No.　A-2-1E

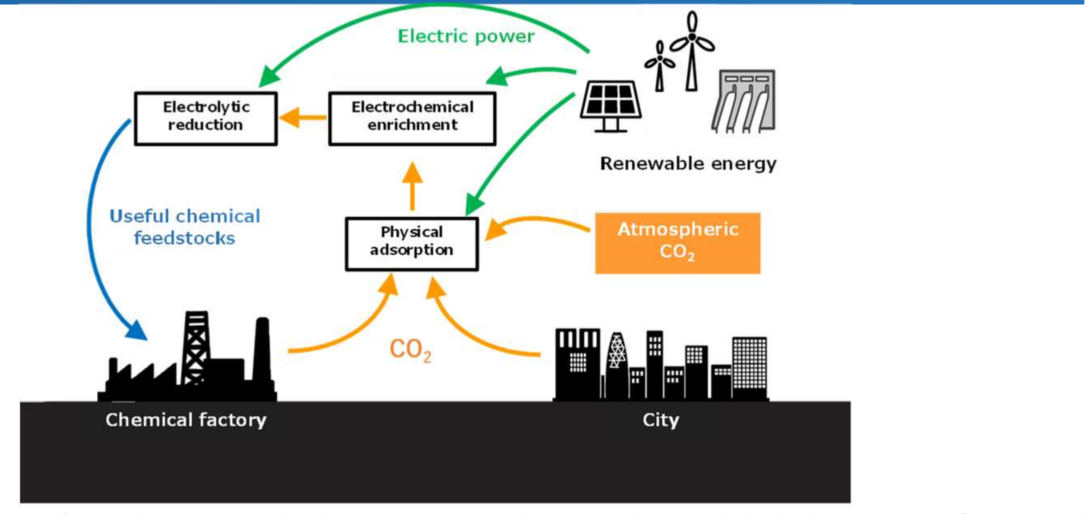
PJ：Integrated Electrochemical Systems for Scalable CO_2 Conversion to Chemical Feedstocks

Theme：Project Overview

Organization：The University of Tokyo
Contact：sugiyama@enesys.rcast.u-tokyo.ac.jp / ebe@enesys.rcast.u-tokyo.ac.jp

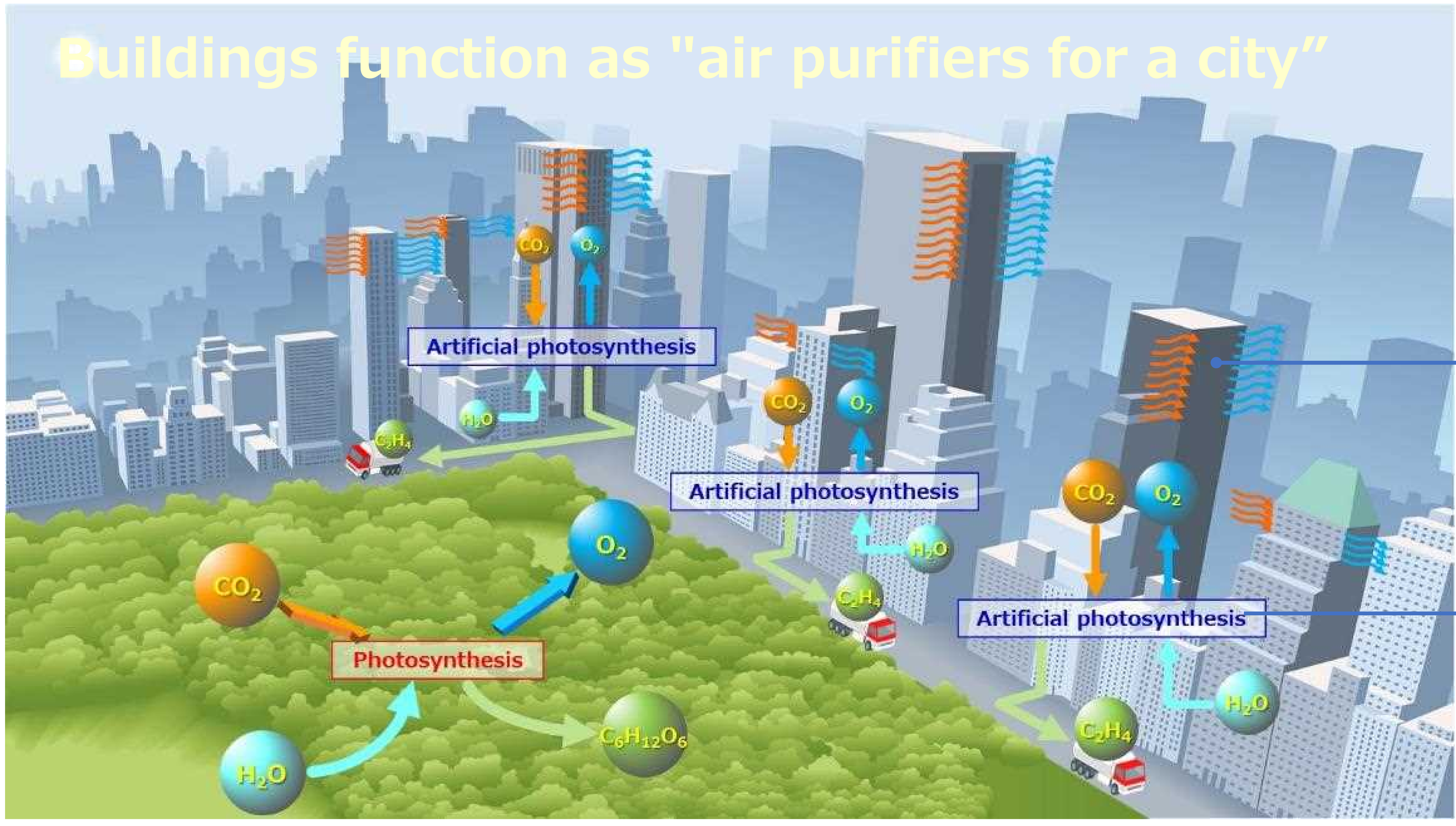
1. Research Outline

- Development of a system to convert atmospheric CO_2 into useful chemical feedstocks based on electrochemical processes.

