

**CSLF Technical Group Meeting
Fukuracia Tokyo Station, Tokyo, Japan
4th October, 2016**

Results from CSLF-recognized Project: CO₂ Separation from Pressurized Gas Stream

Shin-ichi Nakao

**Chemical Research Group
Research Institute of Innovative Technology for the Earth
(RITE)
Japan**

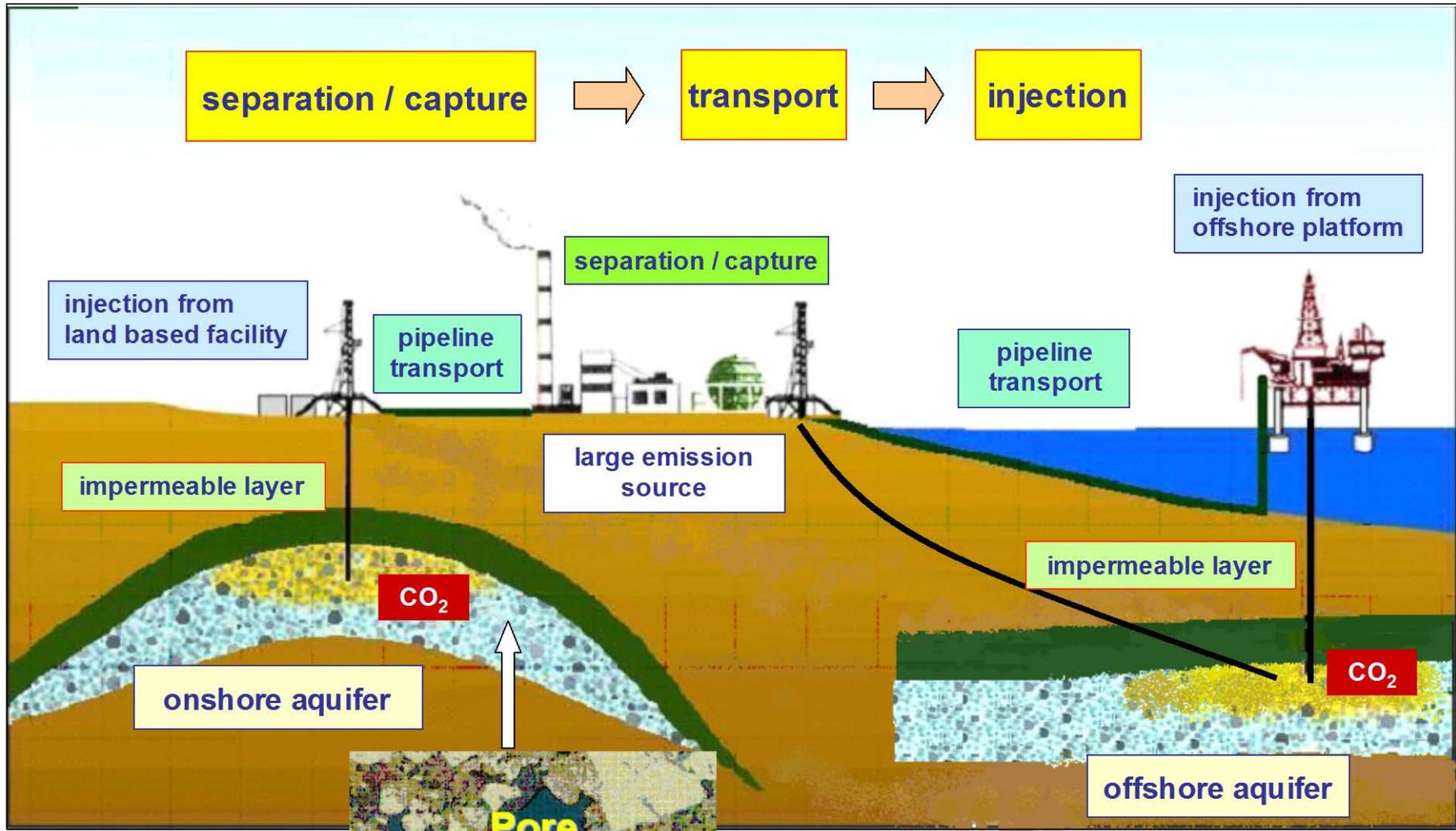


About RITE

- **Objective :**
R&D of industrial technologies that contribute to **both the conservation of the global environment and the progress of the world economy**
- **Establishment : July 1990**
Supported by METI, local governments, academic circles and industries
- **Location : Kansai Science City**
- **Activities :**
Development of innovative environmental technology, expansion of CO₂ sinks

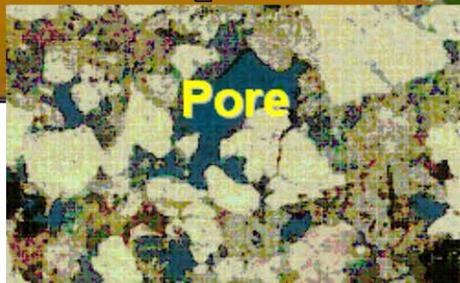


CCS (Carbon Capture and Storage)



