Chemical Research Group

Members (as of Apr. 2023)

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Challenges Associated with the Advanced Industrialization of CO_2 Capture Technologies

1. Introduction

The research and development of CO_2 capture and utilization (CCU) had been conducted separately by the Chemical Research Group and the Inorganic Membrane Research Center until the last fiscal year. To effectively collaborate on the R&D of both polymer and inorganic membranes, as well as CO_2 utilization, we have integrated these two research groups starting from fiscal year 2023 to establish a more competitive and productive organization. In the future, we will focus on promising CCU technologies for their early-stage practical applications. Additionally, we will increase the activities of the Strategic Council for Industrialization to support information exchange and technology cooperation on CCU. The current research topics of the Chemical Research Group are described as follows.

2. Technologies for CO_2 capture

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 Japan as well, in response to the 2050 Carbon Neutral Declaration in October 2020 and the Green Growth Strategy for the 2050 Carbon Neutral Declaration formulated in December 2021 (detailed in June 2021), to prevent global warming various efforts are being promoted in each of the technology fields. CCUS (Carbon dioxide Capture, Utilization, and Storage) / Carbon Recycling is an important innovative technology that enables carbon neutrality. In CCUS/carbon recycling, the combination of both 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.

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 capturing 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 various CO_2 capture materials, while keeping pace with the international trends of 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 process 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" 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. Recently, we started to develop new solid sorbents for low-concentration CO_2 capture at natural gas-fired power plants. Furthermore, Direct Air Capture (DAC), which captures CO_2 from the atmosphere, is proceeding as the NEDO Moonshot Research and Development Project. With the target of separating CO_2 from a high pressurized gas stream in a low-cost and energy-saving process, we have been developing membranes and membrane elements. They are potentially applied in Integrated coal Gasification Combined Cycle (IGCC) and blue hydrogen production.

Efforts have also been devoted to establishing the standardization of CO_2 capture. 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. In addition, we were awarded a NEDO project to establish a common base for evaluating CO_2 separation materials with standard methods, which started in 2022 and have initiated the establishment of Japan's first Real-Gas Test Center in RITE.

As for effective CO_2 utilization technology, we have been conducting carbonate fixation utilization amine technology and methanol synthesis utilization dehydration membrane technology. In carbonate fixation, calcium and magnesium from industrial waste are used and, after reacting with CO_2, produce high-purity calcium or magnesium carbonate. It is an environmentally friendly manufacturing method due to recycling both the carbon source and the metal source. In methanol synthesis, CO_2 emitted from power plants, steel mills, cement and chemical plants is reacted with hydrogen by a membrane reactor to synthesize methanol at high efficiency. We have been awarded a NEDO project for optimal system development for methanol synthesis from CO_2 jointly with a private company since 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. However, energy consumption in the process of solvent regeneration and the degradation of amines cause the cost increases in the chemical absorption method.

Focusing on the fact that the structure of amine molecules is closely related to these technological issues, RITE started a new amine solvent: since the COCS project (METI's Subsidy Project) started in 2004, RITE has been working on the development of a high-performance amine solvent that reduces the cost of CO_2 capture.

In the COURSE50 project (NEDO consignment project) since 2008 with the goal of reducing CO_2 emissions by 30% in the steelmaking process, RITE was working with Nippon Steel Corporation to upgrade the chemical absorption method. The chemical absorbent and process developed by the COURSE50 project were adopted by the energy-saving CO_2 capture facility ESCAP® of Nippon Steel Engineering Co., Ltd., which was commercialized in 2014.

ESCAP® Unit 1 was constructed on the premises of Muroran Works for general industrial use, including beverages. This is the world's first commercial facility using the chemical absorption method for combustion exhaust gas from a hot stove at a steelworks as a CO_2 source. In 2018, ESCAP® Unit 2 (Fig. 1) started operation at the Niihama Nishi Thermal Power Station. This is the first commercial facility in Japan to capture CO_2 by the chemical absorption method for combustion exhaust gas from coal-fired power generation as the CO_2 source. The recovered CO_2 is used as a raw material in a nearby chemical factory.

