Chemical Research Group

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

1. Introduction

The Chemical Research Group, including the R&D division and industry collaboration division, has carried out activities to achieve the technical breakthroughs needed to realize solutions for early-stage practical application and industrialization of various technologies related to CO_2 capture and utilization (CCU). The current research topics of the Chemical Research Group are described as follows.

2. Technologies for CO_2 capture and utilization

The Paris Agreement was adopted at COP 21 in December 2015, and in order to minimize the adverse effects of climate change, such as abnormal weather, the rise in global average temperature before the Industrial Revolution was kept well below 2°C. Pursuing efforts to keep the temperature down to 1.5°C was the goal. After that, in response to the heightened sense of crisis, such as further temperature rises and the enormous natural disasters occurring on a global scale, the Glasgow Climate Agreement at COP 26 in November 2021 demonstrated the determination to pursue efforts to limit the temperature rise to 1.5°C with the world's first numerical target of 1.5°C. According to the IPCC, the 1.5°C target requires a 45% reduction in CO_2 by 2030 compared to 2010 and net zero by 2050.

In May 2022, the Clean Energy Strategy was formulated by the Ministry of Energy, Trade and Industry

(METI), and under the strategy, a practical roadmap for *carbon capture and storage* (CCS) was developed. The long-term plan set a goal of storing approximately 120 to 240 million tons of CO_2 by 2050, and seven CCS projects within Japan have been selected to accomplish the storage of CO_2 goal. *Carbon dioxide capture, utilization, and storage* (CCUS) and carbon recycling is an important innovative technology that enables carbon neutrality. In CCUS/carbon recycling, the combination of captured CO_2 is recycled as a carbon resource for fuels and materials (CCU), and the captured CO_2 storage under the ground (CCS) is expected to have a significant CO_2 reduction effect. Furthermore, it has been shown that CO_2 separation and capture technologies are the basis for CCUS, and the targets for the technologies are to reduce the cost of CO_2 separation and capture to 1,000 yen/t-CO_2 by 2050 and to establish CO_2 separation and capture technologies for various CO_2 emission sources. Negative emission technology, which contributes to the reduction in the concentration of CO_2 in the atmosphere, is required to achieve carbon neutrality. In particular, direct air capture (DAC) of CO_2 from the atmosphere has been attracting attention recently. In the Carbon Recycling Technology Roadmap (Ministry of Economy, Trade and Industry) revised in July 2021, DAC was added as a new technology field in progress. Carbon management, which involves the utilization, reduction, and storage of CO_2 in Carbon Dioxide Removal (CDR) and Carbon Capture, Utilization, and Storage (CCUS) initiatives, is gaining momentum.

Against this background, it is necessary to promote the practical application of CCUS by proposing optimal separation and capture technologies for the various CO_2 emission sources and CO_2 utilization technologies. In particular, in order to introduce and put into practical use CCS, which is expected to reduce CO_2 on a large scale as a measure to address global warming, it is important to reduce the cost of CO_2 capture from large-scale sources. In parallel, promotion of the standardization of CO_2 capture technologies is also important. It is necessary to establish a common evaluation standard for the various CO_2 capture materials, while keeping pace with the international trends in this field. CCU (utilization) implementation into society as soon as possible is also highly needed. It is important to develop innovative CO_2 utilization and carbon recycle technologies to effectively convert CO_2 into chemicals and fuels.

The Chemical Research Group is dedicated to developing innovative CO_2 capture and utilization technologies and to providing world-leading R&D and innovation results with a special focus on chemical absorption, adsorption, and the membrane separation process. Our research topic covers the development of new materials and their innovative manufacturing processes and high-efficiency carbon capture systems and membrane reactors. As for chemical absorption, the solvent developed in COURSE50 (Development of Environmental Technology for Steelmaking Process as commissioned by the New Energy and Industrial Technology Development Organization [NEDO]) has been put into practical use in a commercial CO_2 capture plant owned by a private Japanese company.