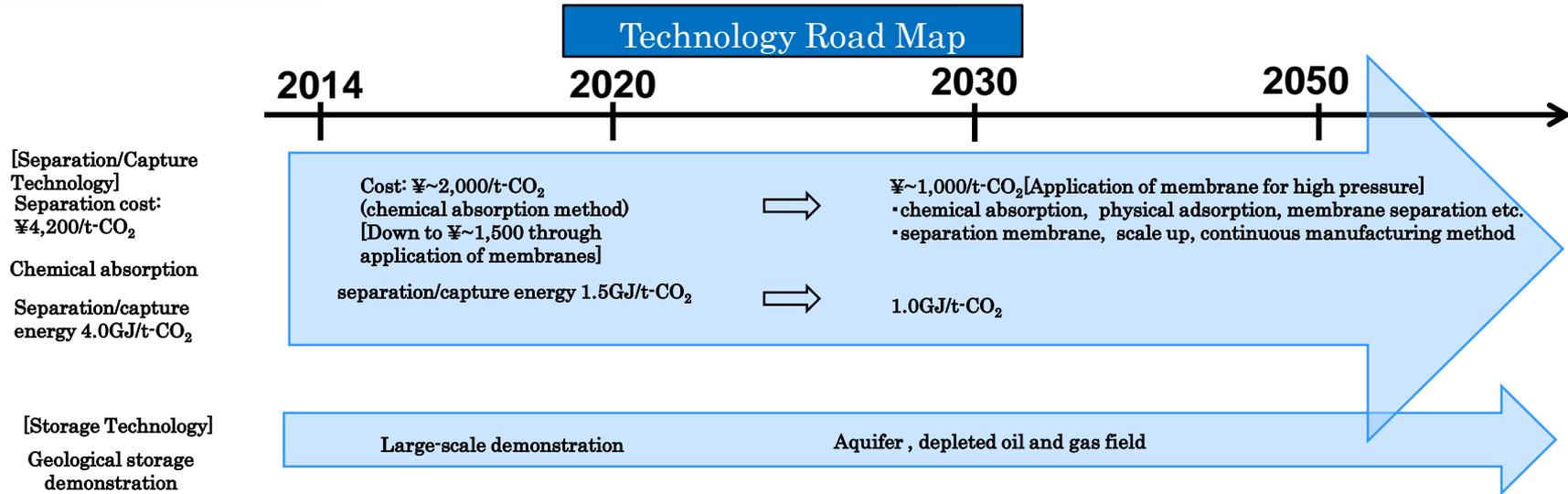
microscopic photo of aquifer rock:

CO₂ will fill the pore space



<METI's CCS2020, July, 2006>

CO₂ Capture and Storage (CCS) Technology Road Map



	2010	2020	2030
Separation Cost [¥/t-CO ₂]	4,200	2,000	1,000
	(Down to ~¥1,500/t-CO ₂ through application of membranes)		
Separation and Capture Energy [GJ/t-CO ₂]	4.0	1.5	1.0

Advisory Committee on Energy and Natural Resources Basic Policies Source “Roadmap and Other Items Pertaining to Each Item of Technology”



METI Projects

Post-combustion:

2003FY-2005FY

“CO₂ molecular gate Membrane Basic Research and Development Project”

-Basic research on membrane materials

※ recognized by the CSLF at its Melbourne meeting, September 2004

Pre-combustion:

2006FY-2010FY

“CO₂ molecular gate Membrane Research and Development Project”

-Research and development on membrane materials

2011FY-2014FY

“CO₂ Separation Membrane Module Research and Development Project”

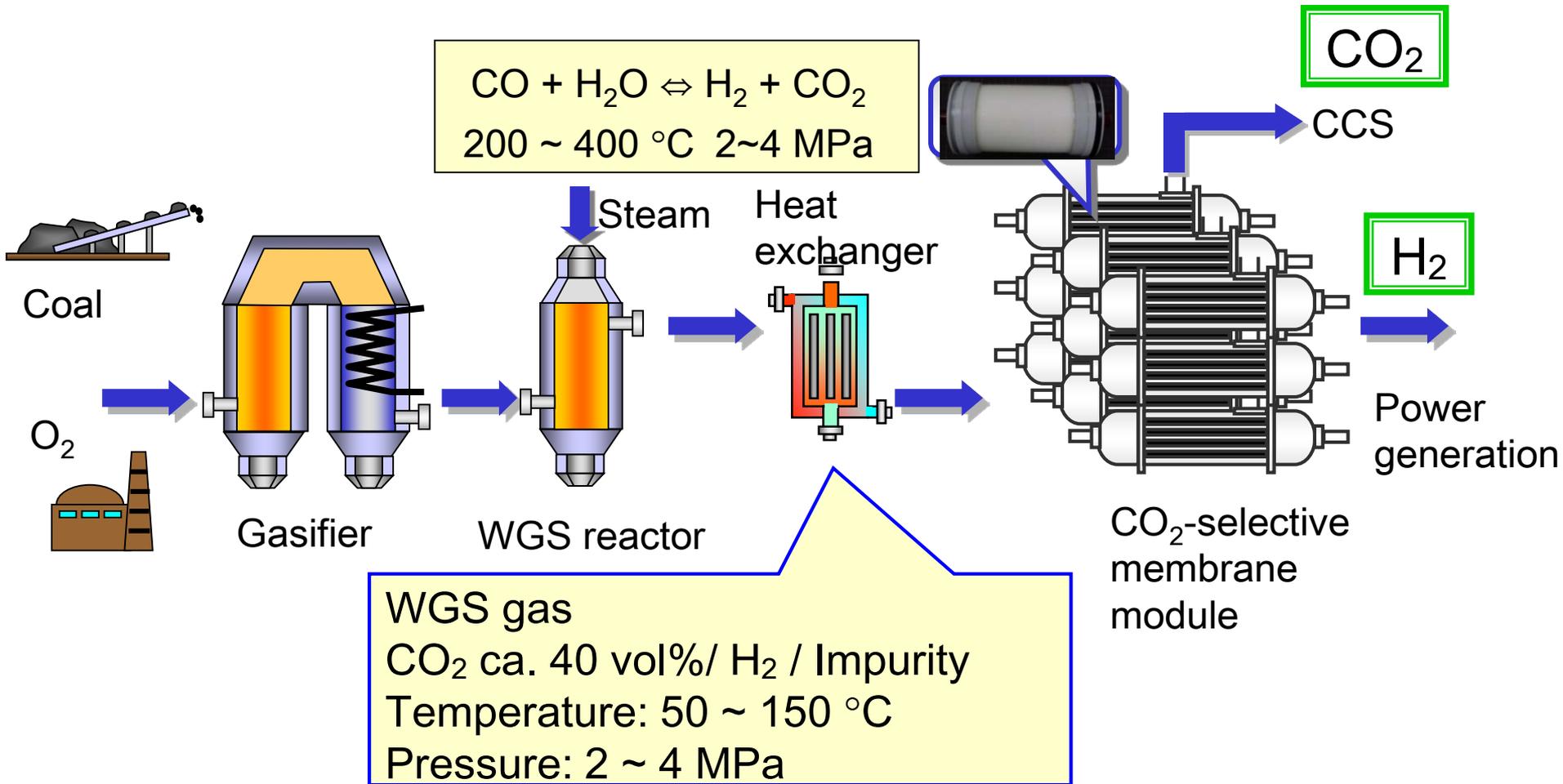
-Development of membrane materials, modules and systems