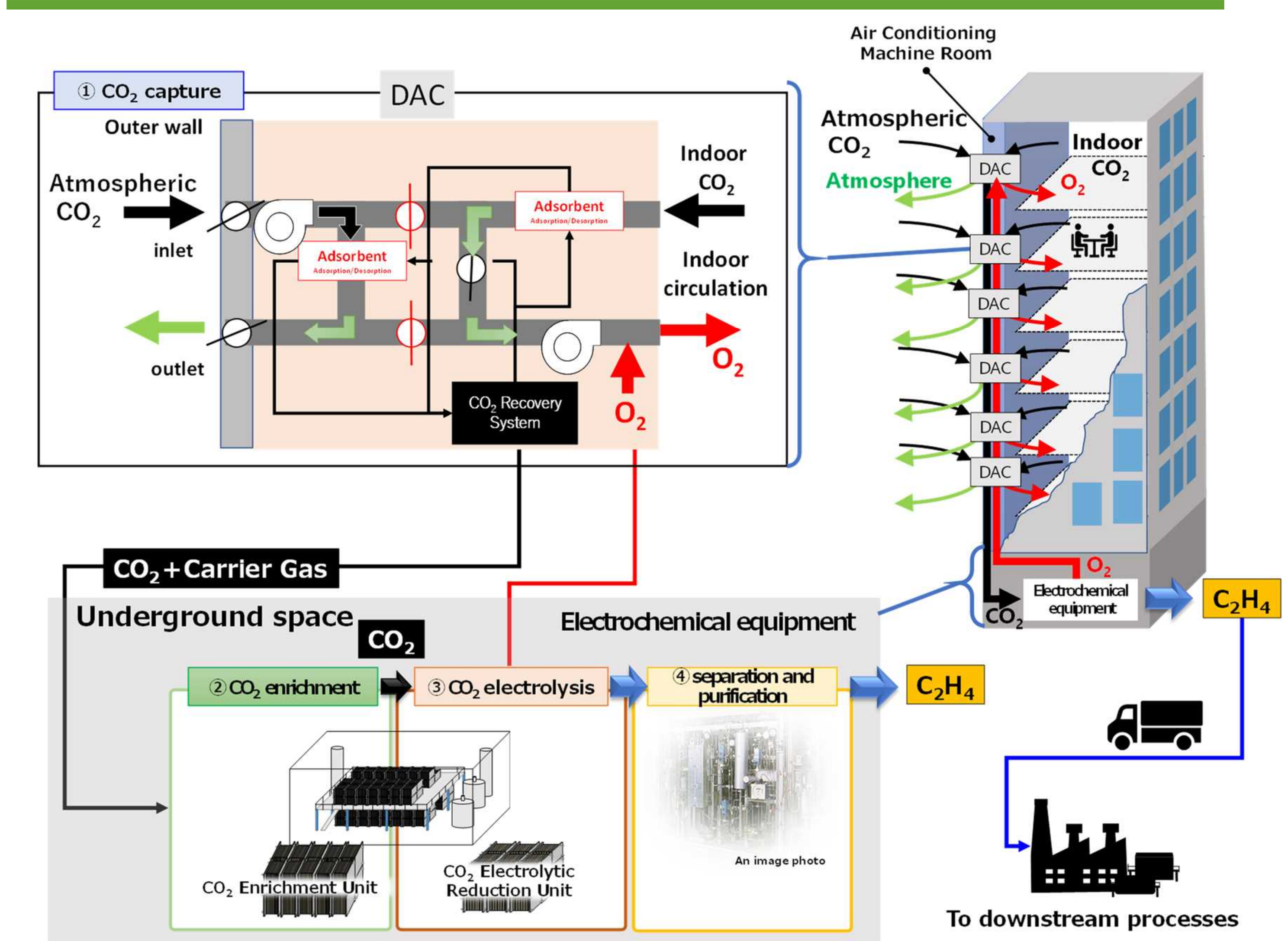


Achievement of carbon cycle based on electricity which is a platform of future energy system
～ Toward 100 million ton/year reduction of CO_2 emissions @ 2050 ～

