Energy-Saving CO_2 Capture System KCC

As an effort toward decarbonization, the demand for CO_2 capture is increasing. However, reducing its cost is a technical challenge to popularizing CO_2 capture. Therefore, we are developing KCC (Kawasaki CO_2 Capture), which is an energy-saving CO_2 capture system that is expected to drastically reduce the energy required to capture CO_2 with the solid sorbent method.

Introduction

Reflecting the Paris Agreement adopted at the 21st Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21), the world is striving to reduce CO_2 emissions to net zero, and there is an urgent need to formulate and implement concrete plans to achieve this goal. Throughout this process, much attention has been placed on maximum deployment of renewable energy, but thermal power generation retains an important function as a flexible means for accommodating for the variability of renewable energy, so decarbonization of thermal power generation is needed.

1 Background

To decarbonize thermal power generation, research and development is underway to change the fuel used to hydrogen or ammonia; meanwhile, installation of CO_2 capture facilities offers the advantage of enabling existing fuel procurement systems and facilities to continue to be used to permanently store CO_2, thereby helping to reduce CO_2 emissions. On the other hand, for unavoidable CO_2 emissions, industrial technologies that can achieve negative emissions are needed, such as Direct Air Carbon dioxide Capture and Storage (DACCS), which captures CO_2 directly from the atmosphere and permanently stores it, and Bioenergy with Carbon dioxide Capture and Storage (BECCS), which captures CO_2 from the flue gas of biofuel combustion and permanently stores it. Demand is growing for such CO_2 capture facilities as a focus of decarbonization efforts, but technological challenges remain, including cost reduction.

2 Emission reduction targets and efforts by country

Based on a recognition that reducing CO_2 emissions is a common challenge for humanity, various CO_2 emission reduction targets have been announced. In particular, the International Energy Agency (IEA) Net Zero Emissions by 2050 (NZE2050) sets specific targets as scenarios for achieving net zero CO_2 emissions from energy use and industrial processes worldwide. Among these scenarios, the expected reductions from CO_2 capture are estimated to be about 7.6 Gt-CO_2/year in 2050 [1)], as shown in **Fig. 1**.

In Europe, the EU Emissions Trading System (EU ETS), a decarbonization initiative, was launched in January 2005. The EU ETS has been revised as necessary, and a notable change for phase 4, which stretches from 2021 to 2030, is an agreement to introduce a Carbon Border Adjustment Mechanism (CBAM). The CBAM is intended to prevent industrial out-migration and consequent carbon leakage to non-EU countries by closing the carbon cost gap between EU products and products imported into EU markets; it is in effect a carbon border tariff. Another notable point is that the auction revenues from the fee-based allocation of

	2020	2030	2050
1. CO_2 captured from fossil fuels			
Power sector	0. 03	3. 40	8. 60
Industrial sector	0. 03	3. 60	26. 20
Hydrogen production sector	0. 03	4. 55	13. 55
Non-biofuels production sector	0. 30	1. 70	4. 10
Subtotal	0. 39	13. 25	52. 45
2. CO_2 captured from bioenergy			
Power sector	0. 00	0. 90	5. 70
Industrial sector	0. 00	0. 15	1. 80
Biofuels production sector	0. 01	1. 50	6. 25
Subtotal	0. 01	2. 55	13. 75
3. Direct Air Capture (DAC)			
Utilization	0. 00	0. 20	3. 55
Permanent Storage	0. 00	0. 70	6. 30
Subtotal	0. 00	0. 90	9. 85
Total [Gt-CO_2/year]	0. 40	16. 70	76. 05

Fig. 1 CO_2 capture scenario (Source: IEA NZE2050)

EU ETS allowances will be invested in a fund to tackle climate change. This innovation fund will support investment in innovative low-carbon technologies, such as Carbon dioxide Capture, Utilization and Storage (CCUS); renewable energy; and energy storage. The carbon price of EU ETS carbon futures exceeds 100 EUR/t-CO_2 for the first time in February 2023, and it indicates that Europe has strong investment potential.

