No. A-1-1E

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

Theme: For realization of carbon recycling society

Organization: Kanazawa University/Research Institute of Innovative Technology for the Earth (RITE)

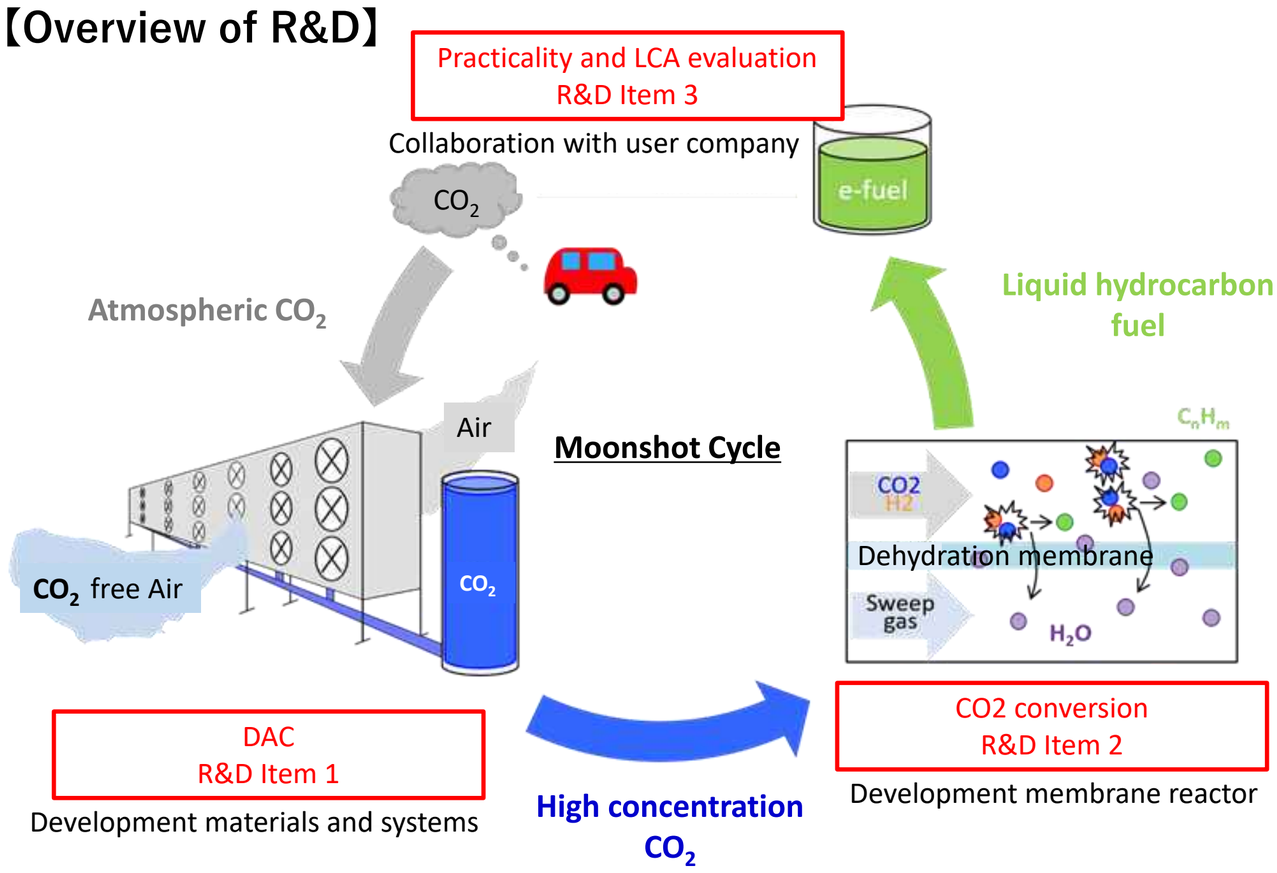
Contact: Kanazawa University (akodama@se.kanazawa-u.ac.jp) /RITE (yogo@rite.or.jp)

