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

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Contents

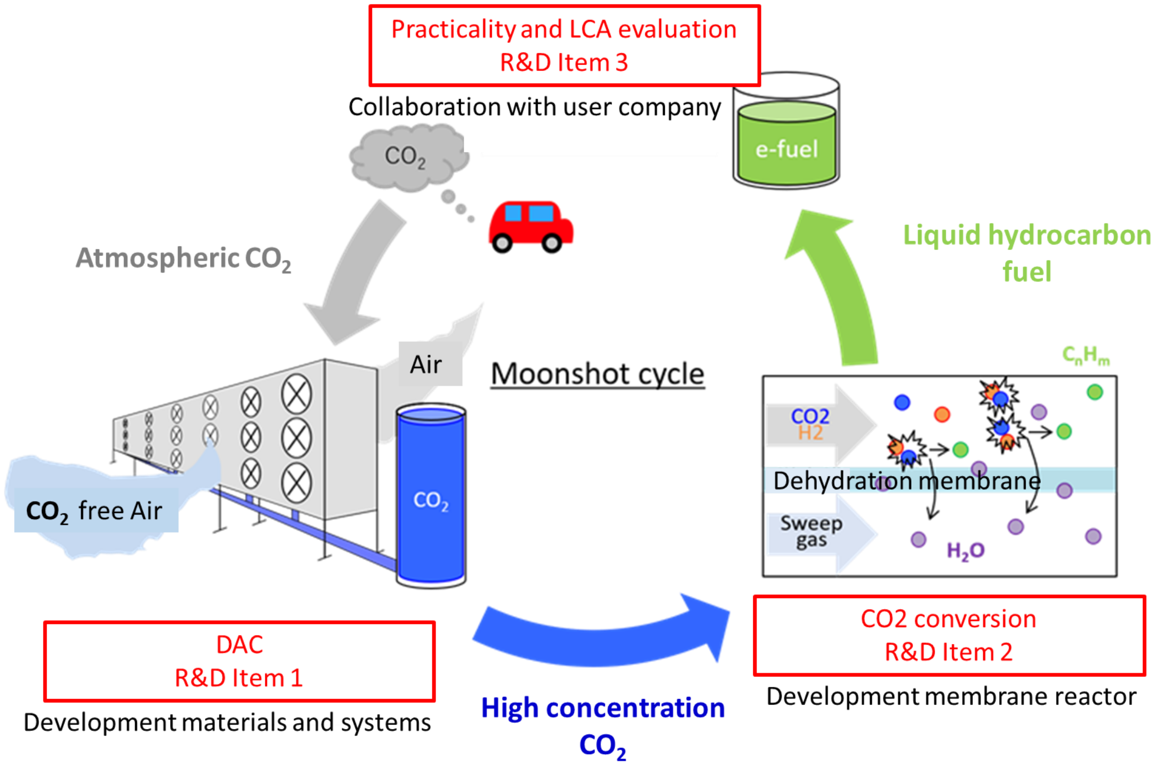
1． Overview of research and development

◆The following three items will be developed for establishing a carbon recycling technology which capture CO2 directory 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
2. Development of CO_2 conversion technology for carbon recycling into valuable resources →Using an inorganic separation membrane reactor for synthesizing liquid hydrocarbon fuel
3. Practicality assessment as a liquid hydrocarbon fuel using LCA method → Collaboration with a liquid hydrocarbon fuel customer

【Duration】 FY2020～FY2029



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

2. Targets of FY2029

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

Target : Achieving performance that exceeds overseas competitors.

- 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.

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

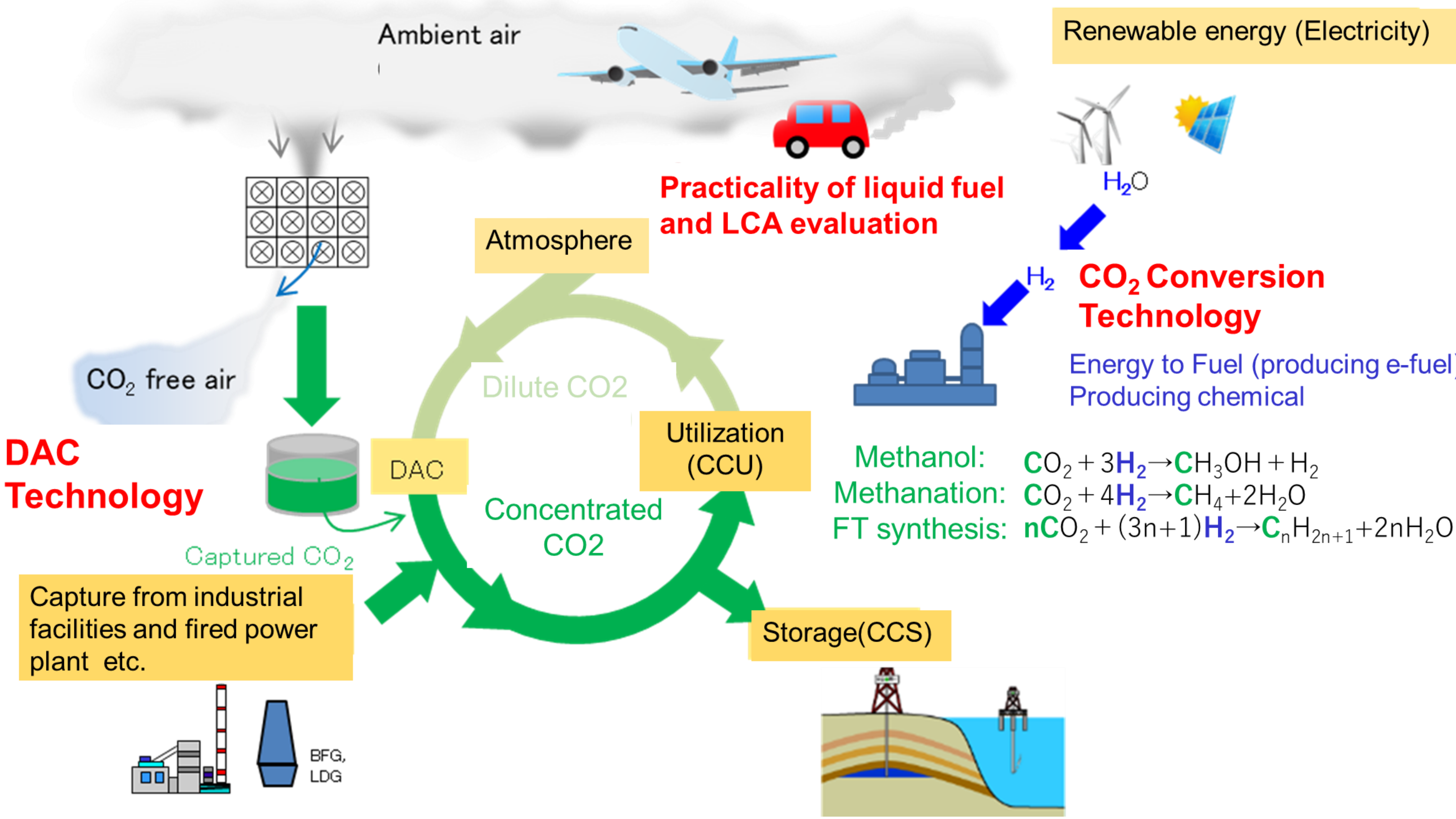
Target：Equivalent to FT synthesis conversion efficiency of 80% in commercial operation.

- CO_2 conversion technology that can produce liquid hydrocarbon fuel with high efficiency using CO_2 captured by DAC will be developed.
- The optimal membrane reaction process that can achieve the conversion rate of CO2 for practical use will be demonstrated at the pilot level.

R&D Items3　Practicality assessment as a liquid hydrocarbon fuel using LCA method

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

3. Image of social implementation



CO_2 utilization and Negative Emission technology (DACCS*, BECCS* etc.) will be inevitable in order to realize Carbon neutral.

➡ Development of high-efficiency CO_2 capture and conversion technology

*Direct Air Capture with Carbon Storage, **Bioenergy with Carbon Capture and Storage

4． 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 of CO_2 conversion technology for carbon cycle」
２－① Development of high efficiency CO_2 conversion technology and investigation of optimal process
R&D item 3.
「Application of liquid fuel, and LCA evaluation」

【Subcontractor】

Mitsubishi Heavy Industries Engineering (MHIENG) (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 .
「Application of liquid fuel, and LCA evaluation」
Collaborate with Toyota motor Corp, (Toyotashi, Aichi)

Outsourcing

Engineering Company
（２－② Detailed design and manufacturing of scale-up test equipment and evaluation test（Liquid fuel synthesis））

Outsourcing

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

5. Schedule

Upper: DAC Technology
Lower: CO_2 conversion technology (Under reviewing)

