Development of Combined Carbon Capture and Conversion (quad-C) Systems for the Utilization of Atmospheric CO_2

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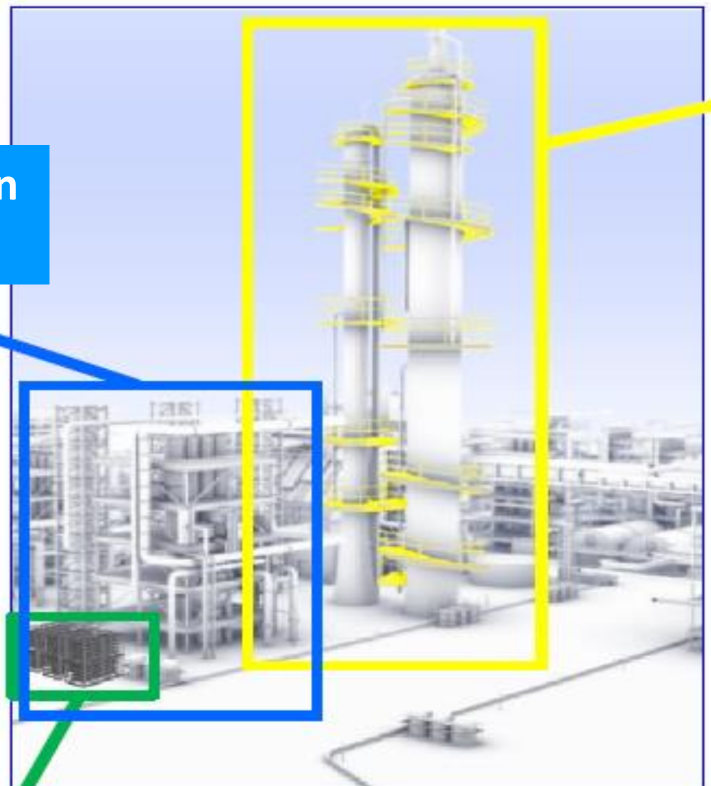
Problems with existing carbon dioxide removal processes

CO2 separation and capture in thermal power plants and hydrogen production plants

Hydrogen production unit



Layout of a hydrogen production plant

CO2 separation membrane unit (Under development)

CO2 separation and capture unit (Chemical absorption method)

Power generation unit

Thermal power plant with CCS

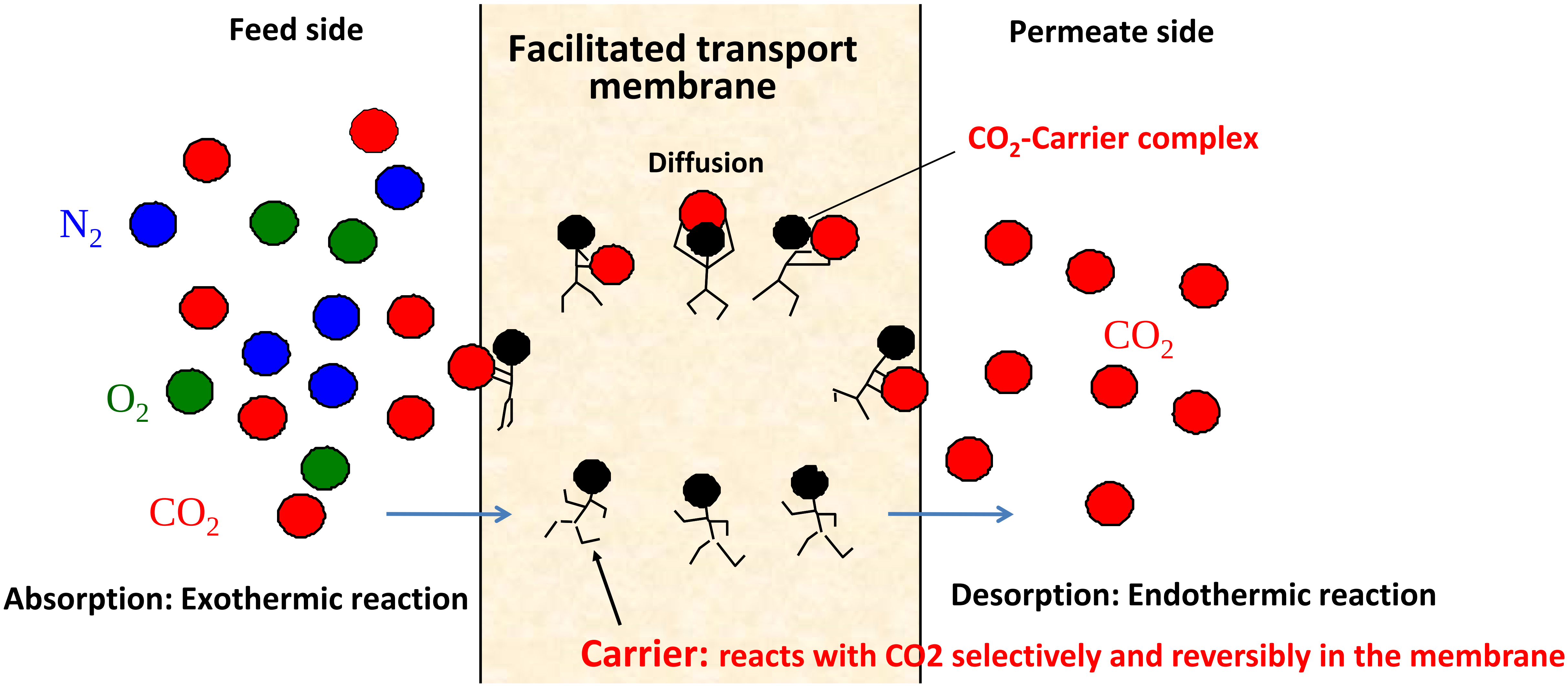
World Future Energy Summit 2010 (Abu Dhabi)

From the exhibition of MASDAR (Abu Dhabi Government's Clean New Energy Project)

Existing CO2 separation and capture technologies are very expensive, require large equipment, and are energy intensive.

Application to the separation and capture from dilute CO2 of 400 ppm in air, such as DAC, will lead to further enlargement of the system, which is problematic in terms of both cost and energy consumption.