For adsorption, pilot-scale tests of solid sorbents with good CO_2 desorption performance at low temperatures and adsorption systems are being conducted in collaboration with private companies in a project commissioned by NEDO using flue gas from coal-fired power plants. The solid sorbents technology is also applied to the low CO_2 concentration carbon capture from the gas at natural gas-fired power plants that featured not only low temperature regeneration but also high residence to oxidation degradation. Furthermore, Direct Air Capture (DAC), which captures CO_2 from the atmosphere, is proceeding as the NEDO Moonshot Research and Development Project.

The membrane-separation-based carbon capture technology is developed for potential high-pressure CO_2/H_2 separation in the Integrated Coal Gasification Combined Cycle (IGCC) and hydrogen production plants. Starting from 2024, sponsored by NEDO, a compact medium-pressure hydrogen production system (CO_2 captured hydrogen production system) will be developed and will be demonstrated in field tests.

Efforts have also been devoted to the standardization for CO_2 capture.

Awarded by the NEDO project to establish a common base for evaluating CO_2 separation materials, Japan's first Real-Gas Test Center will be built at RITE (construction to be completed in 2024), and the standard methods with the use of real gas will be established. As the only organization in Japan that is a member of the International Test Center Network (abbreviated ITCN, a global association of facilities around the world that promote research and development of CO_2 capture technology), RITE regularly exchanges information with overseas ITCN members. Through ITCN, our efforts towards standardization of CO_2 capture will be disseminated throughout the world.

As for effective CO_2 utilization technology, we have been developing carbonate fixation utilization amine technology and methanol synthesis utilization dehydration membrane technology. In carbonate fixation, calcium and magnesium from industrial waste are fixed by reacting with CO_2 from the flue gas. By using amines, liquid calcium and magnesium are extracted and after reacting with CO_2, high-purity calcium or magnesium carbonate are produced. In methanol synthesis, CO_2 emitted from power plants, steel mills, cement plants, and chemical facilities reacts with hydrogen in a membrane reactor to synthesize methanol at high efficiency. We were awarded a NEDO project for optimal system development for methanol synthesis from CO_2 jointly with a private company in FY 2021.

3. 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. 1)

Fig. 1. 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 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 technological issues of cost reduction and practical implementation. In particular, R&D to decrease energy consumption in a solvent regeneration process and enhancement of amine durability for a stable long-term operation are required.

In COURSE50, we also demonstrated the new technological concept with the possibility of further reducing energy consumption by using the absorption solvent with an organic compound instead of water (Fig. 2). We call the new technology *mixed solvent*, which 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 January 2024, bench-scale plant tests started at the Kimitsu Steelworks of Nippon Steel Corporation. The new high-performance mixed solvents developed by RITE are evaluated using actual blast furnace gas.

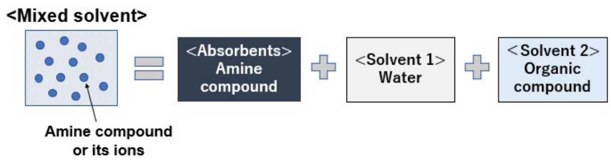


Fig. 2. Concept of mixed solvent

4. 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. In the process of using a solid sorbent, reduction of CO_2 capture energy can be expected because the heat of vaporization and sensible heat caused by the solvent can be suppressed.