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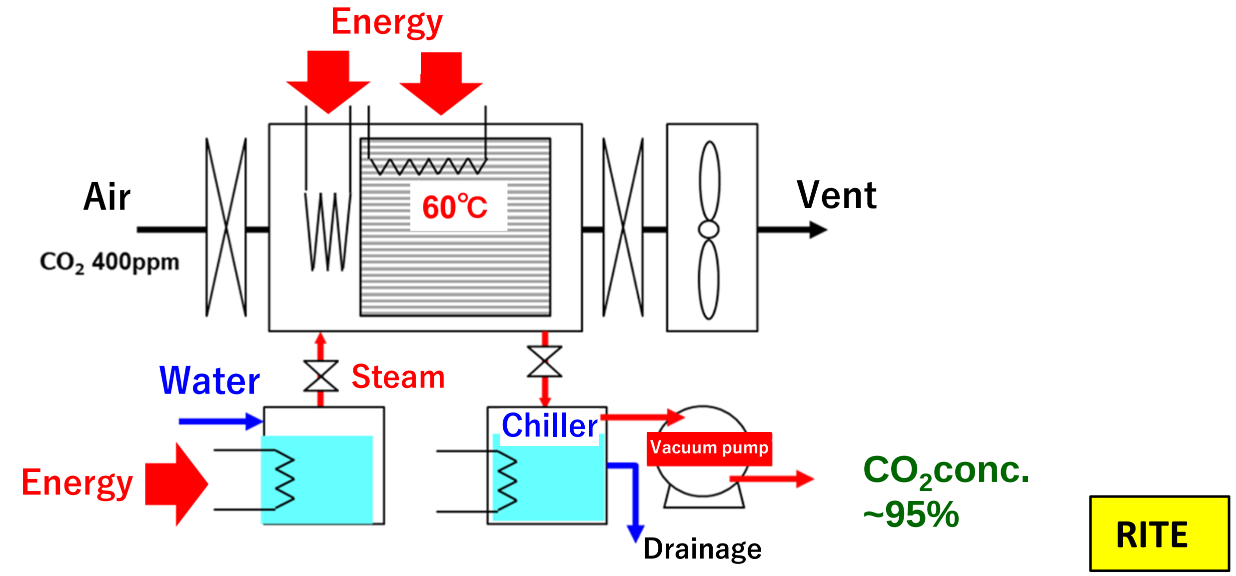
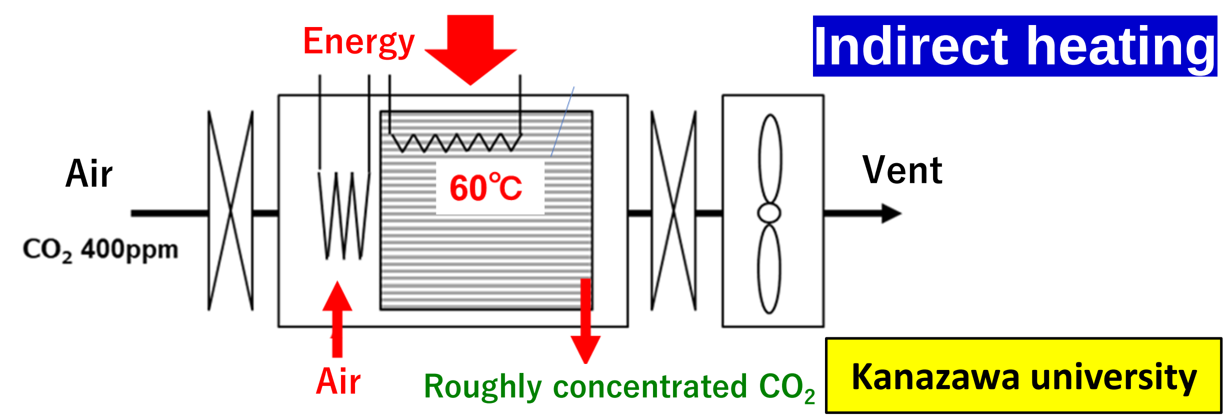
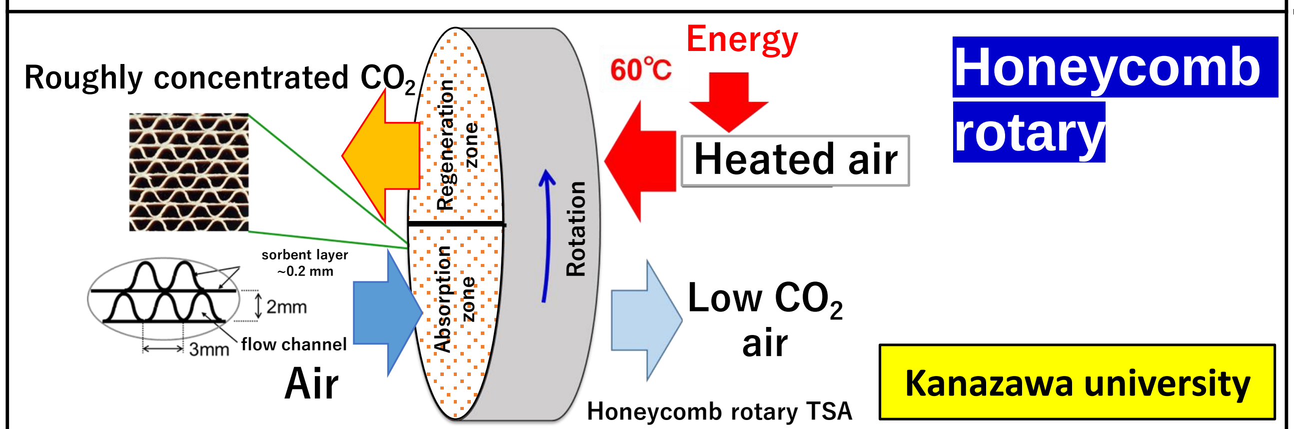
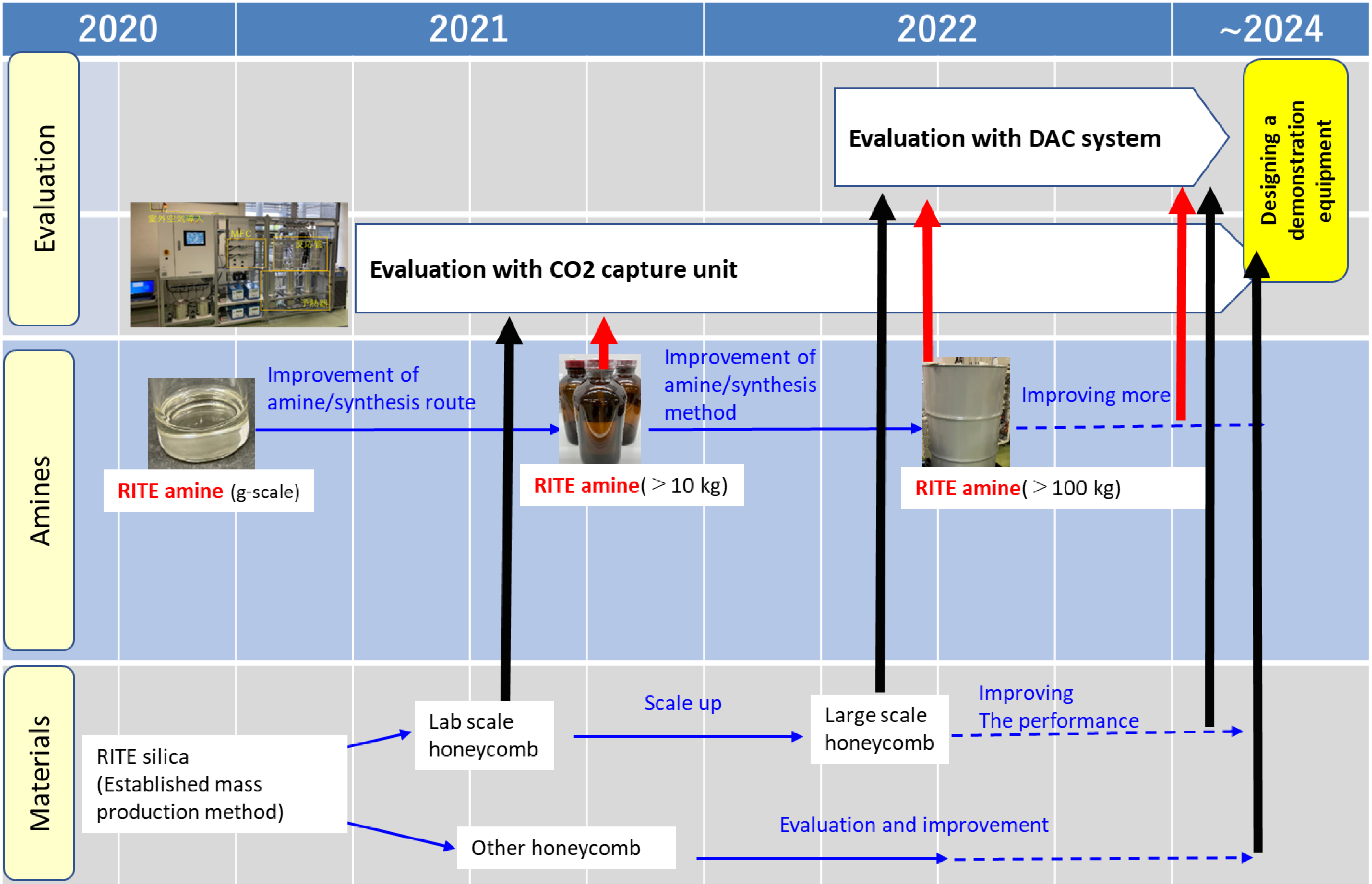
Item \ Fiscal year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Material development・Simulation for DAC (RITE)	New material screening・Lab test		Optimization of preparation method			Improvement of material, production method, and performance (Development of a highly durable material for the air-recovery)				
	Development of simulator (Proposing optimized processes)			Modification of simulator (Improving accuracy)		Simulation (optimization of operation condition)				
Process examination (Air-recovery) Kanazawa Univ.	Examination of low-concentration CO_2 recovery Process (Establishing indirect heating and rotary TSA rough enrichment methods)					Improvement of CO_2 recovery system (suppressing the blower power, installing heat storage equipment) Establishing efficient DAC system based on LCA				
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
Development of membranes and membrane reactors (RITE)	Membrane synthesis; Manufacturing MR (Lab)		Lab test	Under reviewing						
Development of CO_2 conversion process				Under reviewing						
LCA study			preparation	LCA evaluation					LCA and practicality evaluation	