【Duration】 FY2020～FY2029

【R&D Items】

1. Development of high-efficiency 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

【Overview of R&D】

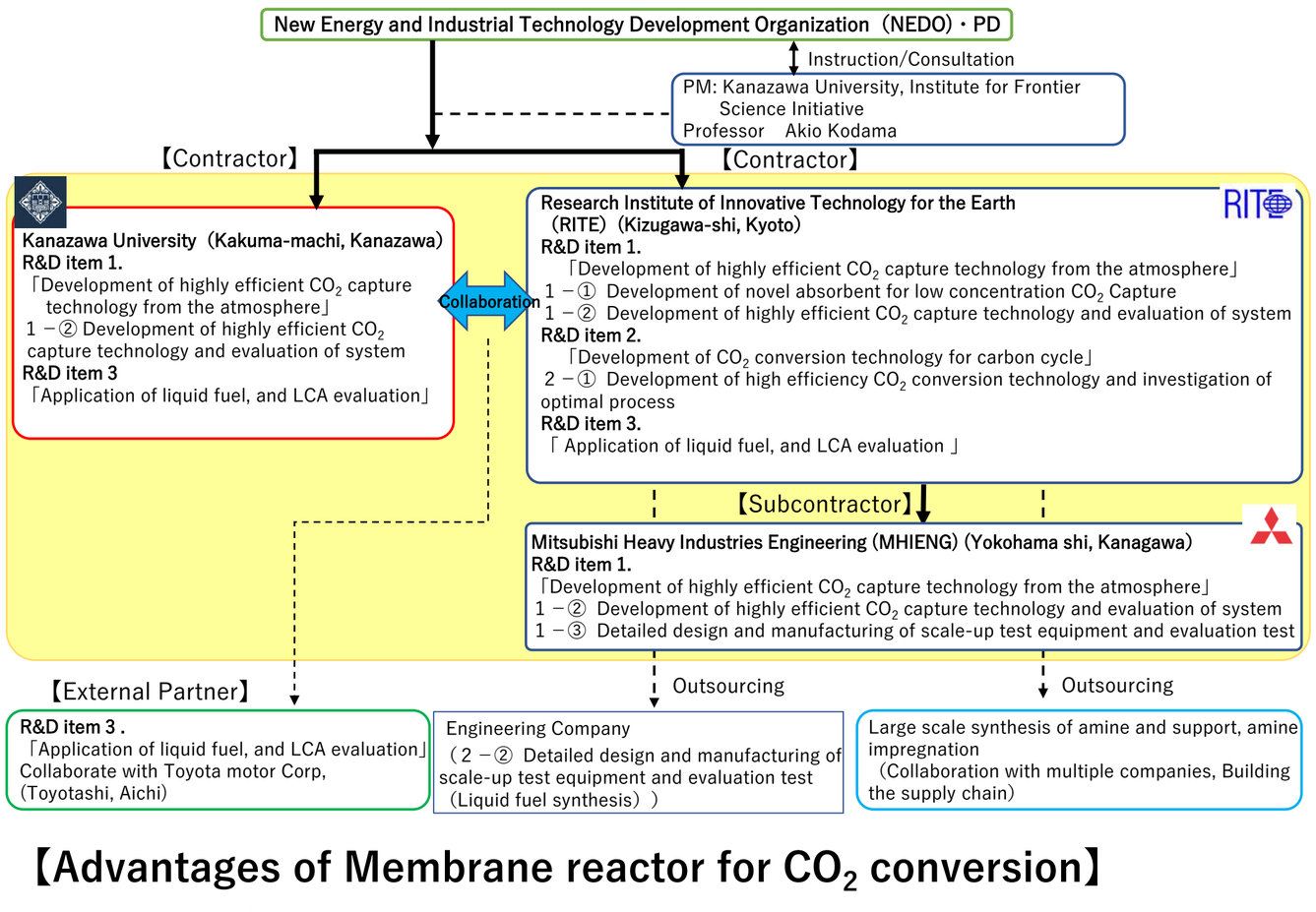


【Development schedule】

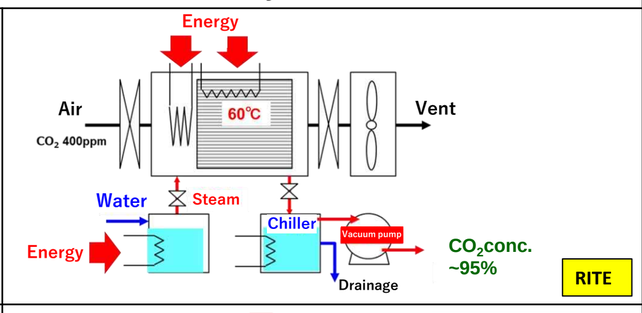
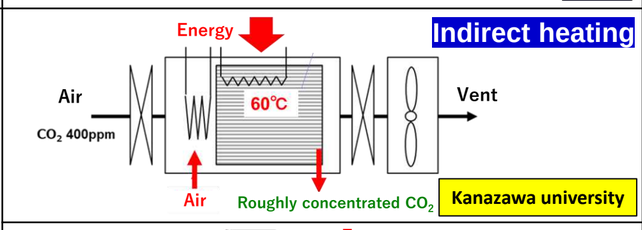
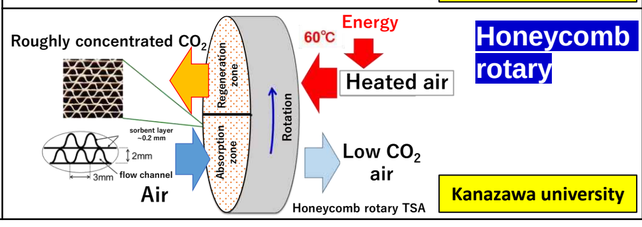
Upper: DAC Technology
Lower: CO_2 conversion technology (Under reviewing)

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							
Development of CO_2 conversion process						Under reviewing				
LCA study			preparation			LCA evaluation			LCA and practicality evaluation	