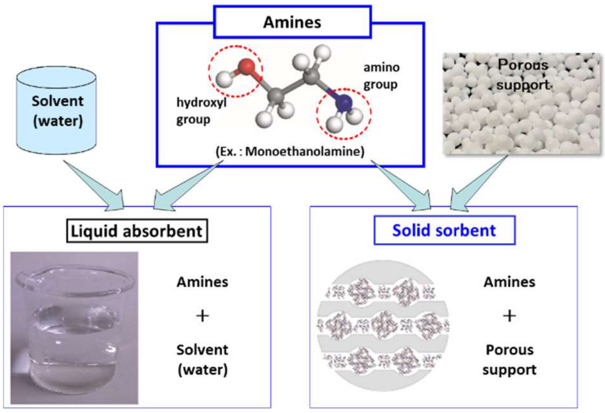


Fig. 3. Liquid absorbent and solid sorbent

1) For coal-fired power plants

In 2010, RITE started the work to develop solid sorbent materials for CO_2 capture from the combustion exhaust gas of coal-fired power plants (METI consignment project). In the fundamental research phase (FY 2010–2014), we created a new amine suitable for solid sorbents, and in a laboratory scale test with the new amine, we obtained the prospect of capture energy of 1.5 GJ/t-CO_2 or less. This solid sorbent system is an innovative material that enables not only low energy capture but also a low temperature process at 60°C. Compared to other technologies that use amine-based solid absorbents, this technology is at the top level globally in terms of low-temperature regeneration.

In the practical application research phase (METI/NEDO consignment project) from FY 2015 to 2019 with Kawasaki Heavy Industries, Ltd., (KHI) as a partner, we conducted scale-up synthesis of solid absorbent (>10 m^3), bench scale tests (>5 t-CO_2/day), and real-gas exposure tests at a coal-fired power plant.

In 2020, RITE was chosen for the NEDO commissioned project with KHI. In this project, with the cooperation of Kansai Electric Power Co., Inc., KHI completed trial operation of the pilot scale test facility (40 t-CO_2/day scale) constructed at the Maizuru power plant. In the second half of 2023, CO_2 capture tests have started using the solid sorbent supplied by RITE against flue gas from the combustion exhaust gas emitted from the coal-fired power plant. (Fig. 4)

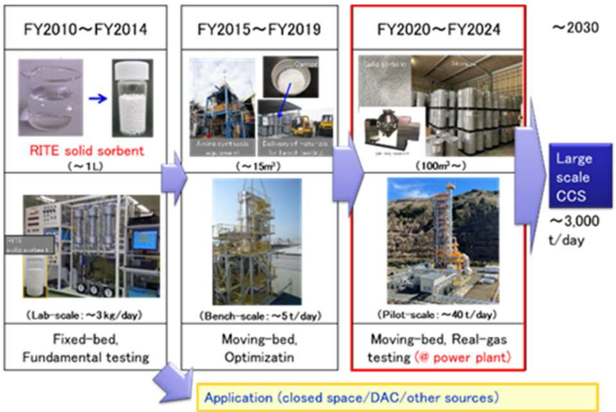


Fig. 4. Development roadmap of solid sorbent method for CO_2 capture

We are now working on elucidating the material deterioration mechanism to develop deterioration prevention technology, studying reuse technology for used solid sorbent, and studying efficient operating conditions using process simulation technology.

For process simulation technology, we are developing a simulator that can predict the amount of CO_2 captured and the energy used for separation and capture with high accuracy in KHI's moving bed system. (Fig. 5)

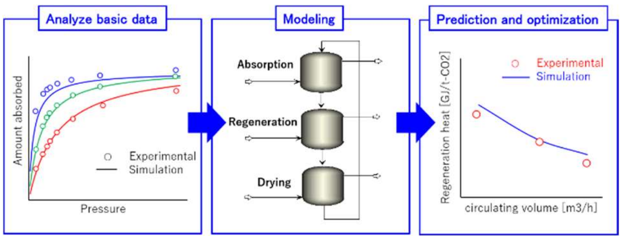


Fig. 5. RITE's simulation technology

In the pilot test, we plan to optimize the operating conditions using this simulation technology.

In addition, the simulation is useful for understanding the adsorption and desorption behavior inside the facility, which is difficult to observe in practice, and the calculation results are also 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 (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.

The stage gate for this project is set for FY 2024, and we have succeeded in developing a solid sorbent that will achieve the target this year. The developed solid sorbent is characterized not only by the fact that it can be regenerated at low temperatures but also by its excellent resistance to oxidative degradation (Fig. 6). Therefore, the sorbent can be applied to natural gas-fired power plant exhaust gases with relatively high oxygen concentrations.