Fig. 1 Equipment of energy-saving CO_2 absorption process ESCAP® at Niihama Nishi power station, Sumitomo Joint Electric Power Co., Ltd.

In addition, our research results in COURSE50 showed 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. We are now on a new R&D stage and have continued to develop novel compounds and optimal formulations for practical use under the NEDO Green Innovation Fund Project for the development of hydrogen reduction technology using blast furnaces, which started in 2022.

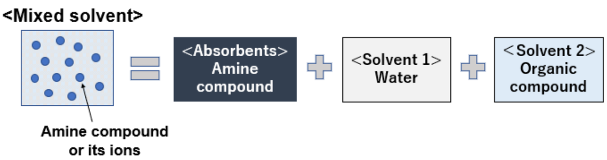


Fig. 2 Concept of mixed solvent

4. Solid sorbent method for CO_2 capture

Unlike a chemical absorbent in which amines are dissolved in a solvent, such as water, a solid sorbent is one in which 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.

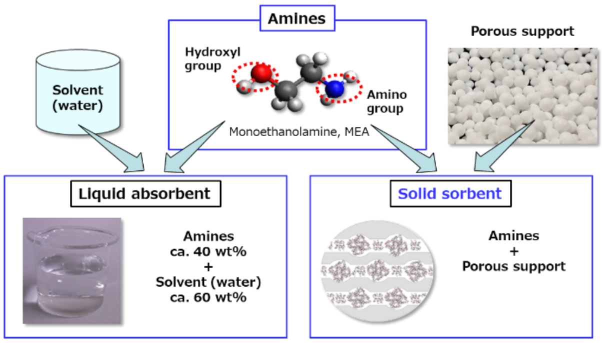


Fig. 3 Liquid absorbent and solid sorbent

1) For coal-fired power plants

In 2010, RITE started the development of 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 developed 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, scale-up synthesis of solid absorbent (>10 m^3), bench scale test (>5 t-CO_2/day), and real-gas exposure tests at a coal-fired power plant were conducted.

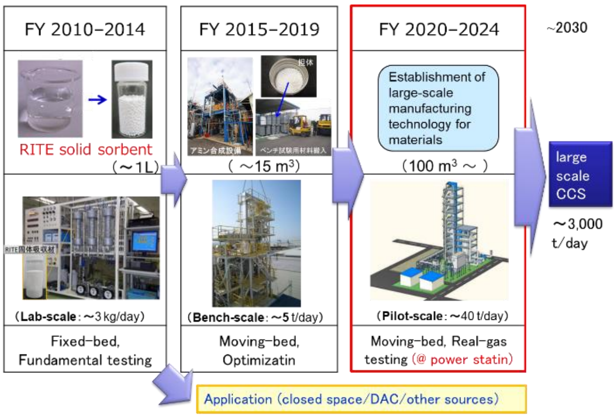


Fig. 4 Development roadmap of solid sorbent method for CO_2 capture

In 2020, RITE was chosen for the NEDO commissioned project with KHI. In this project, with the cooperation of Kansai Electric Power Co., Ltd., KHI constructed a pilot scale test facility (40 t-CO_2/day scale) at the Maizuru power plant and started trial operation in the second half of FY 2022.

RITE manufactured a 100 m^3 scale solid absorbent optimized on the basis of the results of the scale-up synthesis of solid absorbents and bench-scale tests and supplied it to the pilot test facility. In the future, we plan to conduct CO_2 capture tests from flue gas from the combustion exhaust gas emitted from the coal-fired power plant in FY 2023–2024.

We are also elucidating the material deterioration mechanism, developing the technology to suppress the deterioration of solid sorbents, 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 recovery with high accuracy in KHI's moving bed system.

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 device, which is difficult to observe in practice, and the calculation results are also used in material development.