【System for Development】



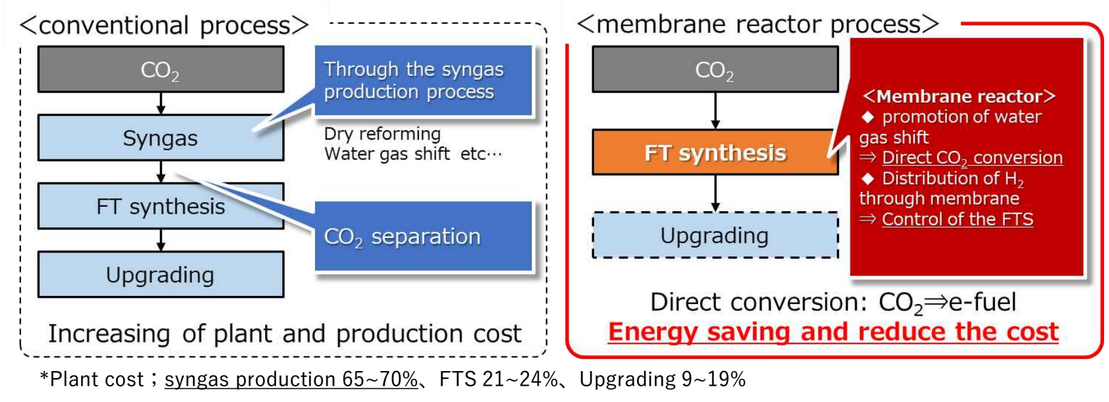
【Development of three kinds of regeneration system for DAC】

	System	Required energy
Regenerated by steam		Absorption process : Blower Regeneration process : Steam Heater (for solid sorbent) Vacuum pump High concentrate
Regenerated by air		Absorption process : Blower Regeneration process : Heater (for solid sorbent) Roughly concentrate
		Absorption process : Blower Regeneration process : Heater (for air) Roughly concentrate

【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 H2O
- Revers water gas shift
- Heat removal owing to exothermic reaction
- Difficult FTS reaction Control

Advantages of membrane reactor

- Remove H_2O through the membrane

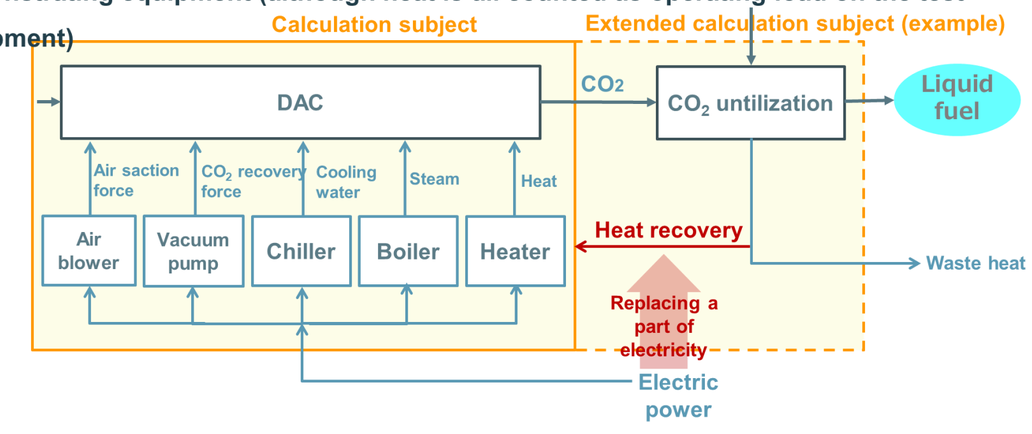
⇒ Promotion of water gas shift, and suppression of catalyst deactivation

- H_2 distribution through the membrane

⇒ FTS reaction control

【Study for 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

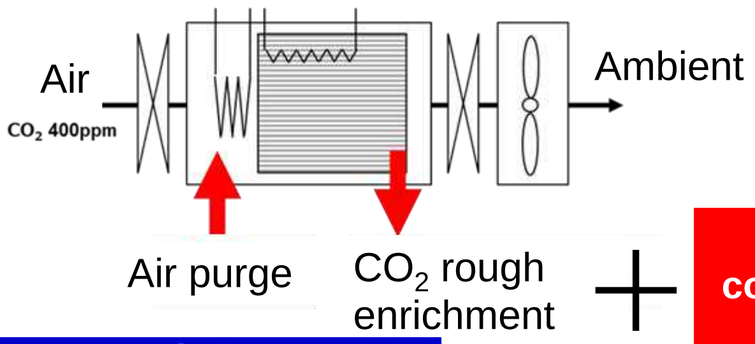
➢ Evaluating the calculation results and optimizing the system by integrating related facilities

No. A-1-2E
PJ: Development of Highly Efficient Direct Air Capture (DAC) and Carbon Recycling Technologies
Theme: Challenge to Air-regenerative DAC
Organization: Kanazawa University
Contact: Kanazawa University, Akio KODAMA/ akodama@se.kanazawa-u.ac.jp

