Chemical Research Group

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

1. Introduction

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

2. Technologies for CO_2 capture and utilization

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

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

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

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

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

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

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

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

3. Technology for capturing CO_2 from the atmosphere

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

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

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

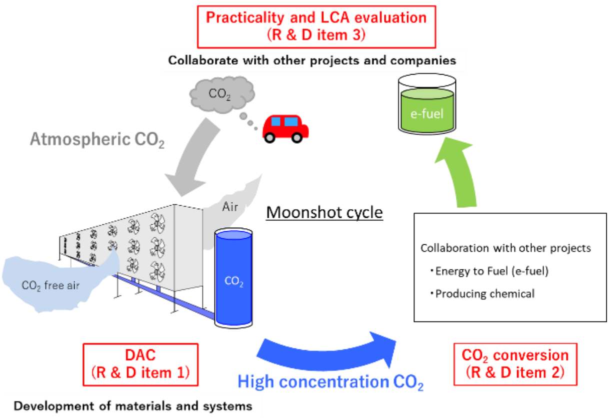

Fig. 1. Development of highly efficient DAC and carbon recycling technologies

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

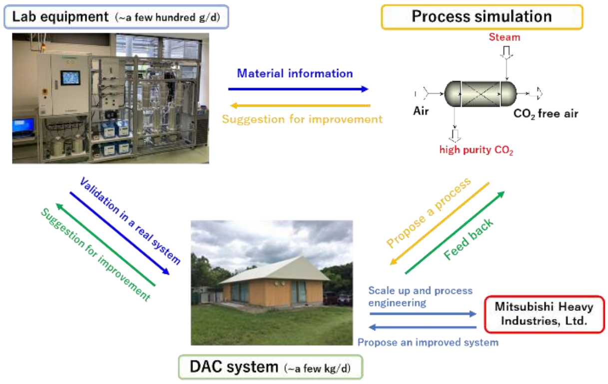

Fig. 2. Development of DAC technology: integration of simulation and laboratory systems

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

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

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

Fig. 4. CO_2 store tanks

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

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

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

4. Common evaluation standard for CO_2 capture materials

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

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

*PSA: Pressure Swing Adsorption

**TSA: Temperature Swing Adsorption

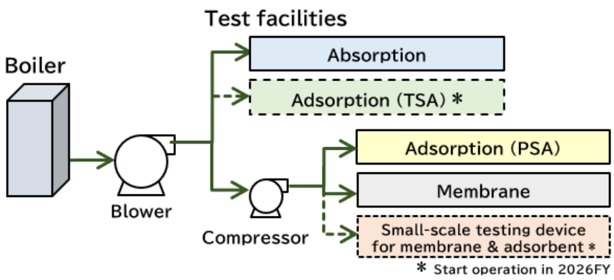

Fig. 5. Overview of RCCC test facilities

(Capacity of each unit: –100 kg-CO_2/day)