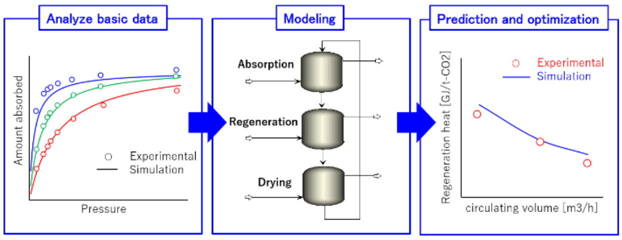


Fig. 5 RITE's simulation technology

2) For natural gas-fired power plant

In 2022, the Technology Development Project of CO_2 Separation and Capture in the Green Innovation Fund project has been 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 knowledge and technology accumulated during R&D histories in this field and the development of solid sorbent materials composed of developed amines and optimal support.

This project is a nine-year project from 2022 to 2030. After passing through the stage gate in Phase 1 (2022–2024), which focuses on the development of solid sorbent materials, we plan to proceed to Phase 2 (2025–2026), where development with bench test equipment will be carried out, and if it passes through the stage gate, we will proceed to Phase 3, where pilot demonstration tests will be conducted using actual exhaust gas at natural gas-fired power plant sites.

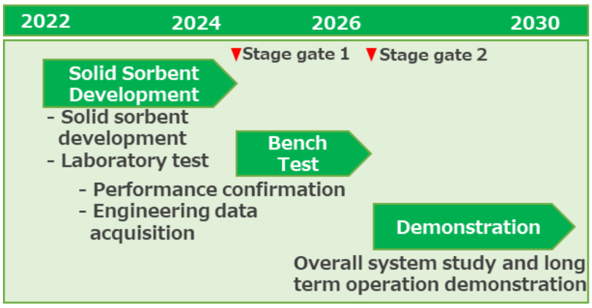
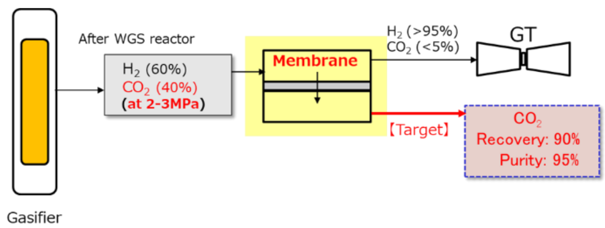


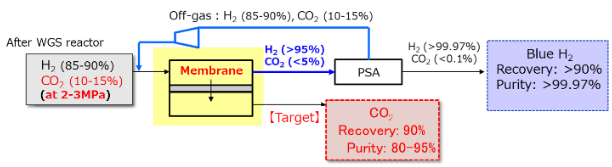
Fig. 6 R&D Schedule

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 with 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 pre-combustion.



(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.

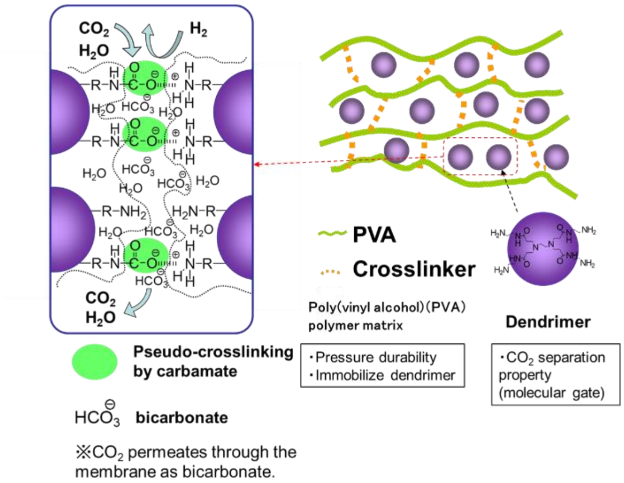


Fig. 8 Schematic illustration of the working principles of the molecular gate membrane

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 dendrimer/polymer hybrid 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 a private company) is researching new membranes, membrane elements, and membrane separation systems. So far, two-inch and four-inch membrane elements with enough pressure durability (2.4 MPa) were successfully prepared. In addition, we conducted pre-combustion CO_2 capture tests of the membrane elements using coal gasification gas.