Feature of CO_2 separation membrane (Facilitated transport membrane)

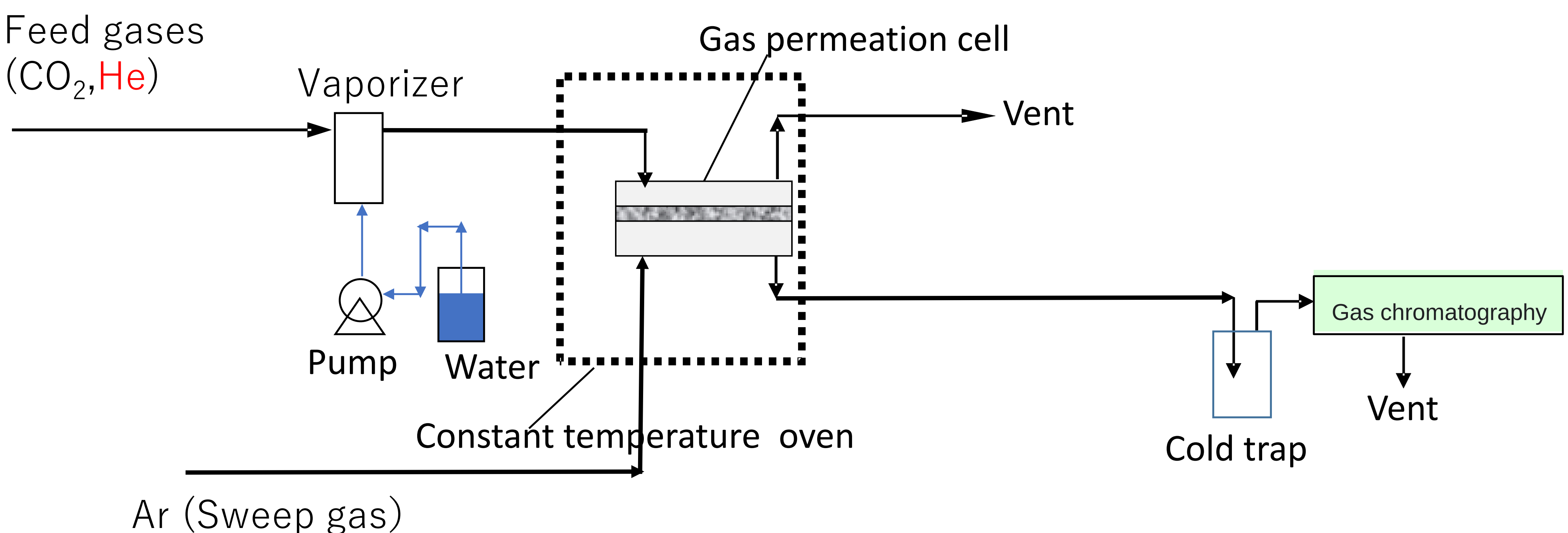


Energy required for CO2 desorption can be supplied from that of CO2 absorption

No energy consumption

- CO_2 reacts selectively with carriers and permeates the membrane very fast. (facilitated transport mechanism)
- O_2 and N_2 physically dissolve in the membrane and permeate through (solution-diffusion mechanism), resulting in low permeation rate and high CO2 selectivity.
- Energy-saving and compact compared to conventional technologies (chemical absorption method and adsorption method)

Membrane evaluation equipment



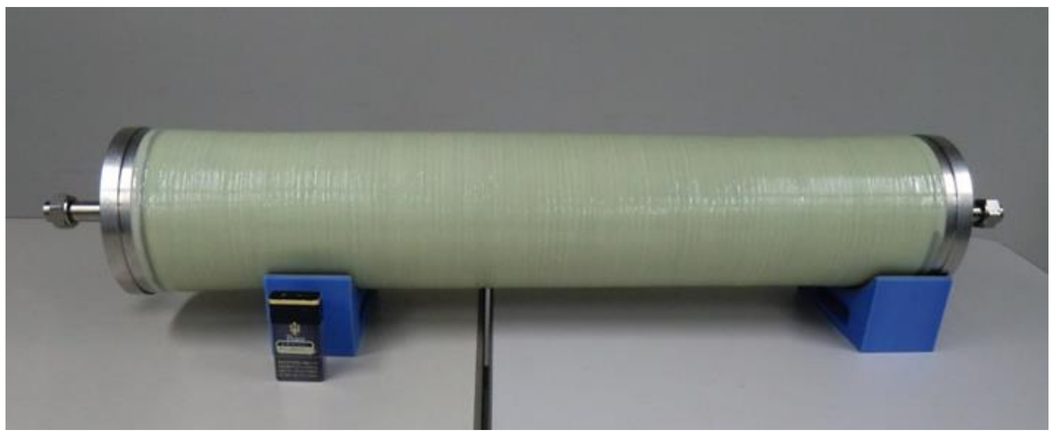

Gas permeation cell

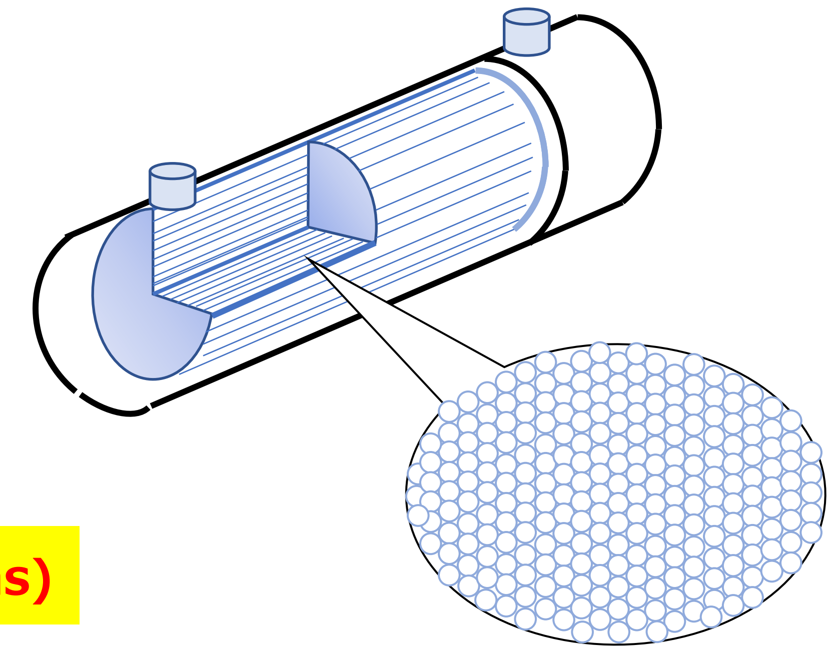

Evaluation equipment

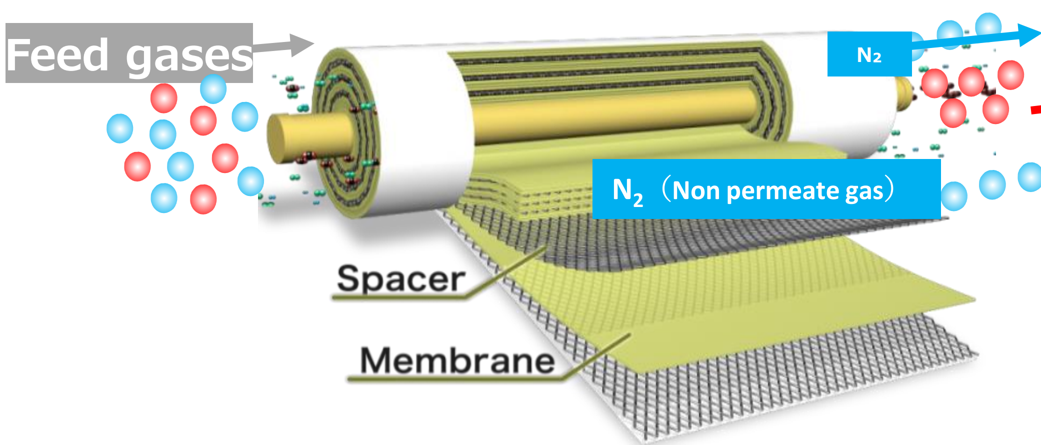

Gas chromatography

Membrane module

The module currently manufactured is a spiral type.
By using a hollow fiber type (separation function layer is formed on a cylindrical porous membrane with an outer diameter of about 1 mm), it is possible to significantly increase the membrane area per module volume.





