【eSep Vision 2025】

2025 January

【Addressing Social Challenges】
Building a Carbon-Neutral Society using Nano-Ceramic Membranes

eSep Inc

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＜Mission＞

Membrane-based separation is one of the promising technology for simplifying processes and reducing energy consumption drastically in future industries.

eSep Inc. will develop and offer membrane-based separation technology for easy, eco, and efficient separation.

smile by
easy, eco, and efficient
separation

eSep

J-Startup
KANSAI

1. Background (1)

Existing technologies face challenges of high energy consumption and greenhouse gases emissions

1. Background (2)

The high cost of infrastructure to supply high-pressure hydrogen makes it difficult to expand hydrogen stations.

1. Background (3)

It is difficult to store and transport large amounts of electricity from renewable energy over long distances using batteries.

2. Our Mission (Overview)

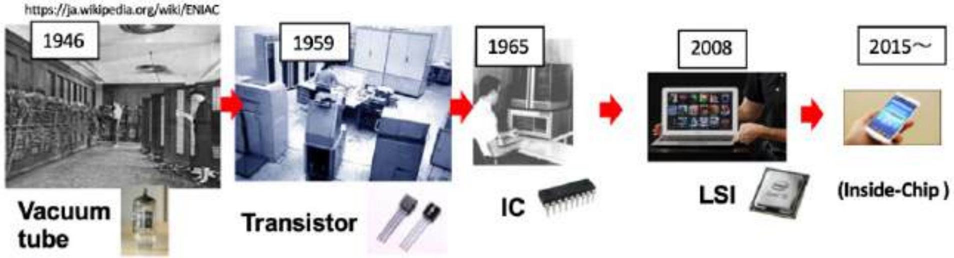
＜ Chemical Industry ＞

Huge & energy Intensive → Massive release of CO_2

＊ Little has changed for over half a century

＜ Computer Industry ＞

＊ Significant downsizing and energy saving



【eSep Mission】

Significant downsizing and energy saving in chemical （mainly reaction & separation） industry

（Now）
Distillation etc.

（Future） High-efficient separation by nano-porous ceramic membrane

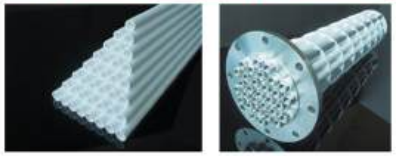
Downsizing for onsite usage

smile by easy, eco, and efficient separation

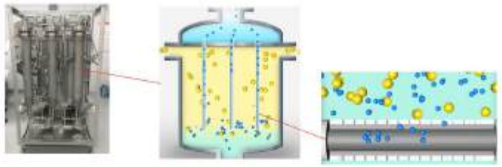
Core technology & Business

- *Nano-porous ceramic membranes*
- *Membrane separation system*

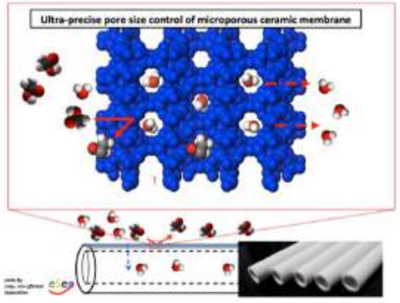
＊ High-efficient separation by molecular level