2. Our Future Vision: Urban DAC-U System (Artificial Photosynthesis)



Air conditioning and ventilation + DAC

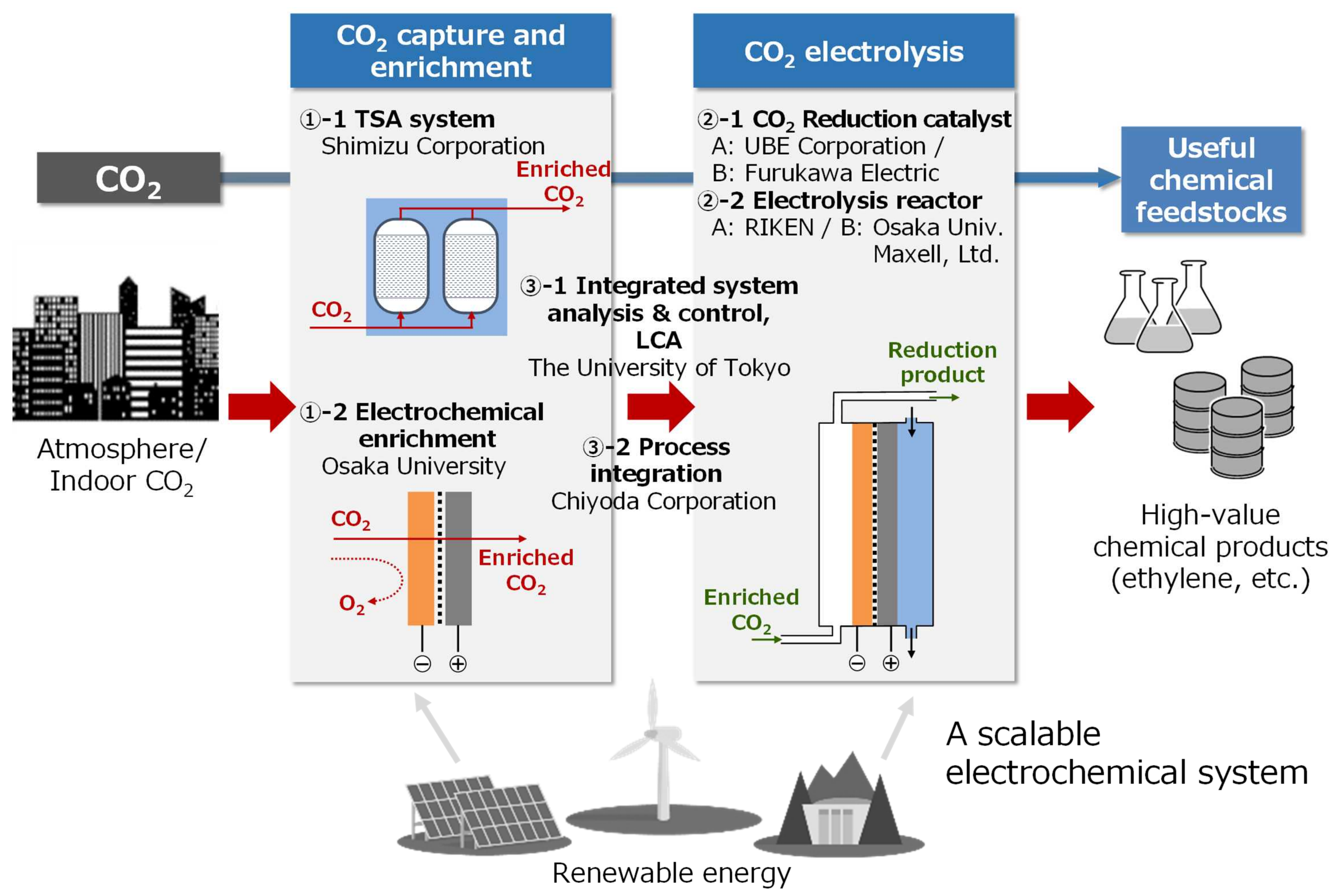


CO_2 Enrichment + Electrolysis

Urban DAC-U system to capture and recycle CO_2 from inside and outside of buildings

- The concentration of O_2 as well as CO_2 can be maintained, even when people are in the office, reducing energy for ventilation.
- Conversion from atmospheric and indoor CO_2 into useful chemical feedstocks

3. Work Packages of the Project



- CO_2 Capture and Enrichment (**Poster No. A-2-2E**)
- CO_2 Electrolysis (**Poster No. A-2-3E**)
- System Integration / LCA (**Poster No. A-2-4E**)

4. Goals and Roles

KPI

	2022	2024	2029
CO_2 emission※ ($t\text{-}CO_2/t\text{-}C_2H_4$)	+1.0 ～ +1.5 at device level	+0.5 ～ +1.0 at laboratory scale 1,000 hours	<−0.5 at pilot plant scale 5,000 hours
CO_2 emission during operation	−0.5 ～ 0.0 (5.0～4.5 V, FE= 55 ～65%)	−1.0 ～ −0.5 (4.5～3.8 V, FE= 55 ～80%)	<−2.0 (3 V, FE= 80%)
CO_2 emission upon equipment manufacturing	+1.5	+1.5	+1.5

※CO_2 emission of the entire system from atmospheric CO_2 capture to ethylene production (including emission upon manufacturing of equipment)