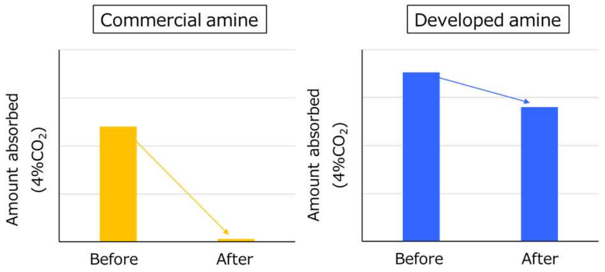
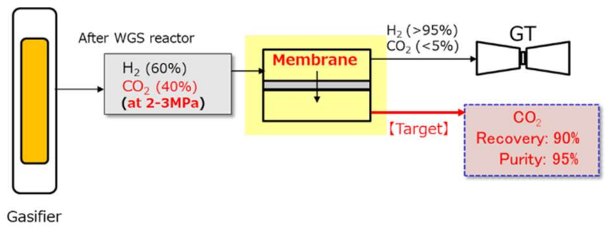


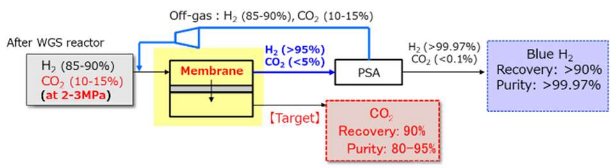
Fig. 6. Comparison of commercial and developed amines by oxidative degradation test. Both y-axials show the same values.

5. 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. So, CO_2 capture at low cost and low energy is expected by applying the membrane processes to pre-combustion (Fig. 7). 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. 7. 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. 8 presents a schematic that summarizes the working principles of a molecular gate membrane.

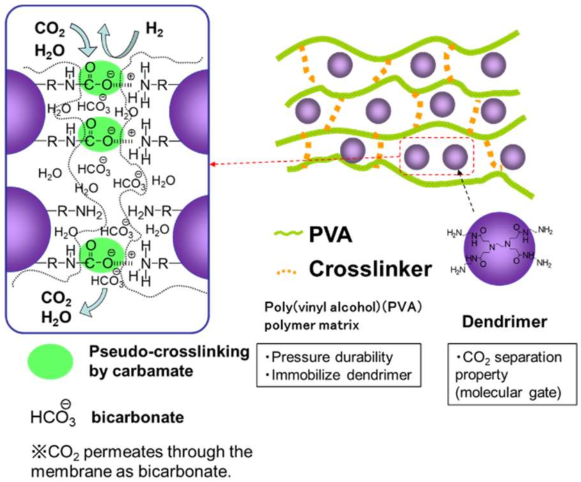


Fig. 8. Schematic illustration of the working principles of the molecular gate membrane

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.

In the NEDO project, CO_2 Separation Membrane System Practical Research and Development/Development of CO_2-H_2 Membrane Separation Systems using High-

Performance CO_2 Separation Membrane Modules, we conducted practical research and development to improve the separation performance and durability of the membrane elements, scale up the membrane modules, and design membrane systems suitable for the CO_2 utilization process based on previous results.

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 the medium pressure was improved as shown in Fig. 9.

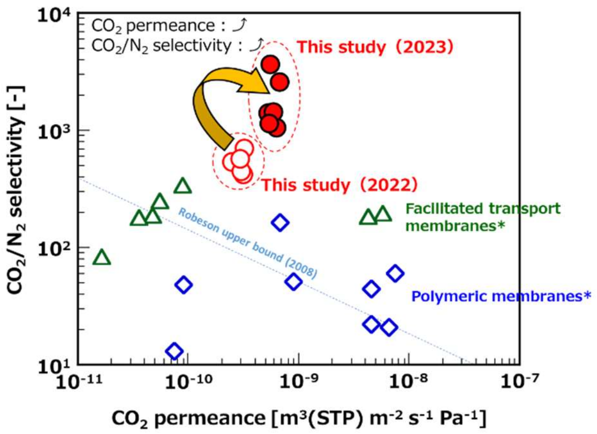


Fig. 9. CO_2/N_2 Separation performances of MGM membranes.