2015FY-

“CO₂ Separation Membrane Module Practical Research and Development Project”

-Development of membrane modules and field test using real WGS gas

CO₂ Separation Membrane Module for IGCC with CO₂ capture



IGCC: Integrated coal Gasification Combined Cycle



Application of molecular gate membrane module to IGCC

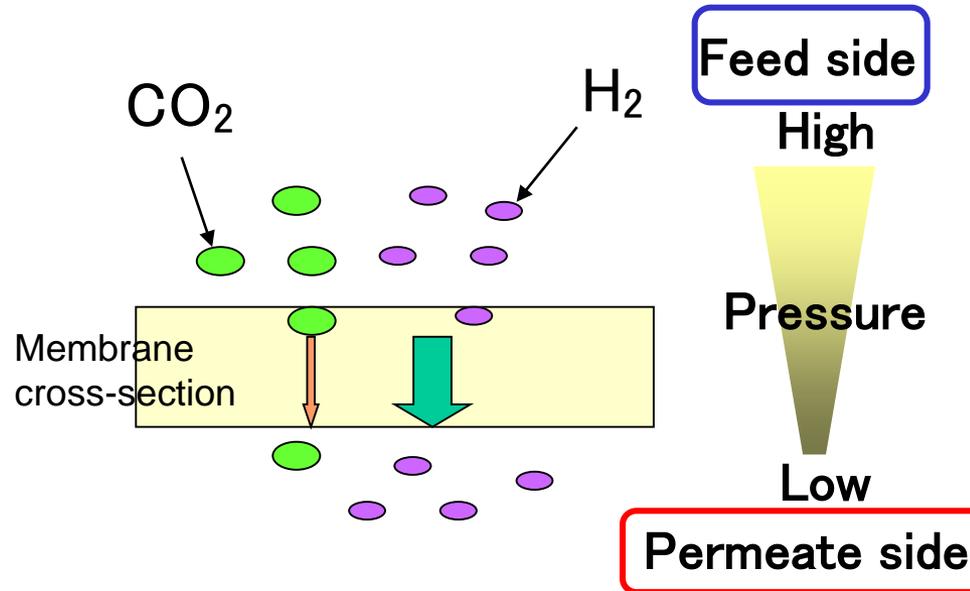
Compared to conventional physical absorption for high pressure gas:

- Low energy
1/3~1/4 of physical absorption *
- Low cost
1,500 yen/t-CO₂ (Target)

* : Cost estimation from Molecular Gate Membrane Module
Technology Research Association

CO₂ Separation Membrane

< Conventional CO₂ separation membrane >



Molecular size (nm)

H₂ < **CO₂** < **N₂** < **CH₄**
0.29 0.33 0.36 0.38

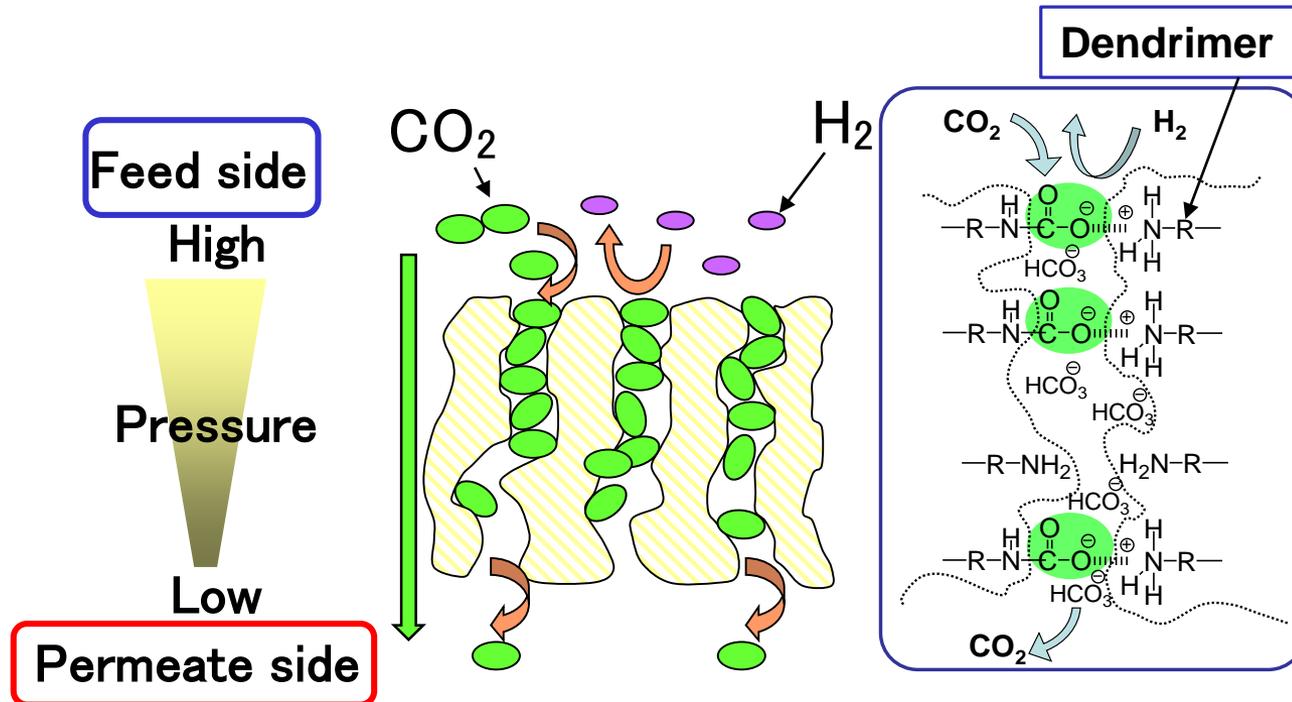
CO₂ selectivity over H₂ ($\alpha_{\text{CO}_2/\text{H}_2}$)