Division of roles

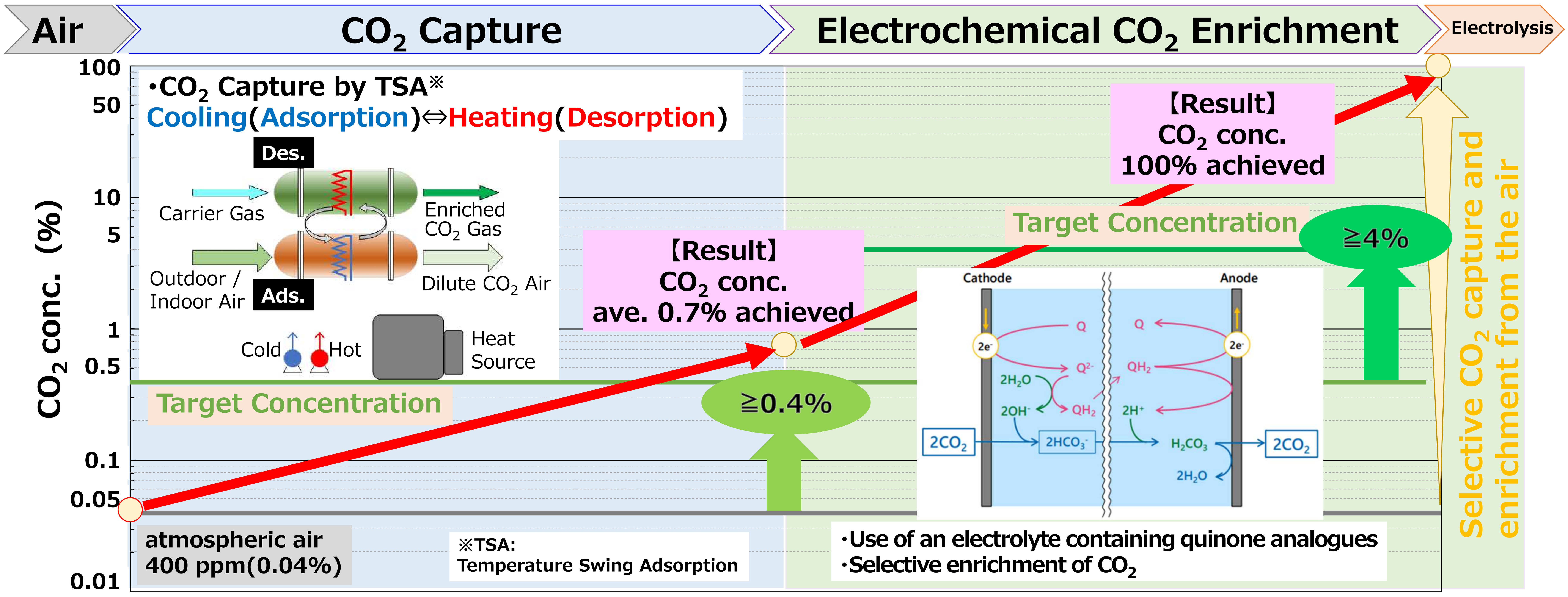
R&D items				Player	
CO_2 capture and enrichment	CO_2 capture by TSA method			SC	Collaborative member
	Electrochemical CO_2 enrichment			OSU	Collaborative member
CO_2 electrolysis	Reactor member	Catalyst	Substrates	OSU UTK	UBE
			Cu-based materials		FKW
		Gas-Diffusion Electrode (GDE)			UBE, FKW, Maxell
		MEA-based reactor	Membrane	RIKEN	Collaborative member
			Reactor		
		Stack			
System integration	Reaction process development / Process integration Integrated system analysis & control / LCA			UTK	CYD

*UTK: The University of Tokyo, OSU: Osaka University, RIKEN: Institute of Physical and Chemical Research, UBE: UBE Corporation, SC: Shimizu Corporation, CYD: Chiyoda Corporation, FKW: Furukawa Electric Co., Ltd, Maxell：Maxell, Ltd.

Poster No.	Theme	Major Results	Future Works
A-2-2E	CO_2 Capture and Enrichment	･Clarified the concept (requirements) of the implementation model for buildings ･Successful enrichment of atmospheric CO_2 from 400 ppm to 100% (pure CO_2)	･Design and manufacturing of prototypes ･Low drive voltage and long-term stable operation
A-2-3E	CO_2 Electrolysis	･FE to ethylene 60%, 2.8 V operating potential between 2 poles achieved ･Efforts to achieve large area / 10cm square cell evaluation and institutional collaboration	･Development of electrodes that simultaneously satisfy current efficiency, current density, and stability
A-2-4E	System Integration LCA	･Conceptual system design from atmospheric CO_2 capture to ethylene production and LCA for CO_2 emission	･Continuous process benchmark of "CO_2 Enrichment + Electrolysis." ･Improvement of LCA accuracy