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 modification of 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. 10). As of FY 2024, we set the new application (small-scale, medium pressure hydrogen production system [hydrogen production equipment with CO_2 capture]), and we will develop membrane module systems and conduct field tests.

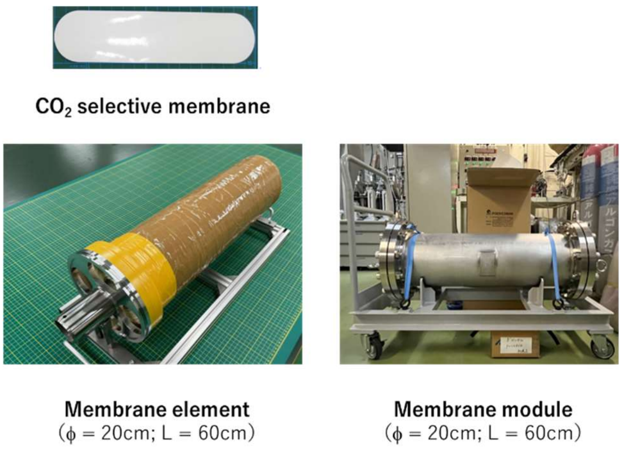


Fig. 10. CO_2 selective membrane, membrane element, and membrane module.

Membrane element: The structure with a large membrane area composed of the membrane, support, and spacer.

Membrane module: The structure in which the membrane element is placed.

6. CO_2 capture technology 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., in the (1) Development of technologies to capture, convert, and detoxify greenhouse gases of Goal 4 "Realization of sustainable resource circulation to recover the global environment by 2050."

The technology for capturing CO_2 directly from the atmosphere called Direct Air Capture (DAC) is expected to be one of the negative emission technologies. Seven research themes on DAC, including the RITE's theme, have been adopted in the Moonshot R&D Project, and six of them are still ongoing in 2023. Fig. 11 shows our R&D items and a carbon cycle society as our goal.

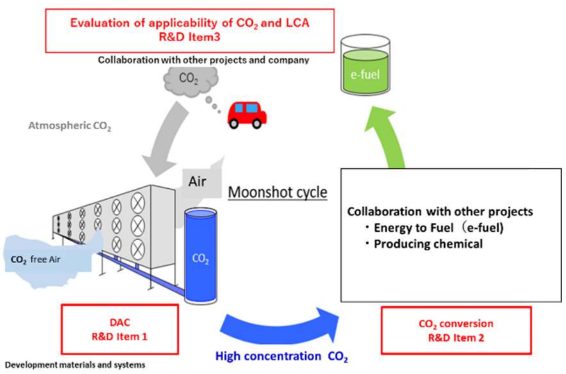


Fig. 11. Development of highly efficient DAC and carbon recycling technologies

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. 12), CO_2 capture performances of real-sized sorbents are evaluated using DAC system evaluation equipment (Fig. 13, 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. Pilot-scale testing (0.5 t-CO_2/day at the maximum) is scheduled for 2025 at Expo 2025 Osaka, Kansai, Japan. Manufacturing of solid sorbents and the pilot-scale DAC system is underway.

Fig. 12. Lab test equipment for DAC

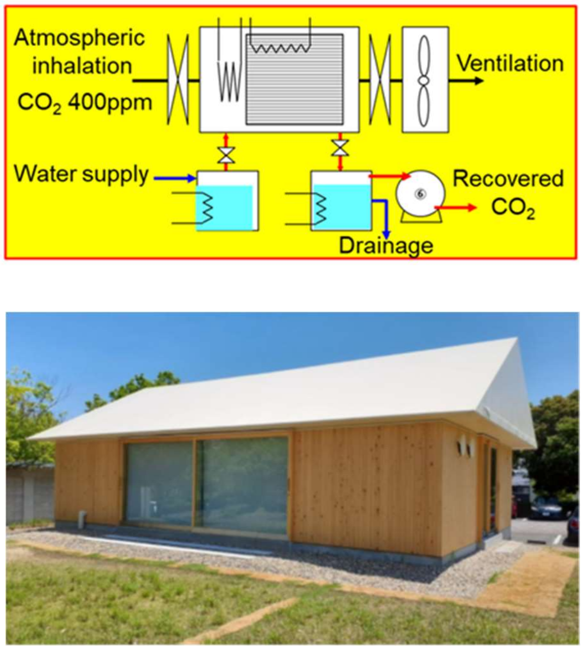


Fig. 13. Schematic image of DAC system evaluation equipment (upper) and DAC experimental laboratory in RITE premise (below)

