be captured and stored for BECCS and negative emissions, which are important factors in promoting decarbonization. Therefore, we are also investigating CO_2 emission source information from biomass fuels with reference to information from the Agency for Natural Resources and Energy's Electricity Survey Statistics, etc., to estimate CO_2 emissions and incorporate them into an emission source DB.

c) Reflection of storage potential information

Storage potential mapping information from the "National Reservoir Resource Survey" conducted by RITE is also reflected in the emission source database.

(2) Realization of information mapping and screening functions

a) In order to properly match CO_2 emission sources and reservoirs, it is important to visually capture their location. Therefore, we realized a function to map the data shown in (1). Figure 8 is an example of such a mapping, which makes it possible to easily capture features such as emission sources are concentrated on the Pacific Ocean side and storage sites are mostly located on the Japanese side.

Figure 8 Example of integrated display of CO_2 emission sources and storage potential

b) Information Screening Function

The visualized map can be freely moved and specific locations can be zoomed in on. Furthermore, by drawing a rectangle around a certain area, information on the CO_2 emission sources in that area can be extracted, which can be used for clustering emission sources. Furthermore, it is possible to display information by emitting business, such as coal-fired power plants and factories. For example, by displaying only CO_2 emission sources from biomass fuels, it can contribute to the planning of CO_2 emission offset strategies through the conversion to BECCS.

This database is available for general use to those who wish to try it from November 2024. If you are

interested, please refer to the following
https://www.co2choryu-kumiai.or.jp/business/theme/

(3) Aiming to predict and display future developments of CO_2 emission sources

The full-scale deployment of CCS requires a long-term effort, and the composition of thermal power plants and factories is expected to change during that time. Therefore, we have begun developing a function that predicts changes in CO_2 emission sources from 2025 to 2050, incorporates this information into the CO_2 emission source database, and displays the time-series changes in emission sources on a map.

We are currently proceeding with the development of this system with reference to the carbon neutralization plans for coal-fired power plants published by electric power companies, but we would like to expand this system to large-scale factories after obtaining knowledge from related parties. We would appreciate your cooperation.

2.2.2. Development of a CCS economic cost estimation tool

In the commercialization of CCS, it is essential to set up an appropriate business model that takes into account economic feasibility, including the combination of emission sources and storage sites, and the transportation routes and technology methods that connect them. To this end, it is effective to utilize the CO_2 emission source database and cost estimation tool described above in an integrated manner.

The following is a description of the basic functions and configuration of the cost estimation tool that RITE is developing, as well as the flow of cost estimation.

(1) Basic Functions

CCS is divided into capture, transportation, and storage processes, and the tool can calculate CAPEX and OPEX per t-CO_2 for each of these processes. Figure 9 shows the modules in the calculation engine.

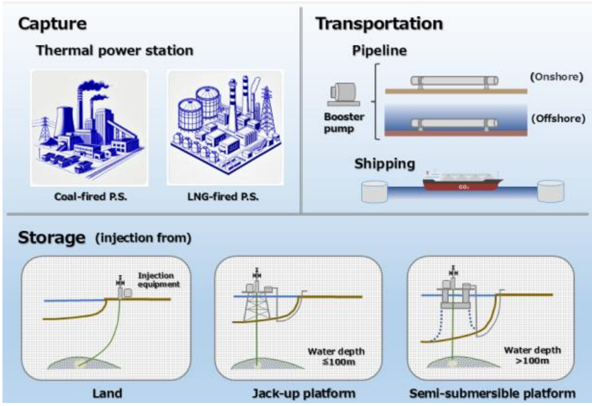


Figure 9 Modules installed in the calculation engine

In terms of capture, estimates are currently available for coal-fired and LNG-fired power plants. In the future, we plan to address emission sources in the industrial sector, such as steel mills and cement plants.

For transportation, the tool supports both land-based and submarine pipeline transportation and ship transportation. For vessel transport, the number and size of vessels that meet the operating conditions are automatically calculated by entering the required parameters, such as transport distance, sailing speed, and number of standby days.