6. Progress and Achievement: R&D Items1. Development of CO_2 Direct Air Capture technology

【Development of three kinds of regeneration system】

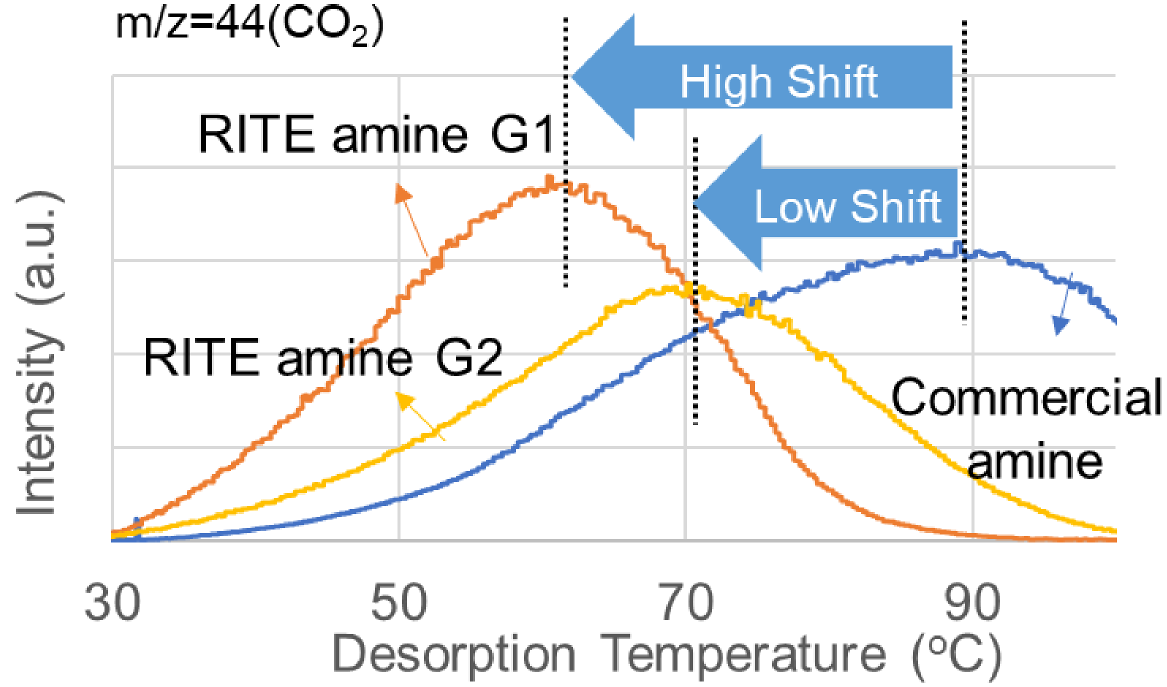
	System	Required energy
Steam regeneration		Absorption step： Blower Regeneration step： Steam Heater (for solid sorbent) Vacuum pump Highly concentrated
Air purge regeneration		Absorption step： Blower Regeneration step： Heater (for solid sorbent) Rough concentration
		Absorption step： Blower Regeneration process： Heater (for air) Rough concentration

6. Progress and Achievment: R&D Items1-①
Development of amines and support materials on DAC



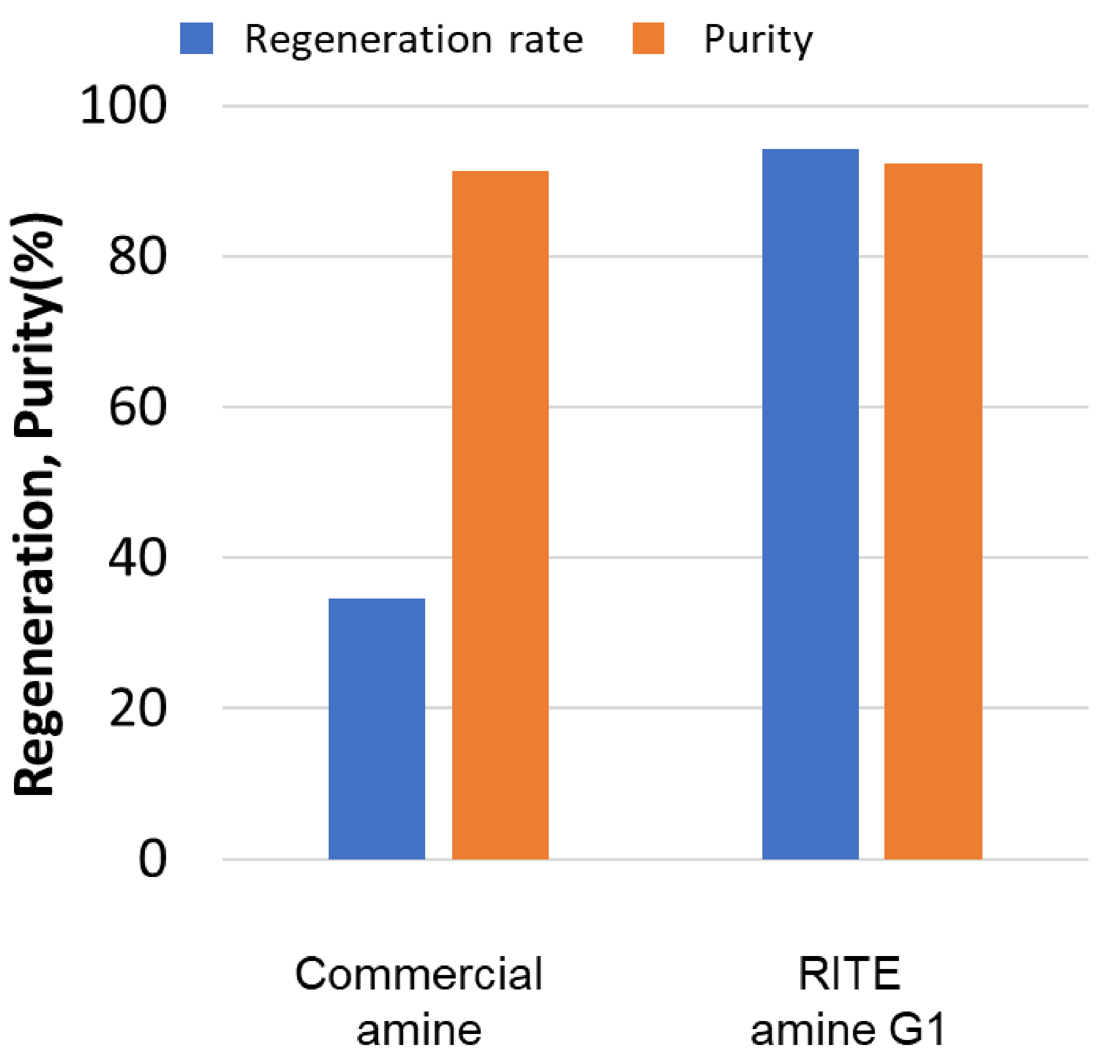
CO_2 desorption property after Air adsorption

- **Result of CO_2-TPD**



	Commercial amine	RITE amine G1	RITE amine G2
Des. Temp.	90°C	60°C	70°C
Adsorption amount	High	Low	mid.
Resistance of oxidative degradation	×	○	◎