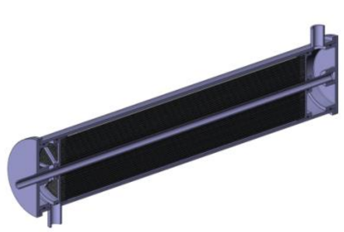


CO_2 (Permeate gas)

Spiral module

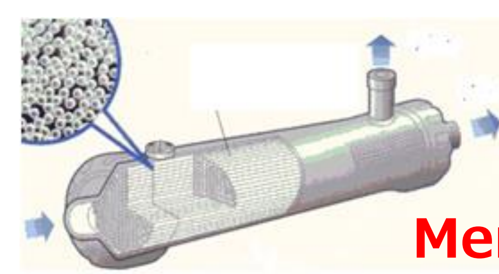
Hollow Fiber Modules

Currently the world's largest Facilitated transport membrane 8-inch module



Dimensions:
ϕ200 × 1000 L

Membrane area: 30.0m²



Dimensions:
ϕ300 × 2000 L

Membrane area: 350m²

Development items and ultimate goal

■Ultimate goal （Fiscal year 2029）

Develop a pilot-level CO_2 separation membrane module for quad-C that meets the required performance based on LCA (life cycle assessment) and TEA (techno-economic analysis).

■Development items

1) Development of CO_2 selective permeation membrane for DAC

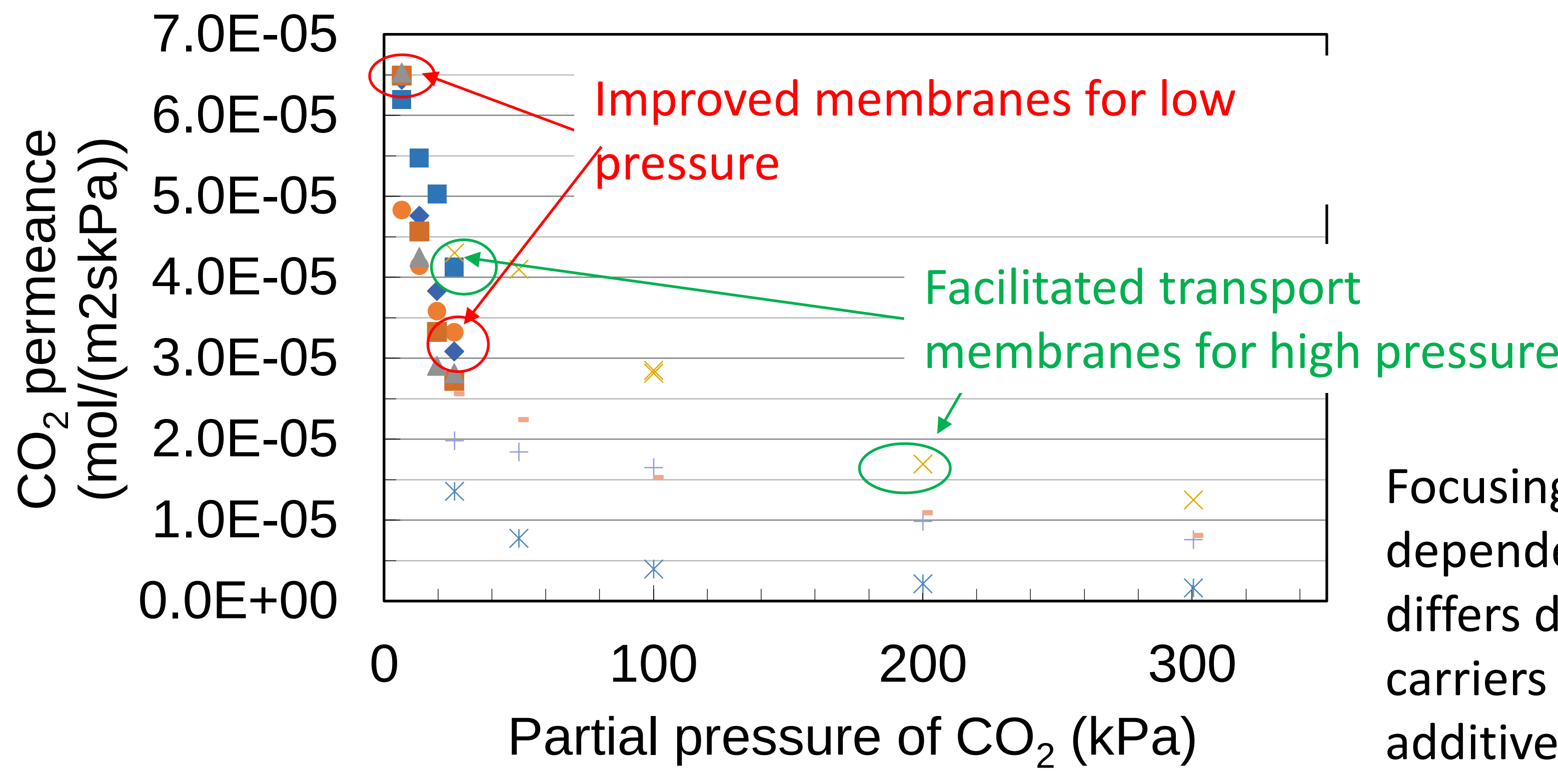
（RER is in charge. Basic data for improvement and optimization of membrane materials is provided by Watanabe Lab. of Tohoku Univ.）