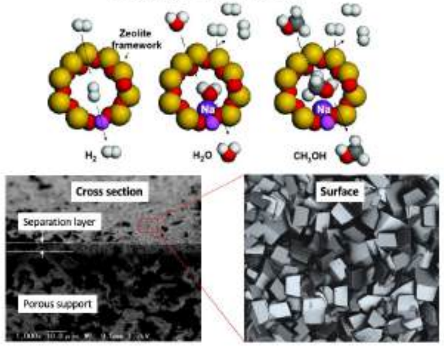
Membrane Elements *Membrane Module*



① Silica-based membranes
＊*Molecular sieving*（0.3-1 nm）



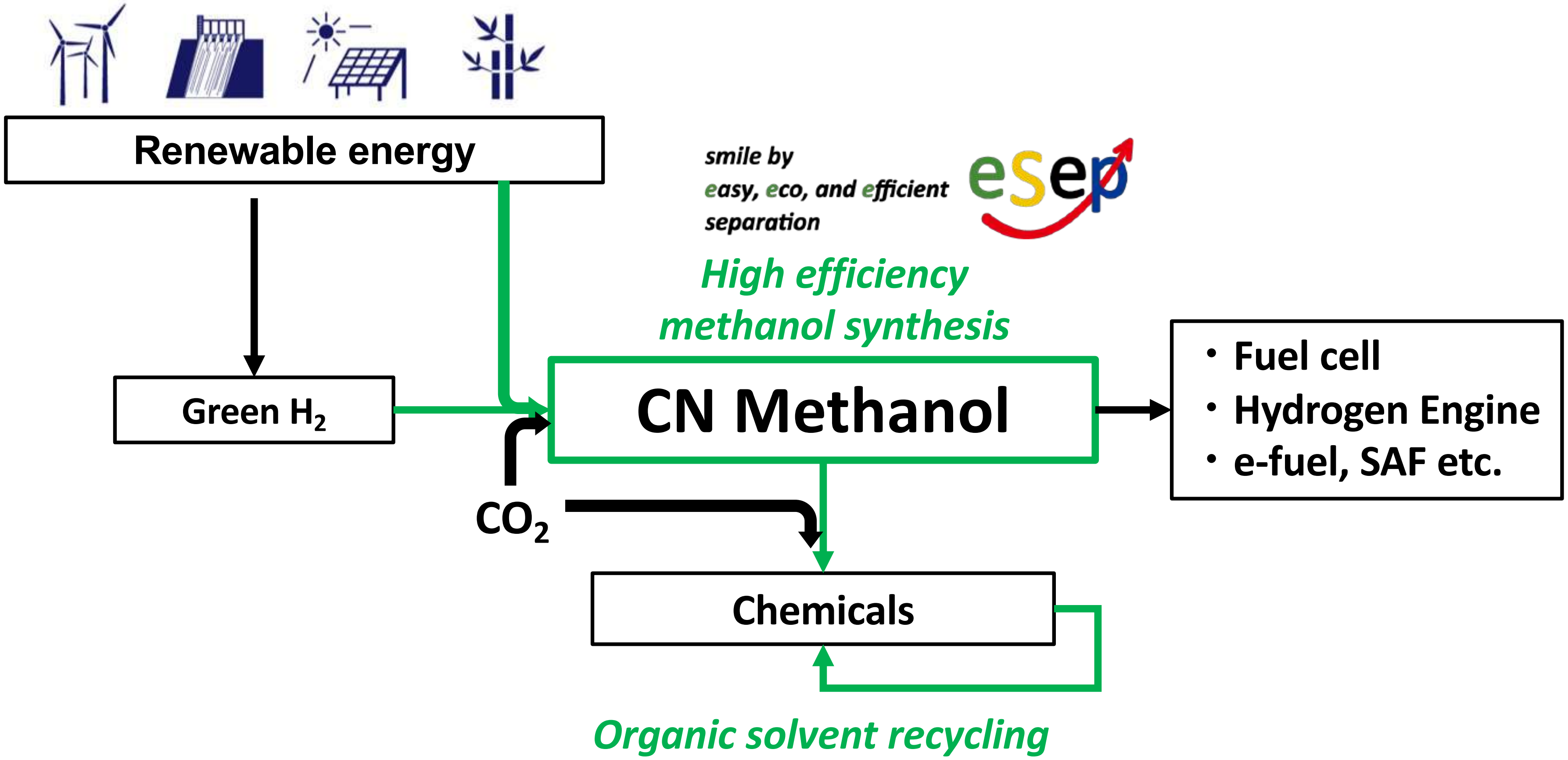
② Zeolite-based membranes
＊*Selective adsorption*



3.1 Our Proposal : Development of carbon neutral chemical processes

【eSep Vision】

Carbon neutral (CN) initiatives led by eSep



Renewable energy

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Green H_2

High efficiency methanol synthesis

CN Methanol

- Fuel cell
- Hydrogen Engine
- e-fuel, SAF etc.

CO_2

Chemicals

Organic solvent recycling

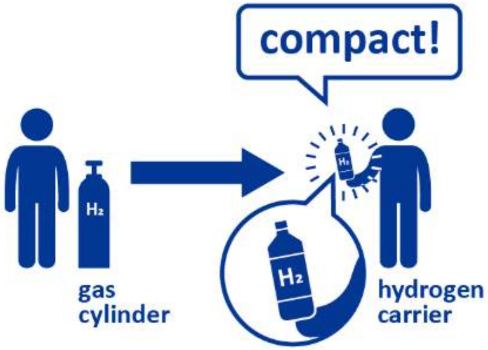
Building societal infrastructure with methanol as an energy carrier.

3.2 Our Proposal: Utilization of methanol-water solution as a hydrogen carrier

$CO_2 + 3\ H_2 \rightleftarrows$ **Methanol (CH_3OH) + H_2O**

Criteria	Methanol（59wt%）-Water	Hydrogen Gas Cylinder (700 bar)	Battery (Lithium-ion)
1. Energy Density	**Approx. 12 MJ/kg**	Approx. 8.5 MJ/kg (including cylinder)	less than 1 MJ/kg
2. Efficiency	Generally 30–40%, but can be improved to over 60% by future development	Approx. 60% (when used in fuel cells)	90% or more
3. Safety	**Non-hazardous (much lower risk than pure methanol)**	High pressure gas, requires careful handling	Fire risk (due to overcharging or damage)

The methanol-water solution as an energy carrier has advantages that hydrogen and batteries do not possess.

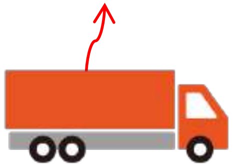


Now

- Waste Heat (Engine)：60-80%
- Waste Heat (Fuel Cell(SOFC))：30-50%

- **Energy Loss**
- **Global Warming**

(Fuel) →



(Effective power)

- Engine：20-40 %
- Fuel cell (SOFC)：50-70%

Future

Hydrogen Carrier

Hydrogen extraction by waste heat utilization →

H_2 H_2 H_2

Liquid hydrogen carrier

Stable at normal temperature and pressure

onsite/onboard H2 extraction and usage

4. Examples of Specific Initiatives (1): Technology Platform for Nano Ceramic Membranes

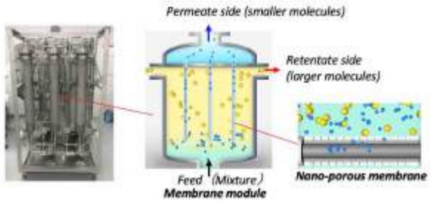
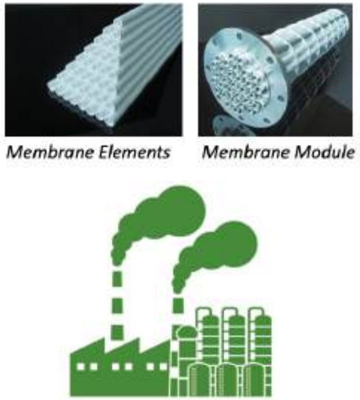
Customers

Fee ↓ ↑ POC verification report

Fee ↓ ↑ Verification development report

Fee ↓ ↑ Membrane system

Fee ↓ ↑ Support

Total Solutions			
Phase 1	**Phase 2**	**Phase 3**	**Phase 4**
POC	**Verification Development**	**Commercial System**	**Manufacturing Support**
			・Membrane maintenance & replacement ・Optimization of system operation etc.