In the new 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 are conducting 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.

In the current project, we are modifying the membrane materials to improve pressure durability. The dependence of separation performance on feed gas total pressure is shown in Fig. 9.

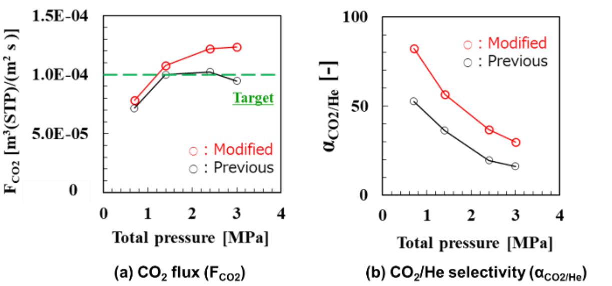


Fig. 9 Dependence of separation performance on feed gas total pressure.

Pressure durability of 3 MPa was obtained by modification of the membrane materials. In addition, separation performance was improved compared to the previous membrane, and we have the prospect of obtaining the target performance as membrane materials.

As for the development of the membrane elements, we succeeded in developing the membrane elements (ϕ = 10 cm, L = 40 cm) (Fig. 10). In the future, we will develop membrane elements using the modified membranes and develop larger-scale membrane modules.

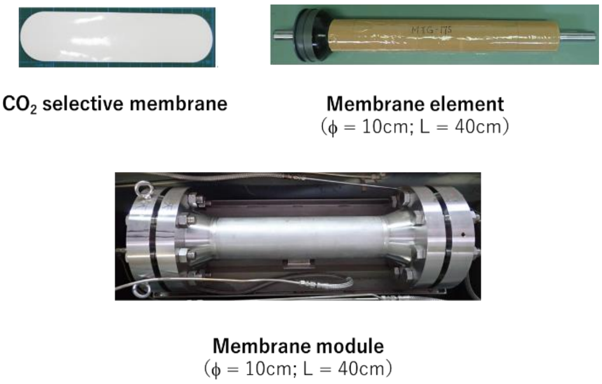


Fig. 10 CO_2 selective membrane, membrane element, and membrane module.
Membrane element: The structure with a large membrane area composed of the membrane, support, and spacer.
Membrane module: The structure in which the membrane element is placed.

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 innovation action plan of the Innovative Environmental Innovation Strategy, which aims to establish technologies that enable Beyond Zero by 2050.

RITE is working to develop high-efficiency CO_2 capture from the atmosphere and carbon circulation technologies in cooperation with Kanazawa University and Mitsubishi Heavy Industries, Ltd., in "(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 2025."

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

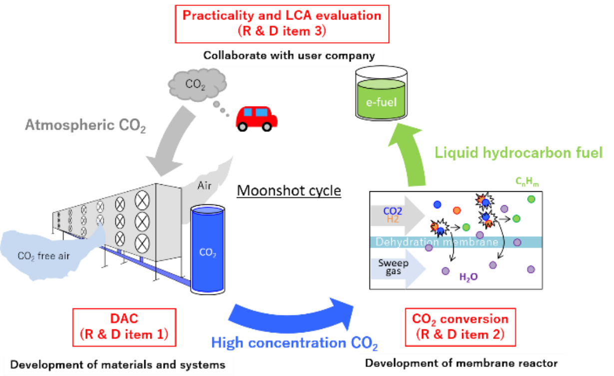


Fig. 11 Development of highly efficient DAC and carbon recycling technologies

RITE is trying to synthesize new amines suitable for DAC and transform solid sorbent materials into low-pressure drop structured materials. The developed materials are tested in the actual air around RITE. Because of the day-to-day variations in the conditions of the local atmosphere, we designed new equipment to control and test the effects of temperature, humidity, and CO_2 concentration in the atmosphere (Fig. 12).