For storage, the system automatically selects one of three technical methods depending on the distance from shore and water depth. For offshore distances of 3 km or less, the method in which an inclined well is injected from land is selected. For offshore distances of more than 3 km, the bottom-fixed type is selected when the water depth is less than 100 m, and the floating type is selected when the water depth is deeper than that.

(2) Tool function configuration

The cost estimation tool consists of three functions in addition to the input interface (Figure 10).

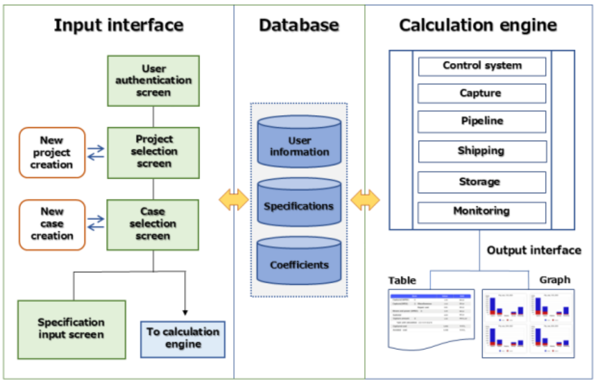


Figure 10 Functional configuration of the cost estimation tool

The input interface is a function that allows the user to input calculation specifications and send instructions to the tool.

The database holds authentication information, calculation specifications, and various coefficients and tables used in the calculations.

The calculation engine is a unit that calculates costs based on specifications. There are multiple modules, such as capture, pipeline transportation, ship transportation, storage, and monitoring, which are executed sequentially under the control of the calculation control program. The calculation engine also implements an output interface function for the calculation results (display of tables and graphs).

(3) Cost estimation process

a) Setting calculation conditions and preparing specifications

First, a business model is established, including the location of the emission source and storage site, the transportation route, and the technology method. Next, specifications such as the business period, CO_2 processing volume, discount rate, exchange rate, transportation distance, transportation method, storage depth, and injection rate are prepared. Since some of these are closely related to management policies and strategies, it is desirable for business planners and analysis engineers to work together to consider them.

b) Use of tools

This tool is a web tool and can be accessed using a standard browser (Edge, Chrome, etc.) anywhere with an internet connection.

The data entry screen (Figure 11) is prepared for each process, such as capture, transportation, storage, and monitoring, and the screen can be switched by tabs. After entering all items, save and return to the case selection screen (Figure 12) and instruct to execute the calculation.