$\alpha_{\text{CO}_2/\text{H}_2} < 1$ (Molecular sieve type membrane)

~ 10 (Solution-diffusion-type membrane)

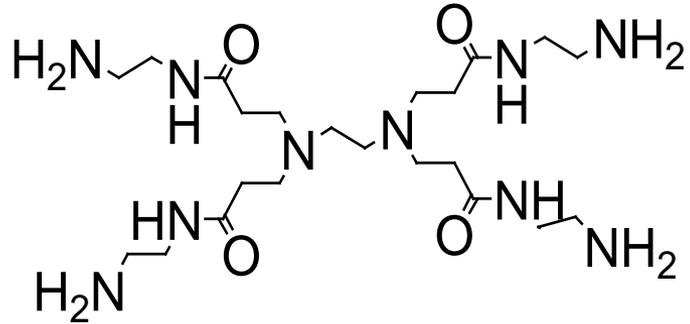
CO₂ Separation Membrane

< CO₂ molecular gate membrane >

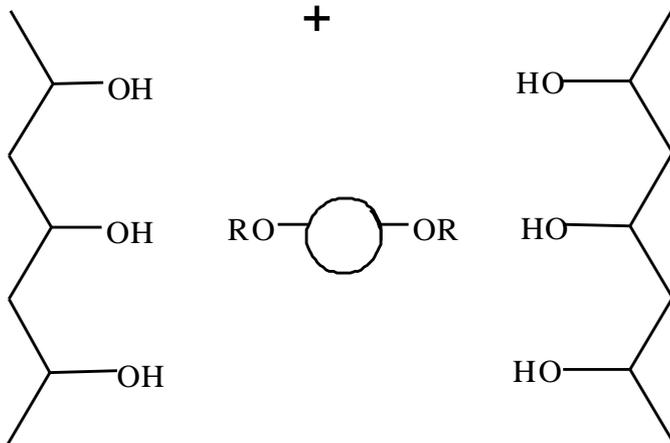


Innovative CO₂ separation membrane having a gate function to penetrate CO₂ molecules selectively.

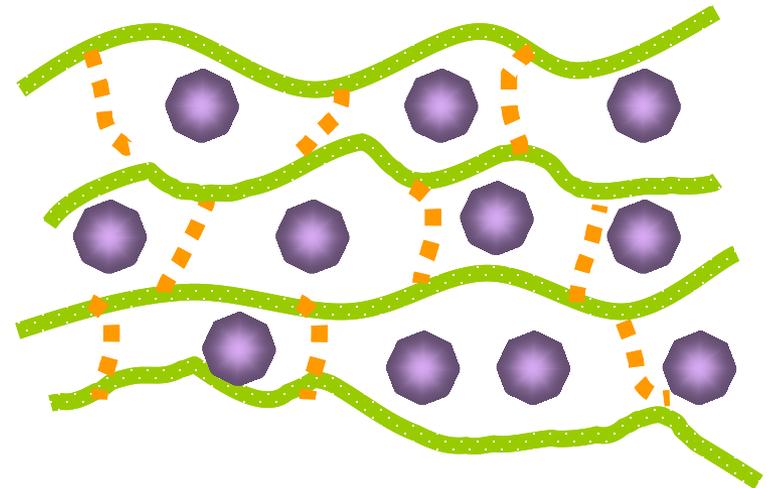
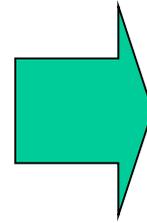
Dendrimer/PVA Hybrid Membrane (an Example)



Dendrimer (example)



PVA + crosslinker



-  **PVA**
-  **Crosslinker**
-  **Dendrimer**

CO₂ selective membranes and membrane elements

CO₂ selective membranes



Membrane1
(1.2 cm²)



Membrane2
(58 cm²)