Fig. 12 Lab test equipment for DAC

In addition, DAC system evaluation equipment that can evaluate solid absorbent structures of the size used in actual DAC facilities has been designed and manufactured by Mitsubishi Heavy Industries Engineering, Ltd. The equipment is installed on RITE premises and research and development that include scaling up technology have started

In order to realize an economically acceptable DAC, not only material development but also process development is important. RITE uses simulation technology to efficiently search for optimal operating processes.

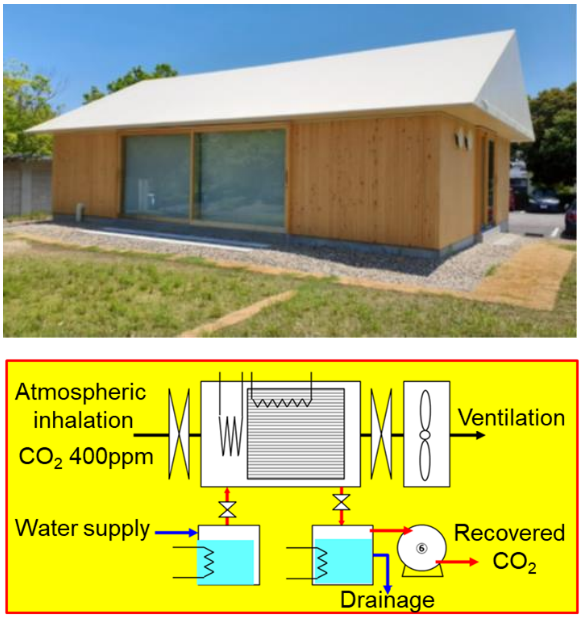


Fig. 13 Schematic image of DAC system evaluation equipment (below) and DAC experimental laboratory in RITE where equipment is placed (upper)

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 energies, 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 concentration.

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 items: (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 where three different CO_2 capture technologies can be evaluated with natural gas combustion gas. RITE has started to design CO_2 capture test facilities to evaluate CO_2 capture for exhaust gas, which assumes flue gases from NGCC power plants. The test facilities will be set up in FY 2024.

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. Installation and operation of a system of facilities where new CO_2 capture materials can be evaluated is strongly demanded. 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, this 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 produces water, which 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 "membrane" and "catalyst."

Methanol is an important intermediate for chemical products, and demand is expected to grow in the future. Methanol is mainly synthesized using syn-gas (mixture gases of CO and H_2); however, synthesis requires high temperatures and high pressures. Generally, Cu/ZnO-based catalysts are used with the reaction within the temperature range of 473–573 K. On the other hand, the one-pass yield shows low values owing to equilibrium limitations. This is remarkable in the methanol synthesis from CO_2 hydrogenation represented by the following reaction formula.

$$CO_2 + 3H_2 \rightleftarrows CH_3OH \text{ (methanol)} + H_2O$$

A membrane reactor as shown in Fig. 14 can be used to solve this problem. The produced water is removed from the reaction system, then this reaction will be promoted to the methanol production side.

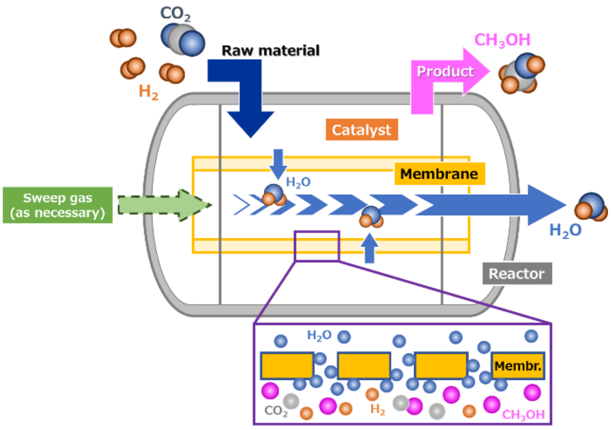


Fig 14 Schematic diagram of membrane reactor for methanol synthesis

At RITE, we successfully developed a novel hydrophilic zeolite membrane, which has higher hydrothermal stability and water/methanol permselective performance compared to the conventional LTA-type zeolite membrane. 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, RITE is conducting the NEDO project, Development of Technologies for Carbon Recycling and Next-Generation Thermal Power Generation / Development, and the demonstration of technologies for CO_2 utilization. In this project, our ovel dehydration membrane with a practical length was developed in FY 2022.