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

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

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

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

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

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

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

5. Solid sorbent method for CO_2 capture

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

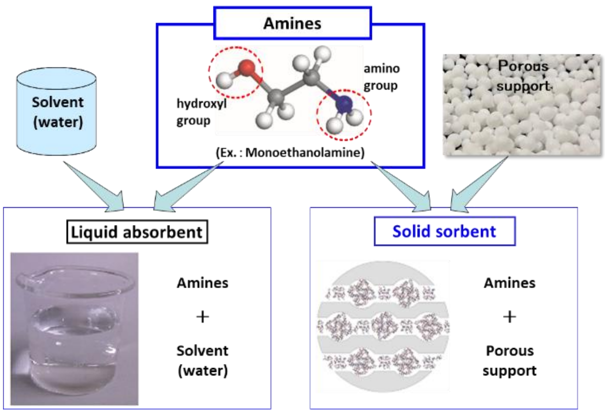

Fig. 6. Liquid absorbent and solid sorbent

1) For coal-fired power plants

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

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

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

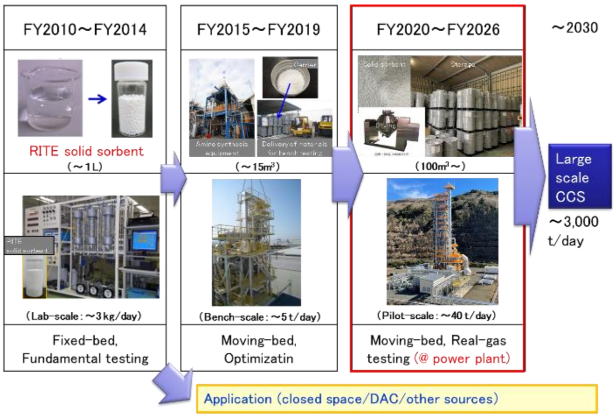

Fig. 7. Development roadmap of the solid sorbent method for CO_2 capture

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

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

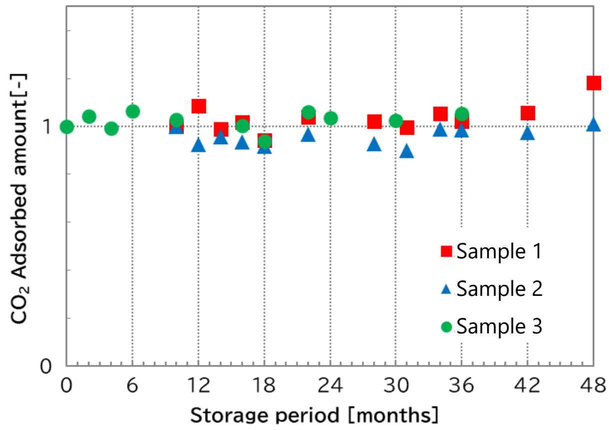

Fig. 8. Long-term storage test results

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

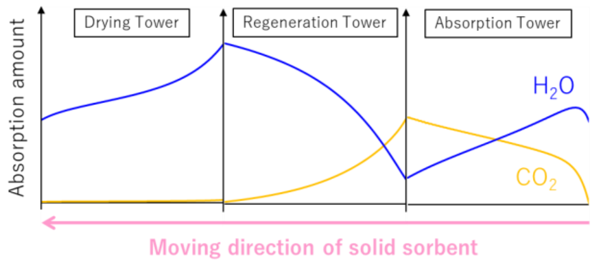

Fig. 9 Absorption/desorption behavior in moving bed system using simulation

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

2) For natural gas-fired power plants

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

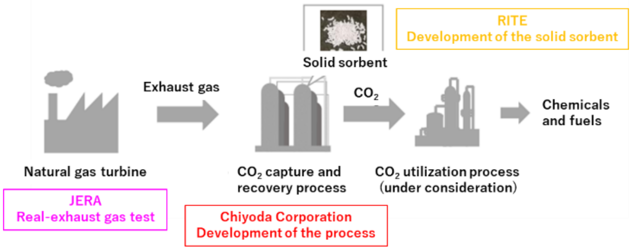

Fig. 10. Project overview

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

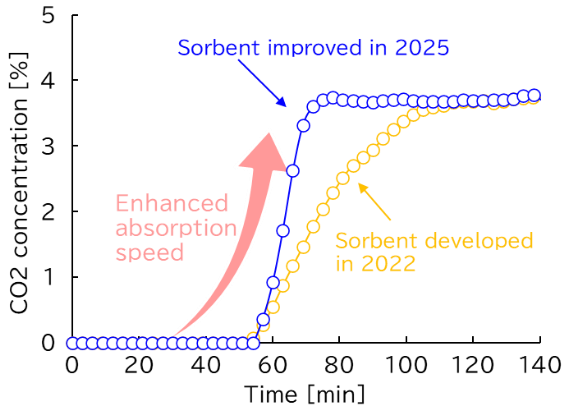

Fig. 11. Marked Improvement in absorption kinetics

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

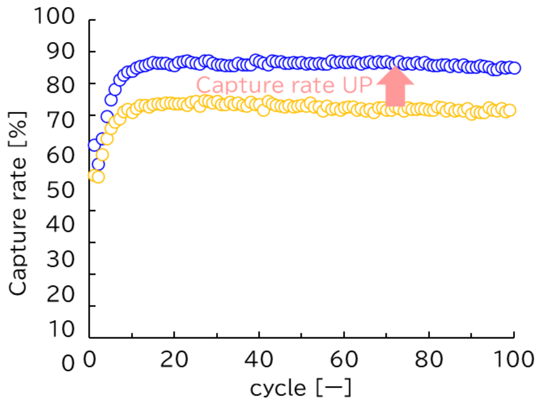

Fig. 12. Effect of absorption rate on CO_2 capture rate

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

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

6. Chemical absorption method for CO_2 capture

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

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

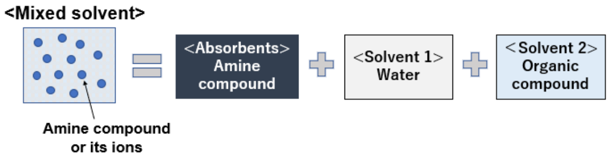

Fig. 13. Concept of a mixed solvent

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

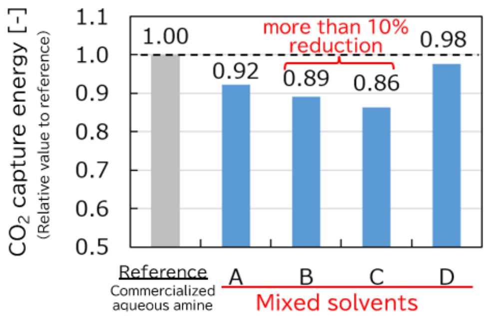

Fig. 14. Bench plant test results

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