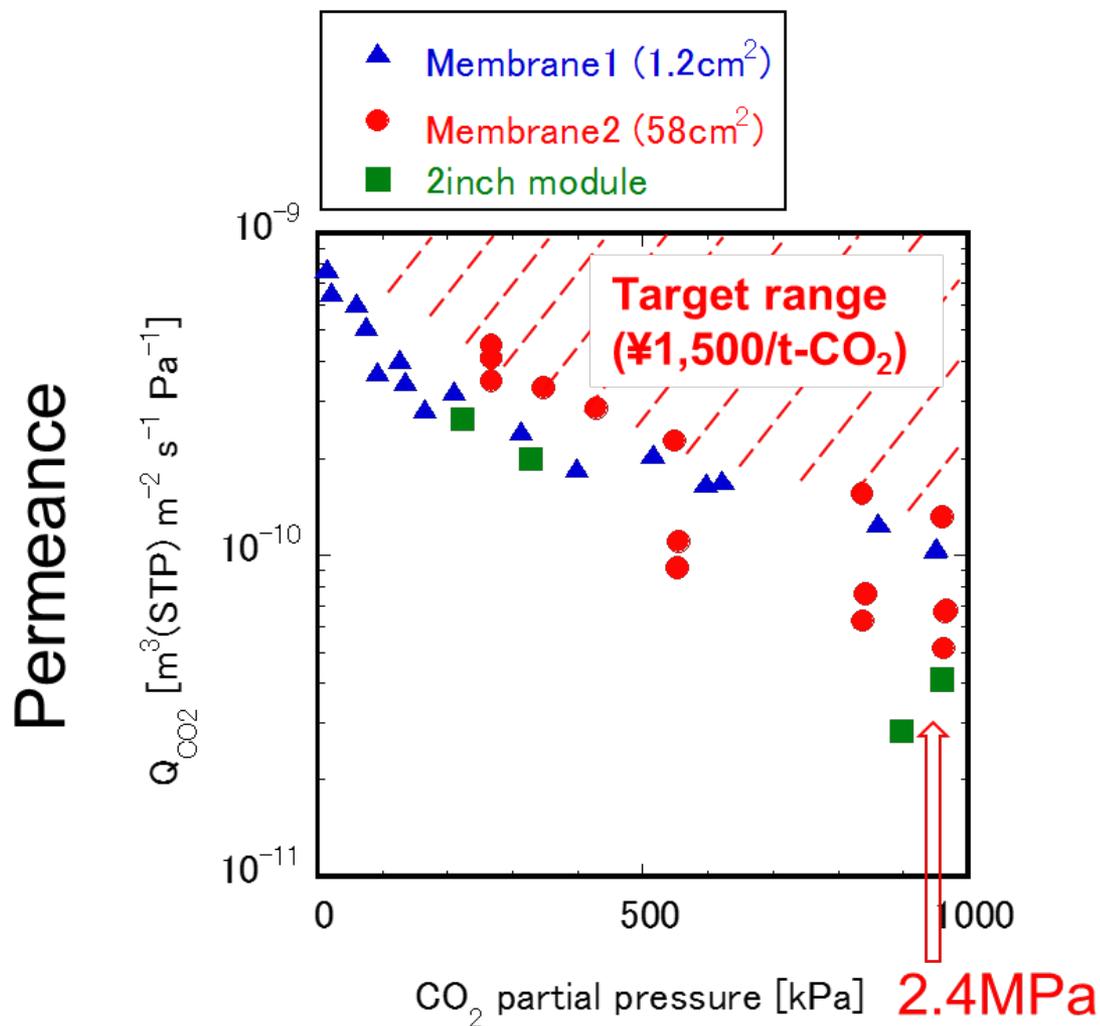


membrane elements

Spiral membrane elements

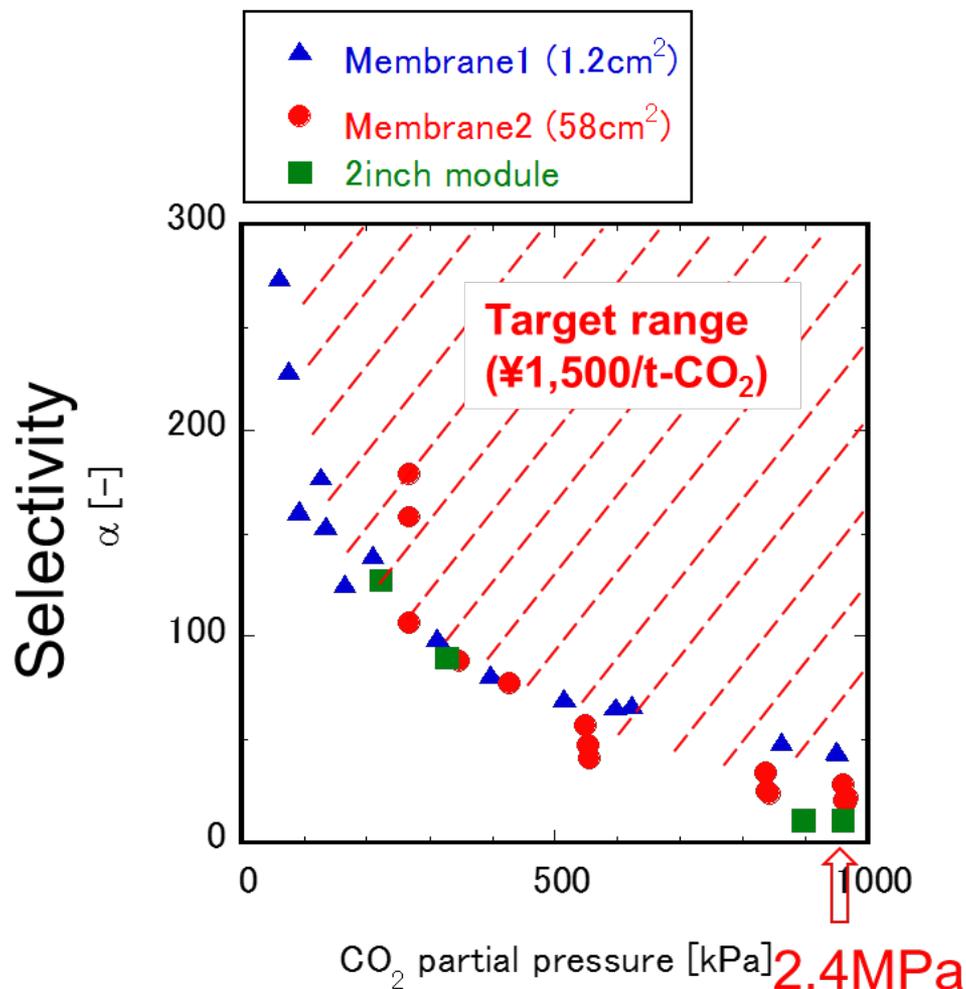
(Left: 2inch, Right: 4inch; L=200mm)