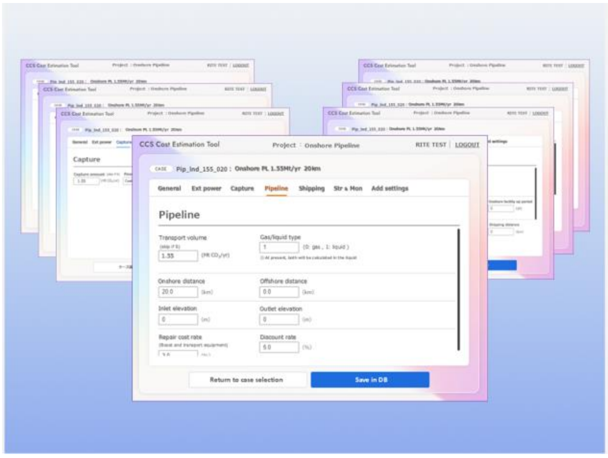


Figure 11 Specifications input screen

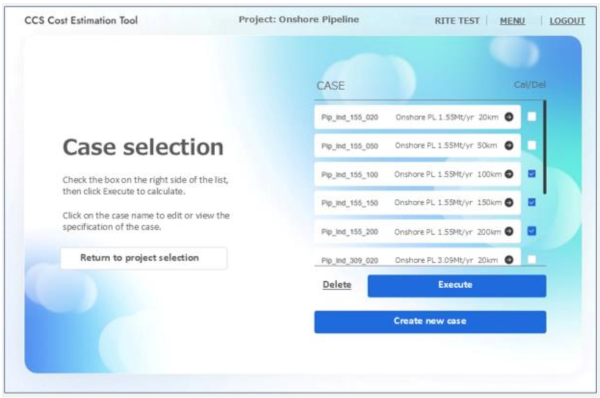


Figure 12 Case selection screen

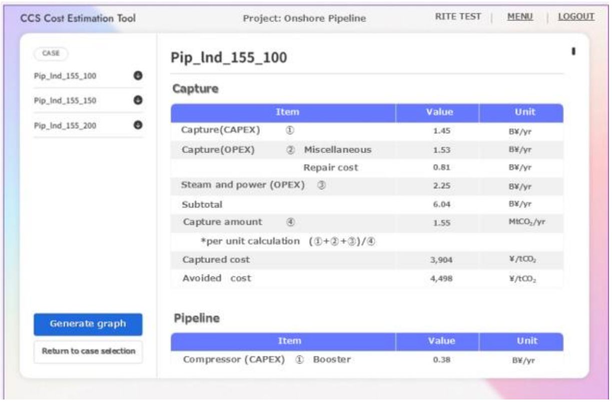


Figure 13 Output screen of the calculation results (table)

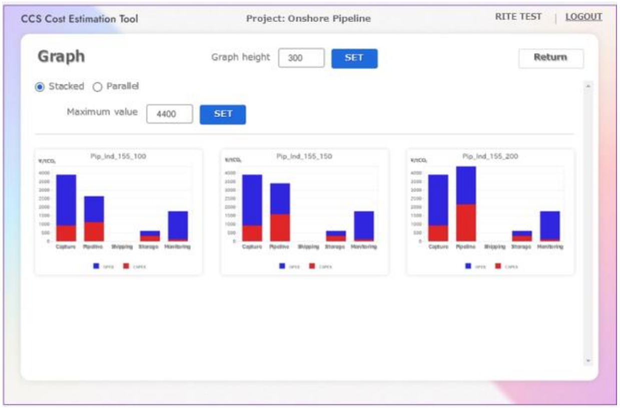


Figure 14 Output screen of trial calculation results (graph)

When the calculation is completed, the costs for each process are output in table format, followed by a list of the calculation specifications (Figure 13). There is also a function to display the costs in graph form (Figure 14). The graph shows the costs for each process, broken down into CAPEX and OPEX, and is designed to display the costs for multiple cases on the same screen so that they can be compared.

2.2.3. Examples of CCS business plan formulation support

We have introduced the functions and usage examples of the CO_2 emission source database and the CCS cost estimation tool so far, and below we will introduce an example of formulating a CCS business plan that combines these.

(1) Setting the business model

As a CCS project, “the basic plan is assumed to be “Two LNG-fired power plants in the Tokyo metropolitan area will be selected as emission sources, and the CO_2 captured there will be stored in the Japan Sea area.”

To materialize the plan, the CO_2 emission source database was used to set up an LNG-fired power plant and a port for transporting the captured CO_2. The Japan Sea area was selected as the storage point, and the transport distance (ship and pipeline transport) was determined.

(2) Economic evaluation and business plan consideration

In order to evaluate the economic viability of the above business model, first set the specifications as shown in Figure 15 and calculate the overall business cost using a economic assessment tool.