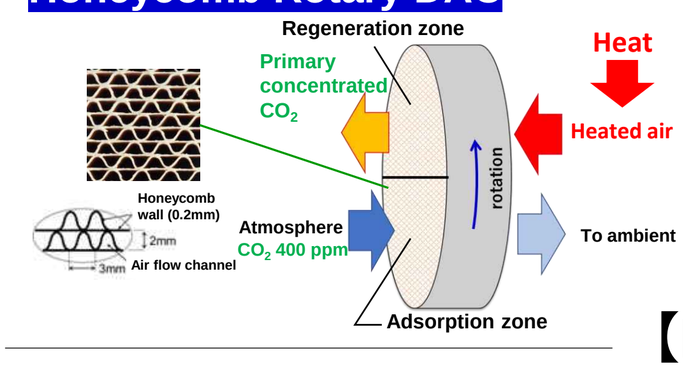
- **Development of Air-regenerative DAC(Direct Air Capture)Technologies**
  Indirect heating type: Air at atmospheric pressure, not steam, is used as purge gas to remove CO_2 from the adsorbent and adsorption column; the air discharged during CO_2 removal does not condense at normal temperature and pressure, and CO_2 remains at a rough concentration, but steam generation and vacuum pumps are not required.
  Honeycomb rotor type: The absorber is heated with heated air to desorb CO_2. Heating the rotor with a small amount of air is an important development issue. On the other hand, heats and cools only the honeycomb rotor, thus minimizing sensible heat loss due to the absorber's heat capacity.

【What's meaning of Air-regenerative DAC for rough enrichment of CO_2】

Indirect Heating adsorber type DAC



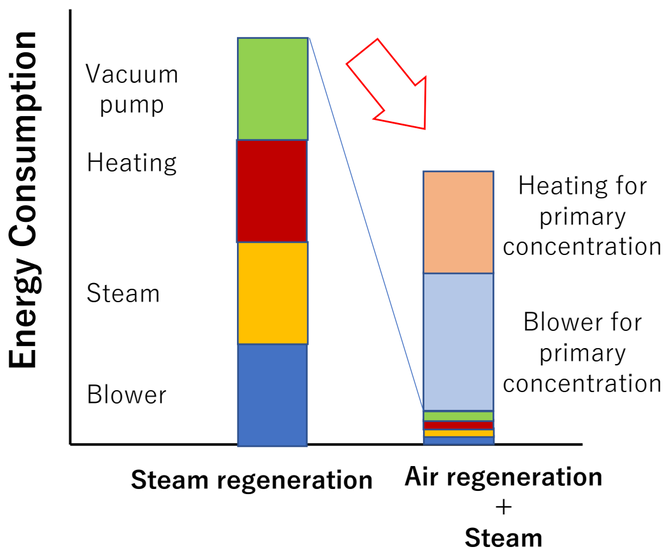
Honeycomb Rotary DAC



Highly concentrated process

Reduced size of the high enrichment process to be connected

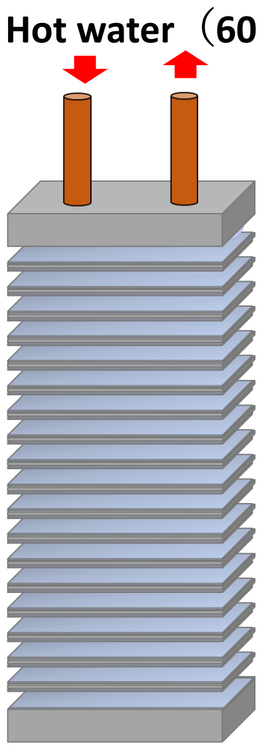
Reduction of energy requirements through a connected process



- **Downsizing of the CO2 enrichment process by placing the air regeneration system in the first stage.**
- **The energy requirements of the enrichment process are reduced to match the size of the process.**
- **The total energy requirements of the air regeneration system, even when added to the energy requirements of the air regeneration system, could be less than the energy requirements of the high enrichment process alone.**

【Progress and challenges of indirect heating systems】

Adsorbent coated Heat Exchanger

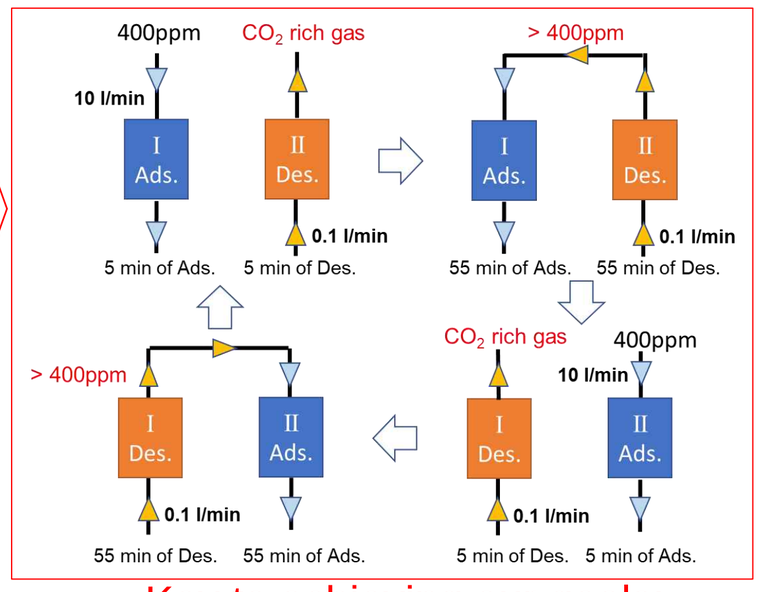


Thermal conduction heating of amine with hot water flowing in a separate channel
CO2 recovery concentration can be increased by minimizing the amount of heated air for CO2 desorption