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Platform of Technology

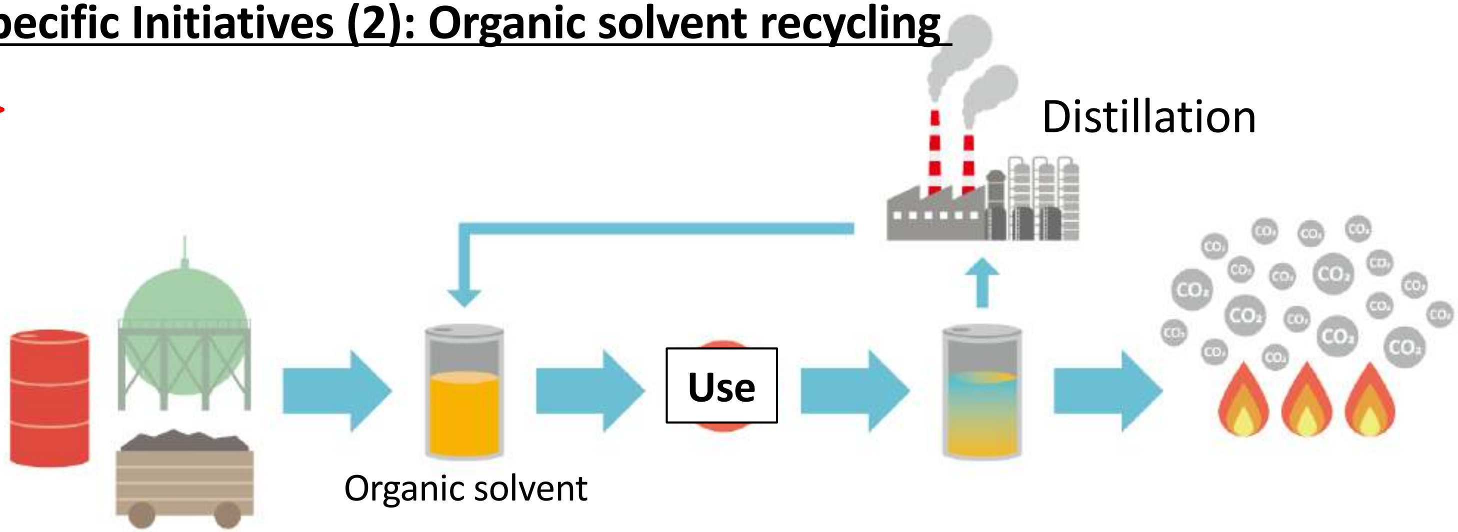
Development Team (Scientists and Engineers)

Development Infrastructure (Laboratories, Pilot Facilities, and Simulator)

Total solutions from R&D to engineering for customers to realize carbon neutral chemical processes