- **Desorption property with SA-VSA at 60oC**

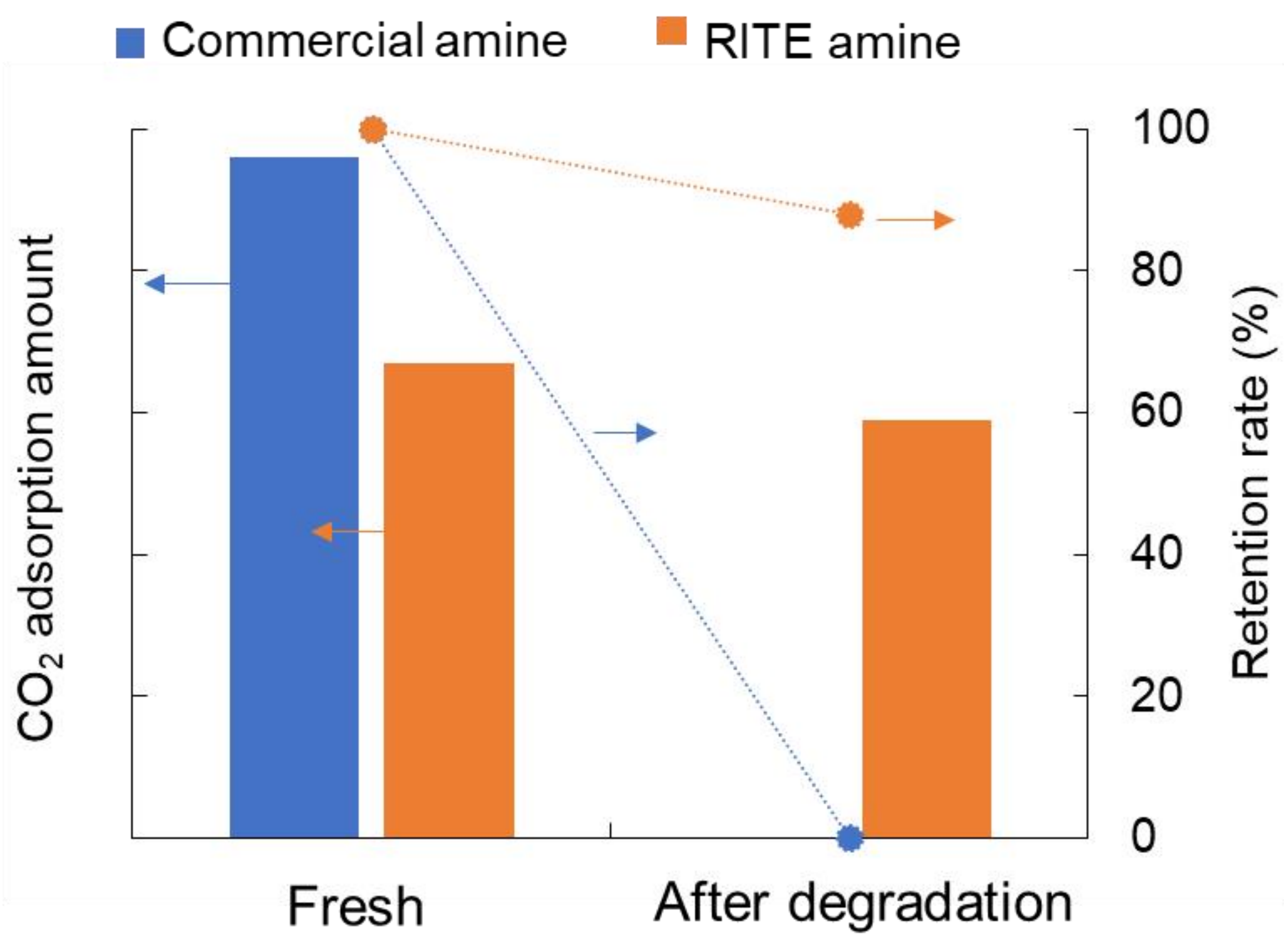


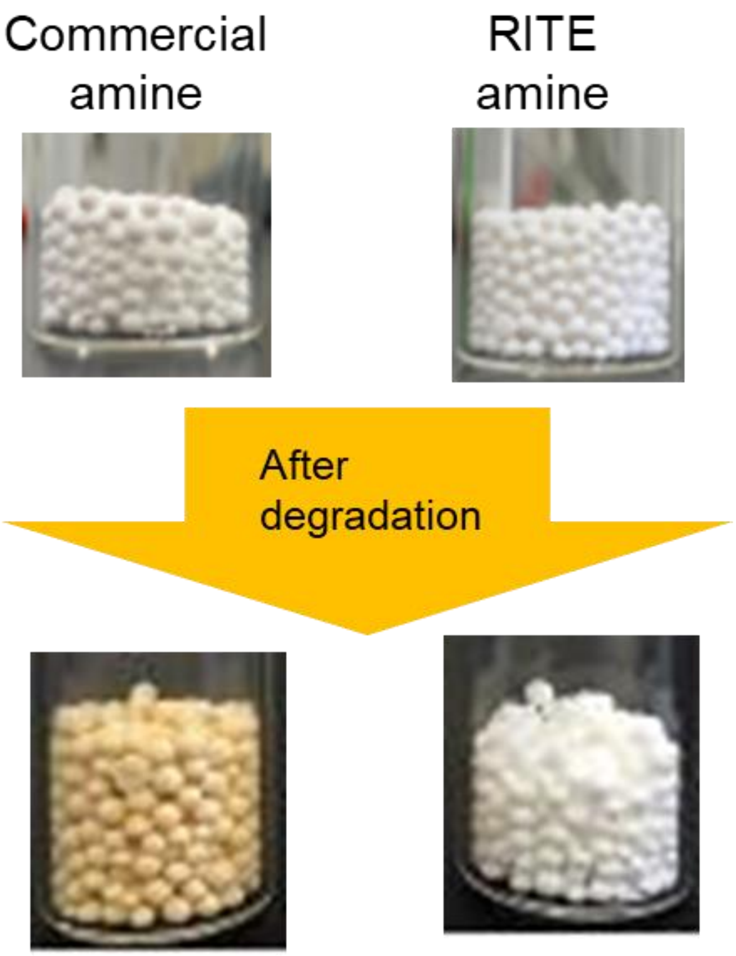
RITE amine G1:
CO_2 can be released at 60°C.

【Oxidative degradation resistance of RITE amine】

(Condition: Air, 100ºC, 42 h)

Adsorption amount (@0.04kPa)

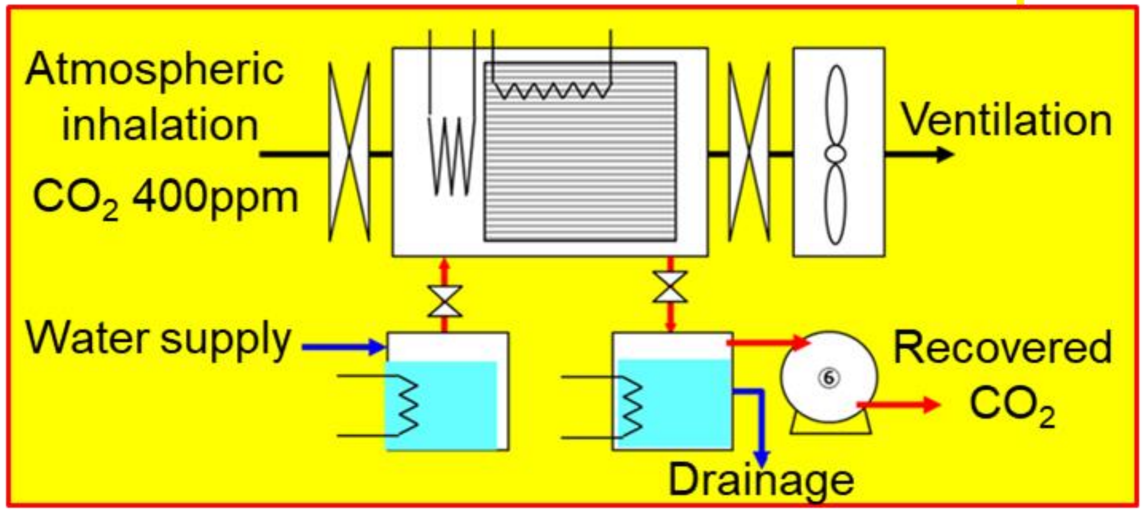




RITE amine G2: High resistance to oxidative degradation (Lab-scale synthesis)
→Improvement of adsorption performance and investigation of industrial manufacturing

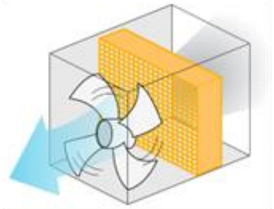
【Evaluation Test started at DAC Experimental Facility in RITE】

（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

Challenge to air-regenerative DAC

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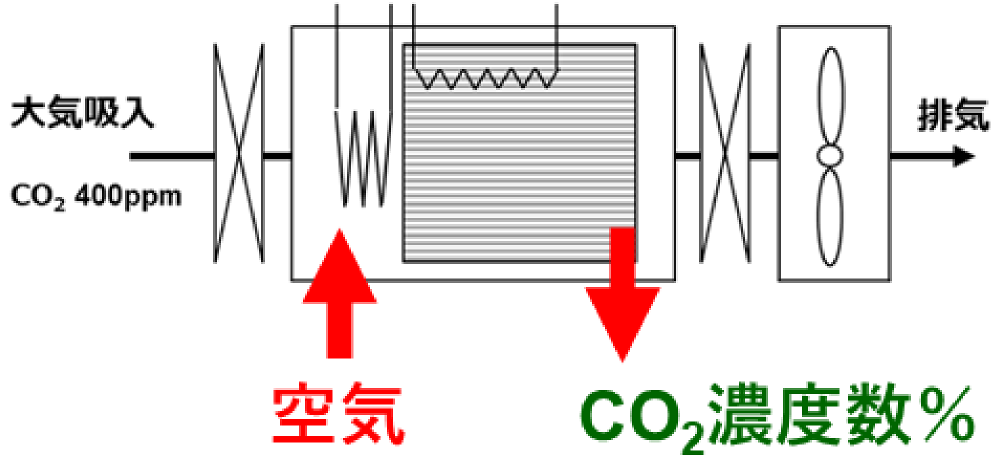
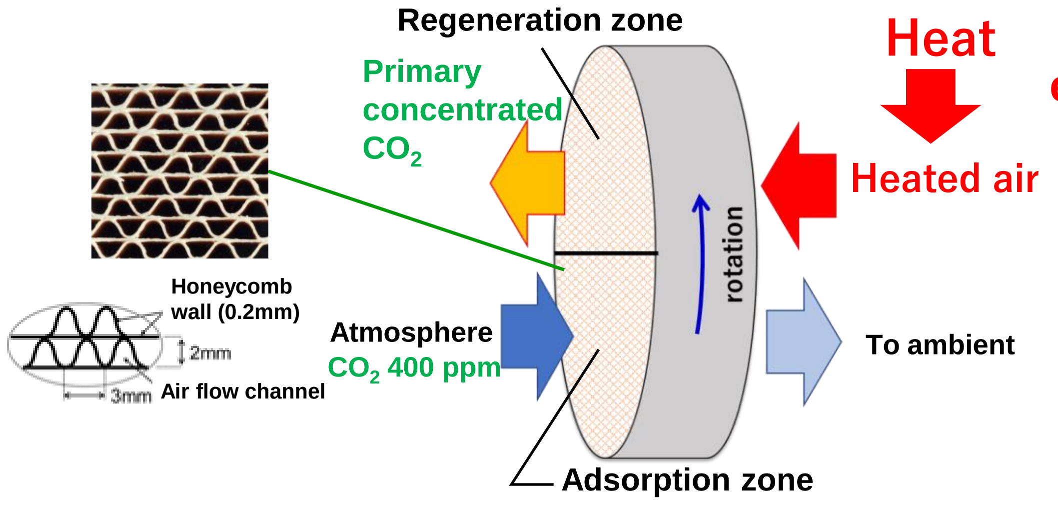
Indirect Heating adsorber type DAC