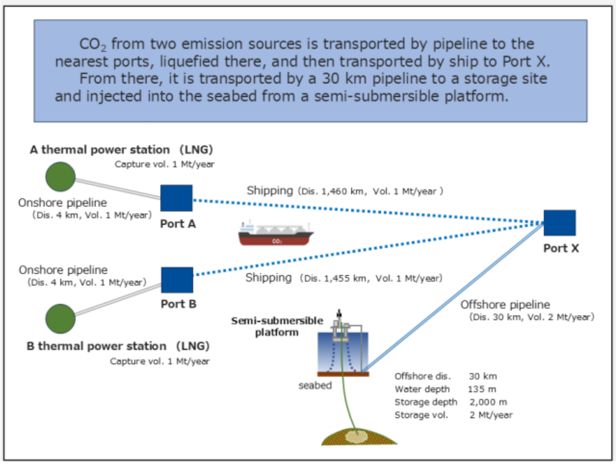


Figure 15 Specifications for cost calculation

In order to optimize the business model, it is necessary to use this as a base case and analyze and evaluate it through case studies.

As an example, we estimated the costs of consolidating CO_2 sending ports A and B into one and replacing ship transport with pipeline transport. The results quantitatively show that cost reductions are possible through port consolidation or pipeline transport (Table 2).

Table 2. Cost estimation case study (example)

case	Cost (relative value)
base	100
Port consolidation	95
Pipeline Transportation	85

In this example, a very simple case was used, but even when multiple business models are used, economic evaluation can be performed quickly by linking the CO_2 emission source database with the CCS cost estimation tool. It is effective as a tool to support efficient business plan formulation.

2.3. International CCS Trends

In order to achieve the goal of commercializing CCS by 2030 as set out in Japan's long-term CCS roadmap, efforts are being made to resolve institutional and technical issues, such as establishing financial incentives, reducing costs through expansion of scale, and promoting Japanese technology overseas.

RITE, aiming at utilizing in discussions on the dissemination of CCS, cooperates with relevant international organizations where efforts have been gaining momentum in recent years, as well as international conferences such as the London Convention on Subsea Storage of CO_2 and Transboundary Transport, collects information at each conference, and disseminates Japan's efforts.

Additionally, we are investigating international trends such as CCS financial support systems and project scale expansion through interviews and literature surveys.

We introduce trends in major countries, with a focus on Europe where support systems and projects have become more active in recent years as followings.

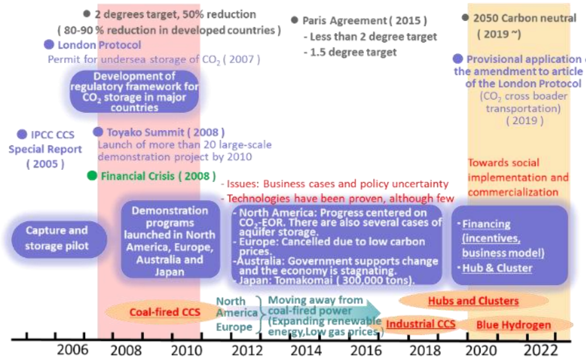


Figure 16 Changes in global regulations and incentives

2.3.1. Background to the introduction of CCS in Europe, policy priorities, etc.

(1) Climate change measures

In response to the 50% reduction by 2050 (80-90% reduction in developed countries) at the 2009 G8 Summit, etc., emissions trading systems and regulatory frameworks for CO_2 storage were established in major countries and demonstration projects, etc. were launched. But some CCS projects were cancelled in Europe due to stagnant carbon prices and expansion of renewable energy.

On the other hand, with more than 100 countries declaring carbon neutrality by 2050 at COP25 in 2019 in response to the Paris Agreement, international understanding has developed that CCS, CDR (CO_2 removal), etc. are essential for hard to abate sectors (cement, steel, oil refining, air transportation, etc.) where CO_2 emissions are inevitable by methods of electrification and hydrogenation, Carbon management policies in each country have been strengthened.

(2) Achieving net zero emissions in the industrial sector and securing CO_2 storage capacity

The Council of the European Union (EU) approved the Net-Zero Industry Act in 2024, setting a goal of securing 50 million tons of CO_2 storage and injection capacity per year in the EU by 2030 in order to reduce emissions from the industrial sector.

(3) The need for international CO_2 transport

infrastructure

In its Industrial Carbon Management Strategy, the EU cited the need for international CO_2 transport infrastructure in addition to storage capacity for CO_2 that cannot be stored or used at capture sites and to create a single EU carbon market.