Key Results of CO₂ Molecular Gate Membrane



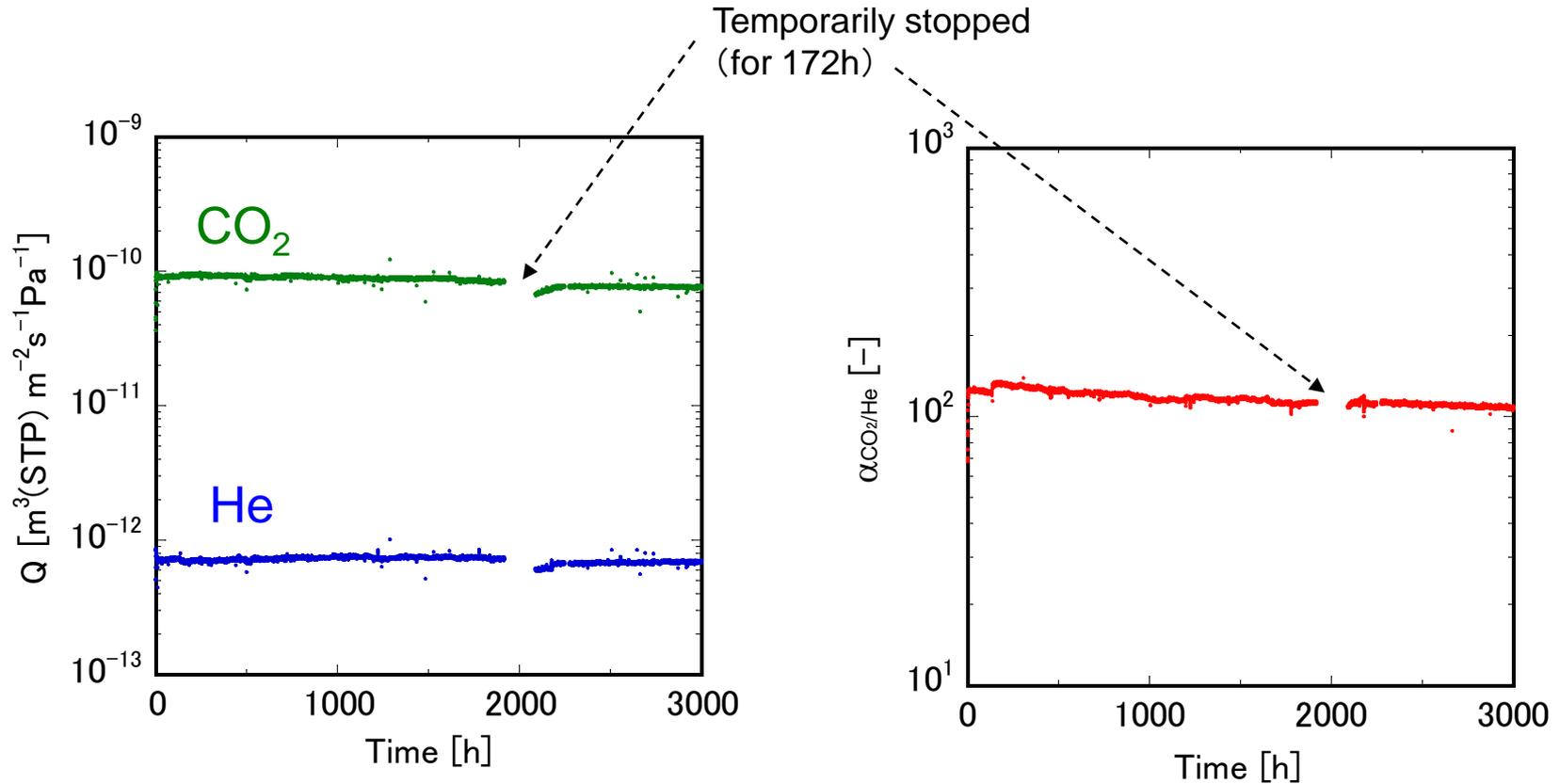
*Operating conditions: Temp: 85°C, Feed gas: 0.7~2.4MPaA; Permeate gas: Atmospheric pressure (Ar sweep gas). He gas was used as alternative gas to H₂, for safety issue.