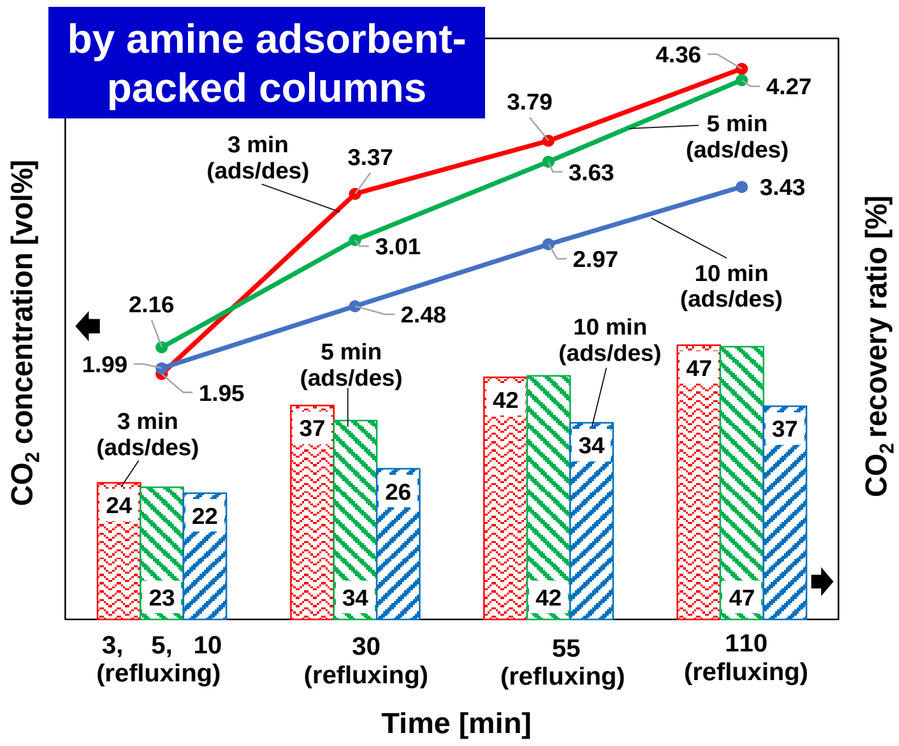
Consideration of changes in CO_2 concentration at the desorption outlet
- Only high-concentration CO_2 in the early stage of the desorption process is recovered.
- Low-concentration CO_2 in the latter half of the desorption process is returned to the adsorption column.