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

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

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

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

7. Membrane separation

CO₂ separation by membranes involves the selective permeation of CO_2 from the pressure difference between the feed side and the permeate side of the membrane. Membranes used for separation are classified into inorganic and organic membranes, with organic membranes further classified into facilitated transport membranes and solution-diffusion membranes. Facilitated transport membranes have carriers that transport CO_2, and therefore selectively permeate CO_2 regardless of its molecular size.

RITE, in collaboration with Sumitomo Chemical Co., Ltd. has formed the Molecular Gate Membrane Module Technology Research Association (MGMTRA) and has been developing a facilitated transport membrane called a molecular gate membrane (MGM) for use in the integrated gasification combined cycle (IGCC) and hydrogen production equipment. A schematic illustration of the working principles of the molecular gate membrane is shown in Figure 15. It is a composite membrane made of a poly (amidoamine) dendrimer which has a high density of amino groups and cross-linked polymer materials. Under humidified conditions, CO_2 reacts with the amino groups in the membrane to form either carbamate or bicarbonate, which then blocks the passage of H_2. Consequently, the amount of H_2 diffusing to the other side of the membrane is greatly reduced, and high concentrations of CO_2 can be obtained. A poly (vinyl alcohol) (PVA) polymer matrix is used for pressure durability and to immobilize the dendrimers.

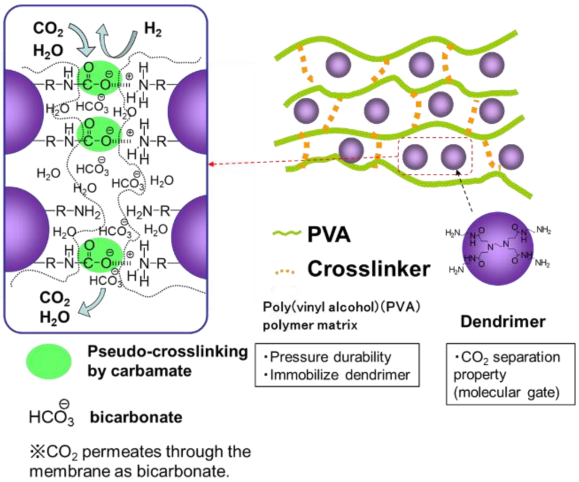

Fig. 15. Schematic illustration of the working principles of the molecular gate membrane

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

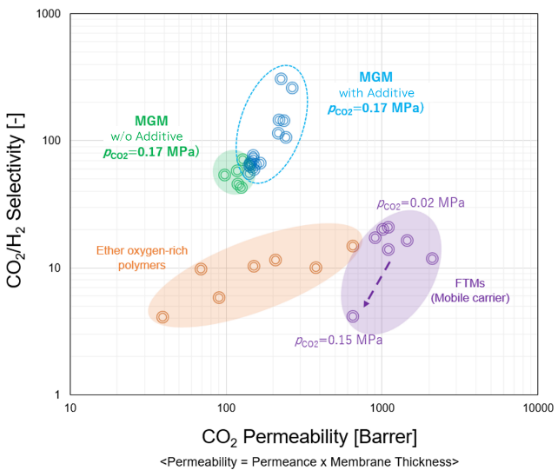

Fig. 16. CO_2/H_2 separation performance of molecular gate membranes

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

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

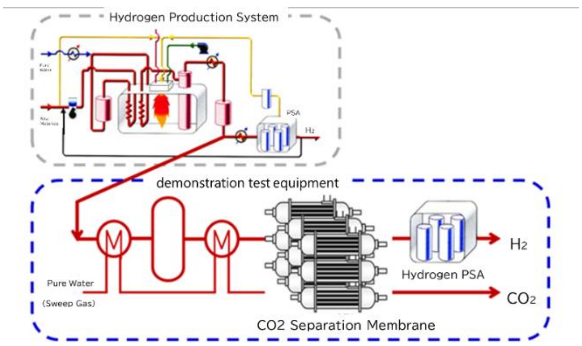

Fig. 17. Schematic illustration of the demonstration test of the hydrogen production system with CO_2 capture