(4) The need for financial support systems

At present, the carbon price under the emissions trading system, which represents the cost of CO_2 countermeasures without introducing CCS, is smaller than the costs of capture, transportation, and storage. At the same time, it is currently difficult to pass on all the introduction costs to customers. Therefore, it is recognized that public support is important for the implementation of CCS.

(5) Promoting hubs and clusters

Emphasis is being placed on hubs and clusters of emission sources and transport and storage infrastructure, from the perspective of reducing costs by bundling multiple projects on a larger scale and prioritizing decarbonization of industrial clusters.

2.3.2. Trends in Europe

(1) EU

To promote the development of international CO_2 transport infrastructure, the CEF-E (Connecting Europe Facility for Energy) Fund, which supports trans-European energy infrastructure, supports cross-border CO_2 transport projects, etc. In addition, the EU Innovation Fund, which is funded by revenues from the EU-ETS, supports CO_2 capture in the industrial sector, etc.

Improvements to the EU Emissions Trading Scheme (EU-ETS) are also underway. EU plans to phase out the free allocation of emission credits to specific industries by 2034. The free allocation is intended to prevent carbon leakage (transfer of production to other countries with less stringent regulations, etc.), but on the other hand, it is a response to the problem of undermining incentives for investment in emission reductions. In addition, a carbon pricing on imports goods equivalent to that in the EU (Carbon Border Adjustment Mechanism (CBAM)) will be introduced.

(2) United Kingdom

UK is promoting CCS with an emphasis on the transition to net zero and employment and economic growth through CCS, with a goal of 20 to 30 million tons per year by 2030. Four clusters that will be operational by 2030 have been selected, and support of approximately 22 billion pounds for two of them was announced by the Prime Minister, the Minister for Energy Security and Net Zero, and the Chancellor of the Exchequer in autumn 2024. Licenses for transportation and storage have also been granted to operators, and an investment decision was made for the East Coast cluster at the end of 2024.

Targets for introduction have been set for each of the following sectors: manufacturing, waste treatment, blue hydrogen, power generation, and CDR (CO_2 removal, BECCS (capture and storage from biomass combustion) and DACCS (direct air capture and storage)), and support programs have been designed to enhance the predictability of the projects. The support system is highly compatible with existing renewable energy support systems and focuses on price differences, specifically, support for price differences between CCS costs and CO_2 control costs such as EU-ETS prices.

(3) Norway

Norway has abundant oil and gas resources and saline aquifers in the North Sea, and has a track record of working on the world's first CCS project for storing in saline aquifers.

Anticipating the development of a European storage hub, the government is supporting the international capture, transportation, and storage project (Longship) for manufacturing industries or so with subsidies and carbon tax exemptions. The facility for the transportation and storage process (Northern Lights) has been completed, and CO_2 shipping and storage from a domestic cement plant or so is scheduled to begin in 2025, with plans to import from the Netherlands, Denmark, and other countries (initial capacity of 2.5 million tons/year). Northen Lights project has received approximately 130 million euros from the CEF-E fund and has decided to make additional investments, including imports from Sweden, with plans to expand capacity to more than 5 million tons/year.

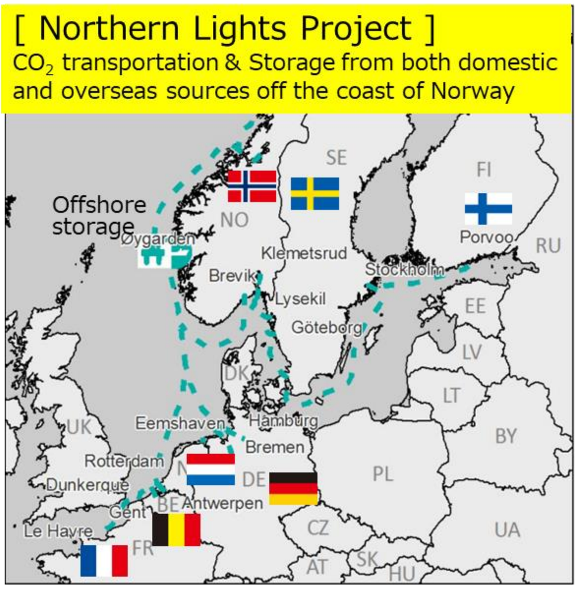


Figure 17 Northern Lights Project (cross-border transport and storage)