In the U.S., the Infrastructure Investment and Jobs Act was further strengthened in 2022 with the passage of the Inflation Reduction Act (IRA), which introduced significant tax credit incentives for carbon-free energy and clean technologies, including renewables, hydrogen, CCUS, and DAC. Under the IRA, CCUS is eligible for large tax credits of \$85/t-CO_2 for permanent storage and \$60/t-CO_2 for utilization. DAC is eligible for tax credits of \$180/t-CO_2 for permanent storage and \$130/t-CO_2 for utilization. These tax credits have an enormous impact and make DAC a realistic investment prospect rather than a pipe dream. As shown in **Fig. 2**, the U.S. has one of the largest carbon reservoirs in the world; thus, the IRA significant impacts the global decarbonization trend.

In Japan, discussions regarding the commercialization of domestic CCS projects have begun, and an emissions trading market is expected to be established through the GX (Green Transformation) League. In addition, the

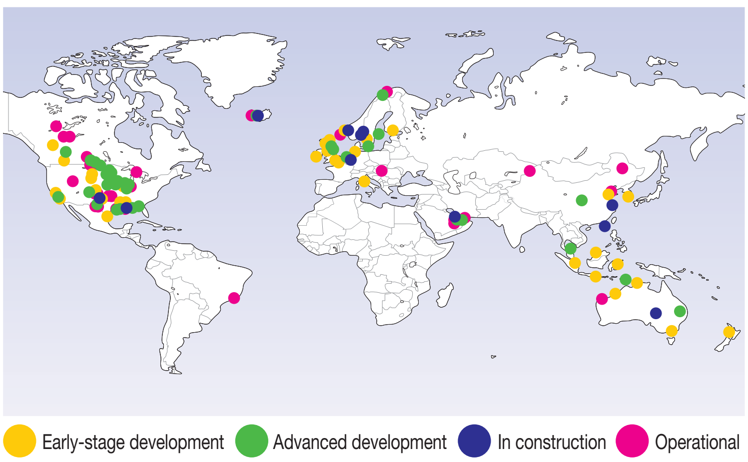

Fig. 2 Global CCS projects [2)]
Source: Based on GCCSI's "Global Status of CCS 2022"

government is actively supporting the development of CCS through the Green Innovation Fund and other grants, and, with the aim of reducing emissions, development efforts to achieve social implementation of CCS, along with hydrogen, are progressing.

In this way, CO_2 capture, storage, and utilization are attracting attention as clean technologies that lead to decarbonization, and they are influencing countries' policies as a realistic solution to reduce emissions. To further promote the global deployment of CO_2 capture facilities, which will be a key technology for decarbonization, the cost of CO_2 capture must be further reduced below that of current technologies through the development of innovative low-carbon technologies.

3 CO_2 capture technologies

(1) Conventional technologies

The solvent process is the well-known commercially available process for capturing CO_2 from flue gases.

In the solvent process, depending on the target gas, an amine- or potassium-based aqueous solution is used as the CO_2 absorbent. When in contact with a CO_2-containing gas, the aqueous solution absorbs the CO_2 in the gas, thereby separating the CO_2 from the gas. The CO_2-containing aqueous solution is then heated to separate and recover the CO_2. This heating process requires the energy of not only the bond dissociation energy between CO_2 and amine but also latent and the sensible heat of water due to the accompanying of moisture to recover CO_2 from the aqueous solution, which consumes a large amount of thermal energy.

(2) Amine-impregnated solid absorption method

To reduce the energy consumption of CO_2 separation, which is challenging with the conventional amine solvent method, we are developing the KCC (Kawasaki CO_2 Capture) process using a solid sorbent, which originated from our technology research for removing CO_2 from the air in closed spaces such as submarines. As shown in **Fig. 3**, our developed solid sorbent is a porous support material coated with an CO_2-absorbing amine on its surface.