4. Examples of Specific Initiatives (2): Organic solvent recycling

＜Now＞



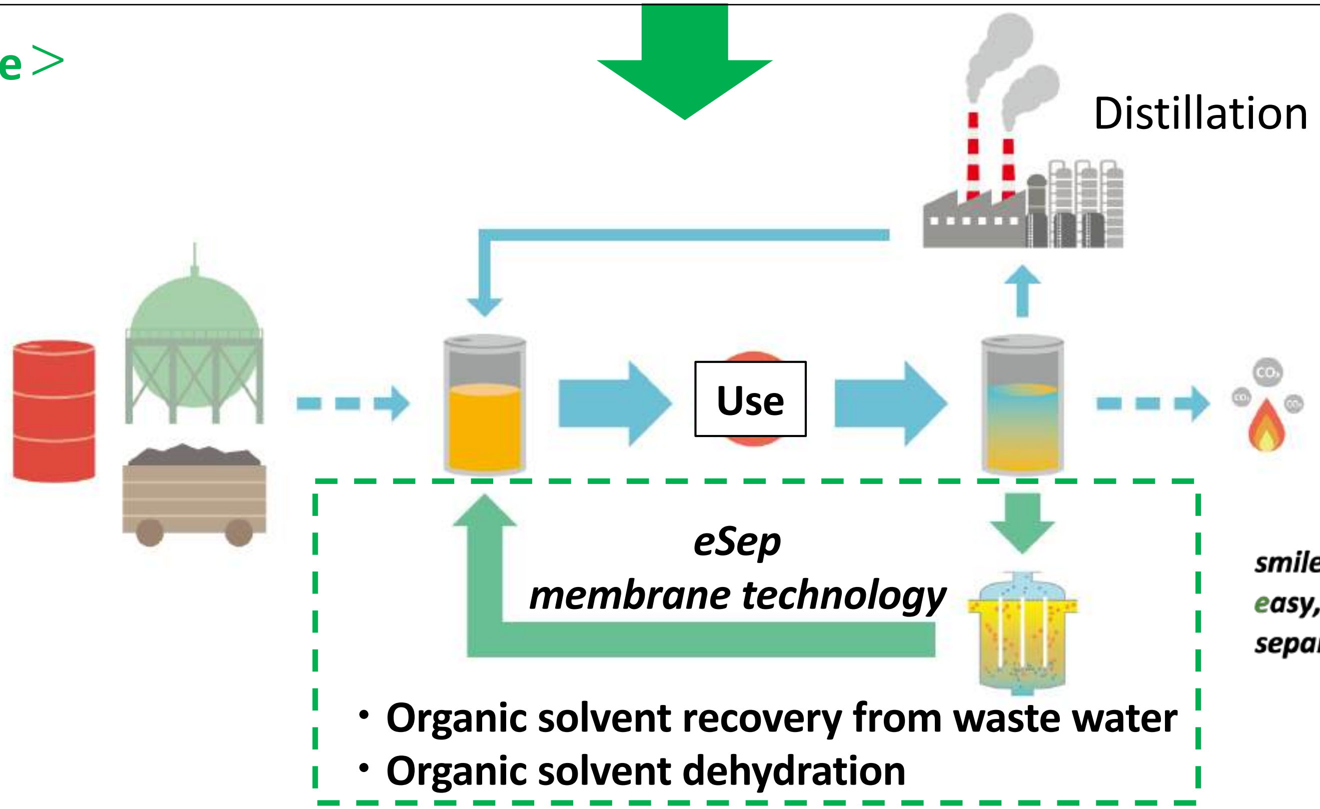
Distillation

Use

Organic solvent

＊ Massive release of CO2 due to the burning and disposal of chemical solvents

＜Future＞



Distillation

Use

eSep
membrane technology

- Organic solvent recovery from waste water
- Organic solvent dehydration

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***s**eparation*

＊ Significant reduction of CO2 emissions through highly efficient recycling of chemical solvents

4. Examples of Specific Initiatives (3): High efficiency methanol synthesis ①

Renewable energy resources
Gasification → $CO_2 + 3H_2$ **⇔** $CH_3OH + H_2O$ → *(If necessary)* **Conversion to Gasoline**

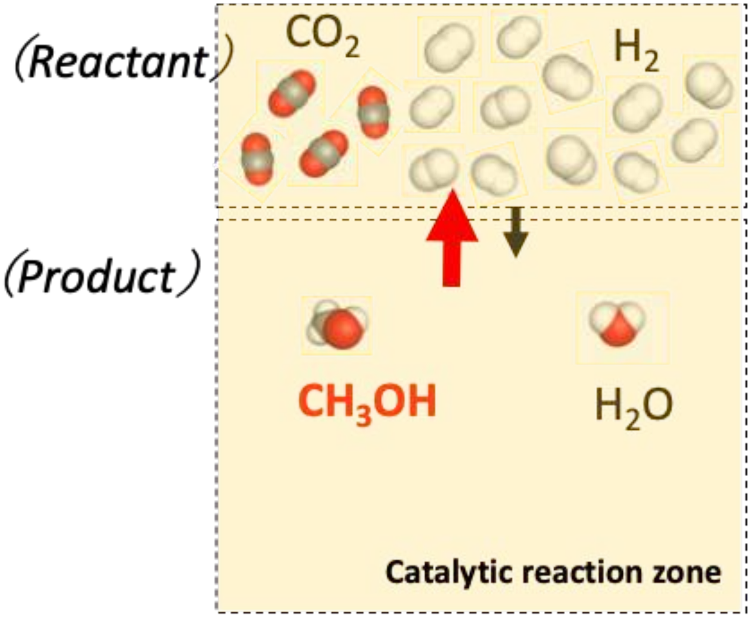
Bottleneck process *(Hydrogen carrier)* ***e-fuel***

【Existing Technology】

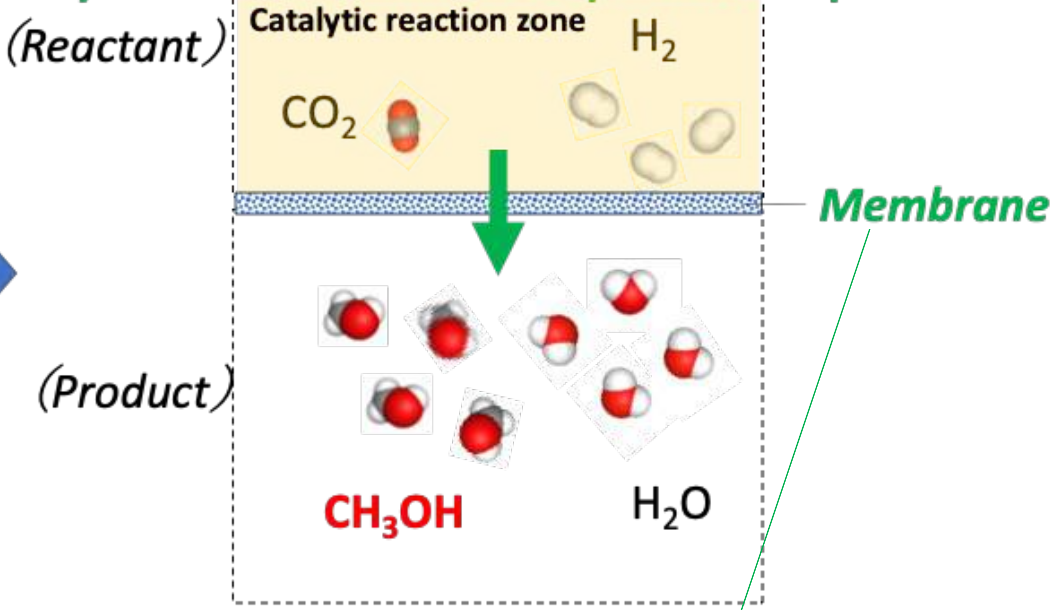
Poor yield because of rapid decomposition