Source: Northern lights project. Project of Common Interest, European Union,
https://ec.europa.eu/energy/maps/pci_fiches/PciFiche_12.4.pdf

(4) Netherlands

The Climate Act in 2019 sets a target of reducing CO_2 emission by 49% by 2030 (compared to 2019). The plan is to utilize offshore CO_2 storage sites and use CCS to address roughly half of industrial emissions. For this purpose, from 2020 the scope of financial support systems for existing renewable energy power generation etc. was expanded, and price differential support for capture, transportation and storage was started.

Four capture projects were selected in Rotterdam in 2020, which will use the Porthos project, the EU's first transportation and storage hub.

The Porthos project (2.5 million tons/year) began construction in 2024, with operations scheduled to start in 2026. The onshore pipeline will be built with a final capacity of 10 million tons/year, anticipated to be shared with the planned international CO_2 transport and storage project (Aramis) which receives approximately 100 million euros from the EU CEF-E fund.

(5) Denmark

In the Climate Act of 2020, the goal is to reduce GHG emissions by 70% by 2030 (compared to 1990 levels) and to achieve carbon neutrality by 2050.

For CCS, the government supports price differentials for installation costs and selected the Ørsted project to export CO_2 from a biomass power plant to the Northen Light project in Norway in the first round of public bidding. In addition, the Greensand project received CO_2 from Belgium and succeeded in the world's first transboundary ship transportation and injection in 2023.

(6) Germany

It is aimed to reduce GHG emissions by 65% by 2030 (compared to 1990 levels) and to achieve carbon neutrality by 2045. However, a federal government report recommended issues such as the fact that the existing legal framework does not allow CO_2 pipeline transportation. As a result, the basic principles of the carbon management strategy were approved by the Cabinet, and based on this, a bill to amend the Carbon Storage Act was submitted to the Diet in 2024.

Additionally, support for climate change measures in the industrial sector began in 2024. As mentioned above, due to delays in the development of legal regulations, public bidding for support for CCS projects are scheduled to begin after 2025.

2.3.3. Trends in North America

The United States and Canada lead the world in terms of progress and deployment of CCS projects, with more than 20 projects in operation.

(1) United States

CCS projects in the U.S. are largely due to the existence of 4,000 miles of CO_2 pipelines and numerous CO_2-EOR sites that have been developed since the 1970s for CO_2-EOR (enhanced oil recovery).

CCS has been supported since 2008 by granting tax credits based on the amount of CO_2 geological storage. Since then, support for tax credits has been strengthened several times, and CCS projects, especially for low-cost ethanol plants have been increasing and DAC has also been added to the list. In addition, subsidies to support CCS in cement and other manufacturing industries with high recovery costs and low-interest loans to support CO_2 transportation infrastructure are being provided

(2) Canada

Although Canada is a resource-rich country, it is working on carbon neutrality by introducing CO_2 emission regulations such as a carbon tax.

Large-scale CCS projects are being implemented in Alberta and Saskatchewan, where oil and gas production is active.

Support measures for CCS vary from province to province, and Alberta, for example, has been supporting CCS projects by granting CO_2 credits. Alberta has also selected projects for hubs and is providing support for exploration costs. Meanwhile, the federal government's investment tax credit was enacted in 2024, supporting collection, transportation, storage, utilization, and DAC, and also providing support by investing in CCS projects through a fund.

