Development of Highly Efficient Direct Air Capture (DAC) and Carbon Recycling Technologies

PM : Akio Kodama
Kanazawa University, Professor
Co-implementer : Research Institute of Innovative Technology for the Earth（RITE）

Contents

1． Overview of research and development

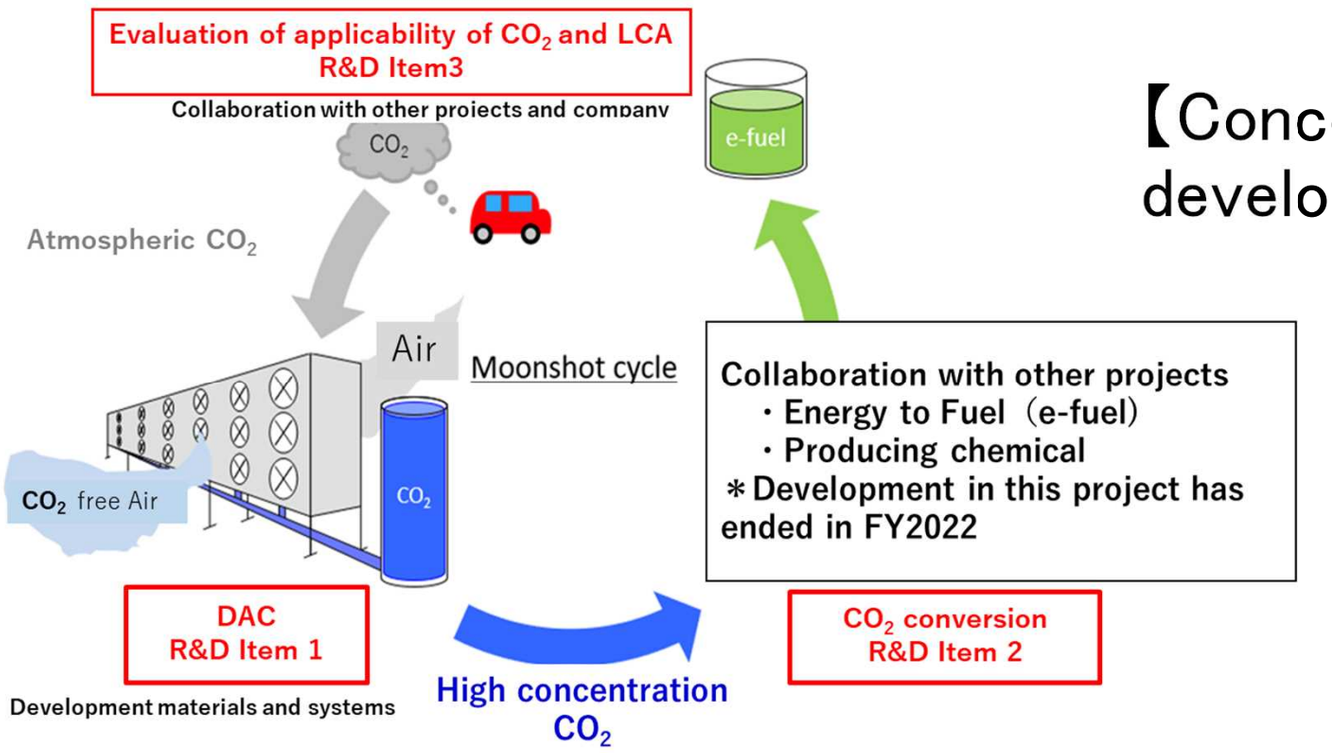
◆The following items will be developed for establishing a carbon recycling technology which capture CO_2 directly from the atmosphere (Direct Air Capture) and convert the recovered CO2 into valuable resources.

【R&D Items】

1. Development of high-efficient CO_2 Direct Air Capture technology from the atmosphere →Applying RITE Sorbent
3. Evaluation of applicability of CO_2 and LCA
   → Collaboration with other projects and company

* Item 2. Development of CO_2 conversion technology for carbon recycling into valuable resources has been ended in FY2022

【Duration】 FY2020～FY2029



【Conceptual diagram of this research and development and image of carbon recycling】

2. Targets of FY2029

R&D Items1　Development of high-efficiency CO_2 Direct Air Capture technology from the atmosphere.

Target :

- DAC technology providing high enough concentrated CO_2 to CO_2 conversion reactions will be established by conducting t/day scale pilot tests using the developed new solid sorbent material.
- In terms of energy and cost, the prospective efficient DAC system as a countermeasure against global warming will be established.

Achieving performance that exceeds overseas competitors.

R&D Items2　Development of CO_2 conversion technology for carbon recycling into valuable resources.

Development in this project has been ended in FY2022. Collaboration with other projects is explored.

R&D Items3　Evaluation of Applicability of CO_2 and LCA

Target :

- CO_2 reduction effect by developed technologies will be verified through LCA evaluation.
- The effectiveness of the global warming problem and possibility of early social implementation of developed technologies will be confirmed

In order to Achieve earlier social implementation the collaborative evaluation with other projects and companies will be necessary.

3． System of research and development

New Energy and Industrial Technology Development Organization（NEDO）・PD

Instruction/Consultation

PM: Kanazawa University, Institute for Frontier Science Initiative
Professor　Akio Kodama

【Contractor】

Kanazawa University（Kakuma-machi, Kanazawa）：
R&D item 1.
「Development of highly efficient CO_2 capture technology from the atmosphere」
1－② Development of highly efficient CO_2 capture technology and evaluation of system
R&D item 3
「Application of liquid fuel, and LCA evaluation」

Collaboration

【Contractor】

Research Institute of Innovative Technology for the Earth（RITE）
(Kizugawa-shi, Kyoto）
R&D item 1.
「Development of highly efficient CO_2 capture technology from the atmosphere」
1－① Development of novel absorbent for low concentration CO_2 Capture
1－② Development of highly efficient CO_2 capture technology and evaluation of system
R&D item 2. (Development in this project has been ended at FY2022)
「Development of CO_2 conversion technology for carbon cycle」
* Collaboration with other project is explored.
R&D item 3.
「 Evaluation of applicability of CO2 and LCA 」

【Subcontractor】

Mitsubishi Heavy Industries, Ltd. (MHI) (Yokohama-shi, Kanagawa）
R&D item 1.
「Development of highly efficient CO_2 capture technology from the atmosphere」
1－② Development of highly efficient CO_2 capture technology and evaluation of system
1－③ Detailed design and manufacturing of scale-up test equipment and evaluation test

【External Partner】

R&D item 3 .
「Evaluation with Applicability of CO_2 and LCA evaluation」
Collaborate with other project and company

Outsourcing

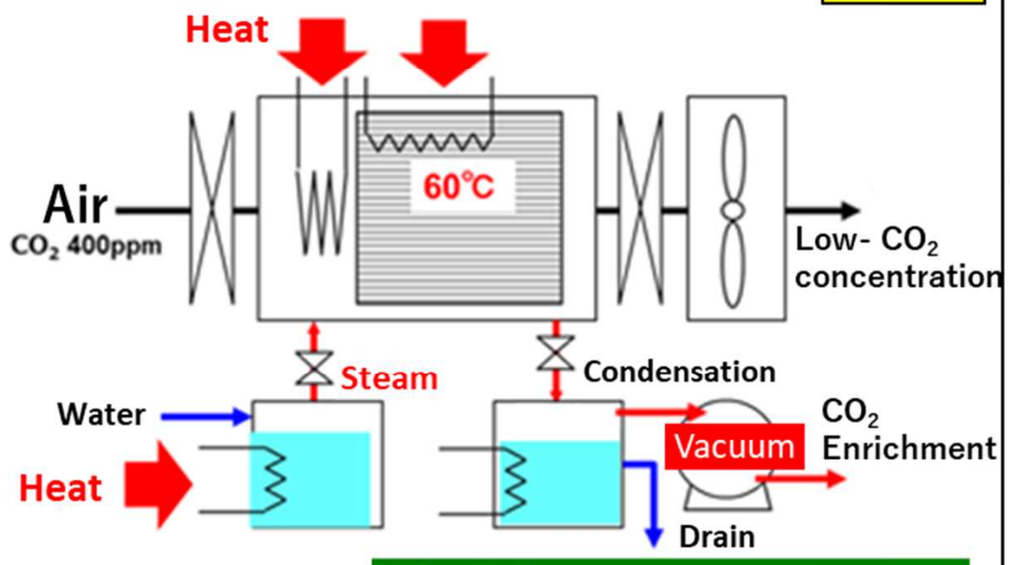
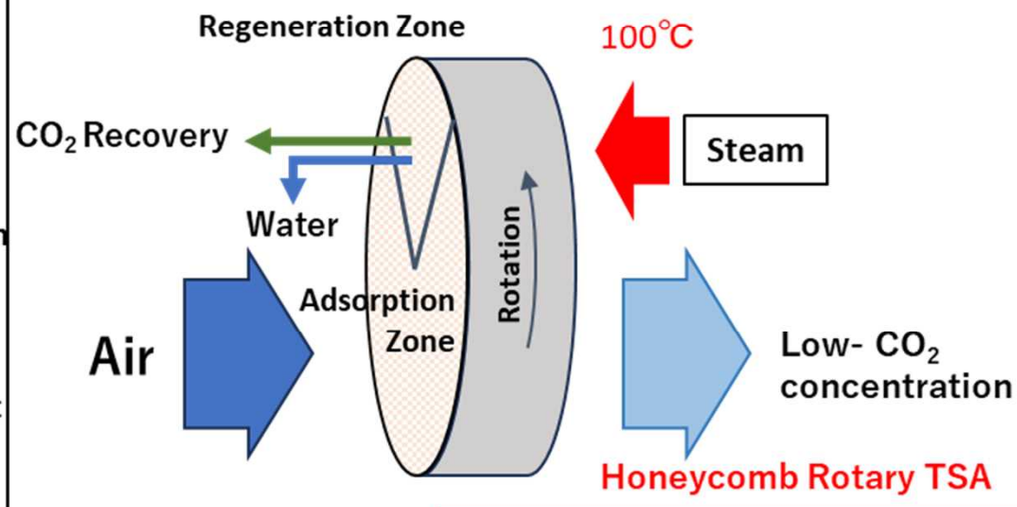
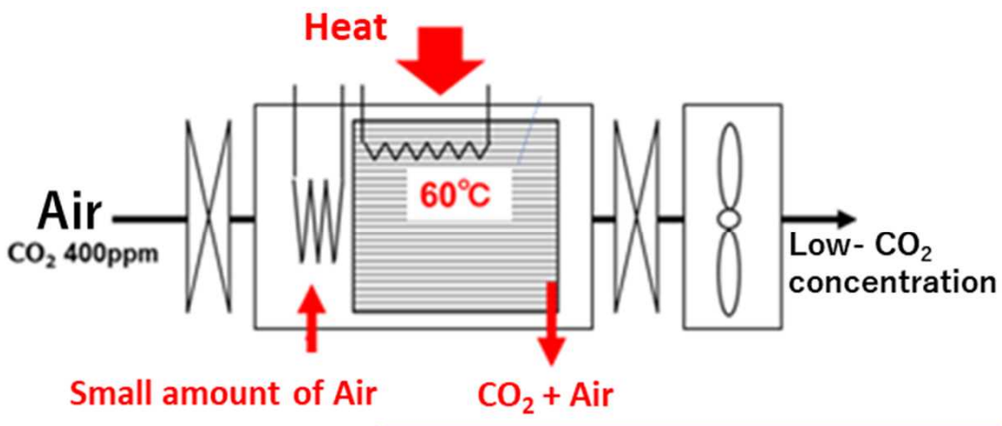
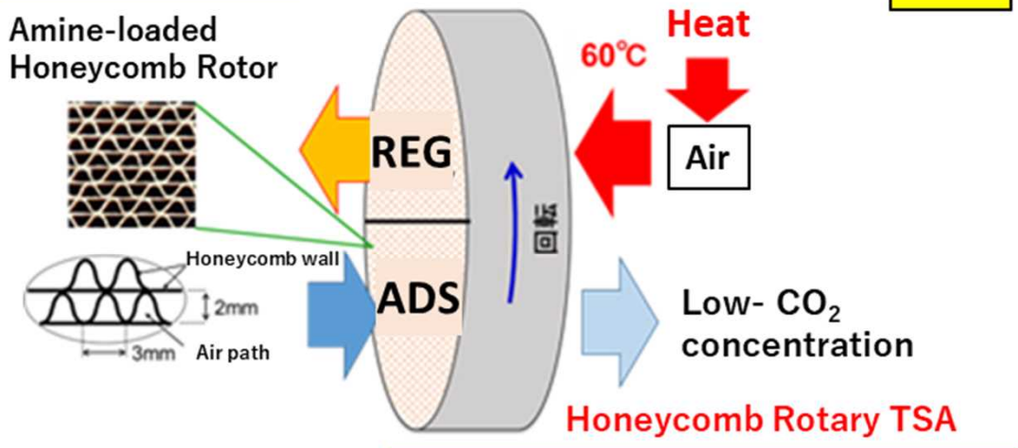
Engineering Company (MPW-ES, MHI-TC)
（1－② Detailed design, manufacturing, installation and evaluation test of DAC bench scale test equipment ）