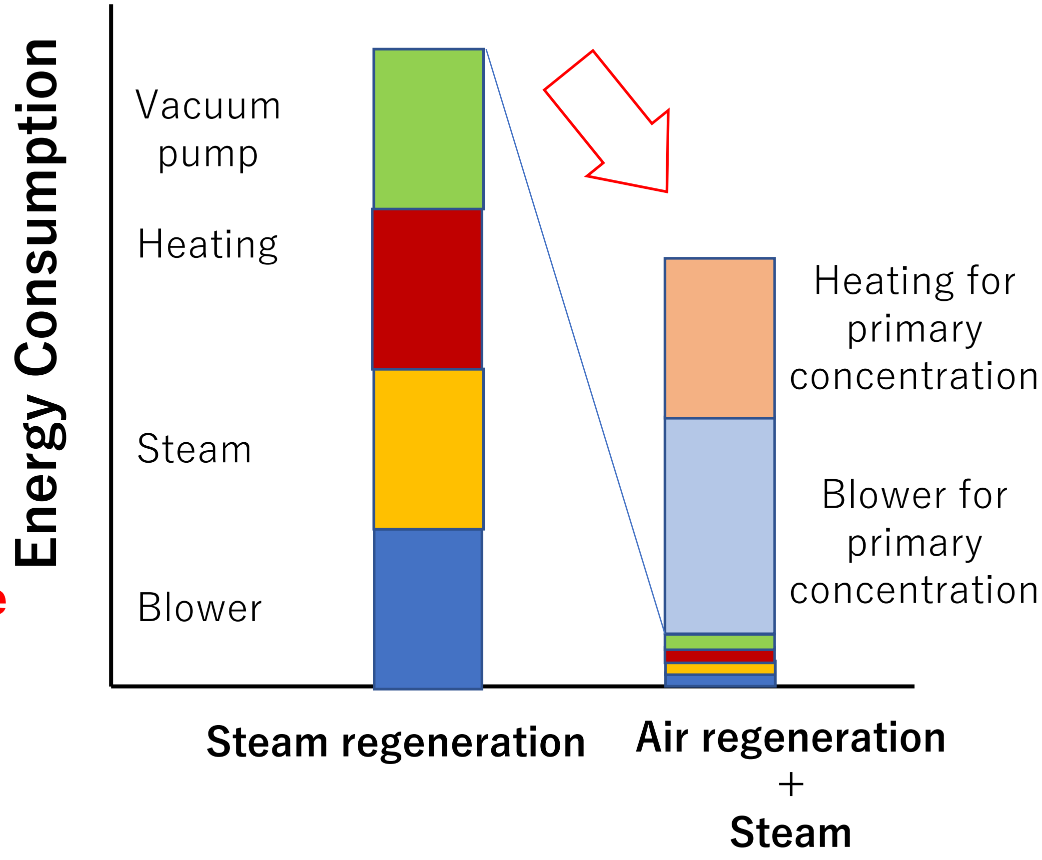
＋ **Highly concentrated process**

Honeycomb Rotary DAC



Reduced size of the high enrichment process to be connected

Reduction of energy requirements through a connected process

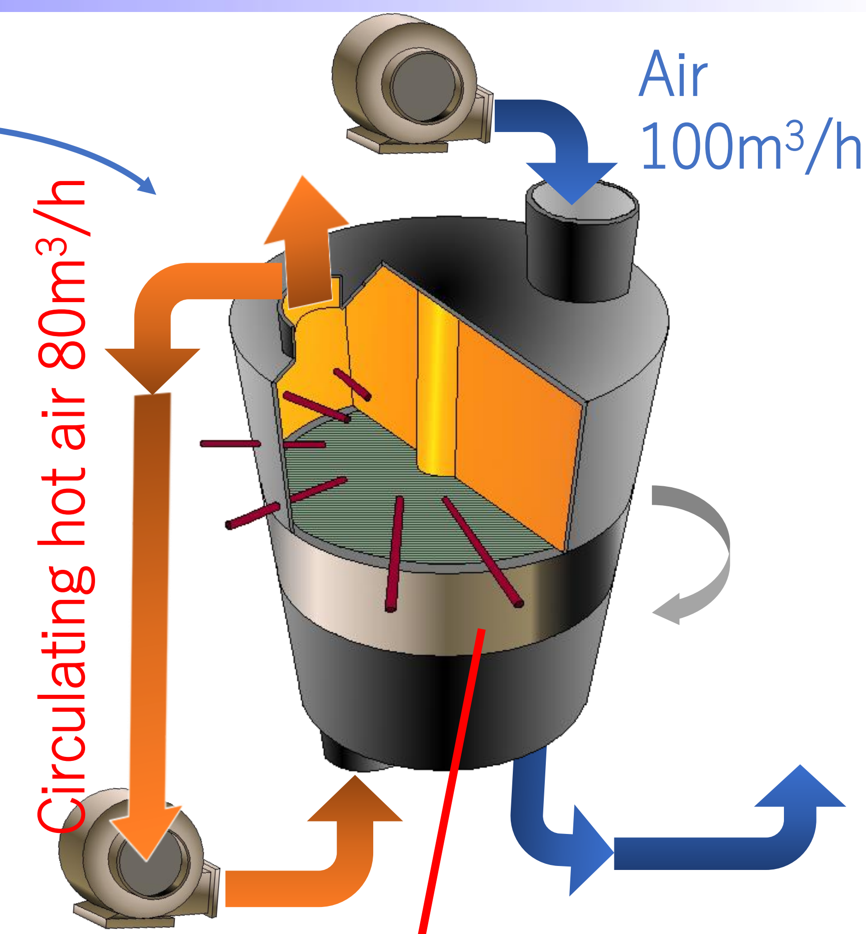


Air regeneration (indirect heating and rotary) as a pretreatment equipment for the conventional high concentration process could increase the energy efficiency of the entire DAC system

6. Progress and Achievement: R&D Items1-②
Air-regenerative honeycomb rotary DAC

A commercial desiccant rotor with commercially available PEI was tentatively prepared. Initial experiments were conducted.

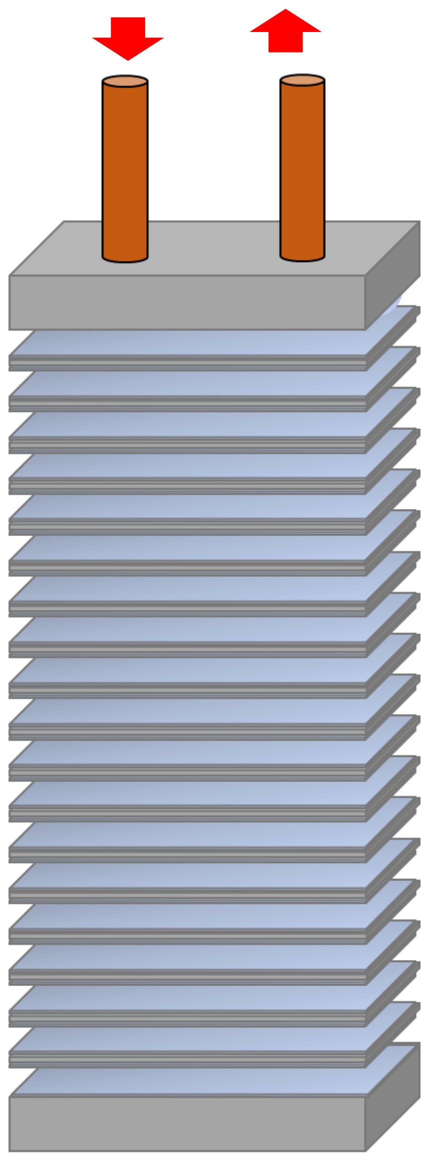
Air-regenerative honeycomb rotary DAC basic experiment equipment



6. Progress and Achievement: R&D Items1-②
Air-regenerative & indirect heating type DAC

Adsorbent coated Heat Exchanger

Hot Water
(60 °C)