2.3.4. Trends in Australia

Australia is a resource-rich country with large exports of LNG and coal, and is promoting decarbonization in all sectors, including oil and gas operations, with the goal of carbon neutrality in 2050 and a 43% reduction by 2030 (compared to 2005 levels). The safeguard mechanism sets an emissions cap for large emitters of 100,000 t-CO_2 or more per year, requiring them to contribute to carbon neutrality by 2050, and the cap will be reduced by approximately 5% each year until 2030. This makes it difficult to release CO_2 associated with natural gas production into the atmosphere, making the application of CCS inevitable. The Gorgon project, which stores CO_2 associated with natural gas production on land, began operation in 2019 and Japanese companies are participating.

There is also storage potential in ocean area (offshore), and exploration permits for 10 areas were opened to the public in 2023, so offshore CO_2 storage is expected to expand in the future.

There is also growing interest in CCS hubs to capture CO_2 emissions from LNG, hydrogen, ammonia production and industrial sectors.

Federal support is provided through the granting of carbon credits. The Moomba project (operational in 2024), which store CO_2 from the LNG plant in an onshore depleted gas field and serve as a CCS hub, is receiving this support.

The state of Victoria, which has abundant storage potential, is planning to build a CCS hub with funding from the federal government (CarbonNet project). The project involves transporting CO_2 via pipeline to offshore reservoirs, and FEED (basic design) has now been completed. The Japanese government agencies and a CCS-related company have also taken notice, and have established a cooperative framework, including signing an MOU with the state government.

The federal government is also working to establish laws regarding the import and export of CO_2. The Bayu-Undan project, which aims to store CO_2 in a depleted gas field in Timor-Leste's territorial waters, is planned in conjunction with gas field development by an

Australian company, and there are also plans to receive and storage CO_2 from other countries as a CCS hub.

The Moomba project mentioned earlier is also studying to receive CO_2 from Japanese companies, and Japanese companies are also involved in several other CCS projects as partners.

RITE Future Forest
Ongoing at World Expo 2025 Osaka, Kansai, Japan!
(April 13 to October 13, 2025)

Members of Office for Expo 2025 Osaka Kansai (as of Apr. 2025)

Director	**Yasuhide Nakagami**	**Noritaka Mochizuki** (concurrent)
Deputy Director	**Tetsuya Deguchi**	**Junichiro Kugai** (concurrent)
Acting Director	**Naoki Kikuchi** (concurrent)	**Saeko Mito** (concurrent)
Acting Director	**Nobuo Umeda** (concurrent)	**Shoichiro Hozumi** (concurrent)
Chief	**Kayoko Mori**	**Yoshiyuki Kubota** (concurrent)
	Maki Kasuga	**Naomi Kurahashi** (concurrent)

1. What is the RITE Future Forest?

As a Silver Partner of the Future Society Showcase, Green Expo in the ongoing World Expo 2025 Osaka Kansai, Japan, the Research Institute of Innovative Technology for the Earth (RITE) is exhibiting the RITE Future Forest to publicize negative emission technologies featuring Direct Air Capture (DAC).

Figure 1 RITE Future Forest (panoramic view)

The exhibition is named "RITE Future Forest" because DAC removes CO_2 from the air in the same way as a natural forest.

In the RITE Future Forest, visitors first watch a 3D video image in the Guidance Hall, which provides an overview of the global warming issue and an explanation of the necessity of DAC and carbon dioxide capture and storage (CCS). Subsequently, visitors are guided through DAC plants where a demonstration test is in progress as part of the Moonshot Research and Development Program of the New Energy and Industrial Technology Development Organization (NEDO), an exhibition on the CCS technology (CO_2 separation, collection, and geological storage technology) that RITE has continuously researched, and other next-generation technologies indispensable for achieving a carbon-neutral society.

Visitors also see exhibition booths for Nagoya University and Kyushu University, which similarly conduct DAC research as part of the Moonshot Program, and for Maeda Road, which pursues CO_2 locking in asphalt with minerals. With hands-on exhibits, these technologies are explained in an easy-to-understand manner.