Outsourcing

Large scale synthesis of amine and support, amine impregnation
（Collaboration with multiple companies, Building the supply chain）

4 . DAC（Direct Air Capture）Technologies developed

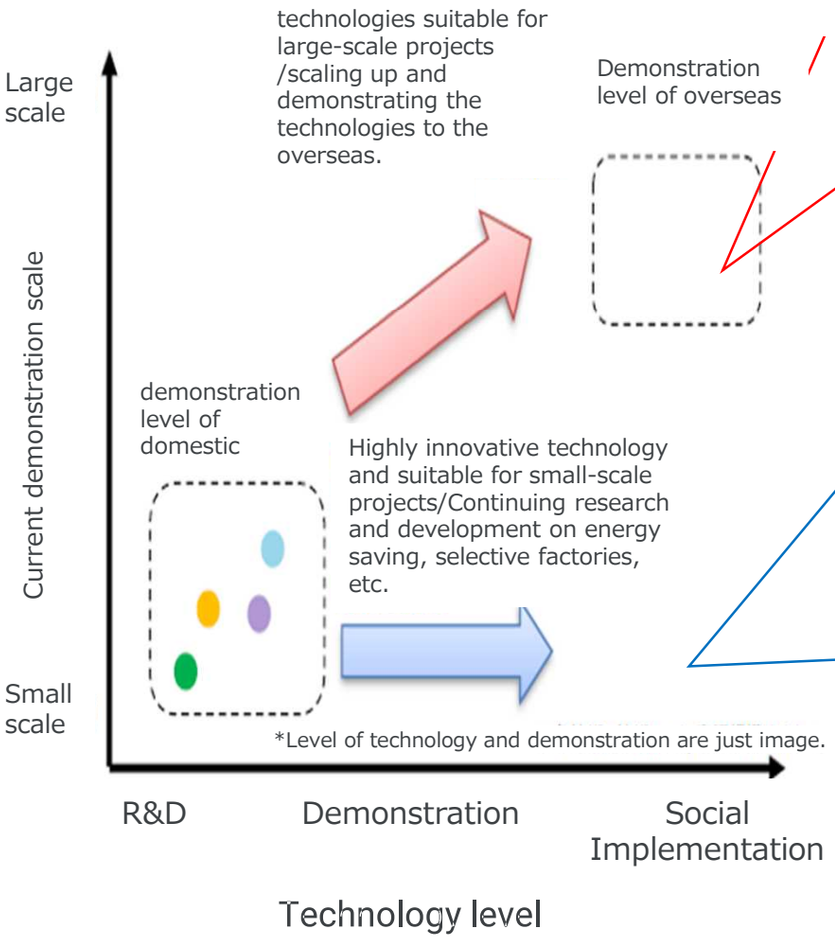
【 “Batch or Rotary Cycle” x “Steam or Air Purge”】

	Batch	Rotary
Steam Purge	**Indirect Heating + Steam purge** — RITE  **Highly concentrated**	**Steam Heating** — Kanazawa Univ.  **Highly concentrated**
Air Purge	**Indirect Heating + Air purge** — KU  **Rough concentration**	**Air Heating** — KU  **Rough concentration**

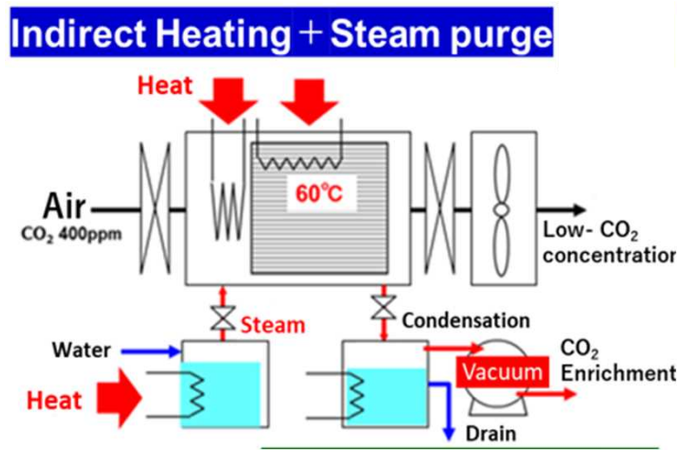
5. Image of social implementation

Goal

Choose future direction depending on the scale.
In particular, technologies suitable for large-scale projects need to be scaled up as soon as possible considering the progress of large-scale demonstrations overseas.

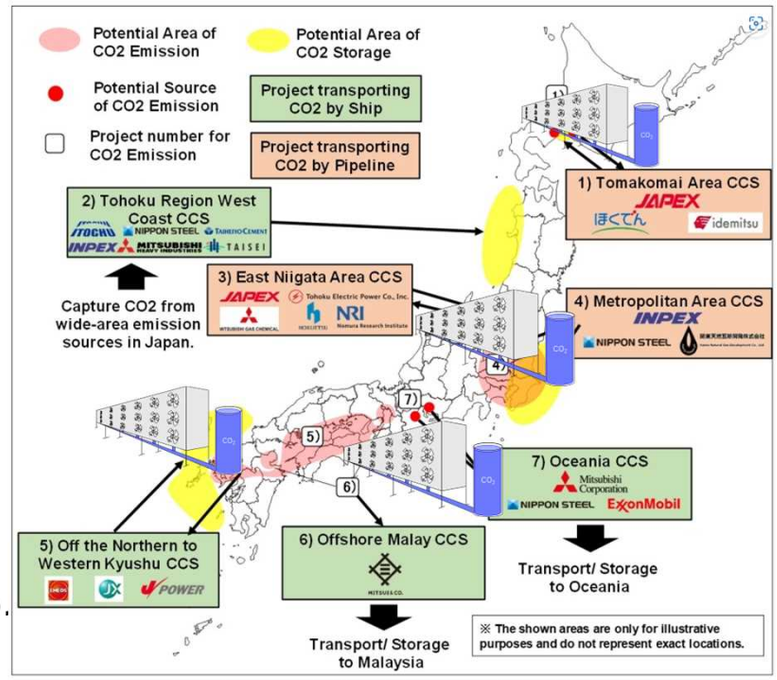


Source : Future policy toward creating a negative emissions market(METI)



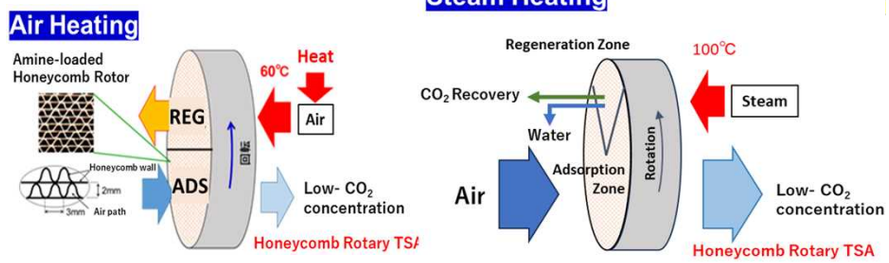
Steam recovery (RITE/MHI)

Domestic : Collaboration with Advanced CCS project.
Overseas : License to foreign companies (material, system).
Participation to foreign projects.



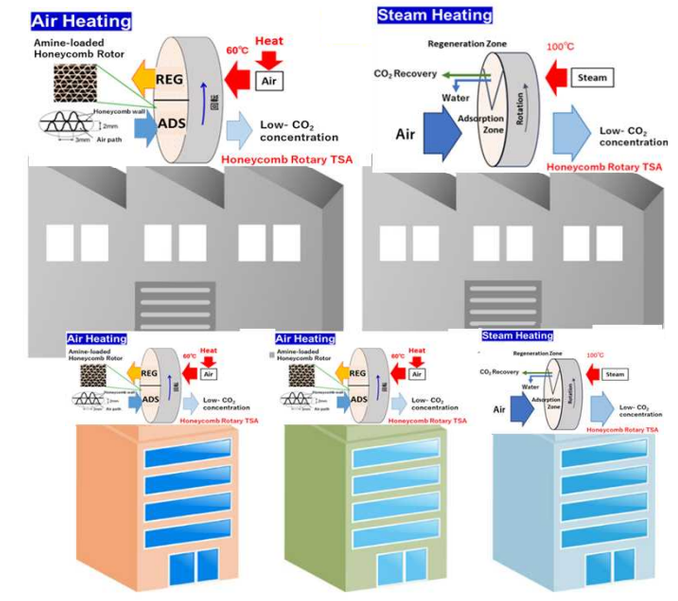
Location of 7 Japanese Advanced CCS Project and companies proposed each project.