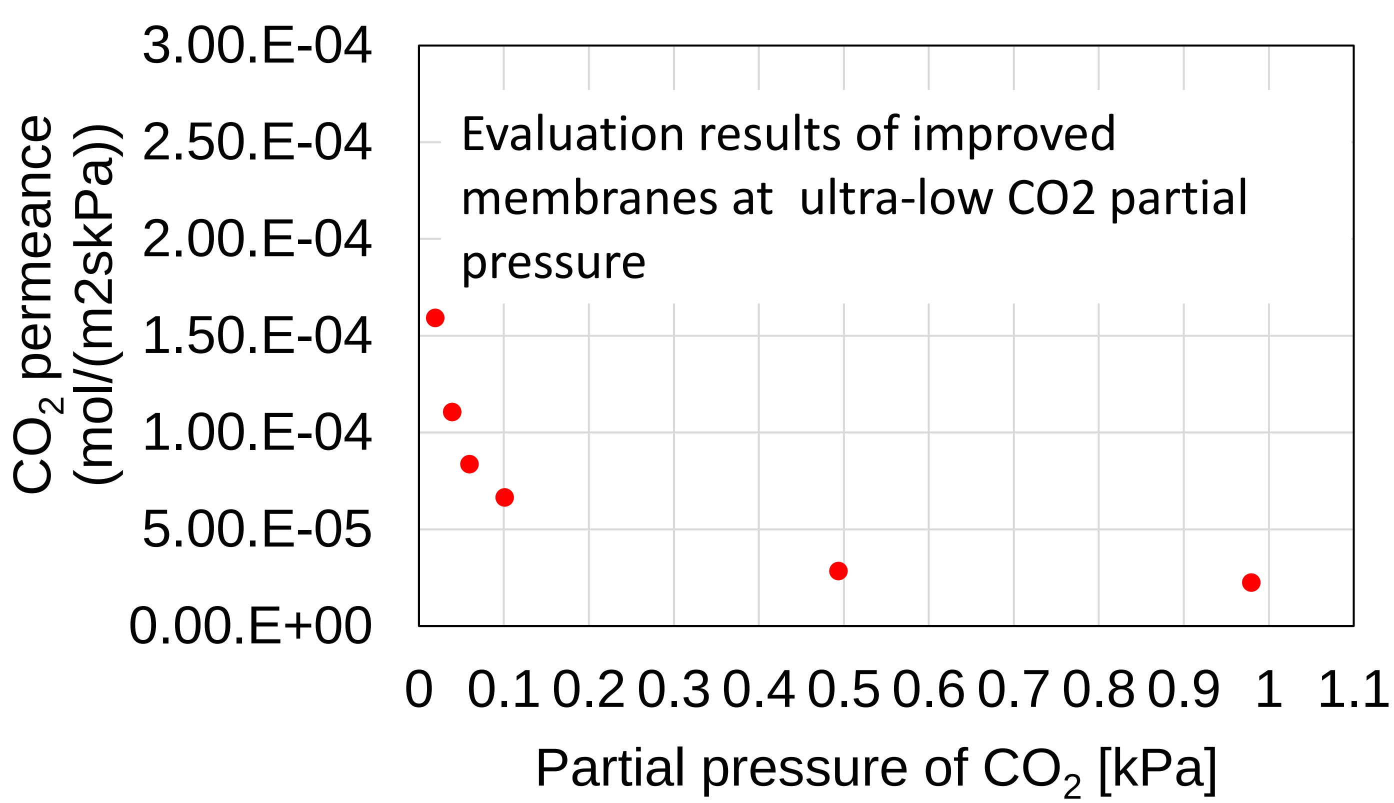
2) Development of high-efficiency separation membrane modules

3) Development of CO_2 reaction separation process for DAC

（RER is in charge. The basic data of the membrane reactor for the reaction with CO2 on the permeate side is obtained from Watanabe Lab. of Tohoku Univ.）

Development of CO2 selective permeation membrane for DAC (1)