2. Guidance Hall and a video image for explanation

The Guidance Hall, which welcomes visitors first, is a wooden building in a Cross Laminated Timber (CLT) panel-folded structure that combines sustainability and architectural beauty. The architectural method that folds a CLT panel in an origami-like manner achieves high strength and an open space without pillars. Inside the Guidance Hall, the latest 3D imaging technology dispenses with goggles and provides explanations on global warming and negative emission technologies in a story format that is easy to understand for children and adults.

Figure 2 Guidance Hall

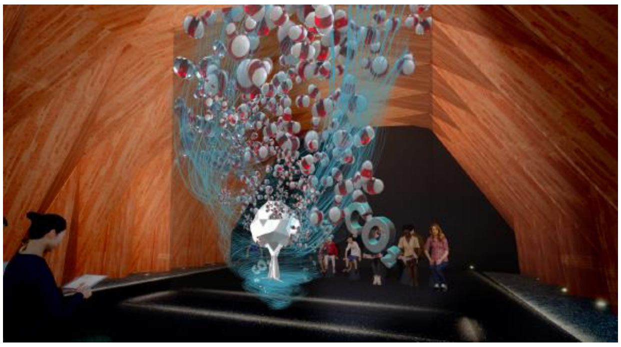


Figure 3 Video image

3. DAC demonstration plants

Visitors can see DAC plants, where a demonstration test is in progress for actually removing CO_2 from the air on the EXPO site. They consist of three plants, all of which are seven meters in total length. And, various tests are conducted there as part of the Moonshot Program during the EXPO period, including process checks and the performance testing of absorbents.

The CO_2 removed by DAC is transported off the EXPO site to be stored on the storage sites of the members of the Geological Carbon Dioxide Storage Technology Research Association. The CO_2 is also supplied for effective use to the adjoining methanation facility of Osaka Gas, and the CO_2 recovery and dry ice production system of Air Water.

Figure 4 DAC demonstration plants

4. Study tours

Study tours of the RITE Future Forest are available (closed every Thursday). Six tours are offered daily, with a maximum capacity of 20 participants in each tour.

Because the RITE Future Forest is located in a controlled area that is not accessible for general visitors on foot, tour participants need to travel on a dedicated EV bus. The tour starts at the East Gate South Stop after passing through the East Gate of the Expo site from Osaka Metro Yumeshima Station. After two or three minutes on an EV bus, participants arrive at the forest to watch the explanation video in the Guidance Hall, visit the actual DAC demonstration plants, and experience RITE technologies through exhibits. The content is easy to understand not only for businesspersons but also for students and general visitors. Reservations for the tour can be made on RITE's website "RITE Future Forest." We look forward to seeing you at the forest!

5. Conclusion

The concept of the World Expo 2025 Osaka, Kansai is "People's Living Lab." Through the Expo as a global forum for promoting future technologies, RITE publicizes these negative emission technologies featuring DAC to the world. Do not miss this opportunity to experience the actual DAC plants as the cutting-edge technology for countering global warming.

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 Apr. 2024	Nara Prefectural Seisho Senior High School	24
14 Jun. 2024	Society of Physics and Chemistry for Nara Prefectural Senior High School	20
26 Jul. 2024	Kyoto Prefectural Nishimaizuru High School	14
1 Oct. 2024	Nara Prefectural Narakita Senior High School	17
10 Oct. 2024	Izumo Senior High School	41
5 Dec. 2024	Seikanishi Junior High School	7
7 Mar. 2025	Kasagi Junior High School	4

◆Environmental Education (Outreach Lecture)

Date	Title	Number of participants
6 Feb. 2025	Takada-Nishi Junior High School	120

◆Environmental Education (Workshop)

Date	Title	Number of participants
6 Aug. 2024	Craft and Science Experiment to Learn about Global Warming and Energy	43

RITE Today

2025 Vol.20

Annual Report

Research Institute of Innovative Technology for the Earth

Research Institute of Innovative Technology for the Earth

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