Illustrated by using followind document. Showing just image, not indicting the actual collaboration
https://www.jogmec.go.jp/english/news/release/news_10_00036.html



Honeycomb Rotary (KU)

Domestic and overseas : Applying to small to mid scale decentralized system in factories or offices (Combined with air conditioning system)



6. Schedule

Upper: DAC Technology
Lower: Evaluation of Applicability of CO_2 and LCA

Research Institute of Innovative Technology for the Earth

Item \ Fiscal year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Material development・Simulation for DAC (RITE)	New material screening・Lab test		Optimization of preparation method			Improvement of material, production method, and performance (Development of a highly durable material for the air-recovery)				
	Development of simulator (Proposing optimized processes)			Modification of simulator (Improving accuracy)		Simulation（optimization of operation condition）				
Process development (Air-purge) (Honeycomb Rotary with Steam purge) Kanazawa Univ.	Development of air-purge type DAC (Indirect heating, Honeycomb rotary)					Development of an effective DAC system based on LCA evaluation (Air regeneration and indirect heating type applied for air conditioning, improvement of steam regeneration honeycomb rotary type)				
				Honeycomb Rotary with steam purge						
				Design & Test		Improvement	Scale-up test		long-term demonstration	
Process examination (Steam-recovery) Test equipment at RITE	reorganization	design・manufacturing	Performance confirmation	Improvement・design						
Bench scale test					Manufacturing construction	Demonstration	Relocation			
Pilot scale test							Improvement・design	Manufacturing construction	Long-term demonstration	Disassembly
Evaluation of Applicability of CO2 and LCA			preparation	LCA evaluation					Evaluation of Applicability of CO2 and LCA	
Development of membranes and membrane reactors (RITE) ＊Development has been ended in FY2022	Membrane synthesis			Collaboration with other projects is explored						
	Manufacturing MR (Lab)	Lab test								

7. Progress and Achievement: R&D Items1 Development of DAC(Direct Air Capture) technology

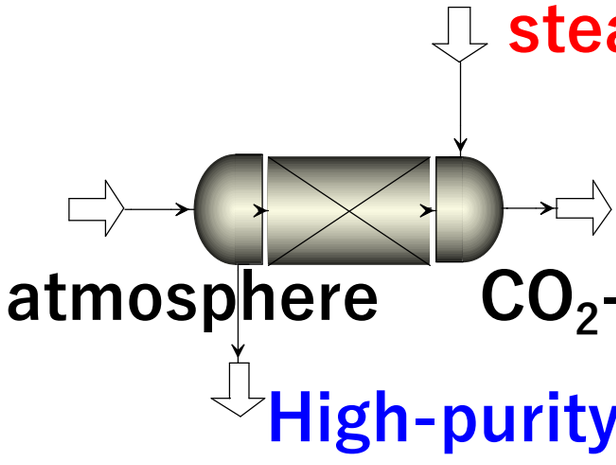
Steam recovery system： Collaborative development system among simulation and lab-scale test, and DAC experimental facility test

Lab-scale test equipment (~a few 100 g/d)

Provision of physical property data

Improvement of material property

Process simulation



Validation of application to real process

Proposal of improved substrate

Optimization of operation condition

Proposal of improved model

Scaling-up, operation condition

Mitsubishi Heavy Industry Co.(株)

Proposal for energy saving

DAC Experimental Facility(~a few kg/d)

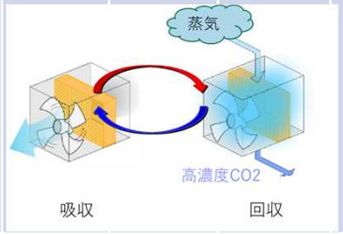
6. Progress and Achievement: R&D Items1-① Development of amines and supports (RITE)

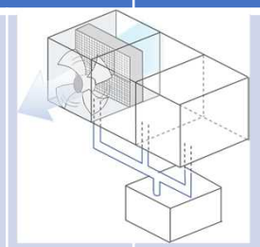
Research Institute of Innovative Technology for the Earth

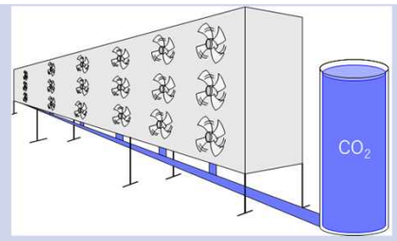
2020	2021	2022	2023	2024	2025~2029

Phase

Materials and systems development







Bench scale DAC development (~500 kg/d)

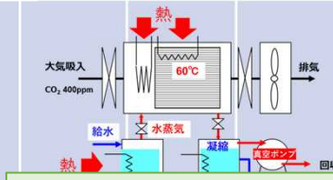
Bench scale test

Pilot scale development

Evaluation

Lab-scale equipment (~100 g/d)

Basic evaluation



DAC system (~10 kg/d)

Practical evaluation

Amine

RITE amine G1

scale up

RITE amine G2

scale up

scale up to tons

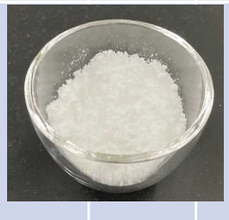
Establishment of industrial production method (RITE amine G1)

RITE amine G2

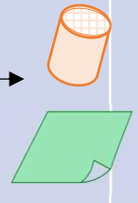
RITE amine GX

Improvement

support



RITE silica



new support

Basic and practical evaluation

Support 1

Support 2

Support X

Improvement

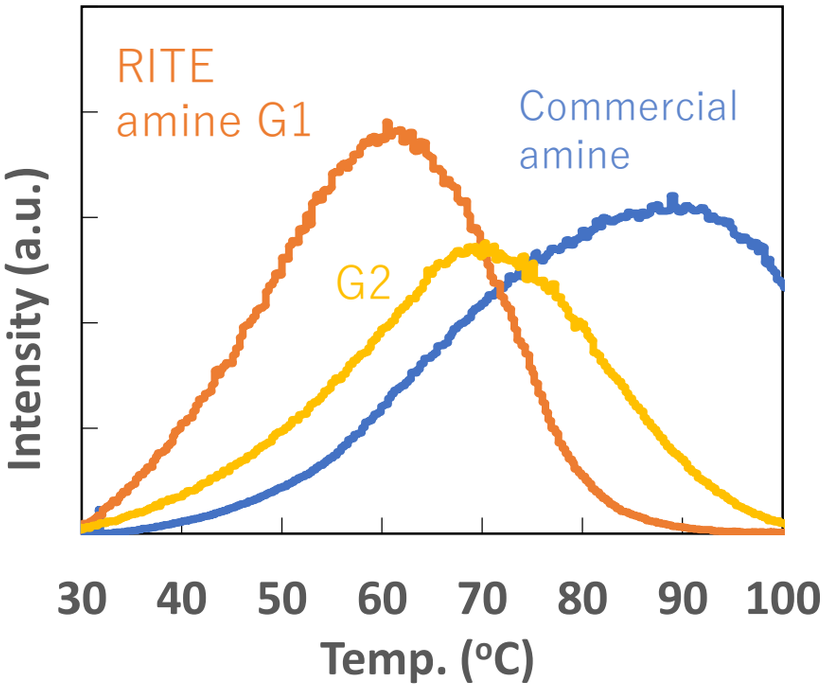
6. Progress and Achievement: R&D Items1-① Performance of RITE amines developing for DAC

Feature of RITE amines

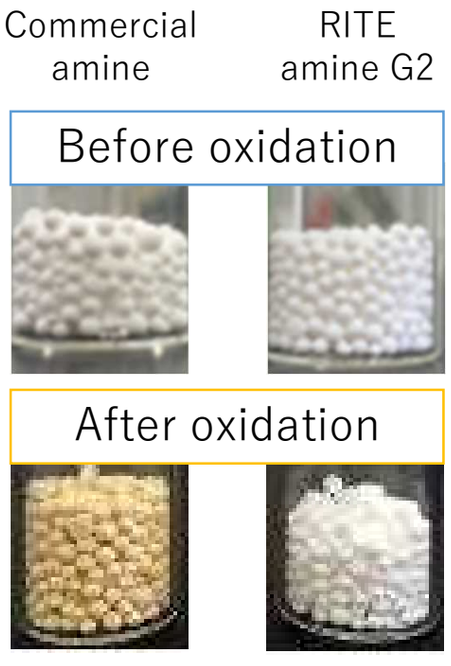
Comparison of commercial and RITE amines

	Commercial amine	RITE amine G1	RITE amine G2
Desorption temp.	90°C	60°C	70°C
Absorption amount	high	low	middle
Oxidative degradation resistance	×	○	◎