➡Improvement of recovered CO_2 concentration and recovery ratio

400ppm➡4%

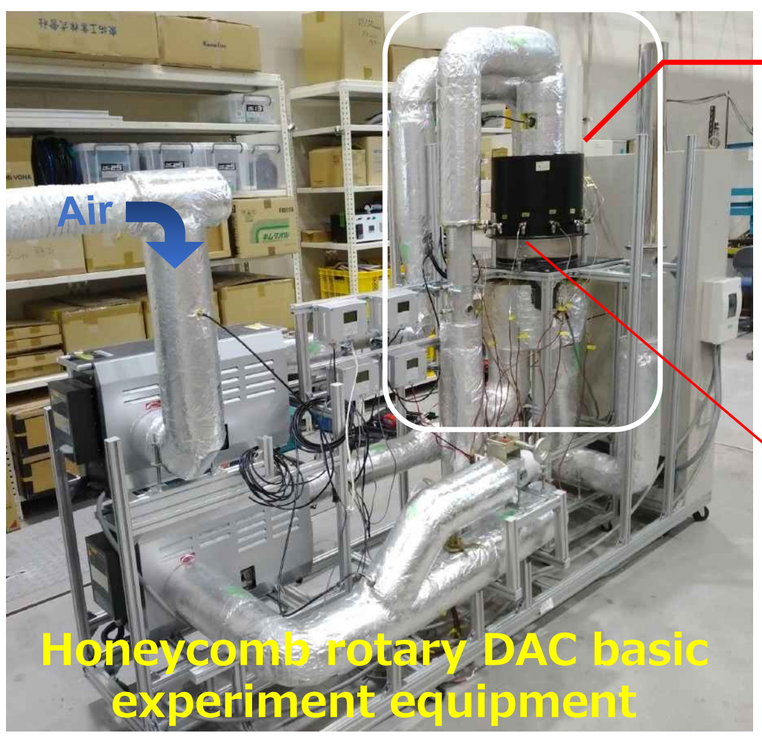


by amine adsorbent-packed columns

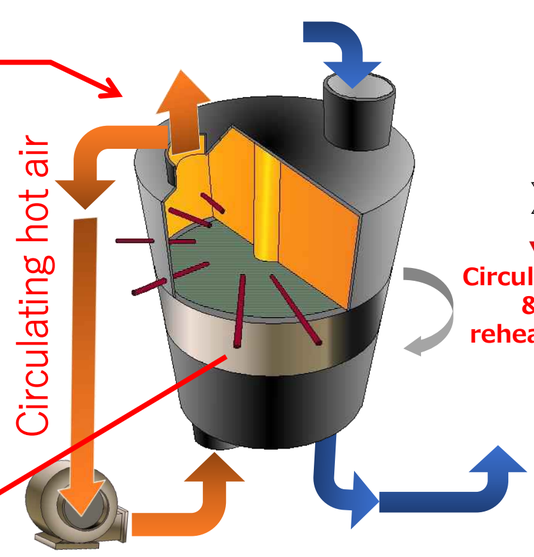


Key to achieving our goals;
Coating of RITE amine on heat exchangers or appropriate materials

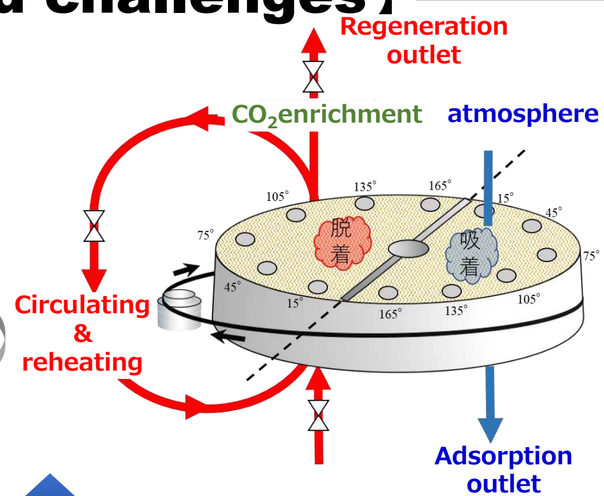
【Progress of Rotary-type DAC and challenges】



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



Reduces the amount of introduced air while providing the heat needed to heat the rotor by circulating and reheating the regenerated air



Measure air temperature, CO_2 concentration and water vapor concentration distribution in the direction of rotor rotation, and reflect the results in the optimization of the flow path configuration and operation/design.

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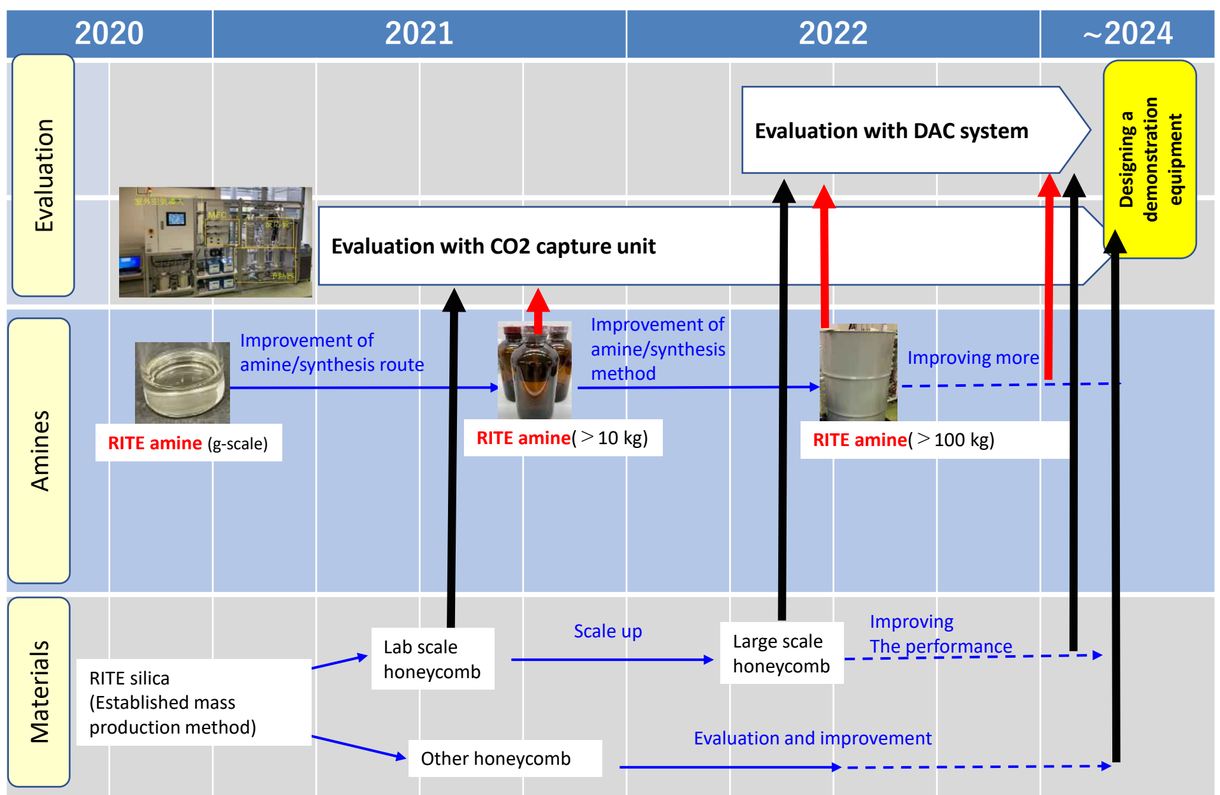
Organization: Research Institute of Innovative Technology for the Earth (RITE)

Contact: Research Institute of Innovative Technology for the Earth(RITE)/ yogo@rite.or.jp

•DAC(Direct Air Capture) technology development: Developing a new solid sorbent material consisting of new amine and support structure for capturing low-concentration CO2 from the air (Direct Air Capture; DAC) and high-efficient process with low energy for recovery.