Since unlike the conventional solvent method, our solid sorbent separates CO_2 using only the energy of the low-temperature steam, it does not require energy from the latent heat of water, resulting in an approximately 60% reduction in energy use for CO_2 capture compared to the conventional method. Furthermore, with this amine-impregnated solid absorption method, the amine is less volatile than the amine used in the solvent method, which reduces the amount of amine dispersed outside the process system and thus lowers the environmental impact.

4 CO_2 capture systems

We have developed two systems that use this solid sorbent for post-combustion flue gas and ambient air: a fixed bed system and a moving bed system.

(1) Fixed bed system

In the fixed-bed system, the solid sorbent is fixed in a tower, and three processes are batch-wise switched among multiple towers. These three processes are the absorption process to absorb CO_2, the desorption process to desorb CO_2 with steam, and the drying process to dry the moisture absorbed from the steam. This system offers a simple plant configuration and is suitable for small-scale CO_2 capture plants intended for testing and evaluation.

Making the most of such plant features, we will conduct an environmental impact assessment test of our developed amine-impregnated solid sorbent in Wyoming in the United States. This test will be implemented under a project of the Japanese Ministry of the Environment entitled "Development Project of Integrated Demonstration Facility and Supply Chain for Sustainable CCUS (CO_2 Capture Technology Demonstration with Solid

Fig. 3 Amine-impregnated solid sorbent

Absorbent)" together with the project leader, the Japan Carbon Frontier Organization (JCOAL). This project is a Japan-U.S. collaboration to construct a demonstration test plant for CO_2 capture technology that will be built at the Integrated Test Center (ITC) adjacent to Dry Fork Station (a pulverized coal-fired power plant) in Wyoming. Tests will be conducted using actual flue gas from the power plant.

In Europe and the United States, there are growing concerns about the effects on living organisms of amine emissions from the amine-based aqueous solution released into the environment during the CO_2 capture process. In this project, in accordance with relevant environmental impact assessment methods, we will conduct analysis of the exhaust gas released from our test plant after the CO_2 capture process as well as conduct environmental monitoring and analysis of amine-containing discharges in the surrounding areas before, during, and after the test period in FY2023. In order to establish an environmentally safe, inexpensive CO_2 capture technology using a solid sorbent, we complete the detailed design during FY2022 and plan to finish the environmental impact assessment test by the end of FY2023.

(2) Moving bed system and demonstration test plant

As shown in **Fig. 4**, the moving bed system continuously recovers CO_2 by moving the solid sorbent itself to an absorption tower for absorbing CO_2, a desorption tower for desorbing CO_2 with steam, and a sorbent dryer for drying the moisture absorbed from the steam, and then circulating the solid sorbent from the sorbent dryer back to the absorption tower by a conveyor. This method enables the desorption tower to continuously desorb CO_2, thus reducing the separation energy compared to the fixed bed system. We have constructed a bench-scale test plant at our Akashi Works with a recovery rate of 5 t-CO_2/day and are developing it as a KCC for large-scale recovery.

Based on our achievements at this bench-scale plant, we are conducting a long-term continuous operation demonstration test of a pilot-scale moving bed plant with recovery of 40 t-CO_2/day at Kansai Electric Power Company's Maizuru Power Station in collaboration with the Research Institute of Innovative Technology for the Earth (RITE). This is being done under a project of the New Energy and Industrial Technology Development Organization (NEDO) entitled "Commercialization of Advanced Solid Absorbents for CO_2 Capture, in R&D of CO_2 Separation/Capture Technologies, under Development of Technologies for Carbon Recycling and Next-Generation Thermal Power Generation." We are responsible for the design, manufacture, installation, and commissioning of the pilot-scale moving bed plant. Construction work started in 2021, and the plant was completed in FY2022 (**Fig. 5**).

Using an amine-impregnated solid sorbent for coal flue gas newly developed by RITE, we successfully demonstrated CO_2 recovery by FY2022. Next, maximum recovery tests, parameter change tests, and continuous operation tests will be conducted using this pilot plant by FY2024 in order to establish an operation method for the KCC process as well as to develop and verify the continuous operation and control response capability to be marketed and applied commercially.