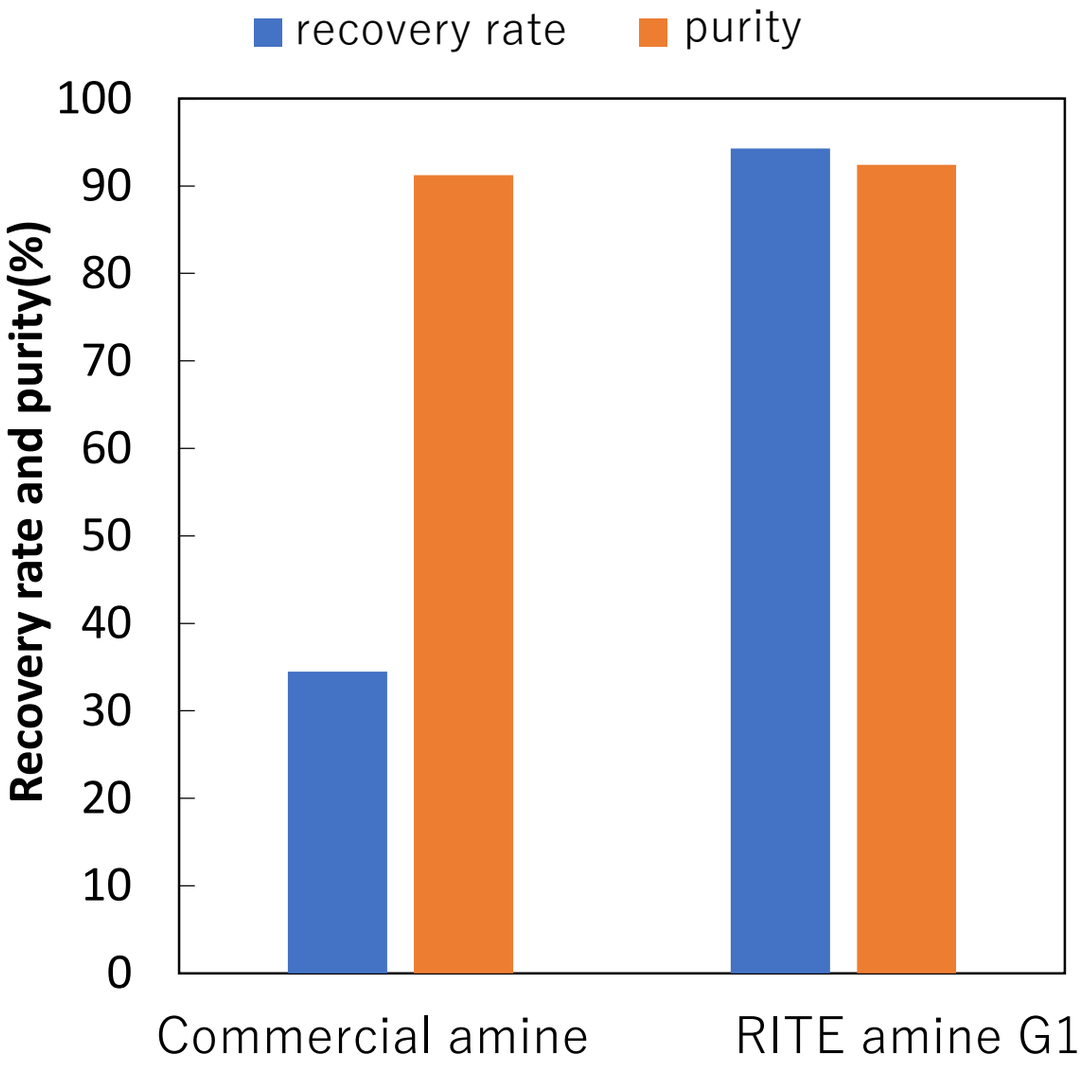
Desorption peak of each amines



Oxidative resistance



Desorption performance using low pressure steam (60°C)



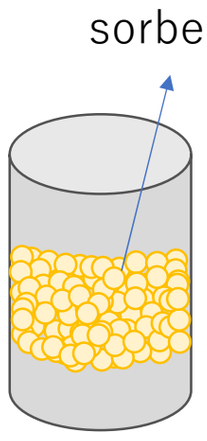
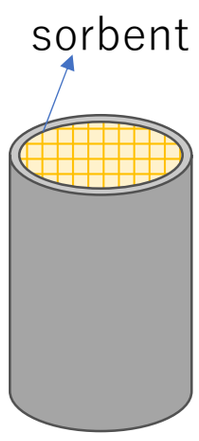
RITE amine G1：CO2 can be desorbed at 60°C, under optimization
RITE amine G2~：New amines improving each performance, under development

6. Progress and Achievement: R&D Items1-①
Development of supports for RITE amine impregnation

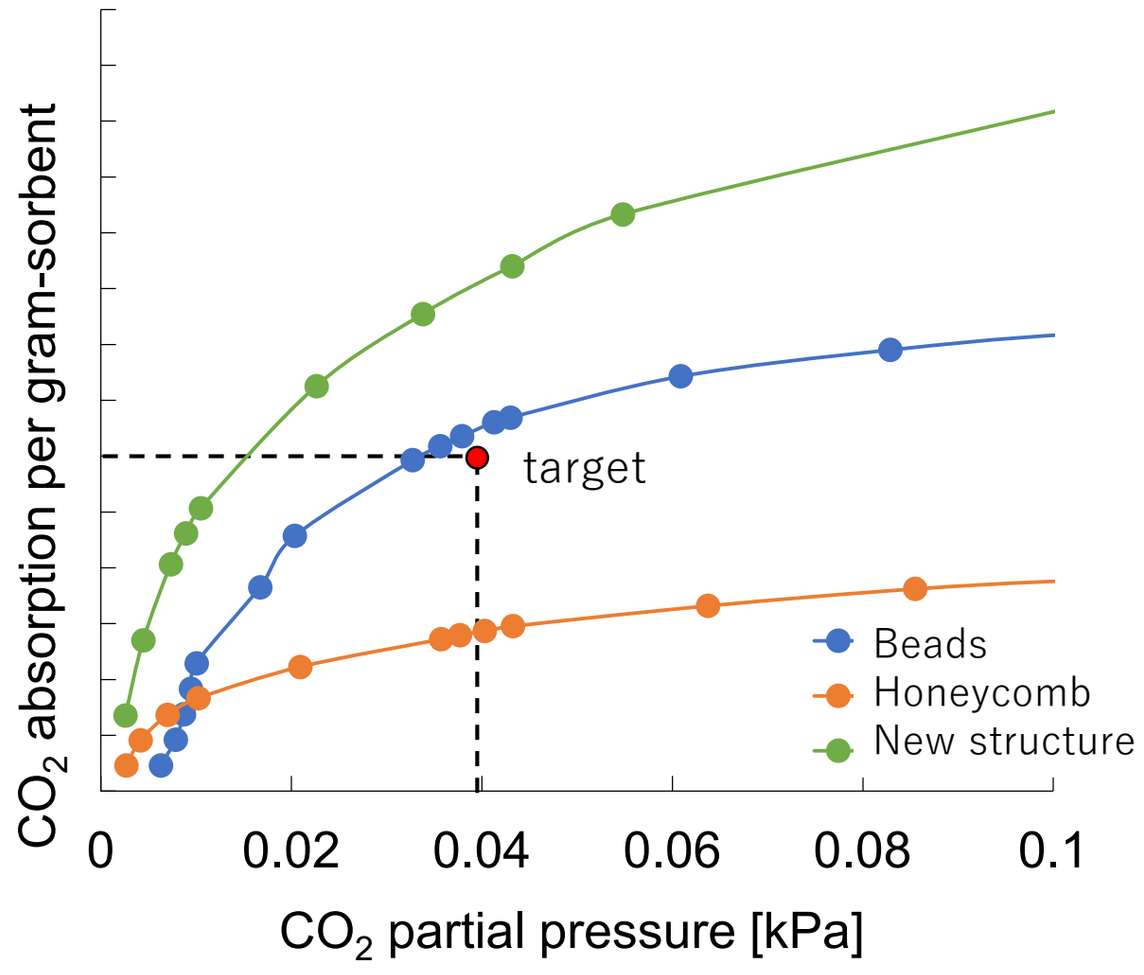
Development of supports

RITE amine G1 impregnated sorbent

Structures and features

Beads	Honeycomb	New structure
		Completely different shape and material
・Highly packing ・Large capacity for CO_2 absorption ・High pressure drop	・Superior CO2-amine contact ・Low pressure drop ・Small absorption amount	・Highly packing ・Large capacity for CO_2 absorption ・Low pressure drop (depend on structure)