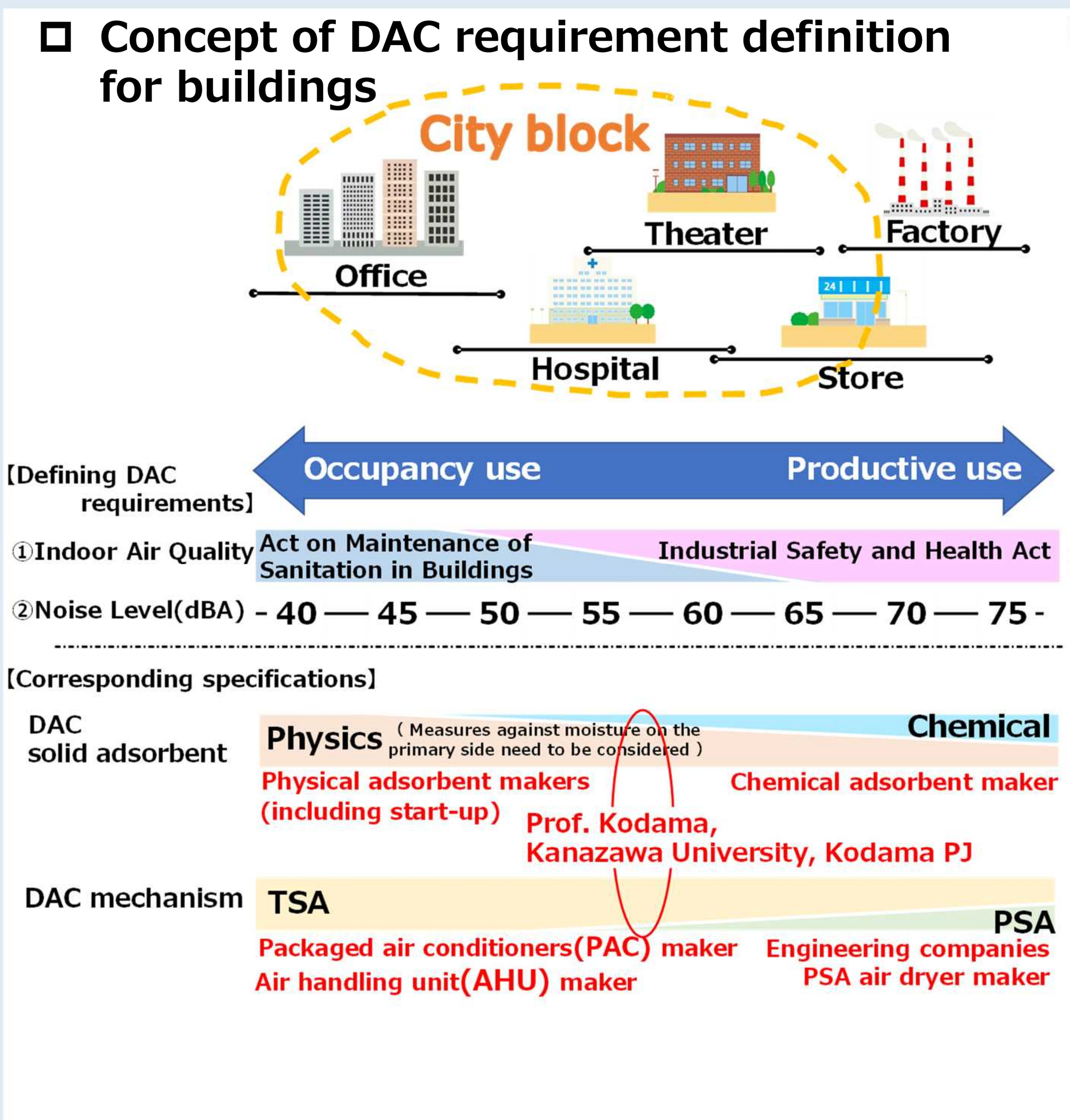
No. A-2-2E
PJ : Integrated Electrochemical Systems for Scalable CO_2 Conversion to Chemical Feedstocks
Theme : CO_2 Capture and Enrichment
Organization : Osaka University / Shimizu Corporation
Contact : nakanishi.shuji.es@osaka-u.ac.jp / yukinori.fuse@shimz.co.jp

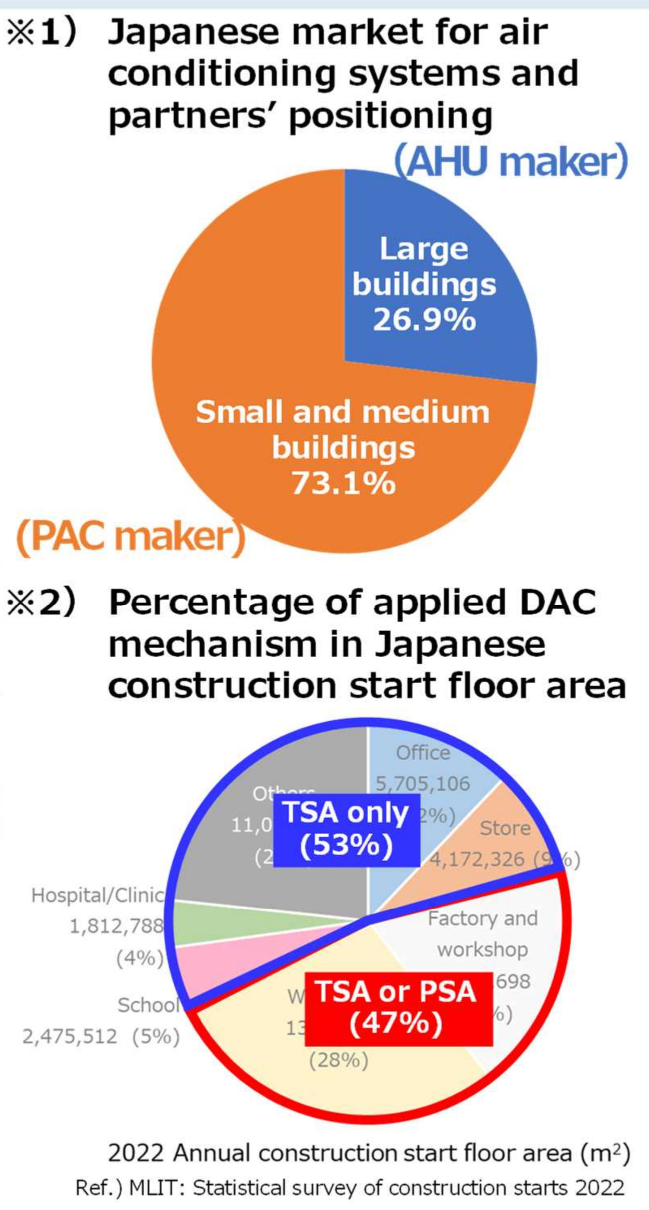
1. Research Outline



2-1. Progress

- Selection of effective adsorbents
- 10-fold enrichment of atmospheric CO_2
- Policy formulation for defining DAC requirements from architecture
- Continuous search for DAC collaboration partners for requirements definition （Signed 7 NDAs）
- Define the boundaries between building equipment and DAC, and create a requirements definition organization template (tentative)