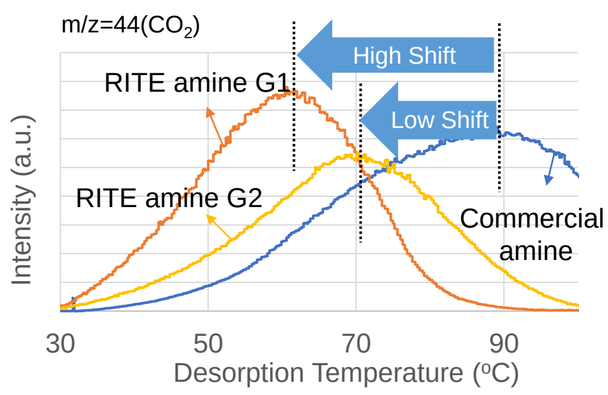
•CO_2coversion technology development:We have developed the synthesis of liquid hydrocarbon using CO2 captured from atmosphere as raw material. By applying the membrane reactor, high efficiency and energy saving can be expected, and the inorganic membranes are also developed to apply the membrane reactor

【Developmenr of amine and support materials on DAC technology】



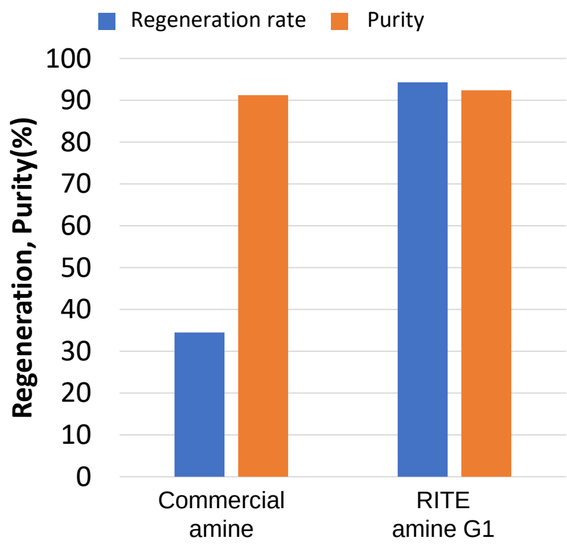
【CO_2 desorption property after Air adsorption】

• **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**

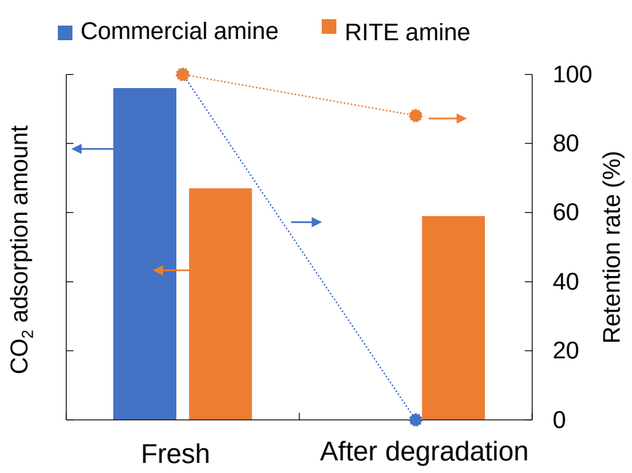


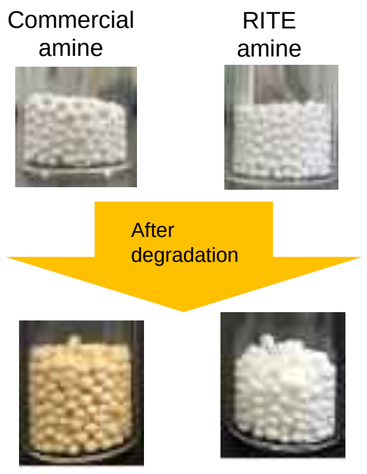
RITE amine G1:
CO_2 can be released at 60°C.