CO2 absorption isotherm
Temp.：20°C

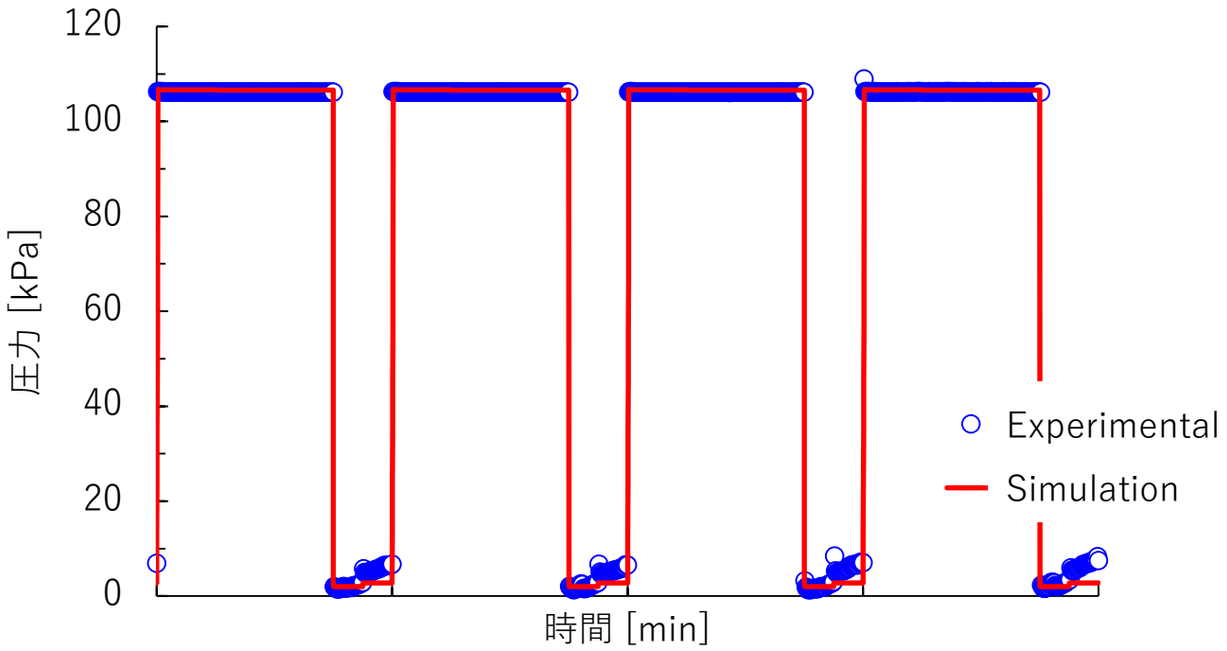


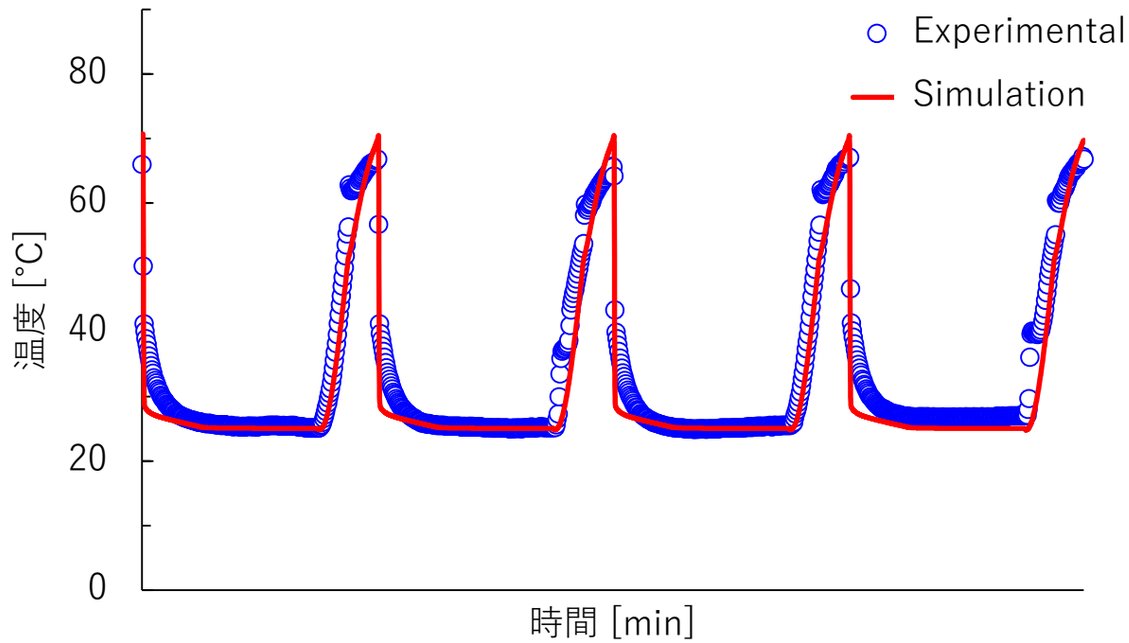
・Under development of porous supports with different materials and structures

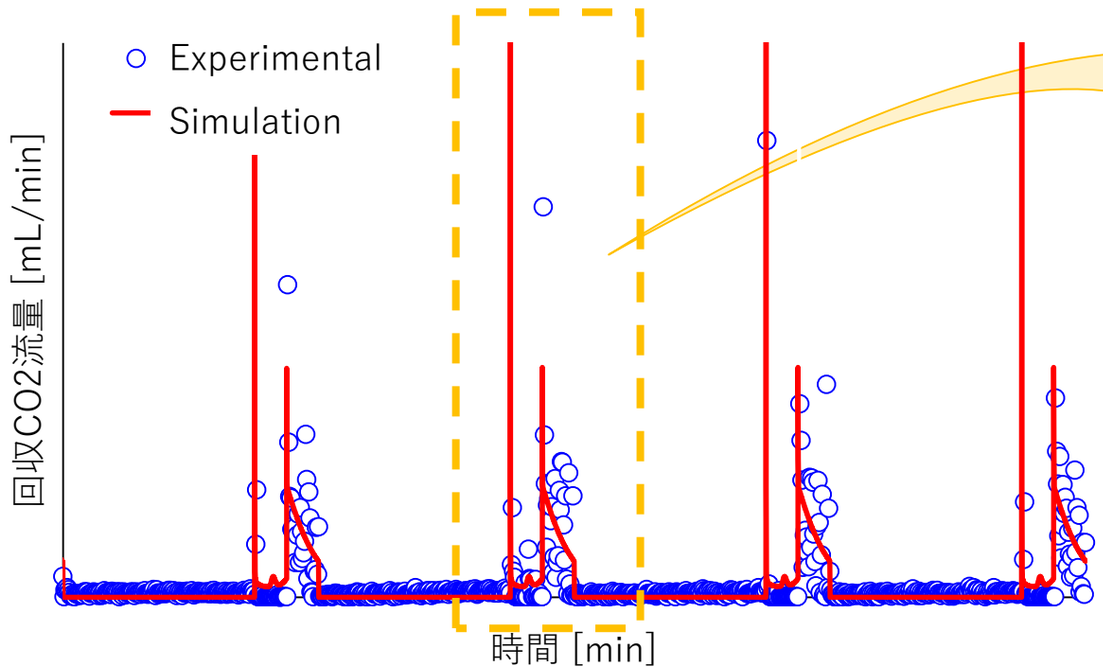
・New structured sorbent is shown the performance far exceeds target values

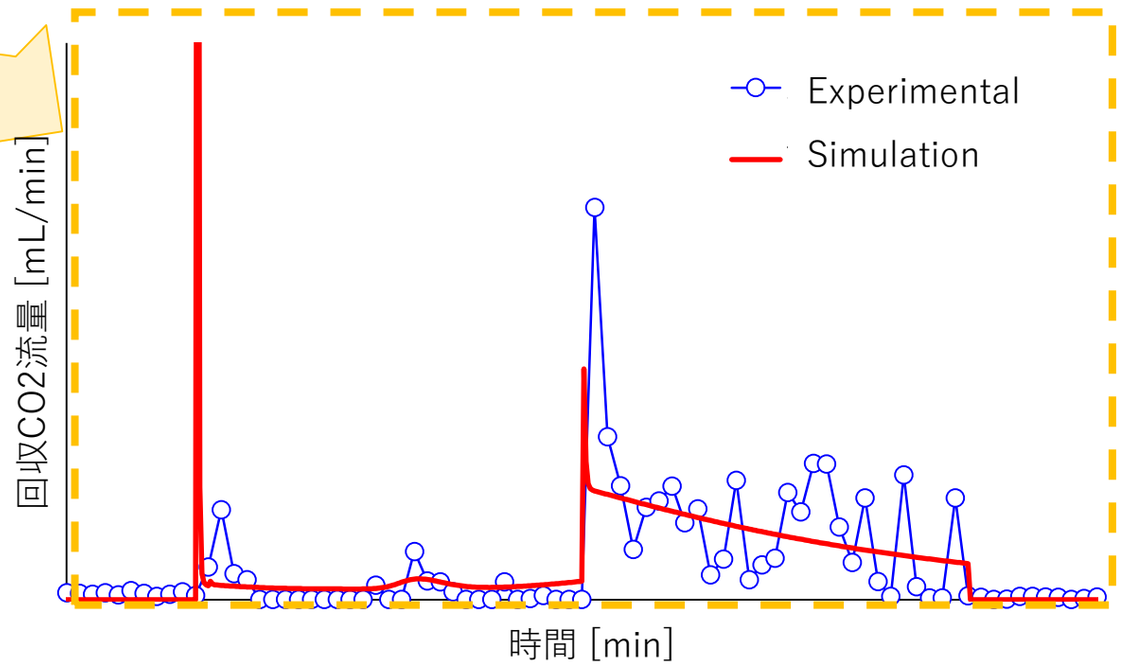
6. Progress and Achievement: R&D Items1-② Development of DAC simulation

Prediction of adsorption and desorption behavior by simulation







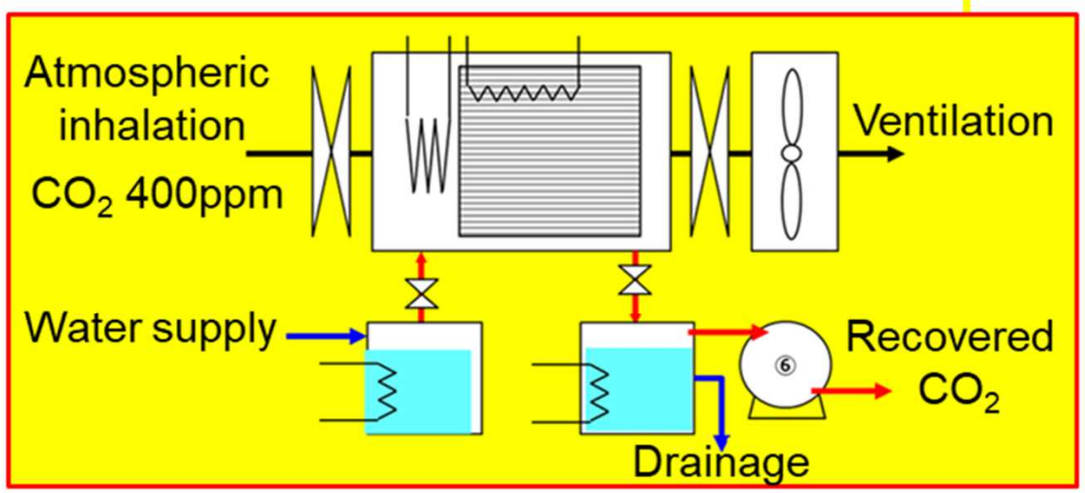


RITE simulation can accurately predict the cyclic behavior of the new structured sorbent.

6. Progress and Achievement: R&D Items1-②
DAC Experimental Facility in RITE premises

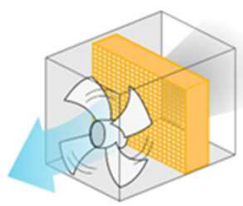
Research Institute of Innovative Technology for the Earth

【Evaluation Test started at DAC Experimental Facility in RITE】 （2022.9.20 NEDO, MHI Engineering, RITE 3 party press release ）



DAC system evaluation equipment (a few kg-CO_2/day)

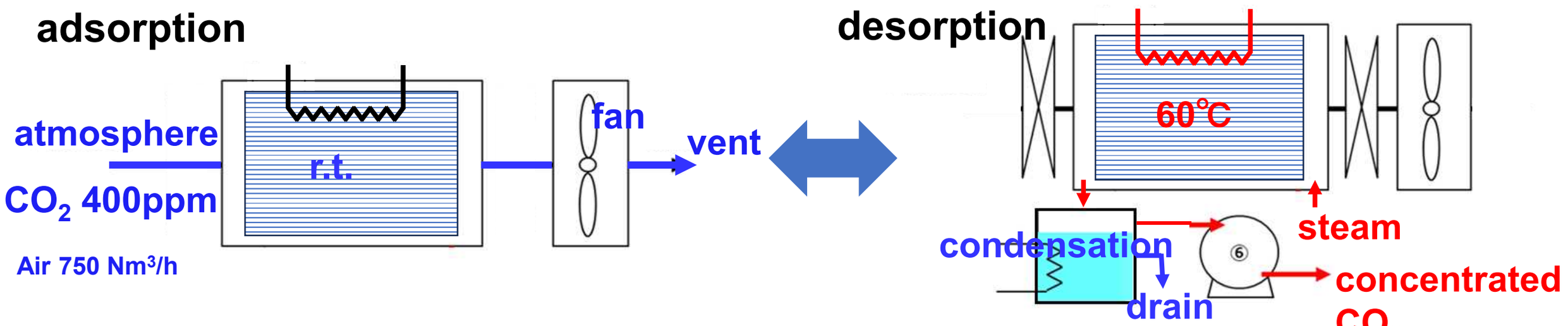
Small test equipment
a few kg-CO_2/day
Performance evaluation
of real-size honeycomb