7. 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 the realization of a carbon neutral society, a common base for CO_2 capture materials will be established, and it will support the enhancement of domestic companies' global share of 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 the test center), (b) establishment of standard evaluation methods for development of innovative capture materials, (c) development of durability evaluation methods, and (d) database construction and the spread of the standard evaluation methods.

RITE will formulate standard performance evaluation methods using actual gas and develop a test center in the first stage up to FY 2024 in order to evaluate CO_2 capture materials at the flue gas conditions of power plants and boilers. The test center will be constructed at the RITE headquarter site in Kyoto. Three different test facilities for absorption, adsorption, and membrane processes will be installed there, and a natural gas combustion boiler will be the source of actual flue gas (Fig. 14). The basic engineering of the test center was completed in FY 2023.

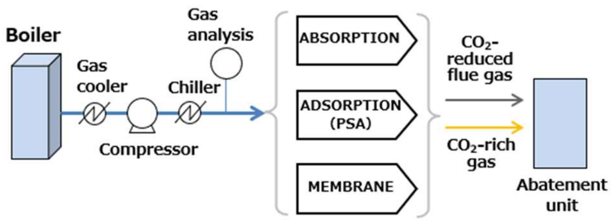


Fig. 14. Schematic of the test units for absorption, adsorption and membrane.
(Each unit capacity: –100 kg-CO_2/day)

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 has not been organized in Japan. 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 ITCN (International Test Center Network) members. RITE will provide the first real gas test center in Japan, which is used by companies and institutions involved in the development of CO_2 capture materials. It 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.

8. Effective methanol synthesis from CO_2 hydrogenation

Carbon dioxide (CO_2) is one of the causes of global warming; therefore, a significant reduction is a critical global challenge and attaches special important to Carbon Capture and Utilization (CCU) technologies. On the other hand, CO_2 hydrogenation as a one of the utilization technologies that produces water and that causes deactivation of the catalyst and decreases the reaction rate. In order to solve these problems, we shed light on methanol synthesis using CO_2 as the raw material using a membrane reactor that combines the membrane and the catalyst.

At RITE, we successfully developed a novel hydrophilic zeolite membrane, which has higher hydrothermal stability and water/methanol permselective performance compared to conventional LTA-type zeolite membranes. This membrane was applied to the membrane reactor for methanol synthesis, and CO_2 conversion was achieved at a rate three times higher compared to the conventional packed-bed 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, and Demonstration of Technologies for CO_2 Utilization, and have succeeded in synthesizing a practical length of dehydration membrane with comparatively high permeation and separation performance. We also succeeded in synthesizing a dehydration membrane with a practical length that has relatively high permeation separation performance. In addition, target values (H_2O permeability: 1 x 10^{-6} mol m^{-2} s^{-1} Pa^{-1}, H_2O/MeOH selectivity: >1,050) were achieved in the reaction temperature range for methanol synthesis. Notably, the long dehydration membrane exhibited high permeability at approximately twice the target value, an achievement that can be expected to improve methanol synthesis efficiency when applied to a membrane reactor (Fig. 15).