Key Results of CO₂ Molecular Gate Membrane



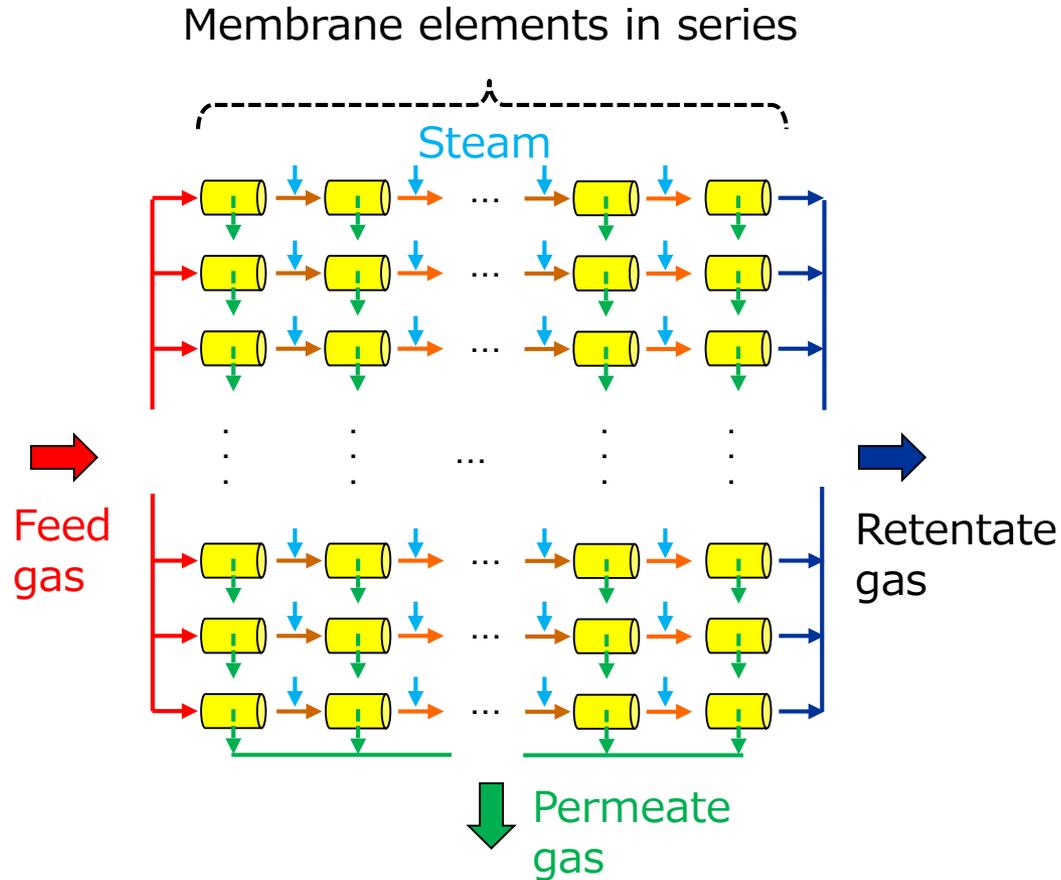
*Operating conditions: Temp: 85°C, Feed gas: 0.7~2.4MPaA; Permeate gas: Atmospheric pressure (Ar sweep gas). He gas was used as alternative gas to H₂, for safety issue.

Long-tem test (3,000h)



*: Operating conditions: Temp: 85°C, total pressure: 0.7 MPa (Abs),
Feed gas composition: $\text{CO}_2/\text{He}=80/20$.

** : Measurement was stopped at 3,000h.



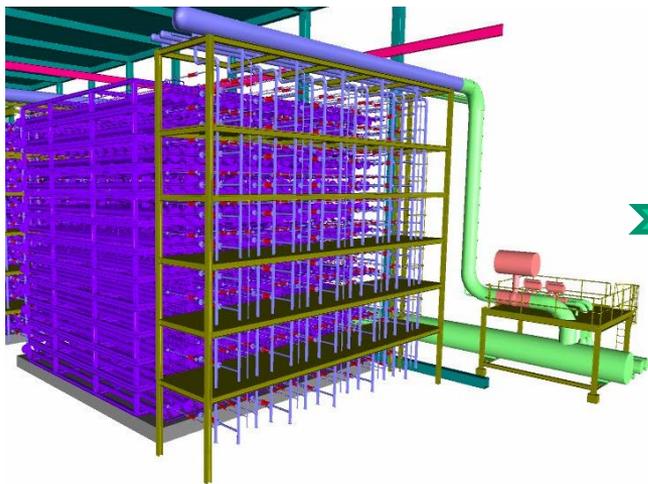
Distribution of relative humidity, total pressure, CO_2 partial pressure in a membrane element was estimated by simulation.

Cost estimate of CO₂ separation

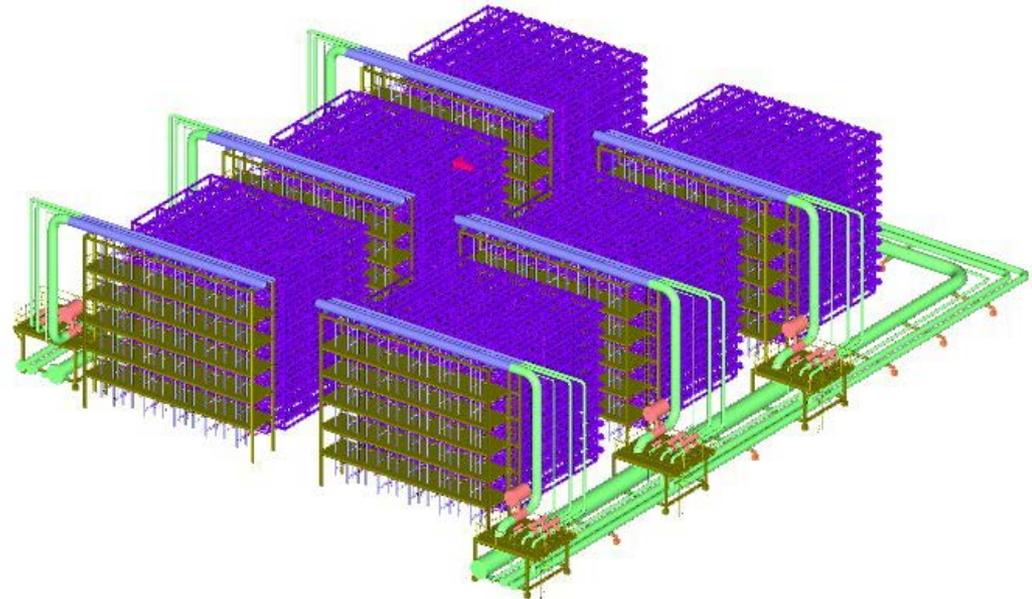
【Facility capacity】 CO₂ Capture 1,000,000-ton/y (63,000 Nm³/h)
(250,000-kW electric power)