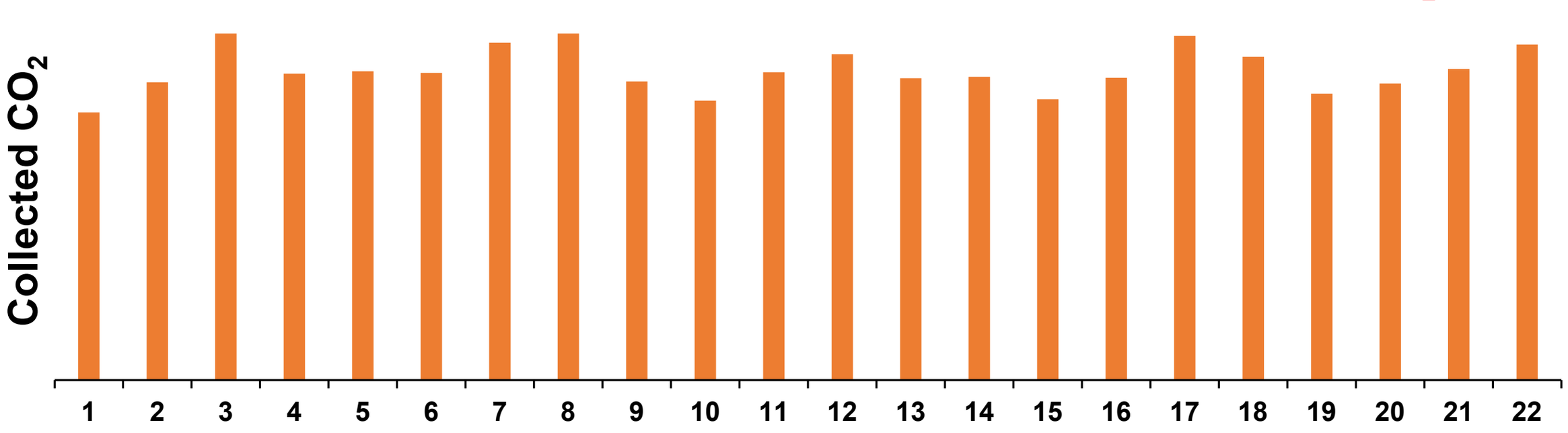


DAC test equipment developed by RITE and Mitsubishi Heavy Industry Engineering was installed

6. Progress and Achievement: R&D Items1-② Test in DAC Experimental Facility

Cycle tests using RITE amine-loaded conventional honeycomb





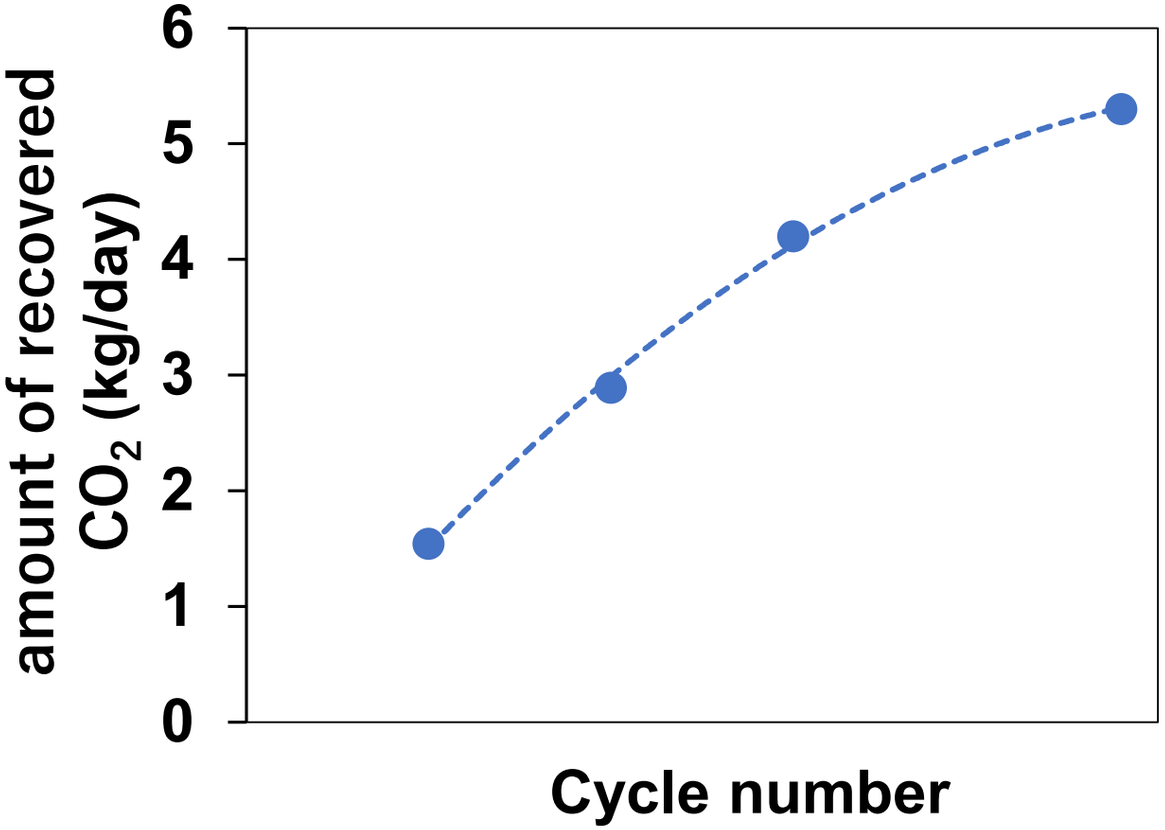
- CO_2 concentration ＞ 95%
- amount of CO_2 collected ~ av. 3 kg/day

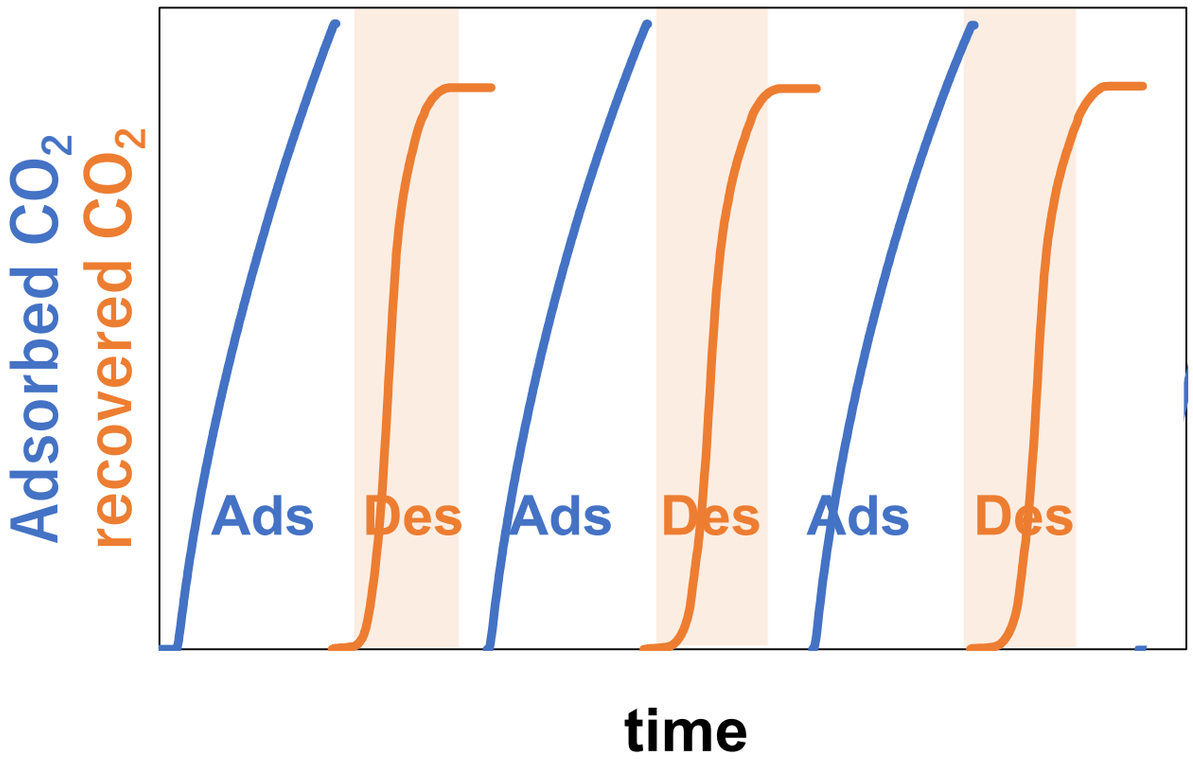
6. Progress and Achievement: R&D Items1-② Test in DAC Experimental Facility

Improvement of adsorbent substrate

①Increasing adsorption capacity
②Improving heat conductivity
③Increasing adsorption rate