【New Technology】

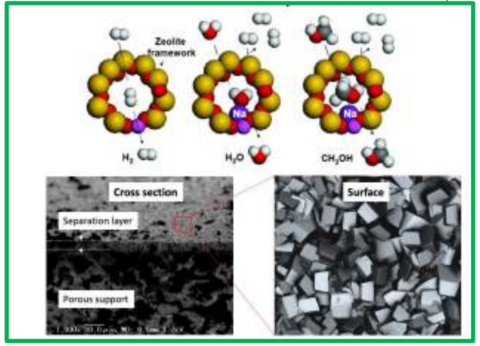
Significant improvement of yield by selective membrane separation of product



One pass yield: less than 20%



One pass yield: > 75%（Now）, 90%（Future target）



4. Examples of Specific Initiatives (4): High efficiency methanol synthesis ②

Example of Membrane Reactor Design Simulation for methanol Synthesis

Methanol synthesis

(1) **CO** + $2H_2 \rightleftarrows$ **MeOH**

(2) $CO_2 + H_2 \rightleftarrows$ **CO** + $\mathbf{H_2O}$

(3) $CO_2 + 3\ H_2 \rightleftarrows$ **MeOH** + $\mathbf{H_2O}$

<Methanol synthesis（Cu/Zn/Al2O3 catalyst）>

（Reaction 1）$CO+2H_2$ = MeOH　ΔH_{298}= - 90.71 kJ/mol

（Reaction 2）CO_2+H_2 = CO + H_2O　ΔH_{298}= + 41.19 kJ/mol

（Reaction 3）CO_2+3H_2 = MeOH + H_2O　ΔH_{298}= - 49.51 kJ/mol

1. Pre-reactor

<Input cell 1> Tubular catalyst packed bed reactor (isothermal and isobaric)

Cell settings for culcalation	
Effective reactor length (total) [m]	**1.0**
Catalyst amount [kg]	**0.3**
catalyst fitting coefficient [-]	**1.0**
Conventional catalyst converted amount [kg]	0.30
Parallel packed reactor system [system]	**1**

<Input cell 2> Reaction conditions

	Pressure [Bar]	Reaction temp.
Feed	**50**	**250**

＜Input cell 3.1＞Gas supply

Feed gas flow rate [NL/min]		
CO	CO2	H2
0	**2.5**	**7.5**

＜Input cell 3.2＞Gas supply

Initial value	Feed gas flow [mol/s]						Feed gas composition [mol %]					
Gas species	MeOH	H2O	CO	CO2	H2	N2	MeOH	H2O	CO	CO2	H2	N2
Inlet supply (Feed)	0.00E+00	0.00E+00	0.00E+00	1.86E-03	5.58E-03	0.00E+00	0.0	0.0	0.0	25.0	75.0	0.0

<Result display cell 1> Reactor performance

CO2 conversion [%]	MeOH selectivity [%]	MeOH yield [%]
24.1	**66.3**	**16.0**

<Result display cell 2> Gas composition after pre-reactor

Initial value	Retantate gas flow [mol/s]						Retantate gas composition [mol %]					
Gas species	MeOH	H2O	CO	CO2	H2	N2	MeOH	H2O	CO	CO2	H2	N2
Inlet supply (Feed)	**2.97E-04**	**4.48E-04**	**1.51E-04**	**1.41E-03**	**4.54E-03**	**1.00E-10**	4.3	6.5	2.2	20.6	66.3	0.0

2. Membrane reactor

<Input cell 1> Tubular catalyst packed bed reactor (isothermal and isobaric)

Cell settings for culcalation		Permeance [mol m^{-2}s^{-1}Pa^{-1}]	
Effective reactor length (total) [m]	0.40	H2	1.00E-08
Membrane diameter [m]	0.012	**MeOH**	1.00E-06
Catalyst amount [kg]	0.6	**H2O**	1.00E-06
catalyst fitting coefficient [-]	1.0	CO	1.00E-08
Conventional catalyst converted amount [kg]	0.60	CO2	1.00E-08
Parallel packed reactor system [system]	1	N2	1.00E-08
Membrane cost [¥10,000/m2]	200	α（H2O/H2）	100
Total membrane area [m2]	0.02	α（H2O/CO2）	100
Total membrane cost [¥10,000]	3.0	α（H2O/MeOH）	1

<Input cell 2> Reaction conditions

Pressure [Bar]		Reaction temp. [℃]
Feed	50	250
Permeate	1	

<Result display cell 1> Reactor performance

CO2 conversion [%]	MeOH selectivity [%]	MeOH yield [%]	MeOH permeate rate [%]	H2O permeate rate [%]	Total H2 leak rate [%]
91.6	**100.0**	**91.6**	**100.0**	**100.0**	**9.3**

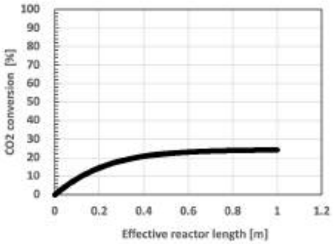
<Result display cell 2> Gas composition after reaction