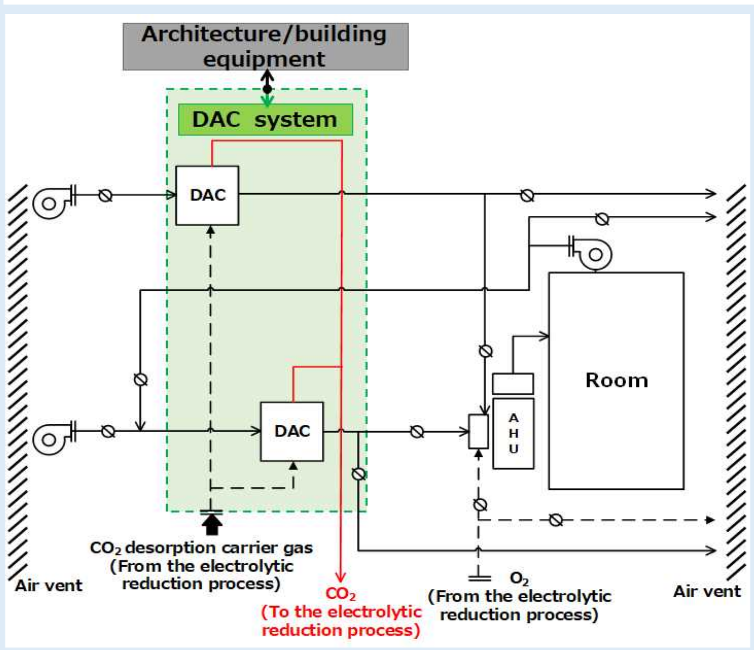


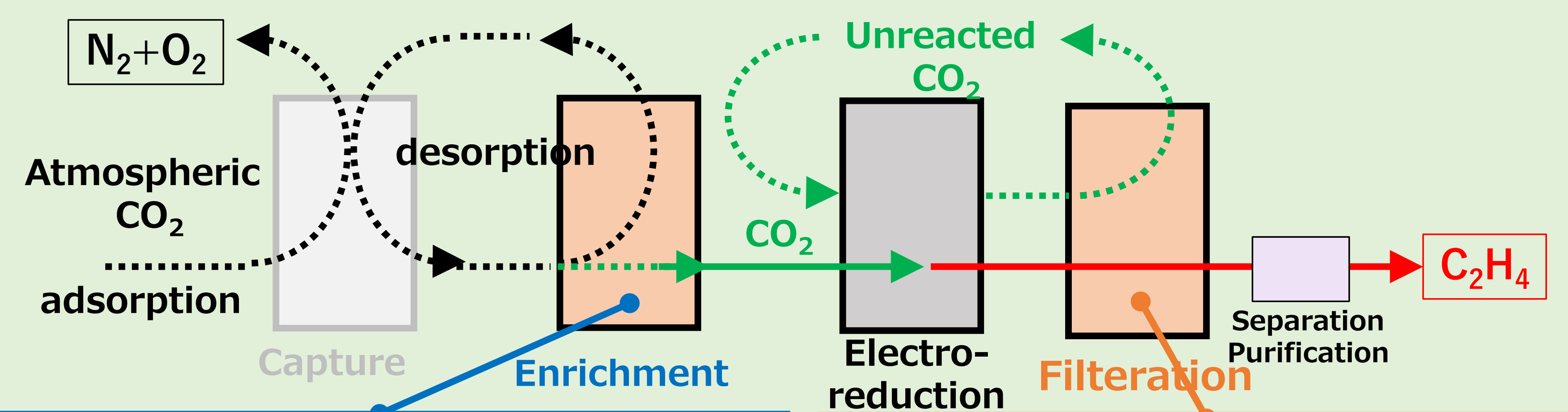
Diagram with the boundary

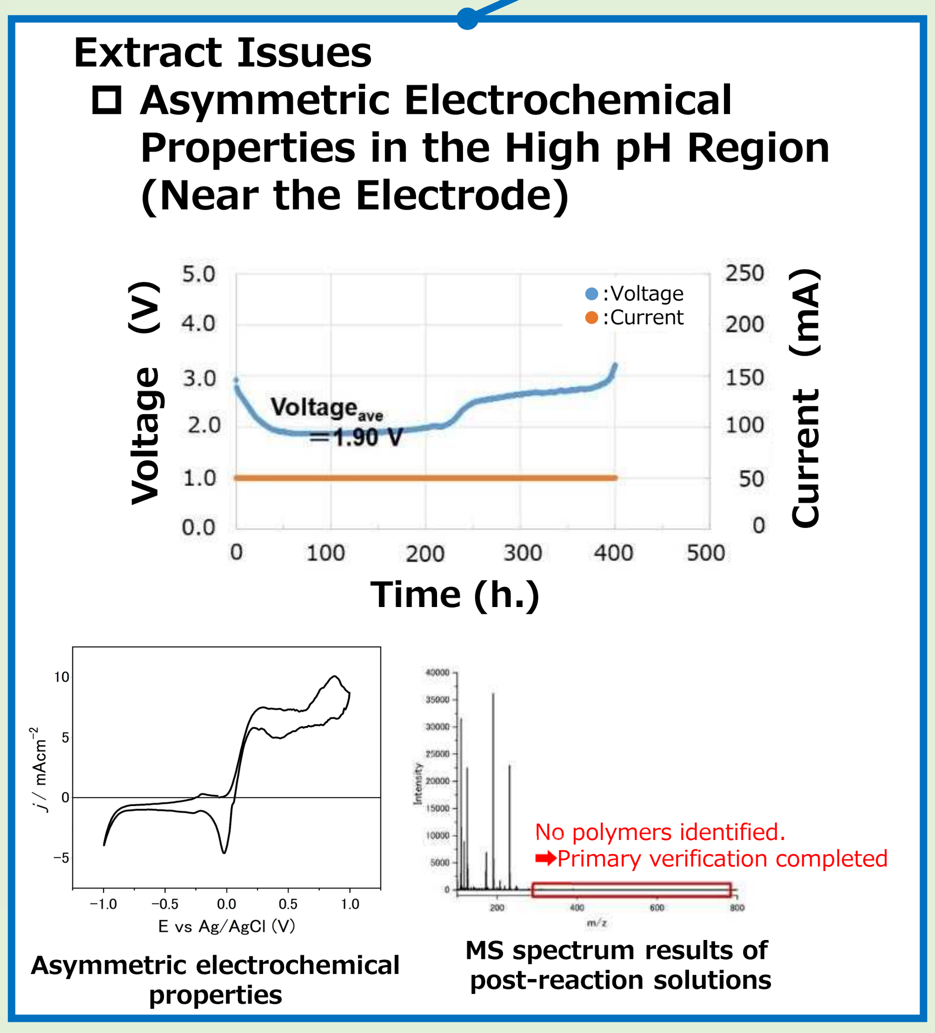
		Office: Complex	Office: Large	Office: Below medium	Theater	Store	Hospital	Factory
Requirements	CO_2 conc.	≦1,000 ppm					≦1,000 ppm	≦5,000 ppm
	Noise /Vibration	NC45/VAL≦			NC45/VAL≦		NC45/VAL≦	NC45/VAL≦
	Space	4～6% of floor area						
	Temp. /Humi.	17～28℃/40～70%R.H.						
	Air quality	HCHO:100 μg/m³, TVOC:400 μg/m³ or less						
	Odor	－						Offensive Odor Control Law
	Energy type	Electricity					Electricity /heavy oil/gas	Electricity /heavy oil/gas