After completing the demonstration test, we plan to develop a commercial plant capable of recovering up to

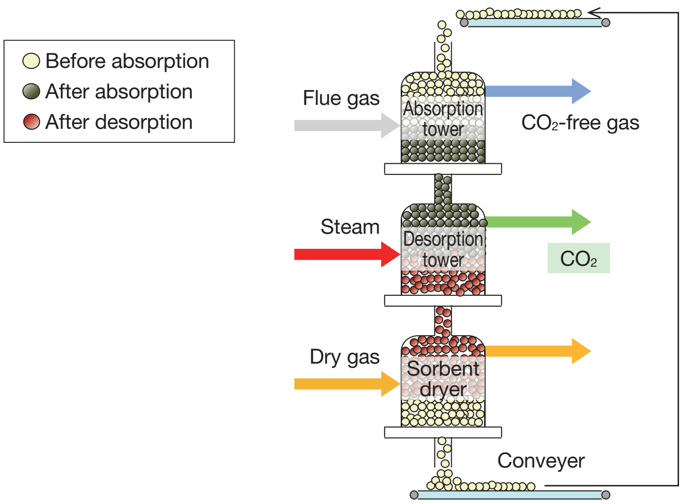

Fig. 4 Moving bed solid sorbent process

Fig. 5 Pilot-scale moving bed solid sorbent plant

Fig. 6 Demonstration plant for DAC

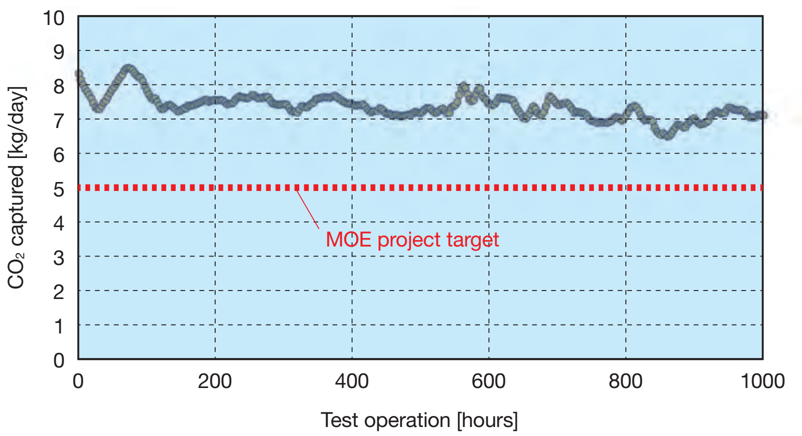

Fig. 7 DAC CO_2 capture test

several thousand tons of CO_2/day and start commercial application to small- and medium-sized emission sources as well as thermal power plants.

(3) DAC development

Our amine-impregnated solid sorbent development stemmed from DAC for submarines and can be applied to direct capture from ambient air, which has a lower CO_2 concentration than flue gas. Under the Ministry of the Environment, Government of Japan (MOE) project entitled "Modeling of Carbon Circulation Society with Direct Air Capture and CO_2 Utilization," we established a small demonstration plant (**Fig. 6**) with a capture capacity of 5 kg-CO_2/day (about 2 t-CO_2/year) at our Akashi Works and completed a demonstration test by FY2022.

In this demonstration test, we used our newly developed solid sorbent. During 1,000 hours of continuous operation, the amount of CO_2 captured was confirmed to be 6.5 to 8.5 kg-CO_2/day, which is higher than the project target of 5 kg-CO_2/day, as shown in **Fig. 7**. The purity of the recovered CO_2 was 99% or more. In addition, CO_2 recovery tests using air that simulated seasonal and weather changes were conducted to evaluate seasonal dependence, and data for commercial deployment has already been obtained.

Conclusion

We are developing our KCC energy-saving CO_2 capture system through demonstration tests in order to realize commercial-scale plants. With our innovative low-carbon solid sorbent technology, we intend to further advance our development to achieve global decarbonization.

References

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2) Global CCS Institute "Global Status of CCS 2022":
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