【Oxidative degradation resistance of RITE amine】

(Condition: Air, 100°C, 42 h)

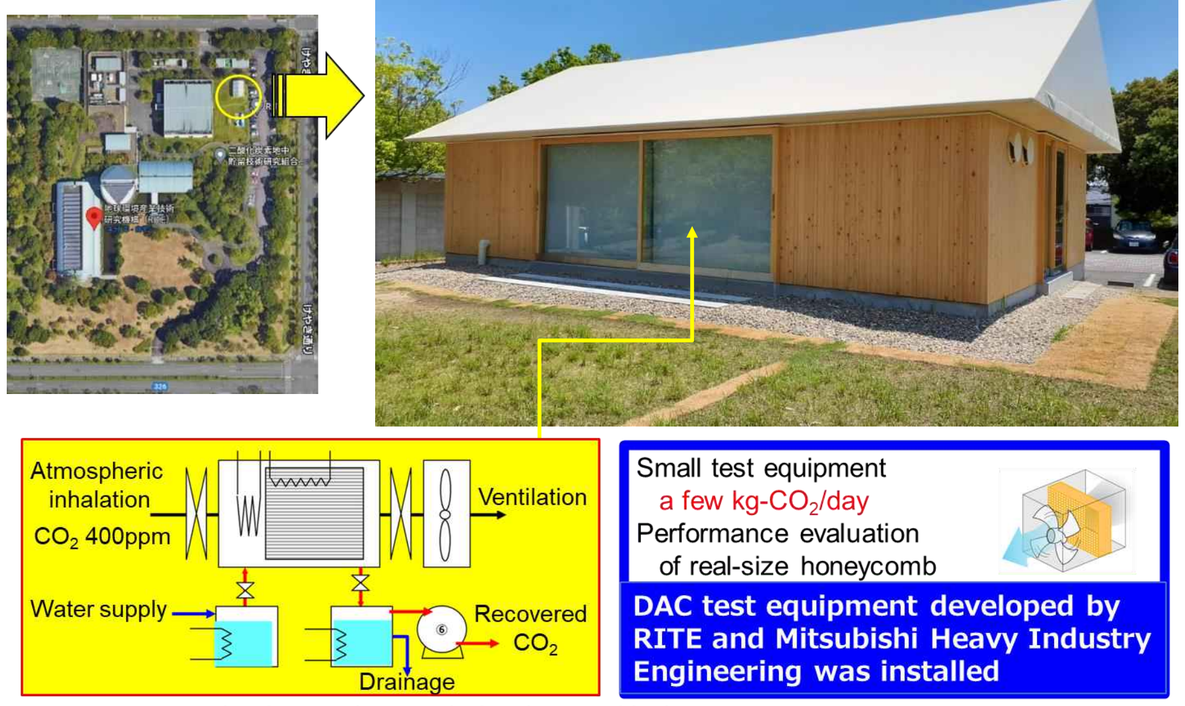
Adsorption amount (@0.04kPa)





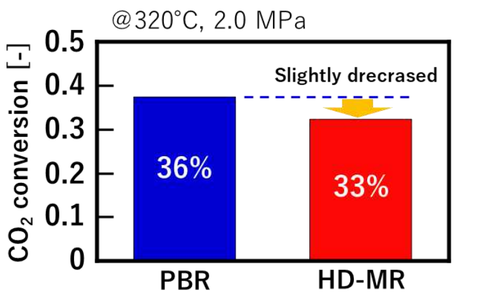
RITE amine G2: High resistance to oxidative degradation (Lab-scale synthesis)
→Improvement of adsorption performance and investigation of industrial manufacturing

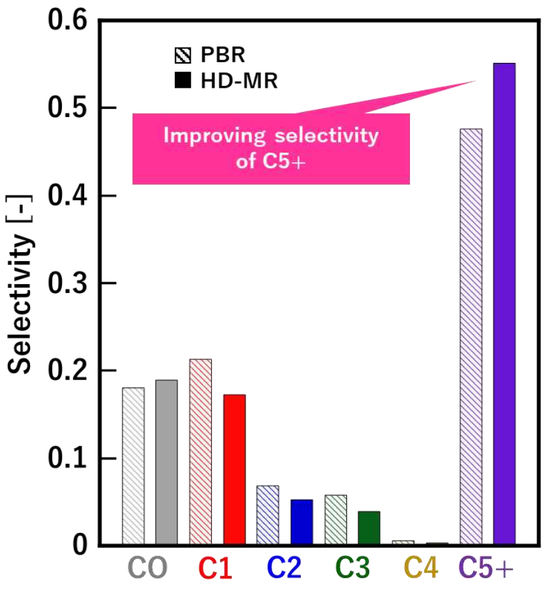
【Evaluation Test started at DAC Experimental Facility in RITE】 (2022.9.20 NEDO, MHI Engineering, RITE 3 party press release)

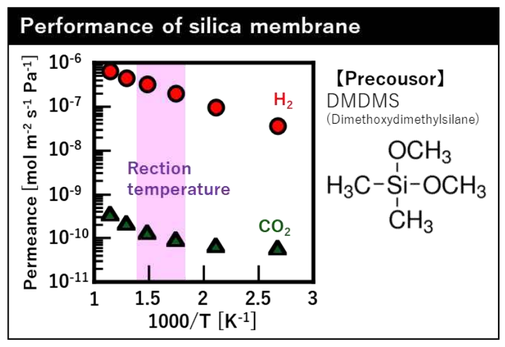


DAC system evaluation equipment (a few kg-CO_2/day)

【Development of membrane reactor for CO_2 conversion】







H2 distributor type membrane reactor is expected increasing of hydrocarbon selectivity.

【Process images of CO_2 conversion using membrane reactor】