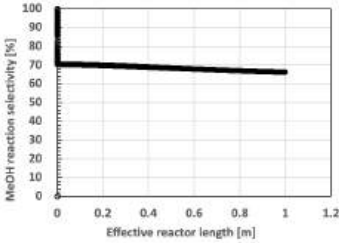
Initial value	Retantate gas flow [mol/s]						Retantate gas composition [mol %]					
Gas species	MeOH	H2O	CO	CO2	H2	N2	MeOH	H2O	CO	CO2	H2	N2
Inlet supply (Feed)	**1.14E-07**	**9.95E-08**	**1.58E-07**	**7.17E-07**	**2.47E-06**	**1.77E-11**	3.2	2.8	4.4	20.2	69.4	0.0
Initial value	Permeate gas flow（Out）[mol/s]						Permeate gas composition（Out）[mol %]					
Gas species	MeOH	H2O	CO	CO2	H2	N2	MeOH	H2O	CO	CO2	H2	N2
Inlet supply (Permeate)	**1.72E-03**	**1.74E-03**	**2.78E-05**	**1.55E-04**	**5.21E-04**	**1.00E-06**	41.3	41.8	0.7	3.7	12.5	0.0

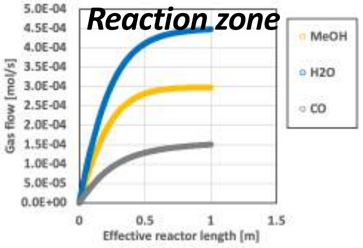
	Product recovery [g/min]		Total product recovery [g/h]
System	MeOH	H2O	
Traditional Reactor	0.6	0.5	
Membrane reactor	**3.3**	**1.9**	**311.5**

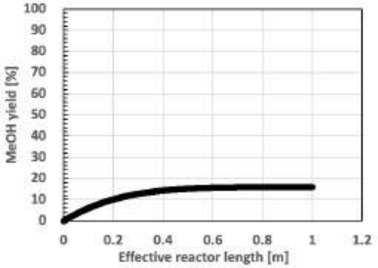
【Traditional Reactor】

Limited by thermodynamic equilibrium



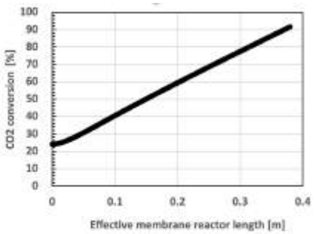


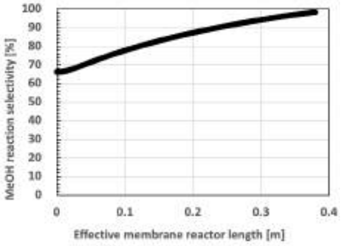


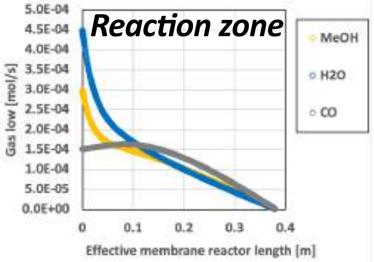


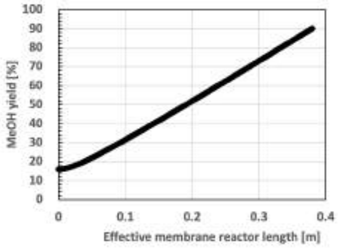
【Membrane Reactor】

Overcoming thermodynamic equilibrium limitation



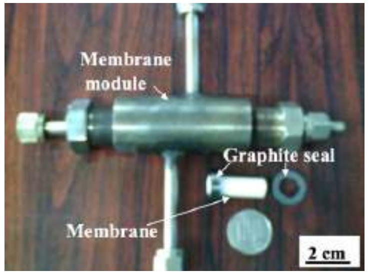






4. Examples of Specific Initiatives (5): High efficiency methanol synthesis ③

Waseda Univ. Seed Technology



Small membrane sample
Φ10mm, length. 3 cm

Commercialization development

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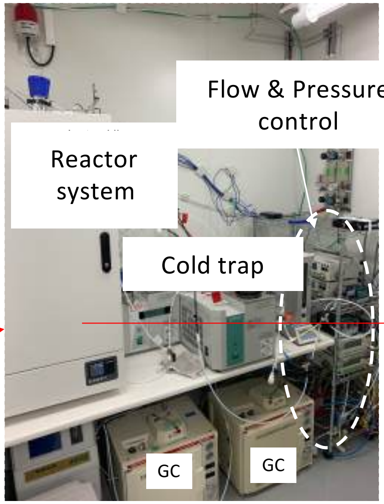
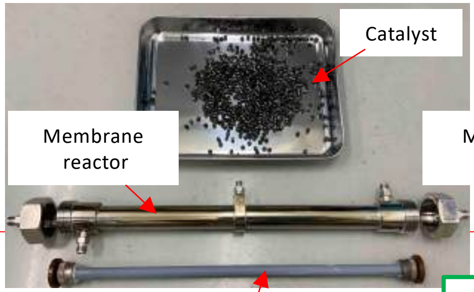
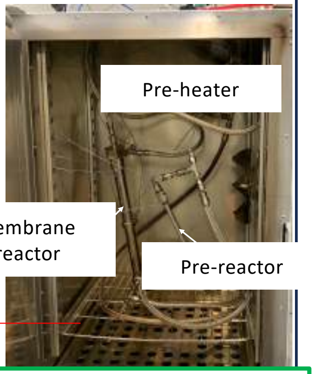
High pressure test chamber