⇒Increase in the number of cycles and the amount of recovered CO_2 per day

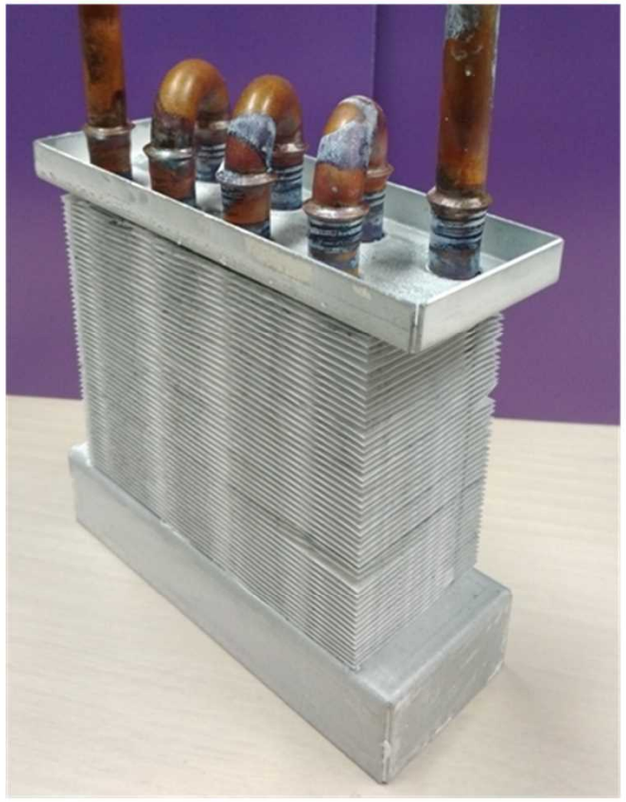


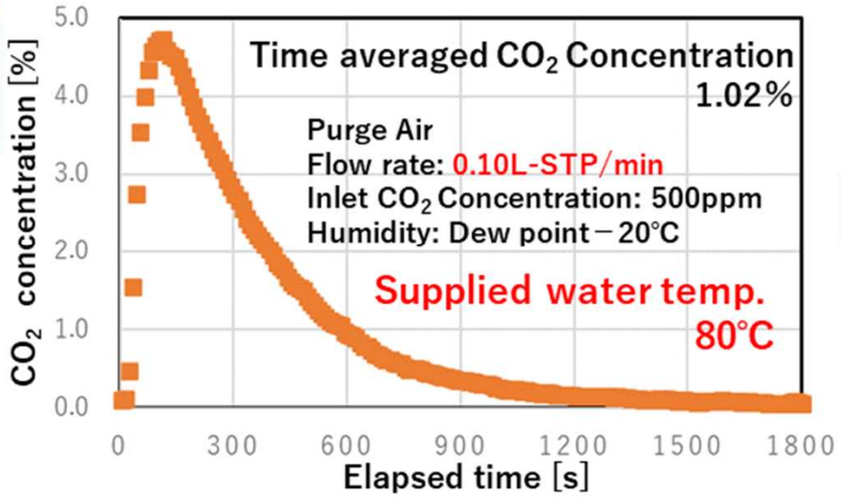


By improving adsorbent substrate, amount of recovered CO_2 increased up to 5 kg/day.

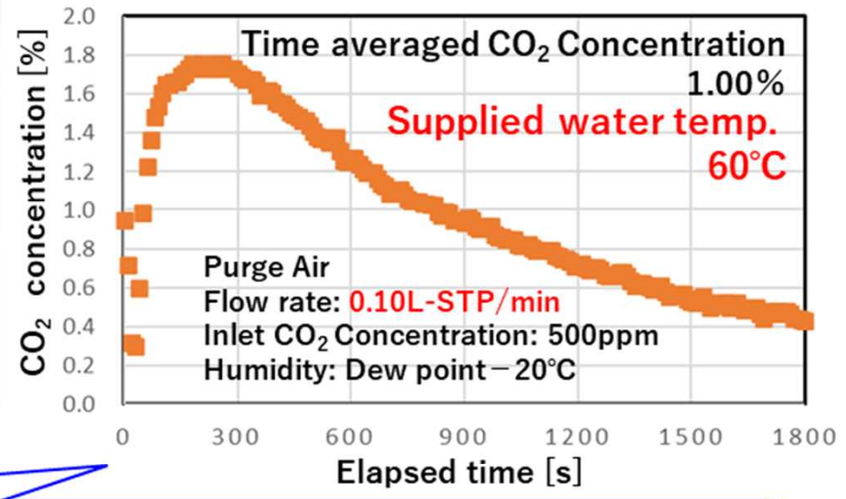
7 . DAC development : Indirect Heating with Air purge

Amine coated Heat Exchanger





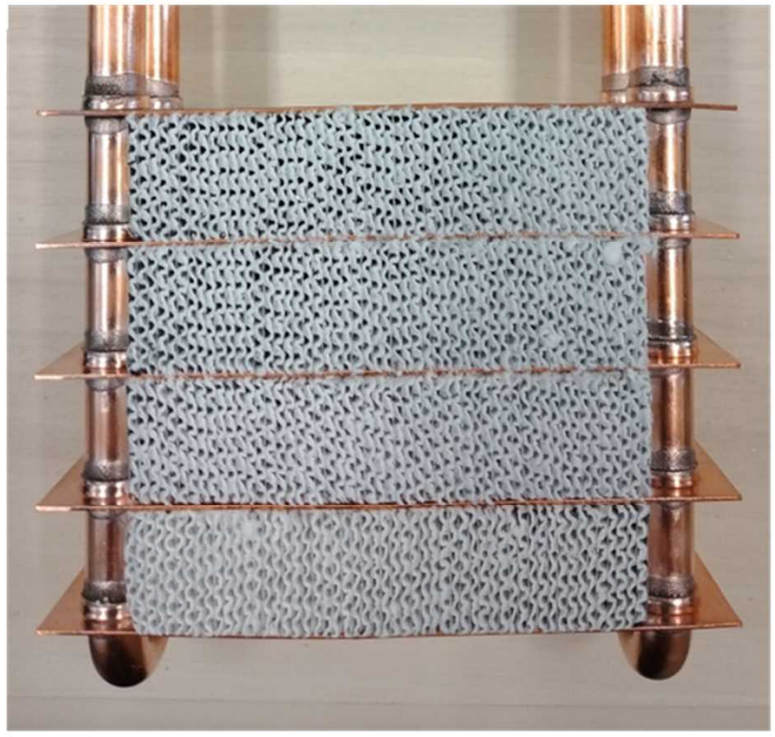
Regeneration outlet CO_2 concentration



CO_2 concentration averages about 1% (20x enrichment) at regeneration temperatures of 60°C to 80°C, reaching 5% momentarily at 80°C regeneration.

Test at a requested air flow rate in actual use

An indirect heating adsorption unit as an alternative to "coating"



【Air Purge】
Water vapor in the air is also adsorbed and desorbed during regeneration step

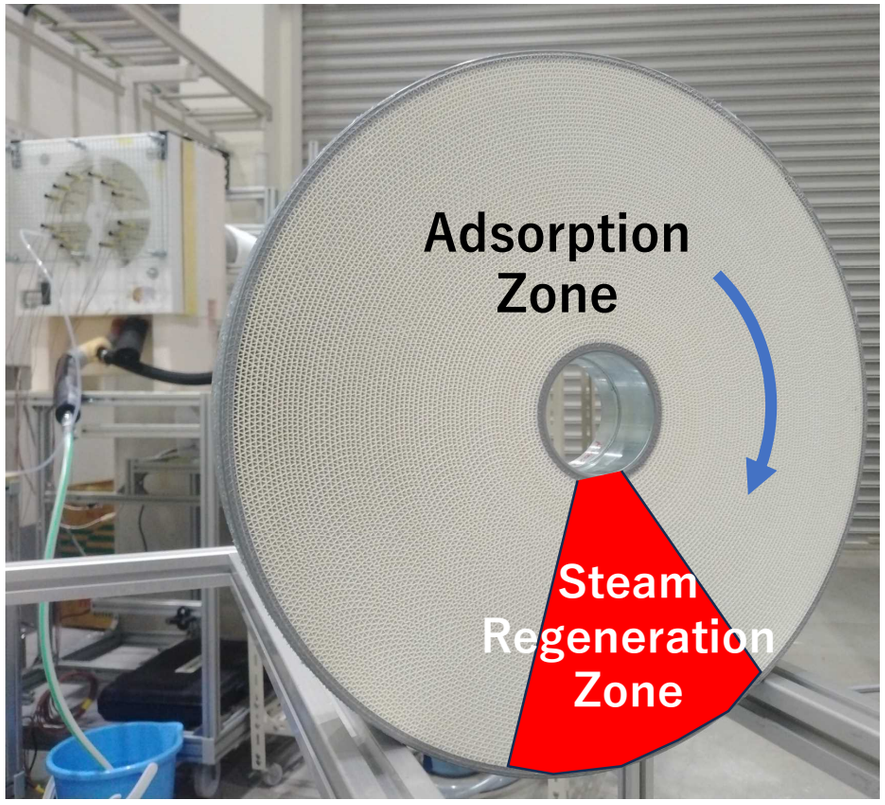
Large heat load due to adsorption /desorption of water vapor

Relatively simple equipment configuration

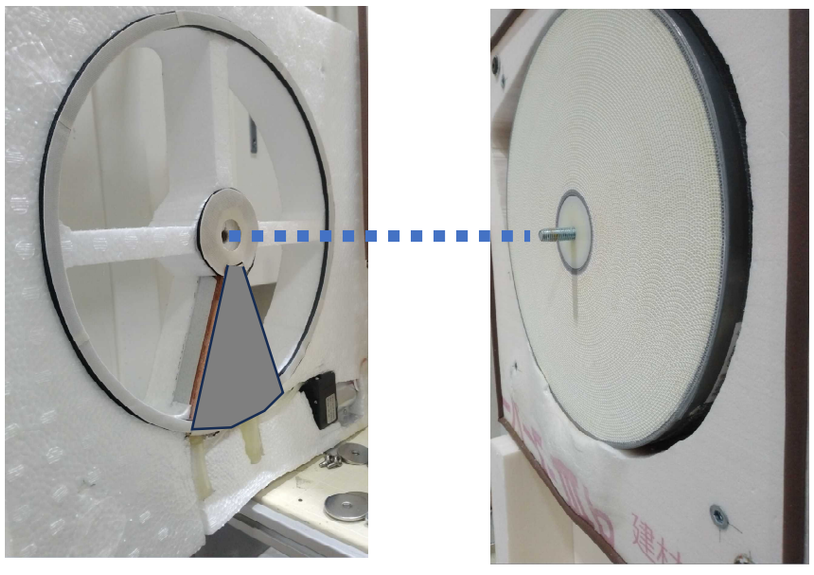
Air Conditioning (Dehumidification) + DAC

Collaboration with PJ to turn building space into a CO2 capture site

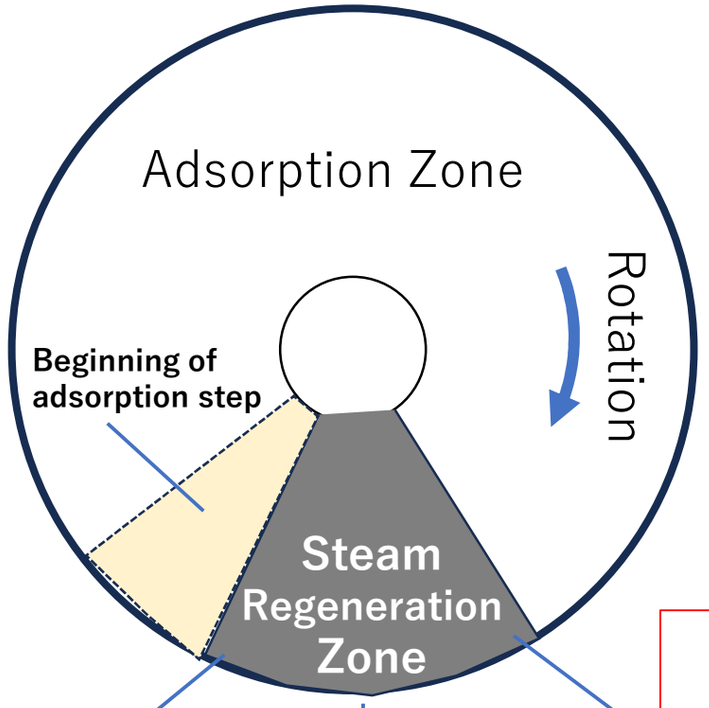
7 . DAC development : Honeycomb Rotary + Steam