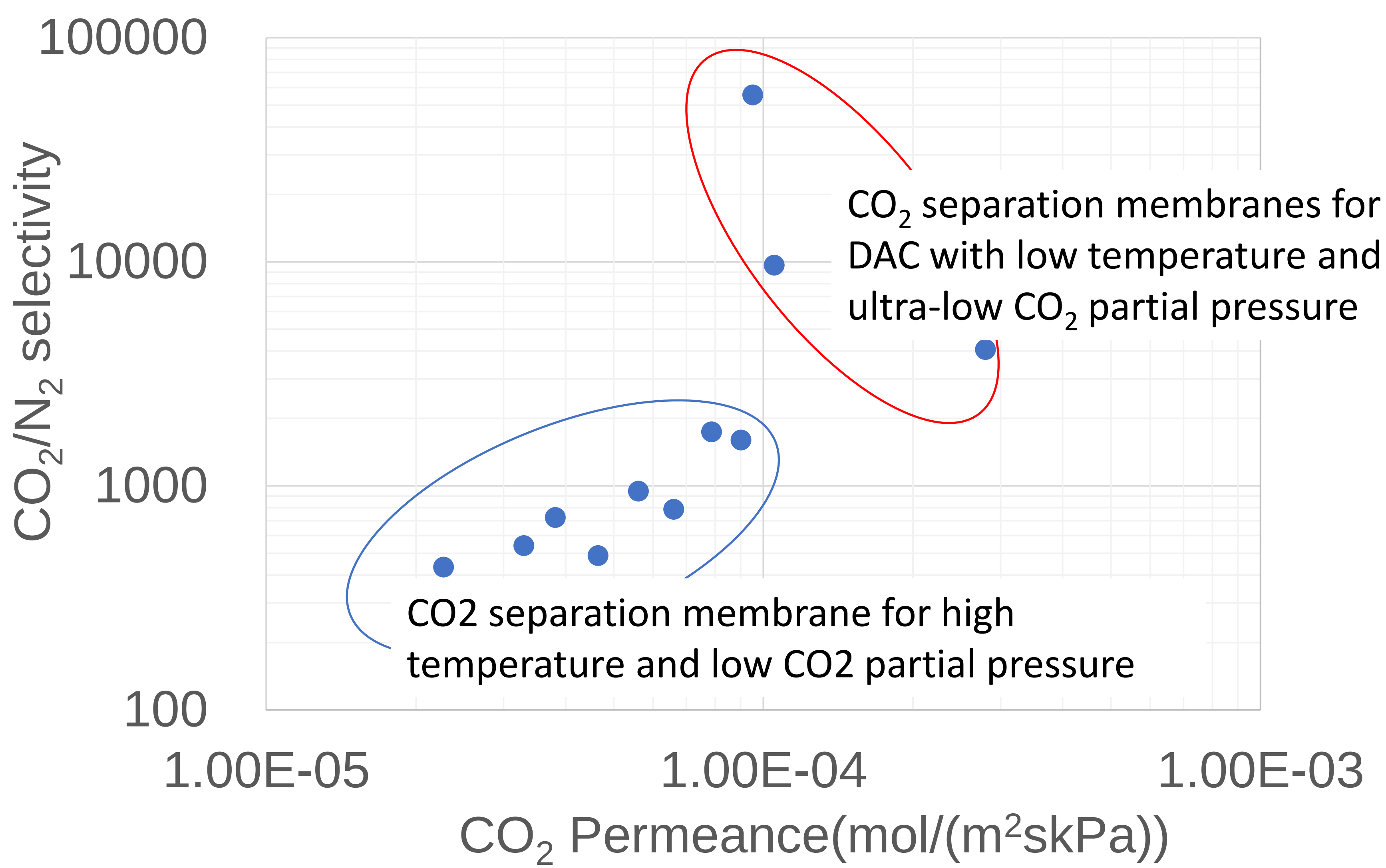


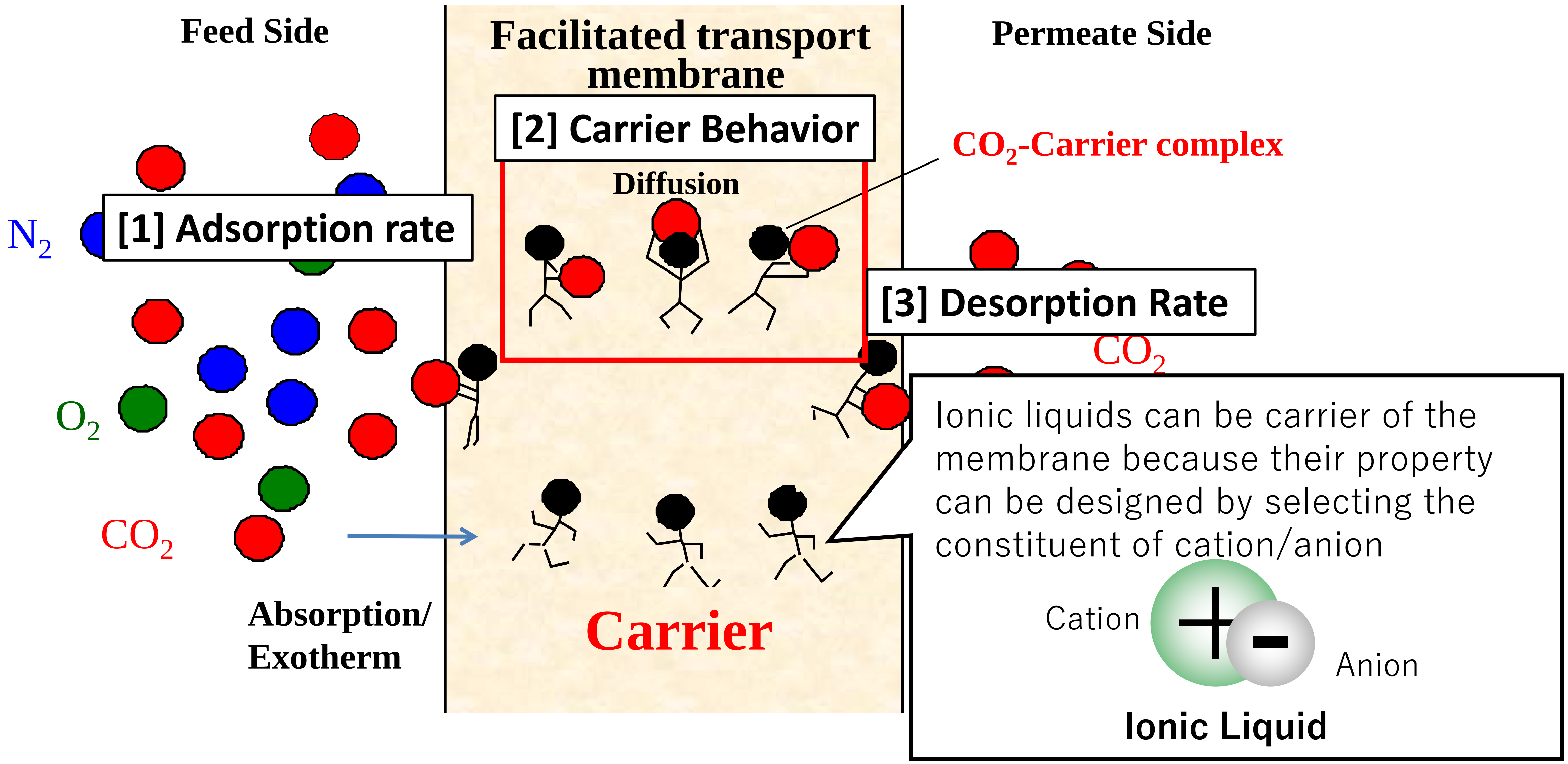


Focusing on the fact that the dependence on CO2 partial pressure differs depending on the type of CO2 carriers and composition of those and additives, we investigated the improvement of the performance of DAC under ultra-low CO2 partial pressure conditions.

We succeeded in producing a prototype membrane with excellent performance in the ultra-low CO2 partial pressure region.

Performance of various membranes plotted as CO_2/N_2 selectivity on the vertical axis and CO_2 permeance on the horizontal axis. (Comparison between membranes for high temperature and low CO_2 partial pressure before development and membranes for low temperature and ultra-low CO_2 partial pressure for DAC)





- **Problems to be solved for searching the optimum membrane composition**

  [1] CO_2 adsorption rate（CO_2 Solubility, Diffusivity, Solution viscosity）

  [2] Carrier behavior（CO_2-Carrier complex: supported by quantum chemical calculation）

  [3] CO_2 desorption rate at permeate side

  ⇨ **Optimization of liquid composition from experimental and scientific approaches: fundamental properties and kinetic behavior**

①Apparatus for Raman Spectroscopy：

- ✓ Experimental in-situ analysis for direct measurement
- ✓ Supported with quantum chemical calculation

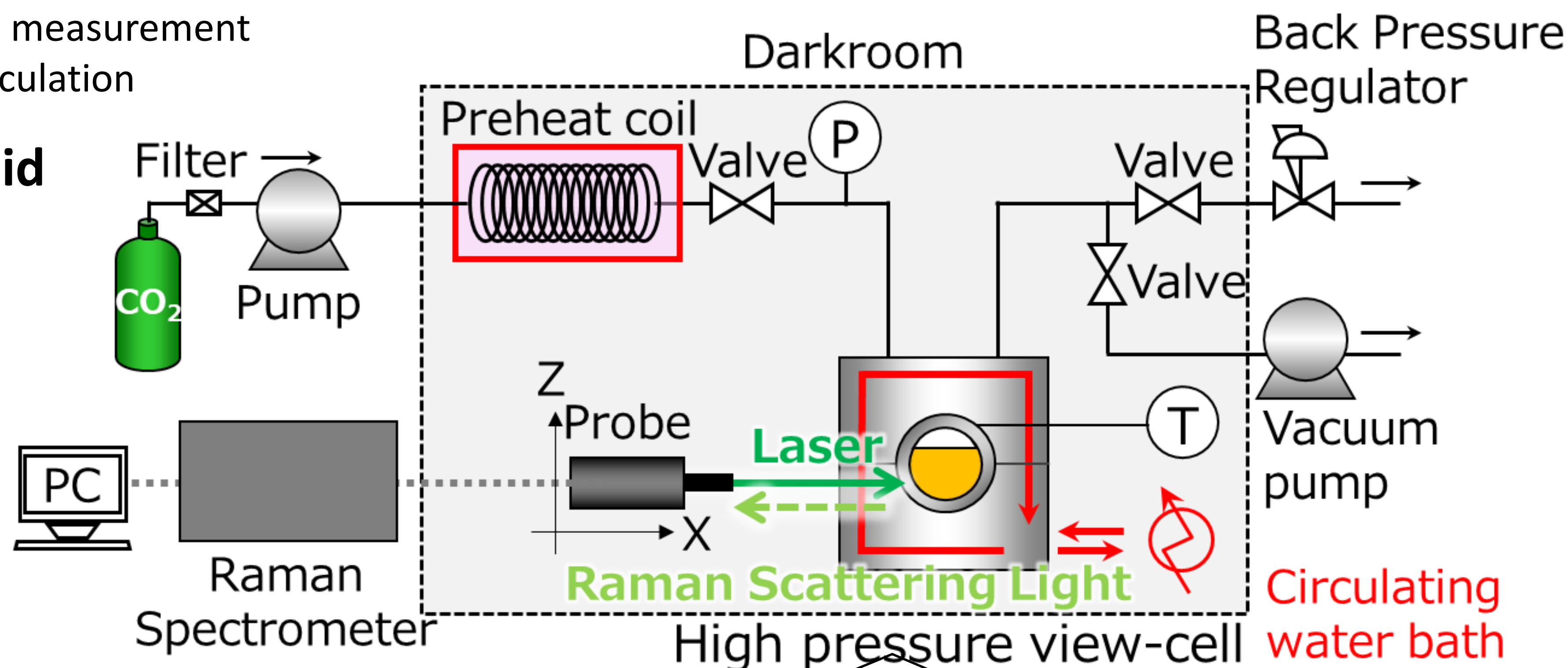
② Viscosity measurement of liquid in the presence of CO_2：