	Special facilities	District heating and cooling					Private power generation	※ cogeneration
DAC mechanism	Adsorbent	Solid adsorbent					Solid adsorbent	Solid adsorbent
	DAC mechanism	TSA			TSA/PSA	PSA /TSA	TSA/PSA	PSA/TSA
	Partner candidate							

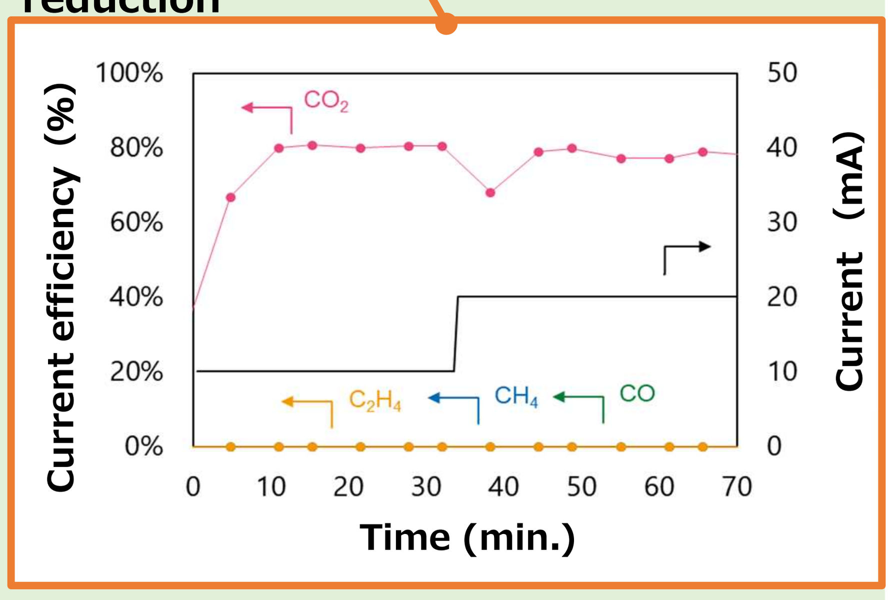
Requirements definition table

2-2. Progress

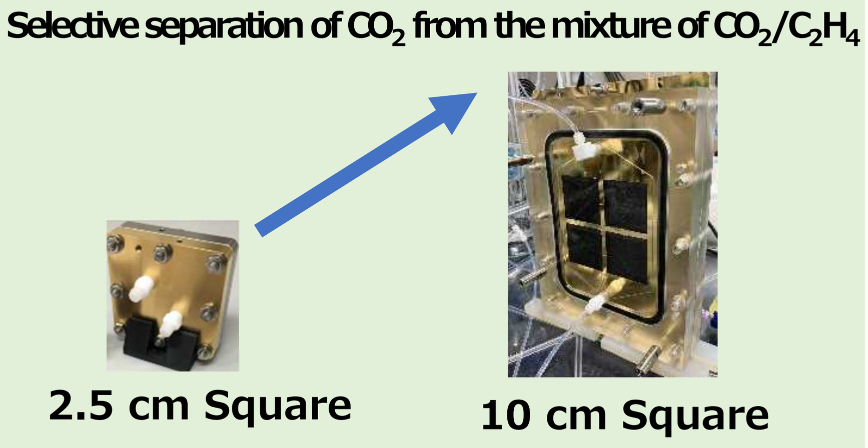
- Enrichment of CO_2 from 0.2% to 100%
- Selective electro-filtration of CO_2 from a mixture of unreacted CO_2 and C_2H_4 emitted from the electrolysis reactor
- Lower voltage and larger area by improving electrodes and reactors
- Identify performance degradation factors and develop guidelines for countermeasures