Total Feed gas flow: 1NL/min ($H_2/CO_2=3$)



Membrane sample Φ12mm, length 40 cm



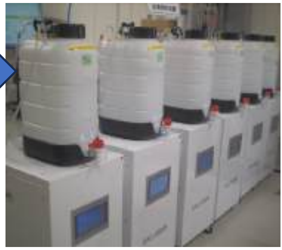
Methanol yield increased from less than 20% to 75.6% @5MPa, 250℃

Scaling up more than 10 times

New facility for demonstration

Renewable energy

Green H2

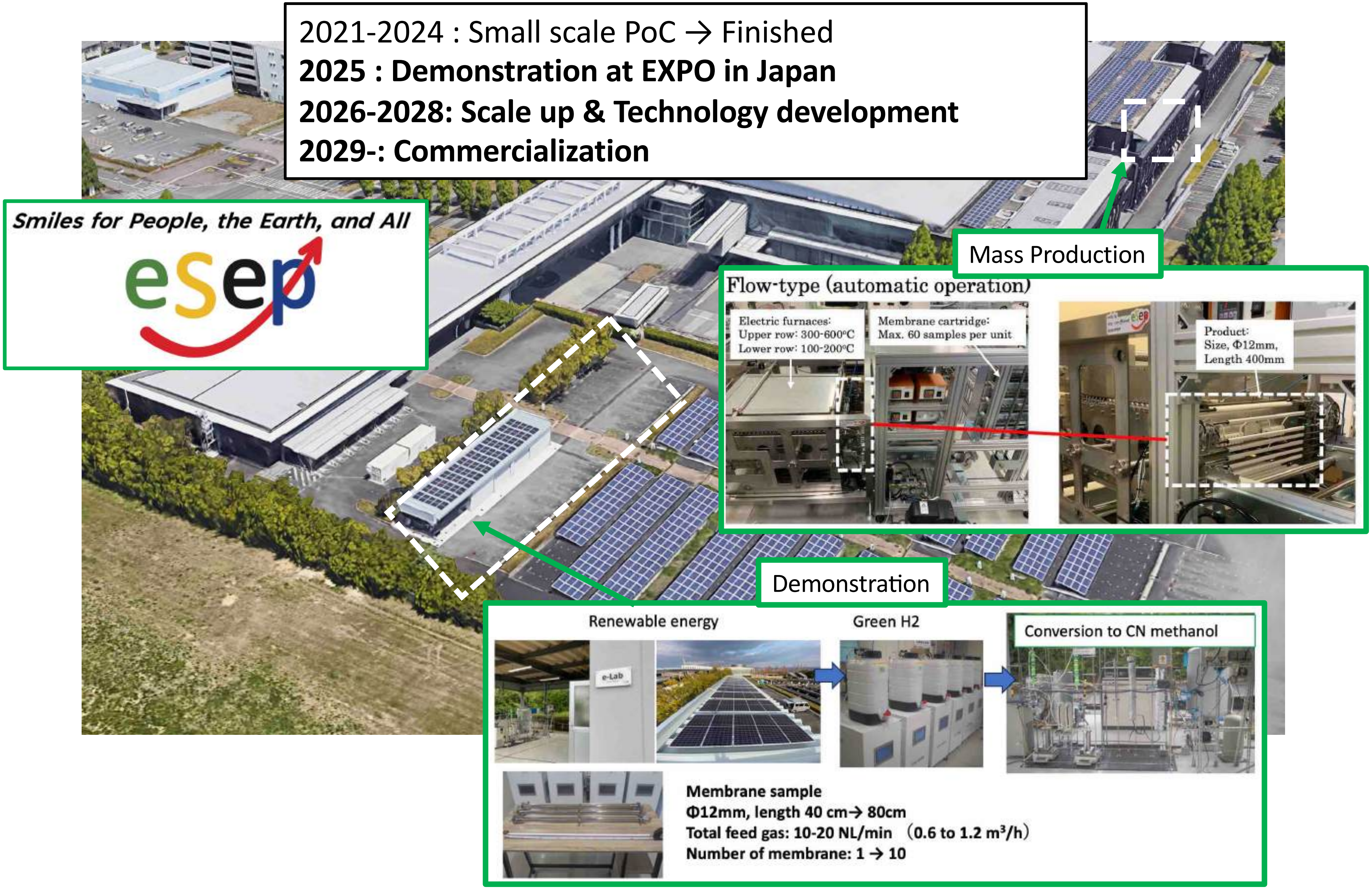


Conversion to CN methanol

Membrane sample
Φ12mm, length 40 cm→ 80cm
Total feed gas: 10-20 NL/min （0.6 to 1.2 m³/h）
Number of membrane: 1 → 10

5. Outlook (1)

2021-2024 : Small scale PoC → Finished
2025 : Demonstration at EXPO in Japan
2026-2028: Scale up & Technology development
2029-: Commercialization



Membrane sample
Φ12mm, length 40 cm→ 80cm
Total feed gas: 10-20 NL/min （0.6 to 1.2 m³/h）
Number of membrane: 1 → 10

5. Outlook (2)

Content	2022	2023	2024		2025		
			April	October	April	July	October
Development of membrane reactor for high efficiency methanol synthesis from CO2 and H2	Poc → Finished		Scaling up	Safety improvement		Demonstration	
Demonstration of the effectiveness of methanol as an energy carrier			PoC Plan	Preparation		Demonstration	