Thermal conduction heating of amine with hot water flowing in a separate channel

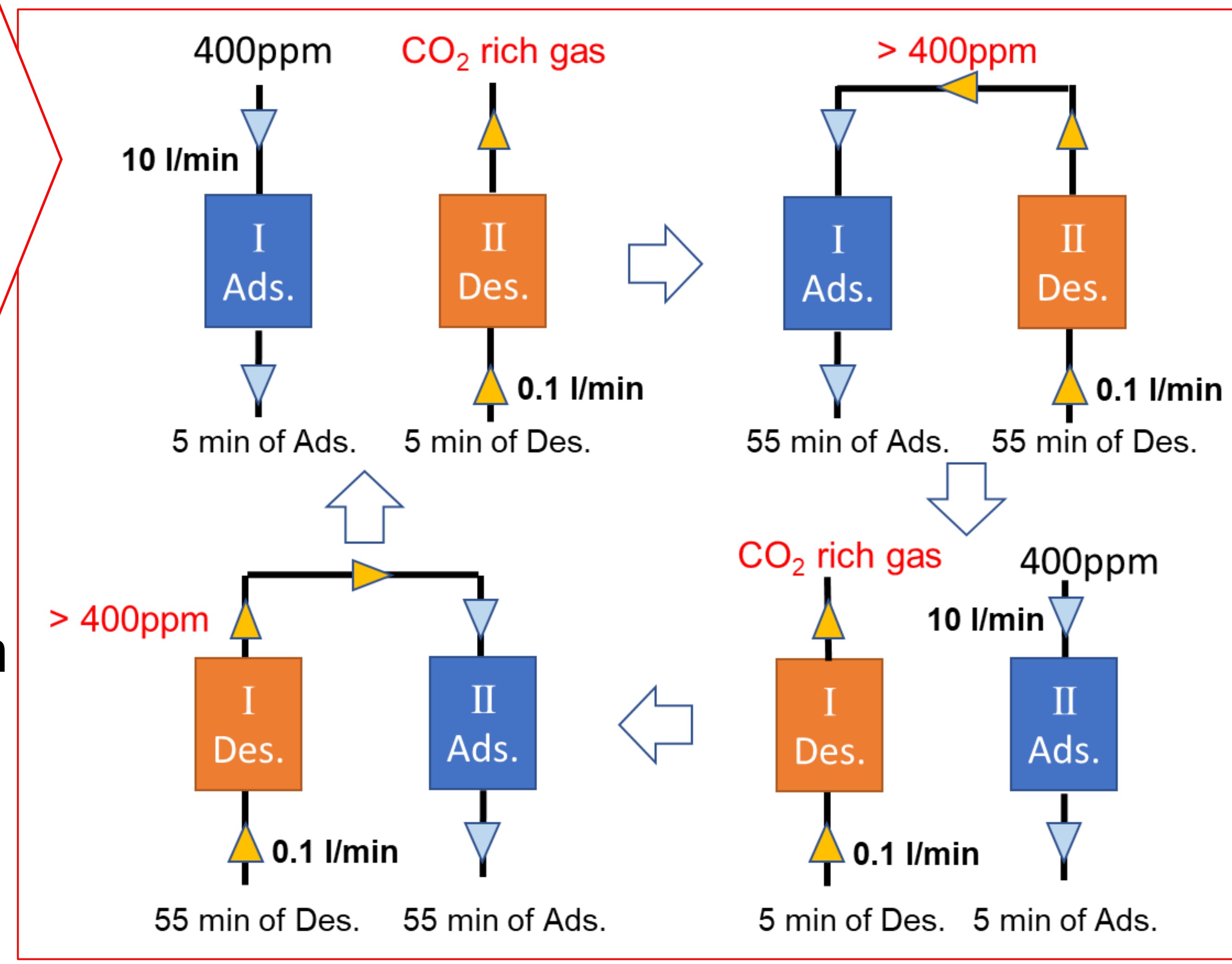
CO_2 recovery concentration can be increased by minimizing the amount of heated air for CO_2 desorption

Concentration section reflux

Consideration of changes in CO_2 concentration at the desorption outlet

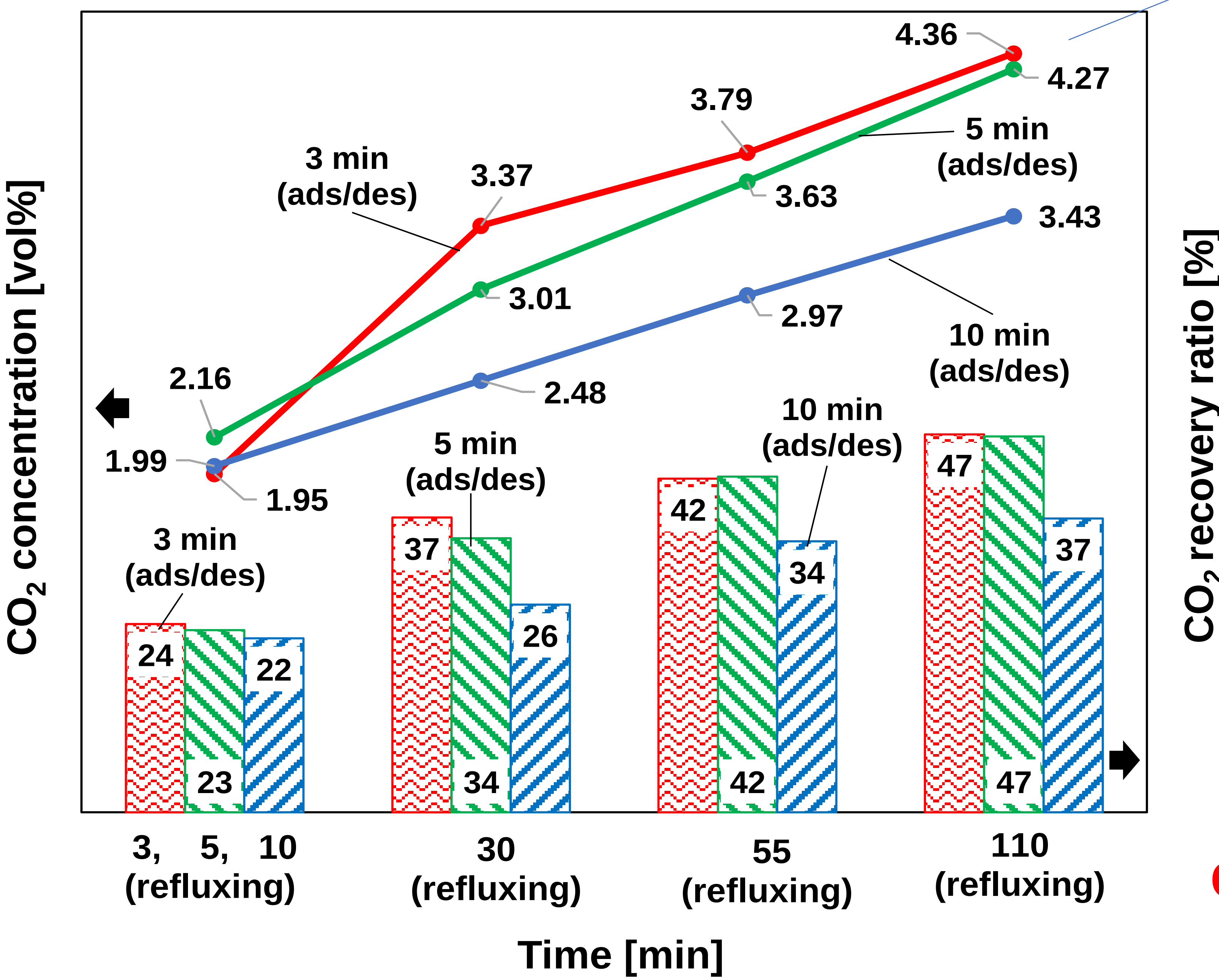
- Only high-concentration CO_2 in the early stage of the desorption process is recovered.
- Low-concentration CO_2 in the latter half of the desorption process is returned to the adsorption column.

➡Improvement of recovered CO_2 concentration and recovery ratio

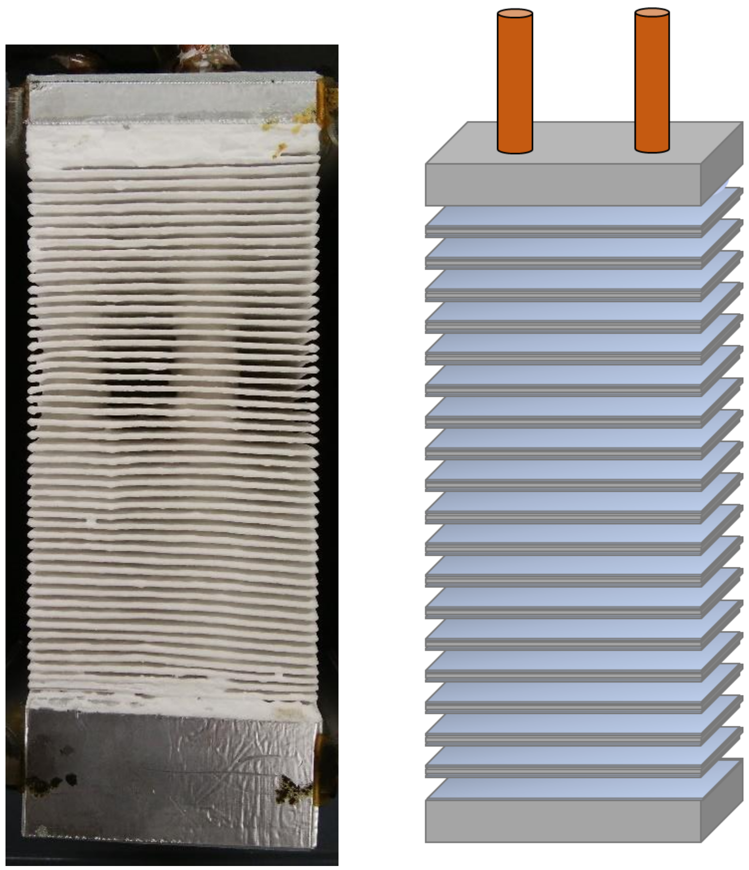


6. Progress and Achievement: R&D Items1-②
Air-regenerative & indirect heating type DAC

Feed gas: 10 L/min (DP=5°C)
Purge gas: 0.05 L/min (DP=5°C)
20°C-60°C TSA



100-fold enrichment with air-regenerative DAC



Key to achieving our goals;
Coating of RITE amine on heat exchangers or appropriate materials