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

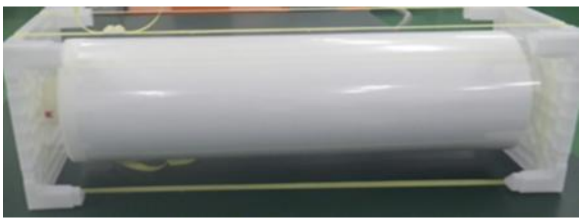

Fig. 18. CO_2 separation membrane roll products

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

Membrane element
(ϕ = 20cm; L = 60cm)

Membrane module
(ϕ = 20cm; L = 60cm)

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

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

Membrane module: Structure in which the membrane element is placed

8. Effective methanol synthesis from CO_2 hydrogenation

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

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

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

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

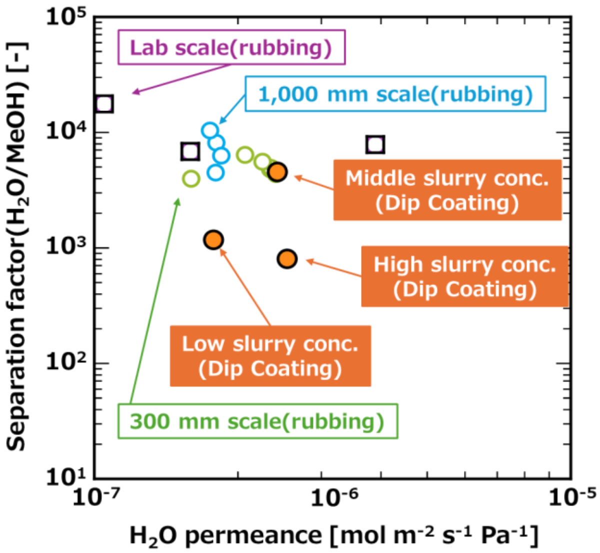

Fig. 20. The effect of changes in seed crystal coating method on permselective performance

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

9. He recovery membrane

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

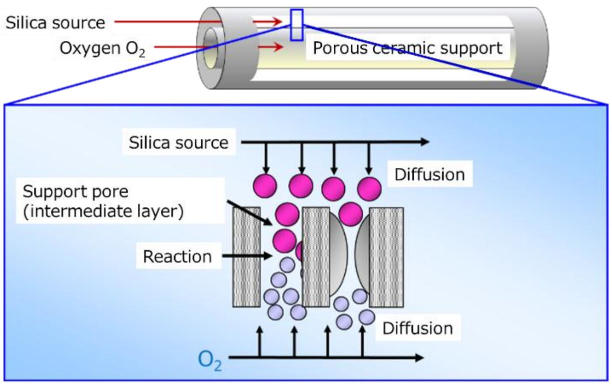

Fig. 21. Schematic diagram of counter-diffusion CVD method

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

10. CO_2 fixation

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

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

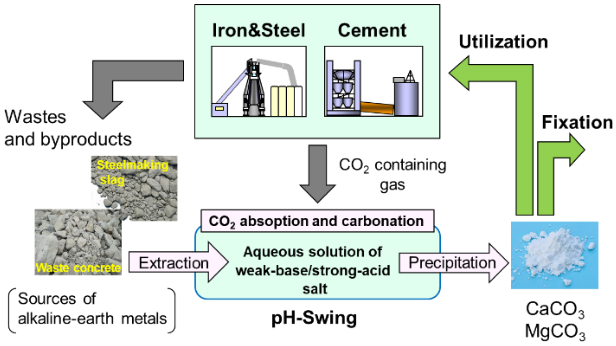

Fig. 22. CO_2 fixation as carbonates

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

11. Activities and efforts toward commercialization and industrialization

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

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

【General Activities】

(1) Sponsorship of research meetings

(2) Free seminars for members only

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

(4) Sponsorship of symposiums

【Individual Activities】

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

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

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

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

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

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

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

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

12. Conclusion

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

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

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