- ✓ Viscosity of carrier-CO_2 complex
- ✓ Relation with transport rate

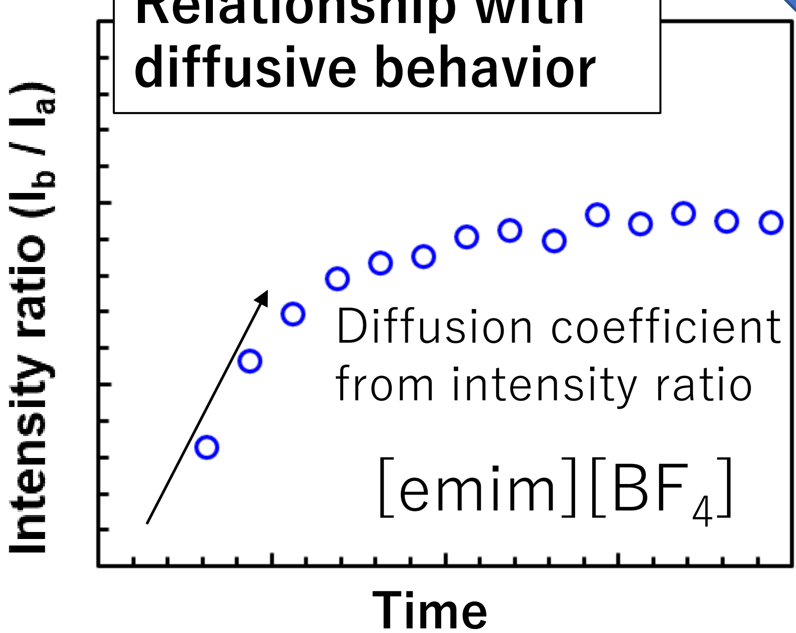
③ Global analysis by numerical calculation

- ✓ Phase equilibria
- ✓ Quantum chemical calculation
- ✓ AI approach

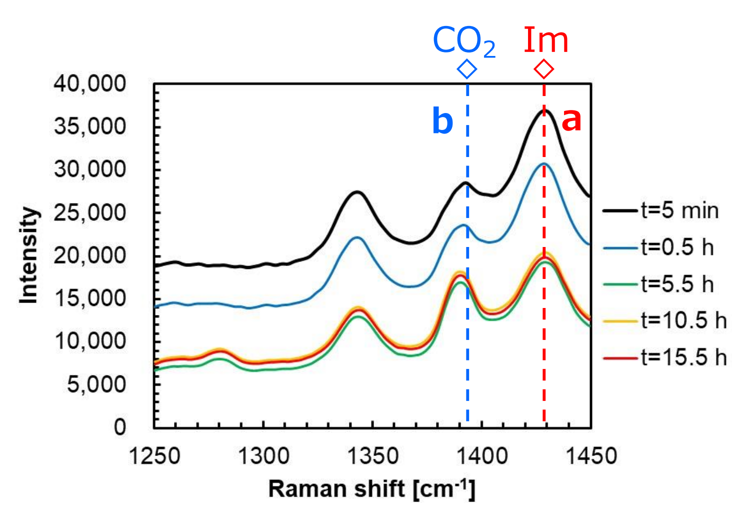
Apparatus for Raman Spectroscopy



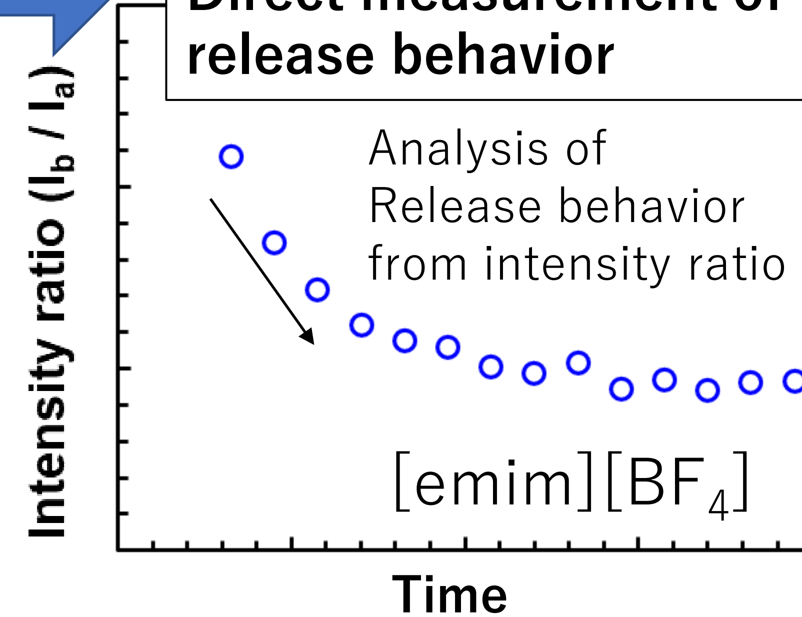
[1] Solubility rate：Relationship with diffusive behavior