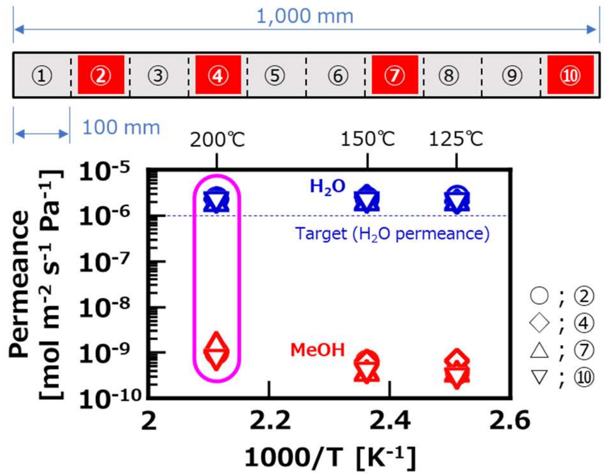


Fig. 15. Temperature dependence of H_2O/MeOH permselective performance though long-scale dehydration membrane (100 mm-cut sample).

Bench-scale membrane reactor tests equipped with multiple dehydration membranes of practical length with this performance are underway at JFE Steel (Fukuyama). We are also examining ways to improve the reproducibility of practical-length dehydration membranes, and have successfully synthesized a membrane as long as that of the lab-scale test (champion data in the figure) by carefully examining the synthesized membranes and as shown in Fig. 16. This performance was higher or comparable to that of dehydration membranes already commercially available (+ plot in the figure). In addition, compared to LTA-type zeolite membranes, which are commonly used dehydration membranes, the Si-rich LTA membranes are expected to have higher hydrothermal stability, which will enable their application in separation systems that have had difficulty applying LTA-type zeolite membranes.

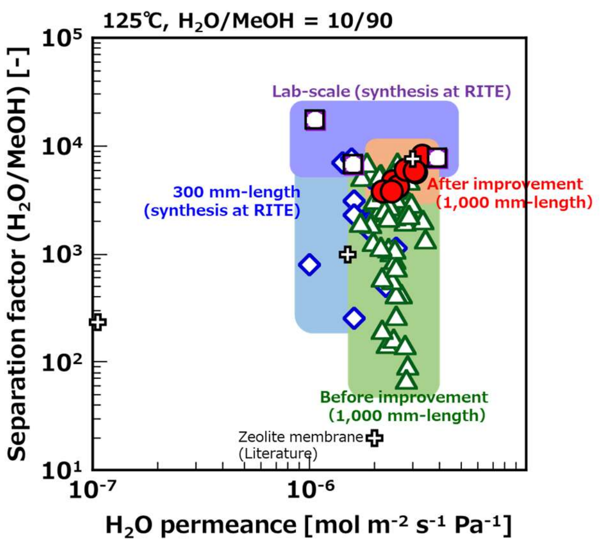


Fig. 16. H_2O/MeOH permselective performance though long-scale dehydration membrane

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.

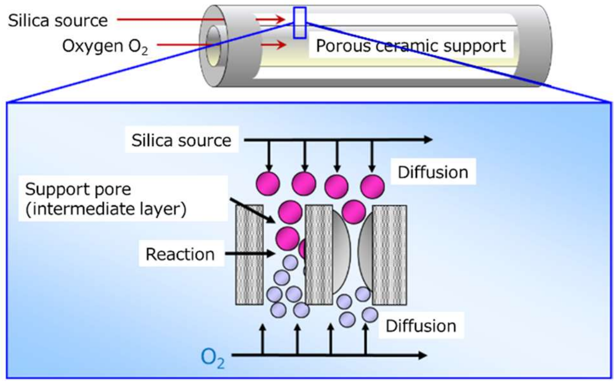


Fig. 17. Schematic diagram of counter-diffusion CVD method.

Recently, the global helium crisis has become an issue, and it is important to find a way to secure helium. Considering energy conservation, a method to recover 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 fixation (CO_2 mineralization) has the same basic concept as enhanced weathering, which is one of the negative emission technologies. It is a technology that reacts CO_2 with alkaline earth metals and immobilizes it as a chemically stable carbonate, which is attracting attention as a CO_2 fixation technology that does not affect the ecosystem. In recent years, early implementation of

CO_2 fixation using byproducts and waste containing alkaline earth metals is expected to contribute to the building of a sustainable society.

RITE has a proprietary process that has been developed over many years for the fixation of CO_2 as carbonate, and since 2020, in collaboration with private companies, has been developing technology to extract alkaline earth metals from steel slag, waste concrete, and other materials in a wet process and recover CO_2 emitted from factories as a stable compound, as well as developing effective technology for the production of carbonate (Fig. 18).