9. 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 the CO_2 fixation by using by-products and waste containing alkaline earth metals is expected to build a sustainable society.

RITE developed a unique process over many years. From 2020, two Japanese private companies and RITE set up a study group to target steel slag and waste concrete and then use the alkaline earth metals extracted from these for use with the CO_2 emitted from factories and other facilities. We are cooperating in the development of technology for recovering carbonates, which are stable compounds, by reacting with CO_2 (Fig. 15).

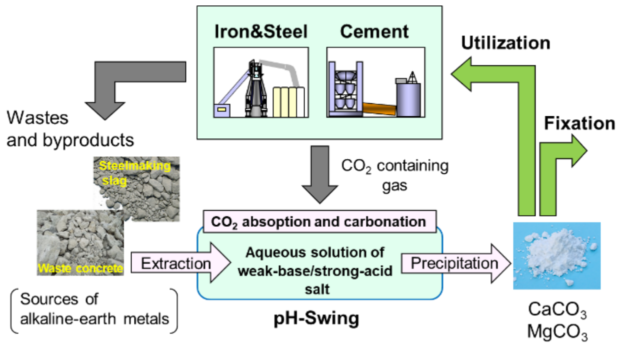


Fig. 15 CO_2 fixation as carbonates

10. Activities and efforts toward commercialization and industrialization

The core of the Industrial Collaboration Department of the IMeRC is the Industrialization Strategy Council. A total of 18 separation membrane and support manufacturers and user companies (as of January 2022) participate on this council. Our goal is to establish an inorganic membrane industry that contributes to innovative environmental and energy technologies by promoting a common vision for manufacturers and user companies, as well as a joint research plan involving national projects and other initiatives.

We are promoting a variety of activities, which include the following:

a) Sponsoring needs and seeds matching meetings toward the practical use of innovative environmental and energy technologies that use inorganic membranes, and the establishment and operation of a research group that will prepare the future roadmap

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

c) Acceptance of researchers from council members to the Research Section of the IMeRC and the implementation of training workshops

d) Offering technical guidance from the IMeRC Advisory Board and Research Section

e) Hosting exclusive technology seminars for council members

f) Offering exclusive supply services (Needs and Seeds Technology Information) to council members

In 2021, because of the spread of the COVID-19 virus, we had to refrain from face-to-face activities, but we actively promoted study group activities and seminars via the Web.

Two study groups, the Membrane Reaction Process Study Group and the Common Infrastructure (Performance Evaluation) Study Group, have started new studies. The Membrane Reaction Process Study Group examined a computational platform that enables comparative studies of performance, energy balance, and cost, which are indispensable for the social implementation of membrane reactors. The Common Infrastructure (Performance Evaluation) Study Group conducted a basic study toward standardization of separation membrane performance evaluation methods with the aim of promoting the industrialization of inorganic membranes.

We also held a seminar for council members online. There were lectures from universities, member companies, and membrane-related companies on the latest R&D trends and the introduction of needs, seeds, and practical development cases of membranes, along with lively question and answer sessions. In addition, we conduct patent and literature searches related to the content of the lectures, and regularly provide members with needs and seeds information with comments from the IMeRC in the summary.

11. Conclusion

The Chemical Research Group will continue to actively participate in the development of technology for CO_2 separation and capture from various CO_2 emission sources. 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 its development toward a small-scale on-site demonstration at Expo 2025 Osaka, Kansai. As for membrane separation, in FY 2023, we will complete the fabrication of a prototype of a commercial-size membrane module and develop a plan for a field test with the aim of moving forward into the development phase. About the Real Gas Test Center, its detailed design will be conducted in FY 2023. We will survey potential users to determine the key configurations desired and to make the center user-friendly for domestic researchers working on CO_2 separation materials. It will open in FY 2024.

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 also 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.

Efforts will be 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.