6. Progress and Achievement: R&D Items2 Development of CO_2 conversion technology

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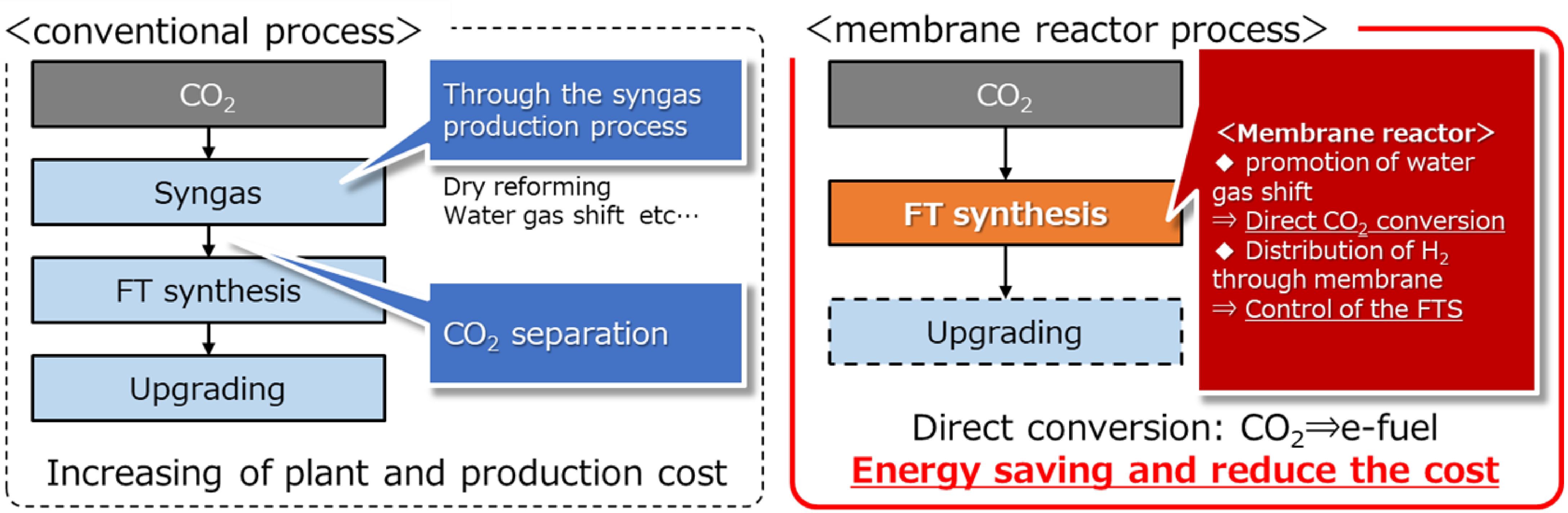
【Advantages of Membrane reactor for CO_2 conversion】

Conventional process

Liquid hydrocarbon （FT synthesis） ⇒ Including production of syngas



*Plant cost；syngas production 65~70%、FTS 21~24%、Upgrading 9~19%

Technical challenges

- Catalyst deactivation owing to H_2O
- Revers water gas shift
- Heat removal owing to exothermic reaction
- Difficult FTS reaction Control

Advantages of membrane reactor

- Remove H_2O through the membrane

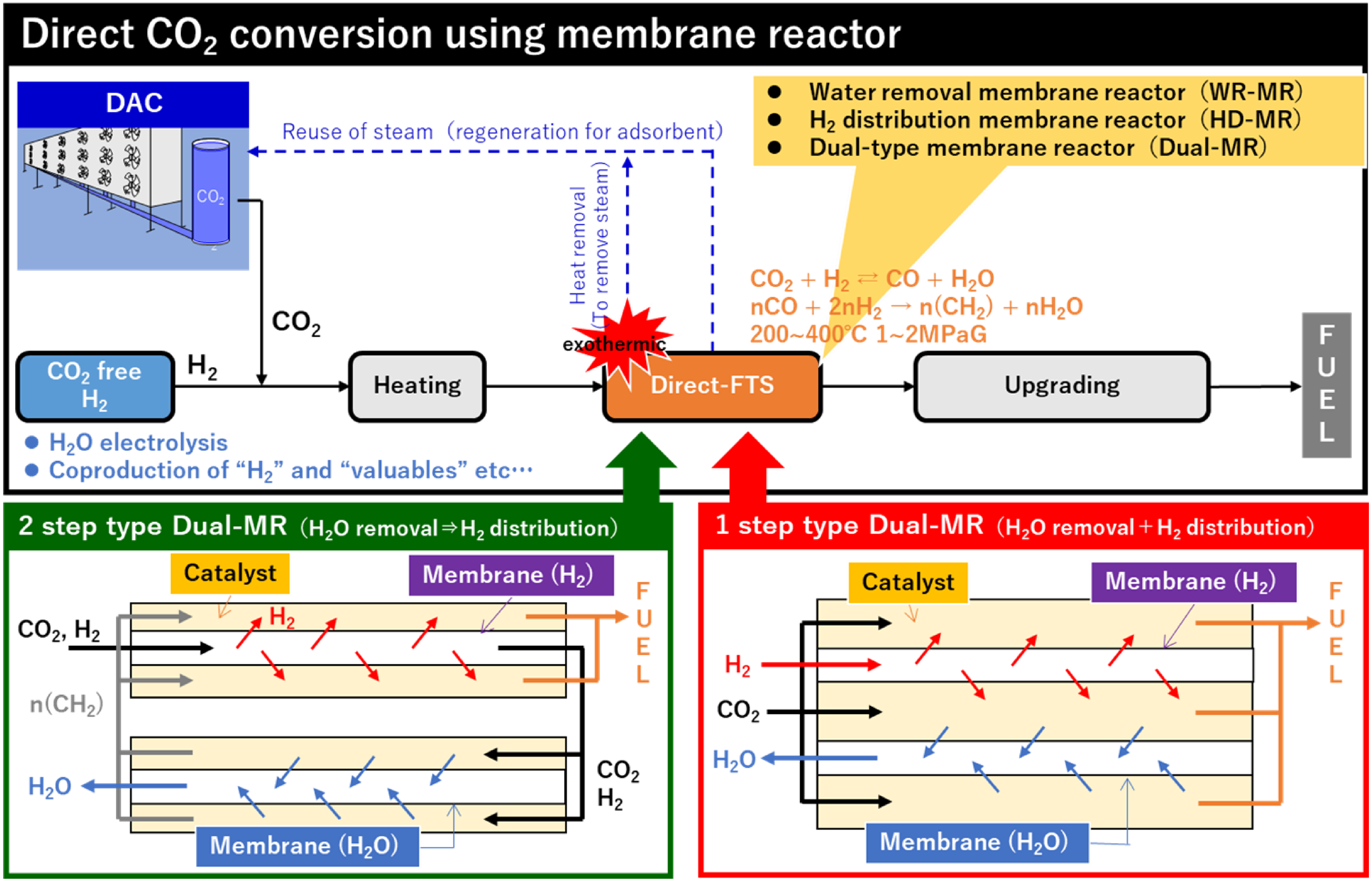
⇒ Promotion of water gas shift, and suppression of catalyst deactivation

- H_2 distribution through the membrane

⇒ FTS reaction control

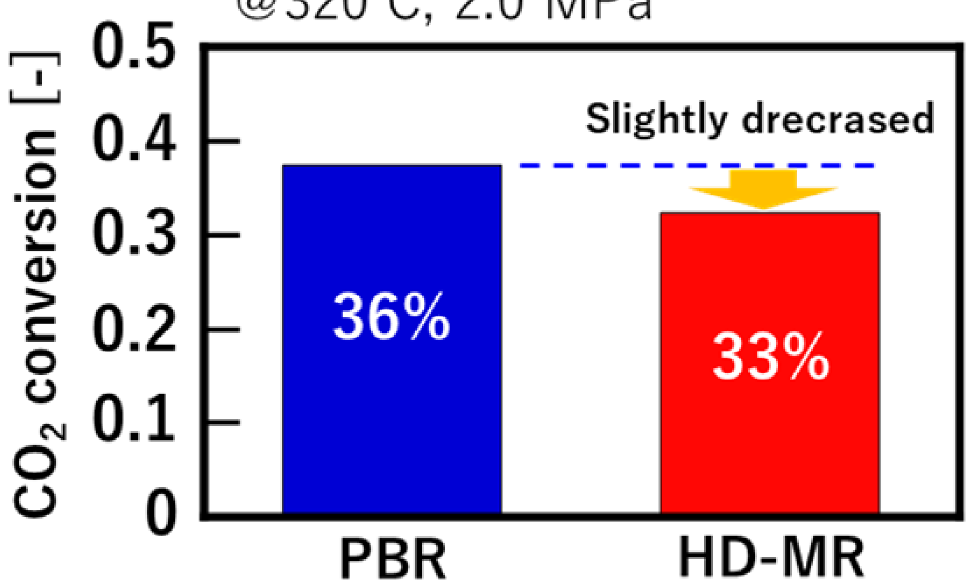
6. Progress and Achievement: R&D Items2-①