With this process, energy savings have been achieved by lowering the reaction temperature and shortening the reaction time, and a process in which the liquid used once can be used again (application of regenerated liquid) has been established. It has also been shown that the process can be scaled up. In addition, by improving the solution used during extraction, a reduction in material costs can be expected. Based on the knowledge and information that has been acquired so far, studies are currently being conducted with the aim of industrialization.

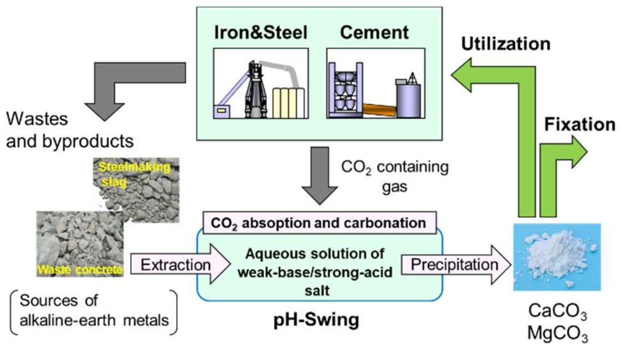


Fig. 18. CO_2 fixation as carbonates

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 33 private companies (as of March 2024) 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 IMeRC and the implementation of training workshops
(3) Offers for technical guidance from the IMeRC Advisory Board and Research Section
(4) Hosting exclusive technology seminars for council members

In FY 2023, 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, the Chemical Research Group presented an overview of the DAC technology and topics of each DAC company.

In the Membrane Reactor Group, the Chemistry Research Group provided information on membrane reactors in general and CO_2-free hydrogen production in particular.

The members-only free seminars were held three times at the 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* twice with comments from Chemical Research Group researchers, and *hot topics* once with the latest information from academic society topics, METI, and NEDO, 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 2024.

12. Conclusion

The Chemical Research Group will continue to actively participate in the development of technology for CO_2 separation and capture from a variety of CO_2 emission sources. In future, the Chemical Research Group will be fully committed to the above-mentioned research topics. For carbon capture technologies in a stage very close to practical applications, we will conduct scale-up studies and tests under real-gas conditions with the aim of establishing the technology at an early stage for early implementation into society. It is necessary to develop technology that can handle low-concentration CO_2 emission sources. The negative emissions technologies, such as DACCS making a significant contribution to sustainable development scenarios for decarbonization, will be the focus. As the CO_2 concentration decreases, the amount of gas to be treated increases, and the oxygen concentration increases. The development of materials at low cost with higher deterioration resistance and its corresponding system is highly Important. We will accelerate the development of these technologies so that we can implement energy-saving and low-cost CO_2 capture technologies into our societies as soon as possible.

Specially, the chemical absorption process will be enhanced by the development of practical high-performance chemical solvents. For solid sorbents, we will steadily conduct a pilot test planned to start FY 2023 on a scale of 40 t-CO_2/day captured from flue gas at a coal-fired power plant and steadily develop new sorbents for natural gas-fired flue gas. Regarding the DAC technology, we will accelerate the system development and sorbent manufacturing for a bench-scale on-site demonstration at Expo 2025 Osaka, Kansai. As for membrane separation, the project of a compact medium-pressure hydrogen production system started from 2024. About the establishment of a common base for evaluating CO_2 separation materials, the construction of the Real-Gas Test Center will be completed in 2024, and the test using real gas will be initiated.

Also, efforts will be continuously devoted for the effective utilization of the captured CO_2 and hydrogen production technologies for that purpose. We will develop technology for CO_2 fixation into carbonates using steel slag and waste concrete and then explore technology for recycling CO_2 into fuel and chemical feedstocks. Furthermore, we will further strengthen the cooperation with the carbon capture industry through the establishment of the Real-Gas Test Center and the activities of the Industrialization Strategy Council. We will continue to contribute to the development of domestic carbon capture technology.