Candidate applications:

Direct Methanol Fuel Cell) DMFC for

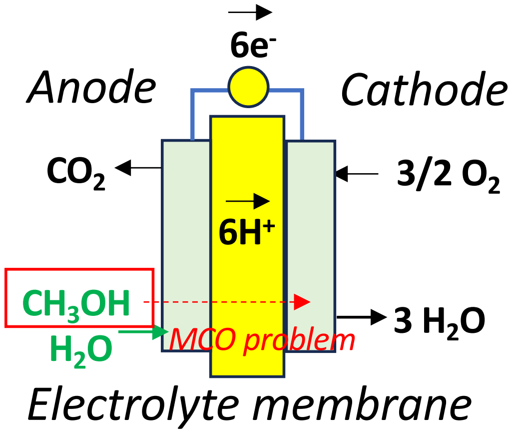
Step1: Automated guided vehicles (AGVs)

Step2: Senior cars (electric wheelchairs)

Step3: Long Range Drone

Challenge:

Improving efficiency by suppressing methanol cross over（MCO）by improvement of the electrolyte membrane



【DMFC Principle】

Anode (Fuel Electrode) Reaction:

$CH_3OH+H_2O \rightarrow 6H^+ + CO_2 + 6e^-$

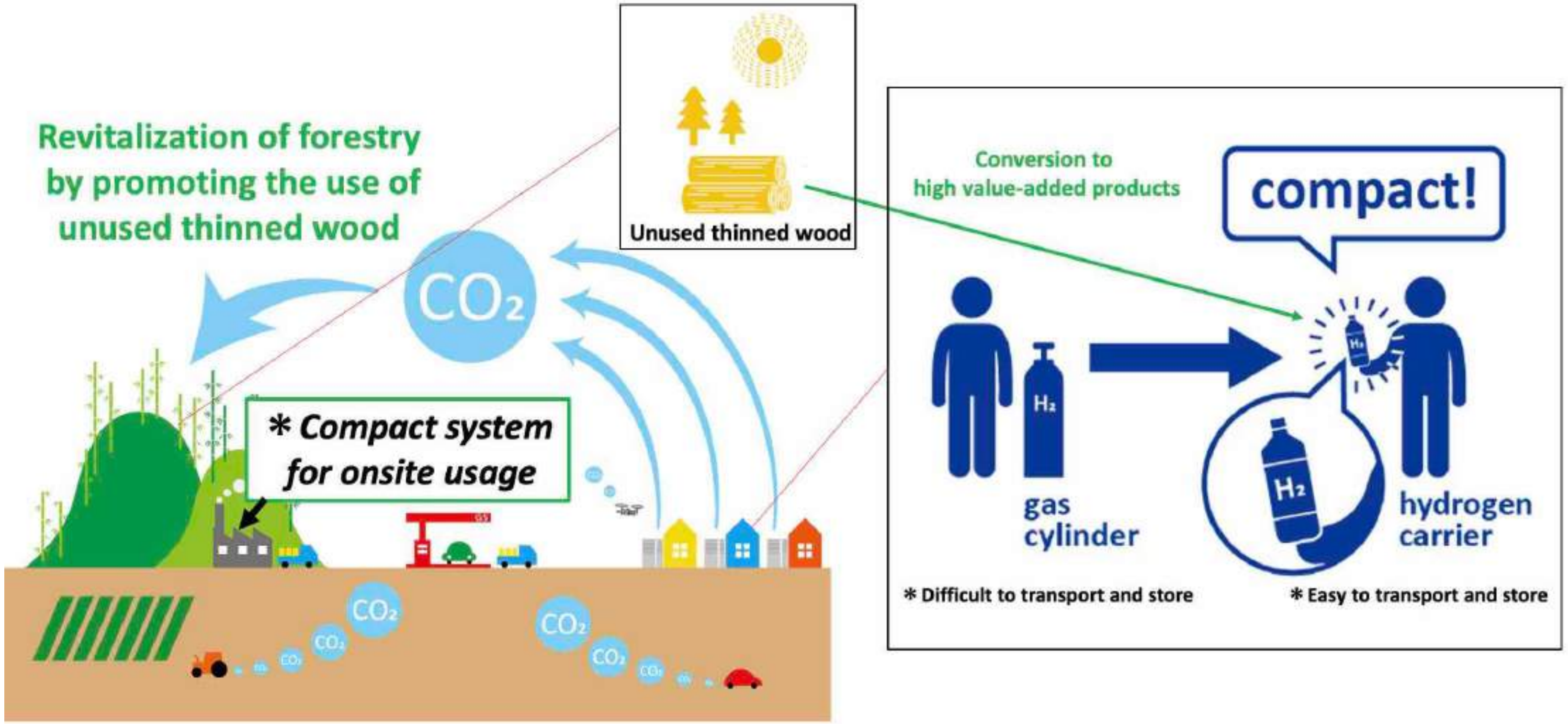
Cathode (Air Electrode) Reaction:

$6H^+ + 3/2O_2 + 6e^- \rightarrow 3H_2O$

Overall Reaction:

$CH_3OH + 3/2O_2 \rightarrow CO_2 + 3H_2O$

5. Outlook (3)



Example situations where the methanol fuel is advantageous:

1. **Long-duration operations**
2. **Frequent refueling**
3. **Portable power generation**
4. **Off-grid or remote locations**

Smiles for People, the Earth, and All

esep

Welcome collaboration for carbon neutral society !