Amine loaded Honeycomb Rotor
（Φ320mm×50mm）



Specials of Steam Regenerative Honeycomb Rotary DAC



Rapid cool down of adsorbent by evaporation heat of condensed water in regeneration zone
⇩
Protects amines from degradation

Decrease of the amount of highly concentrated CO2 moved to the adsorption zone
⇩
CO_2 Recovery ratio↗

Steam supply and CO_2 desorption
⇩
Latent heat of supplied steam can be used for heating as well as its sensible heat

Prevents air contamination into the regeneration zone
⇩
CO_2 recovery concentration↗

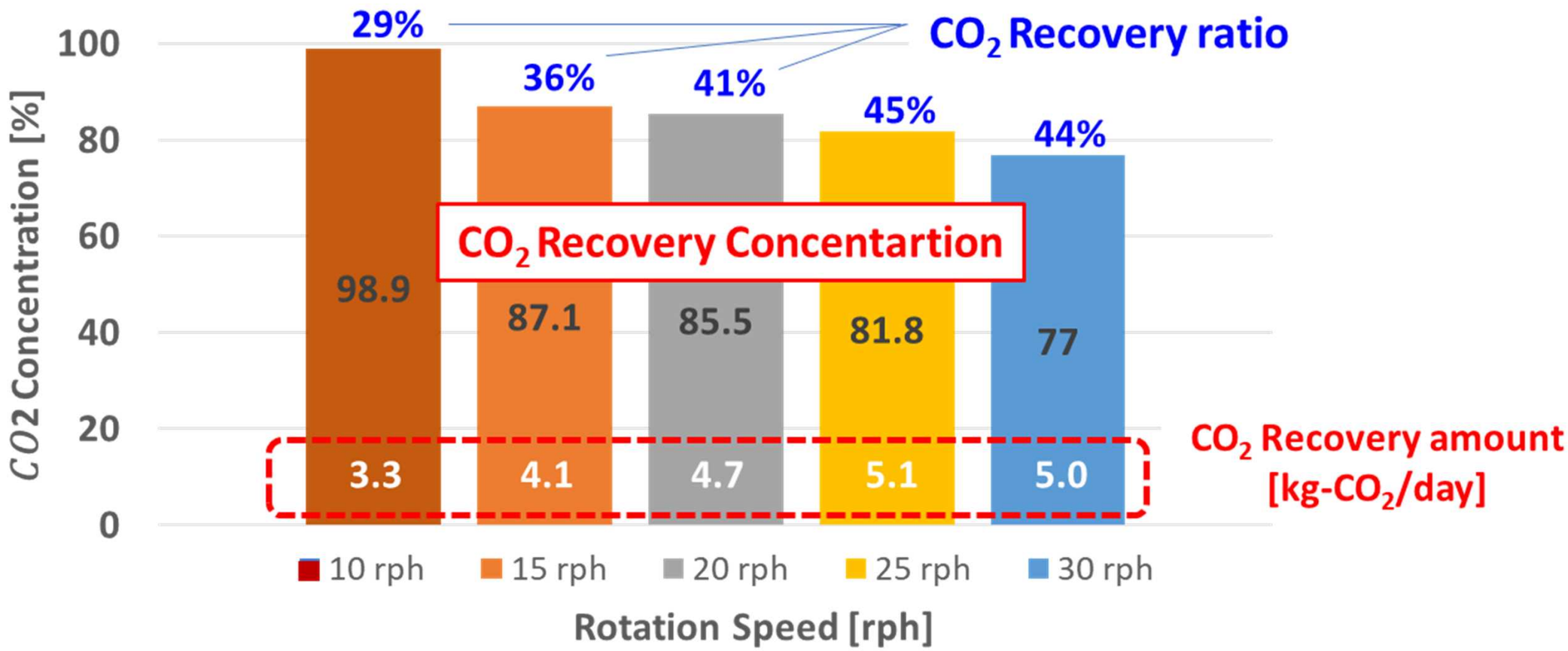
Avoid condensation in the adsorbent layer in conventional steam regeneration
⇒ Only steam sensible heat is used

7 . DAC development : Honeycomb Rotary + Steam

【Experimental condition】
Air flow rate = 600m³/h
(superficial air velocity = 2.6m/s)

【Amine loaded Honeycomb Rotor】
diameter 320mm x thickness 50mm
(Effective diameter: 300mm)

Air temperature, humidity, CO2 concentration and Steam supply = Not controlled



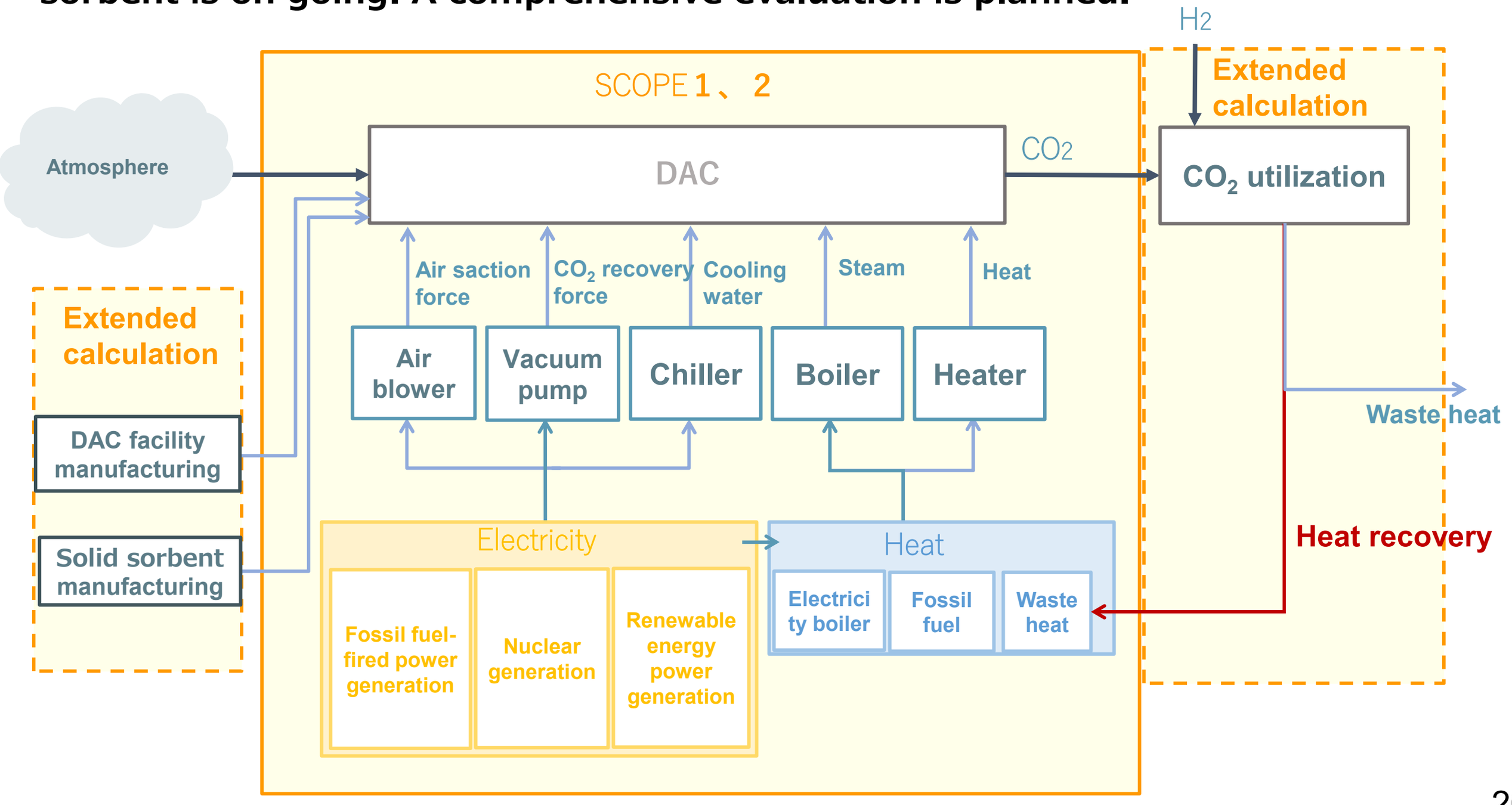
Optimization of equipment and operation
⇒ Both CO_2 recovery concentration and recovery ratio at high values

Demonstrated that CO_2 in air can be highly concentrated with a relatively simple equipment configuration, although 100°C steam is required.

Amines with superior resistance to oxidative degradation are under development (RITE)

7. Progress and Achievement: R&D Items3-① Study of LCA

- **Setting calculation subject for operation evaluation based on the data of test equipment as a first step of LCA**
- **Investigation of CO_2 emission related manufacturing of DAC facility and solid sorbent is on going. A comprehensive evaluation is planned.**



Summary

Development of Highly Efficient CO_2 Recovery Technology from the Atmosphere

①Development of new absorbent material for low-concentration CO_2 recovery

- Ongoing improvement of amine candidate material with excellent adsorption/desorption at low temperatures and durability performance.
- It was confirmed that application of the new matrix for solid sorbent improved CO_2 adsorption/desorption performance.
- Improvement of the new matrix for solid sorbent has also been confirmed to improve the adsorption rate, and is expected to further improve CO_2 recovery.

②Development of a highly efficient low-concentration CO_2 capture process and system evaluation

- A simulation that can reproduce the adsorption/desorption process of a new matrix for solid sorbent in a laboratory was constructed.
- Using DAC test equipment capable of evaluating actual size structures, it was confirmed that the solid sorbent with improved new matrix can achieve 5.0 kg/day of CO_2 recovery capacity with fewer.
- For the air purge and indirect heating type, a rough concentration of CO_2 in the air was succeeded and a guideline for improving performance was found. Application to air conditioning (dehumidification) is considered as a form of application to actual society, and the possibility of collaboration with other PJs has been started.
- For the steam regeneration honeycomb rotary DAC, although 100^{o}C steam is required, it was demonstrated that high concentration of CO_2 in air can be achieved with a relatively simple equipment configuration.

Thank you