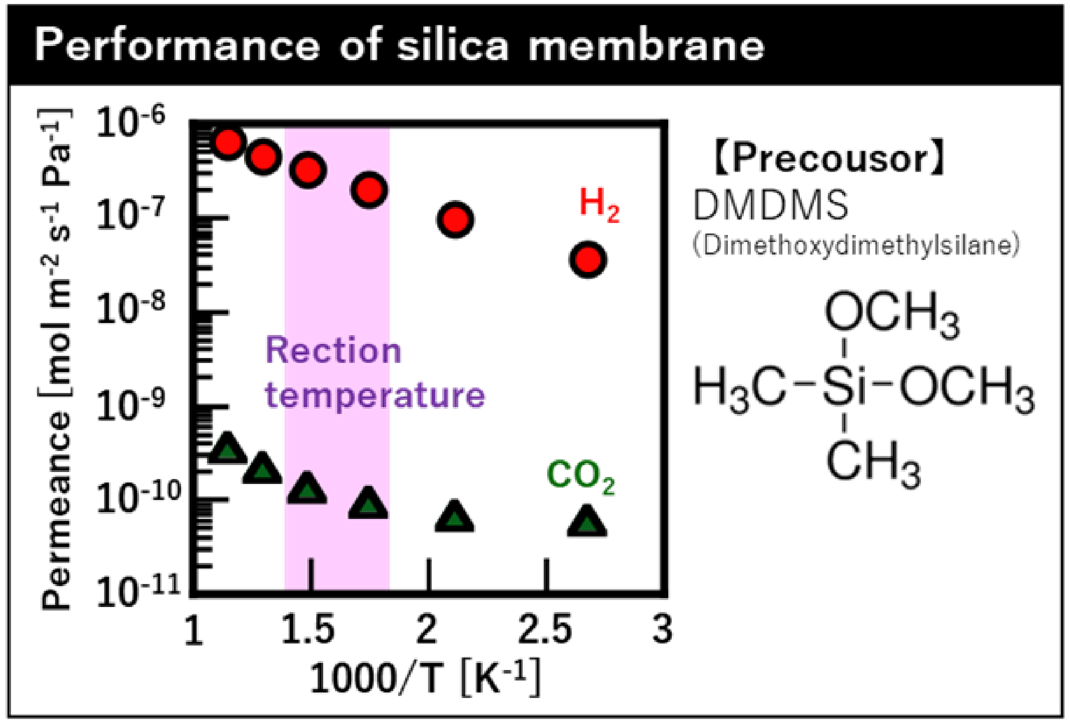
Process images of CO_2 conversion using membrane reactor

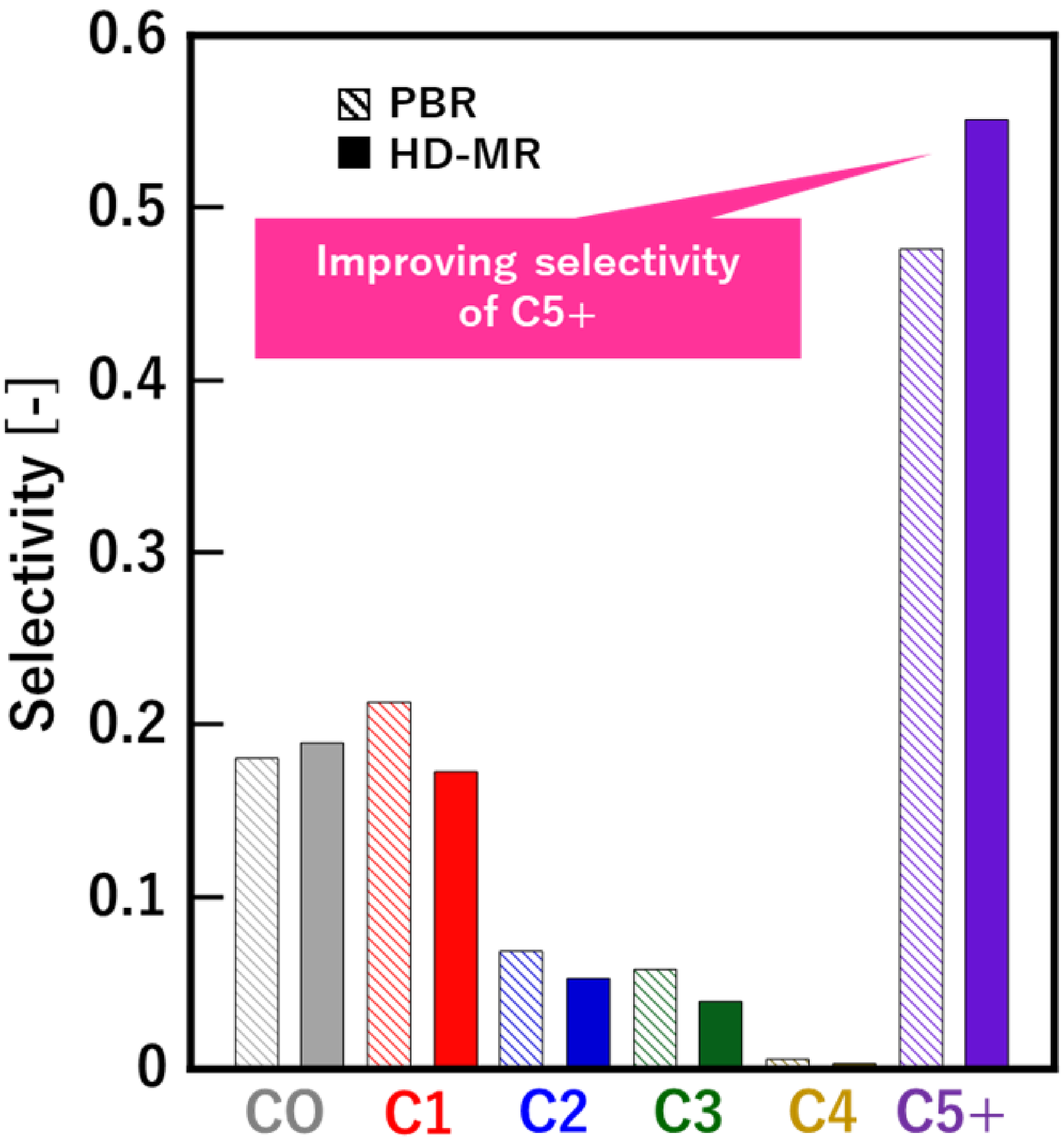


6. Progress and Achievement: R&D Items2-① Development of membrane reactor for CO_2

@320°C, 2.0 MPa



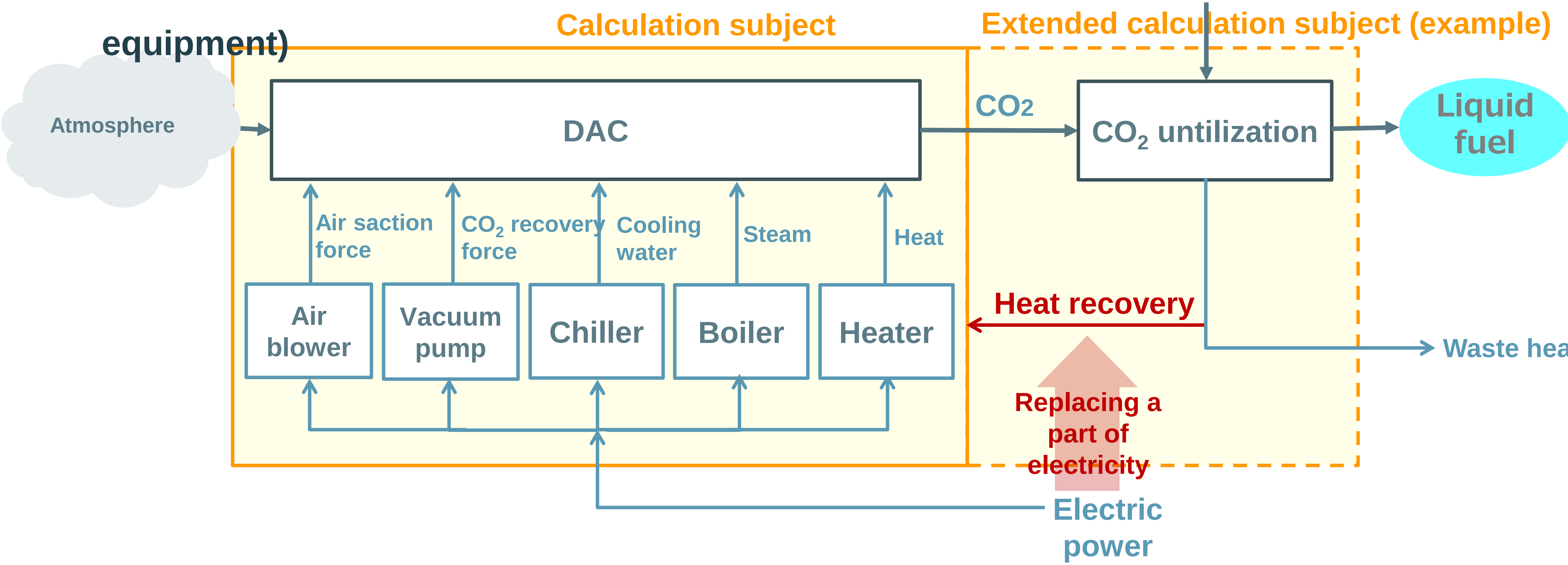




H_2 distributor type membrane reactor is expected increasing of hydrocarbon selectivity.

6. 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
- Examining direct utilization of waste heat for better energy balance on a large-scale demonstrating equipment (although heat is all counted as operating load on the test equipment)



- ➢ Constructing framework for operation evaluation based on the test equipment
- ➢ Evaluating the calculation results and optimizing the system by integrating related facilities

Summary

1: Development of Highly Efficient DAC Technology

①New absorbents for low-concentration CO_2 recovery

- Finding amine-based candidate materials with excellent adsorption/desorption performance and durability at low temperatures
- Improvement of amine loading and adsorption performance of honeycomb materials

②High-efficiency DAC process and its evaluation

- Constructed a test facility for steam regenerative DAC and started demonstration tests.
- Understanding the impact of regenerative steam supply volume through simulation and proposing an efficient operation principle for the steam-regenerative DAC
- Challenged air-regenerative DAC and succeeded in enriching atmospheric CO_2

2: CO_2 conversion technology for carbon cycle

①High Efficiency CO_2 Conversion Technology and Optimal Process

- Membrane Reactor: Improvement of selectivity for hydrocarbons above C5 in HD-MR and confirmation of usefulness of membrane reactors

∗Schedule of development on CO_2 conversion technology is under reviewing.

Thank you