[2] Carrier behavior：Spectral identification

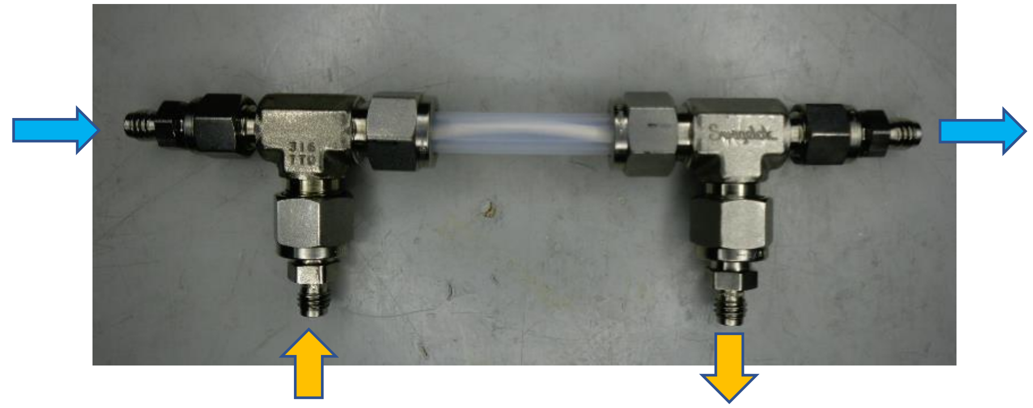


[3] Desorption rate：Direct measurement of release behavior



Development of high-efficiency separation membrane modules

Coating the inside of a porous tube with preparation solution



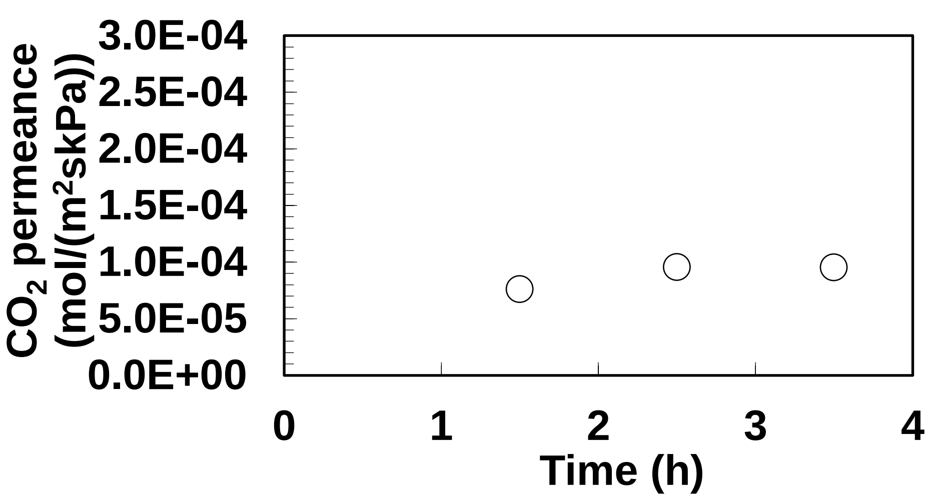
■Evaluation condition

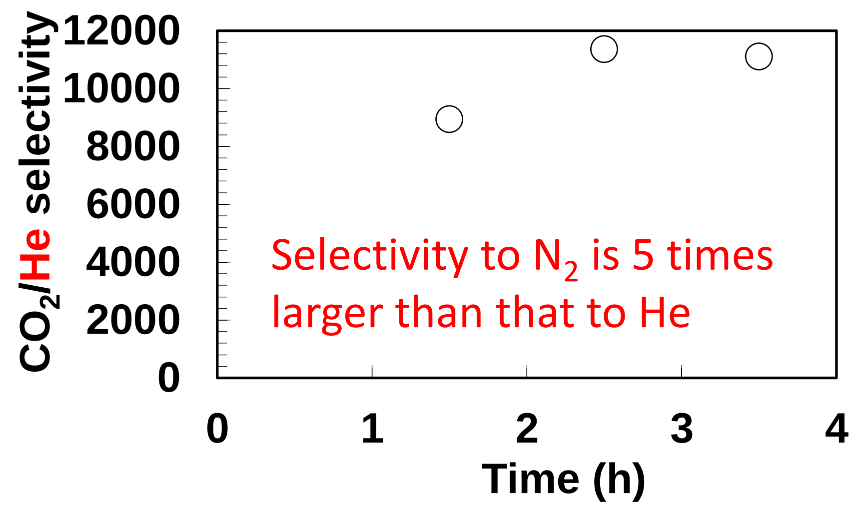
CO_2 400ppm,　Temperature: 27℃

Target membrane performance

- CO_2 permeance: 1×10-3 mol/m²skPa or higher
- CO2/N2, O2 selectivity: 20,000 or higher

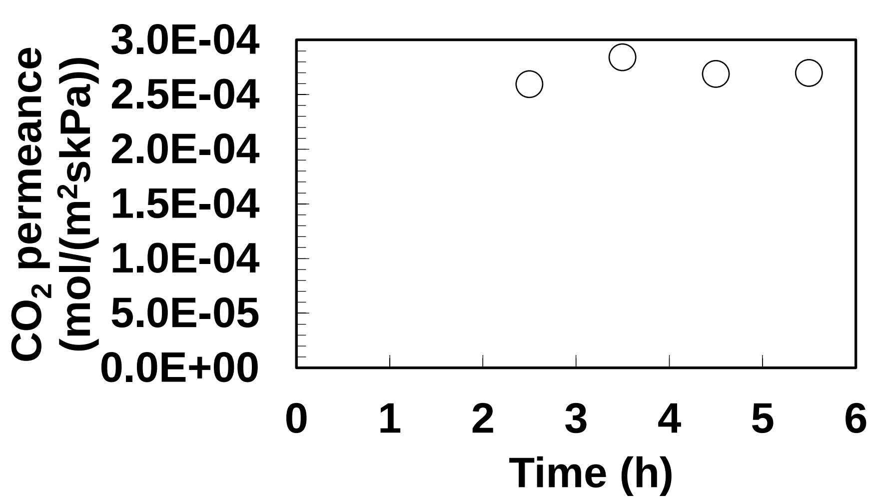
Membranes using porous tubes with an outer diameter of 3 mm and an inner diameter of 2 mm

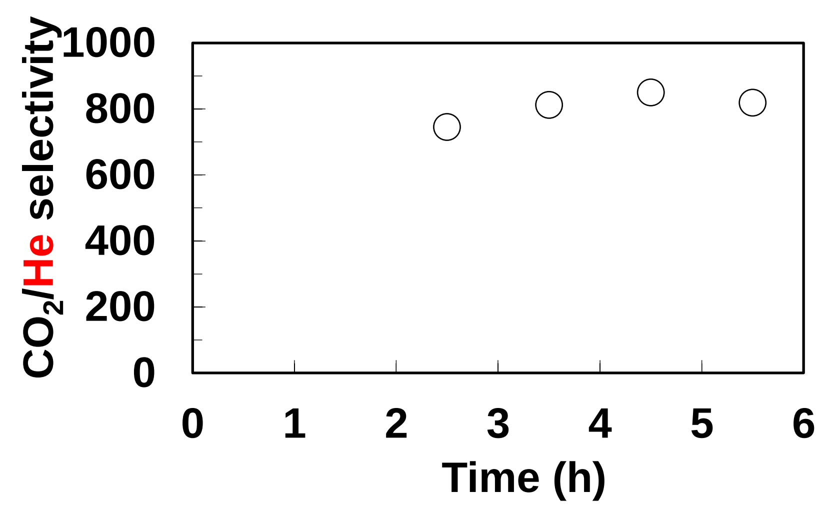




Membrane using a substrate of 3 mm in outer diameter
CO_2 permeance: 9.5×10-5 mol/m2skPa and
CO_2/N_2 selectivity: 55,000

Membranes using porous tubes with an outer diameter of 1.2 mm and an inner diameter of 0.7 mm