【Capture condition】 CO₂ concentration 95 vol%, CO₂ recovery 90%

【Feed gas】 IGCC gas conditions
CO₂ 36.4vol% (Dry), H₂ 63.6vol% (Dry)
Temp.: 85 °C, Total pressure: 2.4 MPa.



Overview image of the skid
(11.5m x 10m x 11.3m)



Overview image of the facility
(33m x 45m x 17m)

Cost estimate of CO₂ separation

	Estimated value	Unit
CO ₂ recovery	125.3	t/h
Membrane area	190,000	m ²
Steam	24.1	t/h
Equipment cost	600	Vt-CO ₂
Membrane elements and module vessel	350	Vt-CO ₂
Variable cost	540	Vt-CO ₂
Total	1,490	Vt-CO₂

Estimate of energy of CO₂ separation

	Estimated value	Unit
Steam	24.1	t/h
Energy of steam	0.549	GJ/t-CO ₂
Electric power	50	kW
Energy of electric power	0.001	GJ/t-CO ₂
Total energy	0.55	GJ/t-CO ₂

- Majority of energy is steam to keep humidity for high membrane separation performance.
- Power for compression etc. is not needed.
- Electric power in the table is for lighting, control etc.

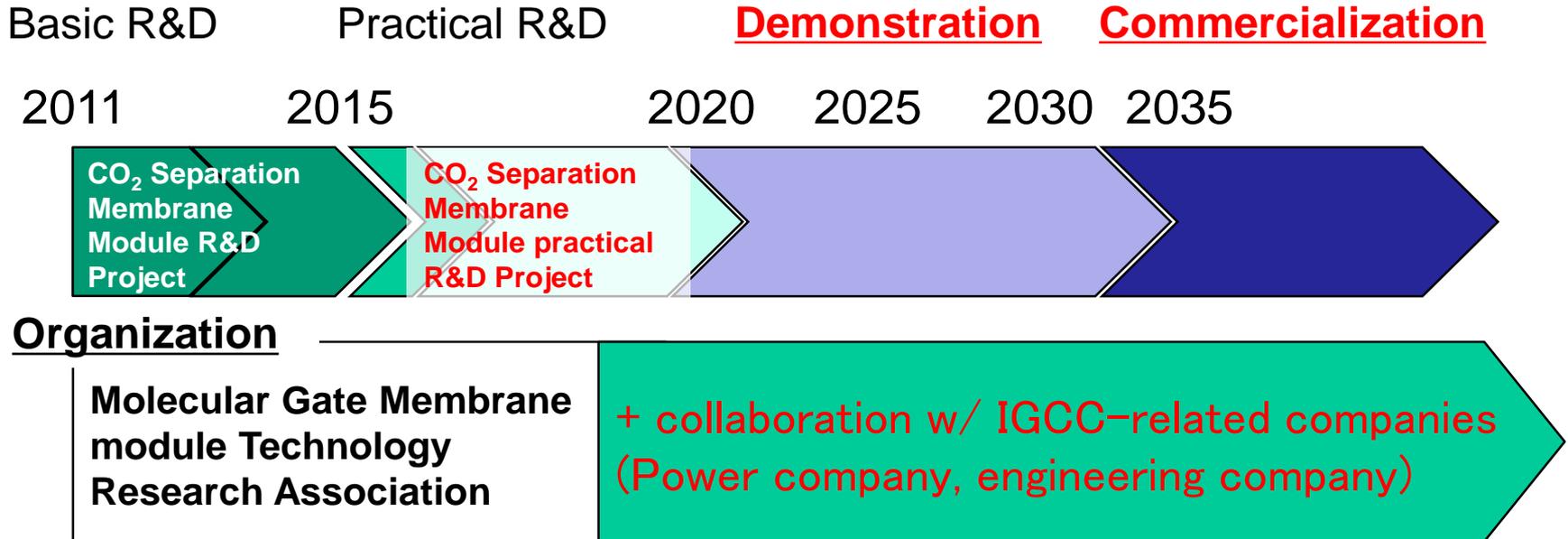
"CO₂ Separation Membrane Module Research and Development Project" (2011FY-2014FY)

- Basic technology for Membrane materials, modules and systems were established.
- Project target was achieved using lab-scale membrane.

In the current project:

- Find and solve the technical problems by field test of membrane modules using real WGS gas.
- Development of membrane module system that enables CO₂ separation cost less than ¥1,500/t-CO₂ (practical stage).

Roadmap toward commercialization of CO₂ separation membranes



Challenge in demonstration & commercialization phase

- Accumulate experience by long-term test of membrane modules using real IGCC gas, large-scale field test.
- Organize mass production process of membrane and membrane modules.
- Activity to adopt CO₂ separation membrane process for IGCC.

Acknowledgements

This work, conducted by Molecular Gate Membrane module Technology Research Association, was supported by Ministry of Economy, Trade and Industry (METI), Japan.

*Thank you for
your attention!*

Research **I**nstitute of
Innovative **T**echnology for the **E**arth
(**RITE**)