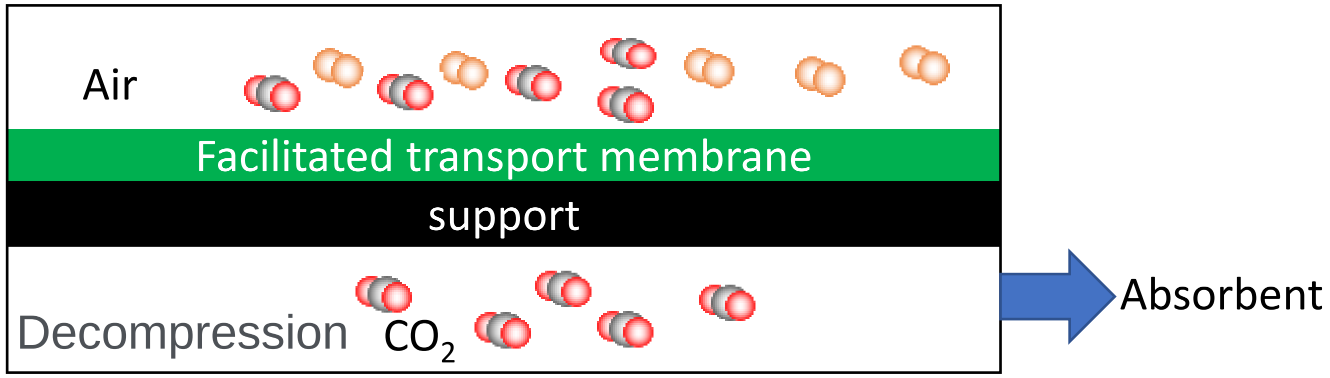




Membrane using a substrate of 1.2 mm in outer diameter
CO_2 permeance: 2.7×10-4 mol/m²skPa and
CO_2/N_2 selectivity: 4,000

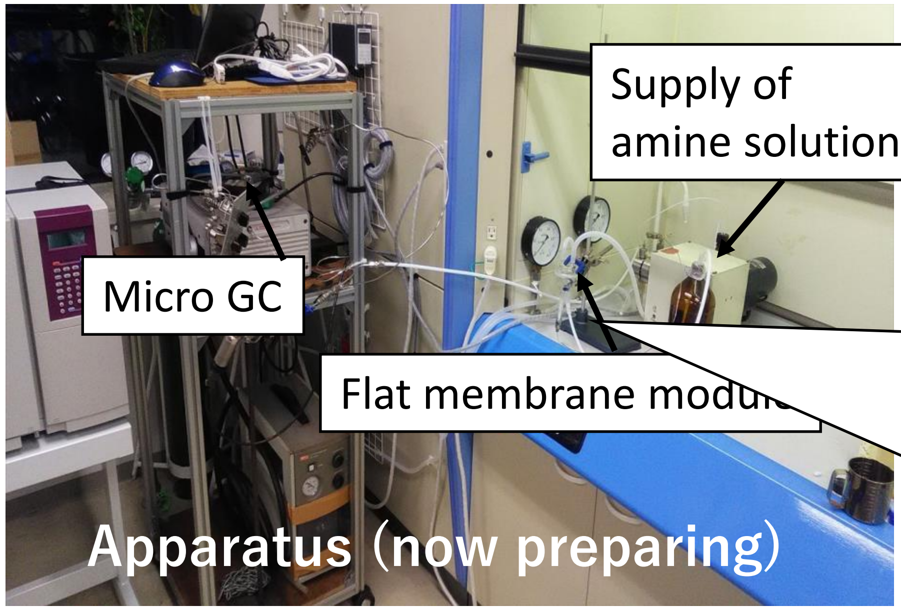
■Gas(Air) – Membrane – Gas (CO_2 rich gas) type

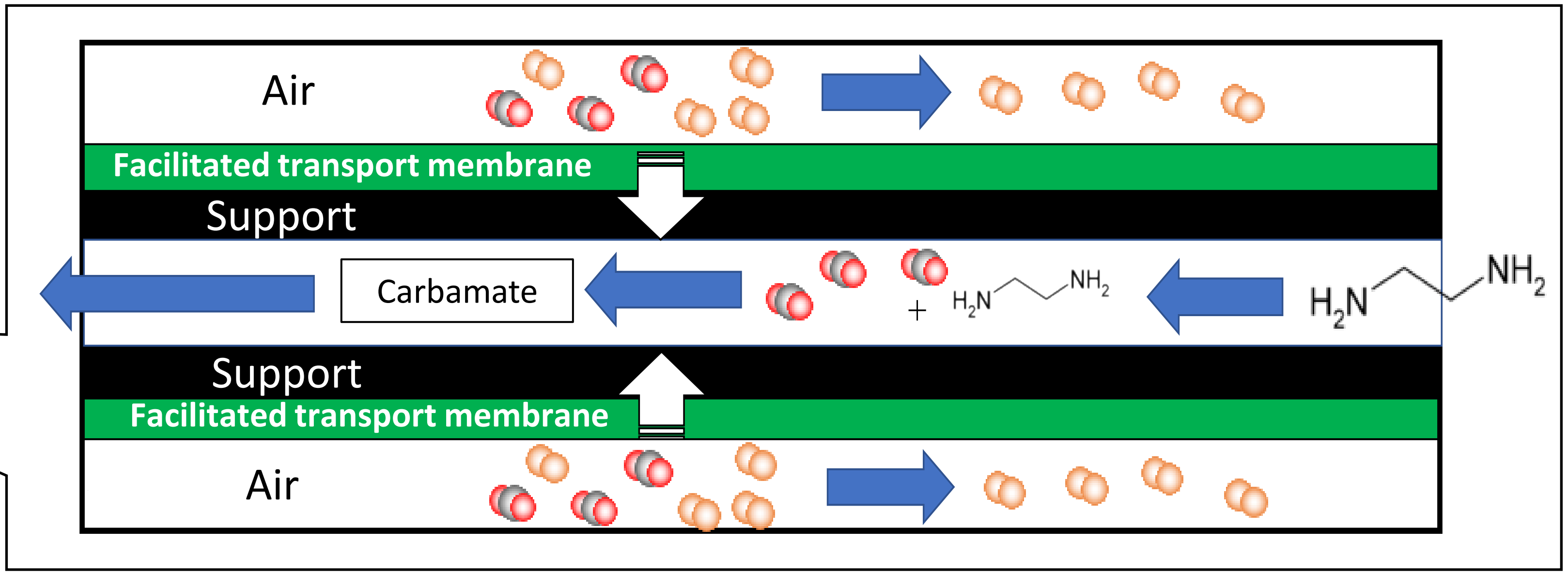
A method to obtain the CO_2 partial pressure difference, which is the driving force for CO2 permeation , by depressurizing the permeate side. Experimentally, it is possible to evaluate the performance of membranes by supplying sweep gas such as Ar to the permeate side instead of depressurization.



■Gas(Air) - Membrane - Liquid(Amine + Carbamic acid) type

By direct reaction of CO_2 and chemical reactant such as ethylenediamine (EDA) on permeate side, valuable chemical compounds such as ethylenediamine-carbamic acid (EDA-CA) will be synthesized. Loss of amine reactant by volatilization is prevented by selecting amine on the permeate side, and the driving force of CO2 permeation can be maintained by lowering the CO2 partial pressure at the permeate side by the reaction with amine. As the high performance quality membranes are completed, a new equipment to evaluate new membrane systems (that use amine solutions as the permeate) is being prepared .





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