■ Selective separation of CO_2 from the mixture of CO_2/C_2H_4



Improved reactor and larger area

Type	Operation voltage	Advantages	Disadvantages
Organic electrolyte	～1 V	Low voltage	Vulnerable to moisture Low durability
Bipolar electrodialysis	>1.5 V	High durability	High voltage
Aqueous electrolyte	3～4 V	Simple structure	High voltage Low durability
This Project	1.9 V (Target : 1.1 V)	Low voltage	Low durability System design freedom: wide

3-1. Future Works

- Formulation of DAC requirements from architecture
- Continuing to search for DAC collaboration partners to formulate the requirements definition

3-2. Future Works

- Reducing the operation voltage
- Preparing the integrated system
- Enhancing the system durability

No. A-2-3E

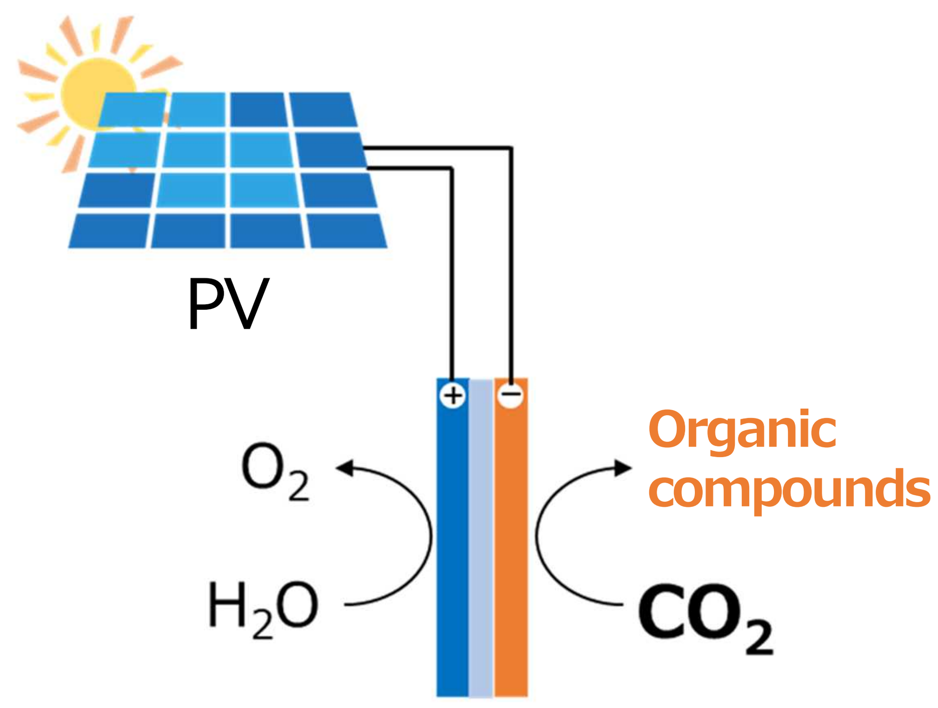
PJ : Integrated Electrochemical Systems for Scalable CO_2 Conversion to Chemical Feedstocks

Theme : CO_2 Electrolysis

Organization : Osaka University / RIKEN / UBE Corporation / Furukawa Electric Co., Ltd. / Maxell, Ltd / The University of Tokyo

Contact : nakanishi.shuji.es@osaka-u.ac.jp / katsushi.fujii@riken.jp

1. Research Outline



R&D items				FY2024 Development Targets	Player *1)	
CO_2 electrolysis	Materials & Composition	Catalyst	Substrates	☐ Current efficiency of 60% ☐ more Large area ☐ Stacked	OSU UTK	UBE
			Cu-based materials			FKW
		Gas-Diffusion Electrode (GDE)				UBE、FKW、Maxell
		MEA-based reactor	Membrane		RIKEN	Collaborative member
			Reactor			
		Stack				

*1)
UTK: The University of Tokyo,
OSU: Osaka University,
RIKEN: Institute of Physical and Chemical Research,
UBE: UBE Corporation,
SC: Shimizu Corporation,
CYD: Chiyoda Corporation,
FKW: Furukawa Electric Co., Ltd,
Maxell : Maxell, Ltd.

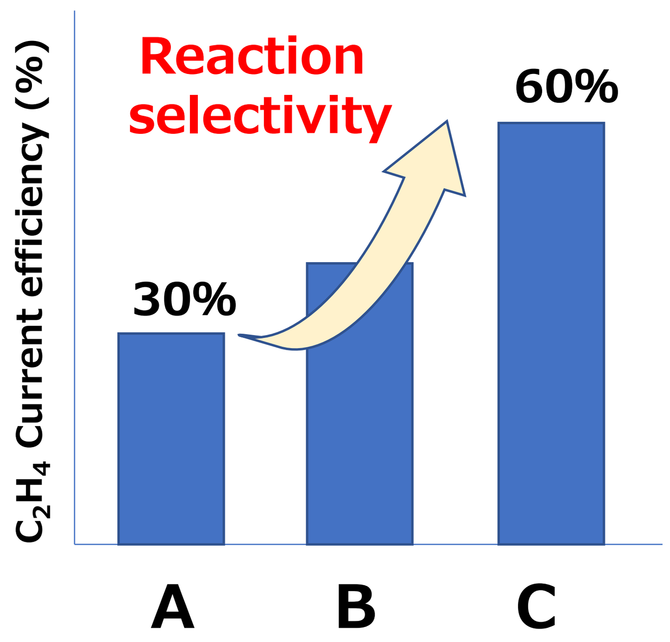
2. Progress

1) Improvement of Reaction Selectivity/Reduction of Operation Voltage

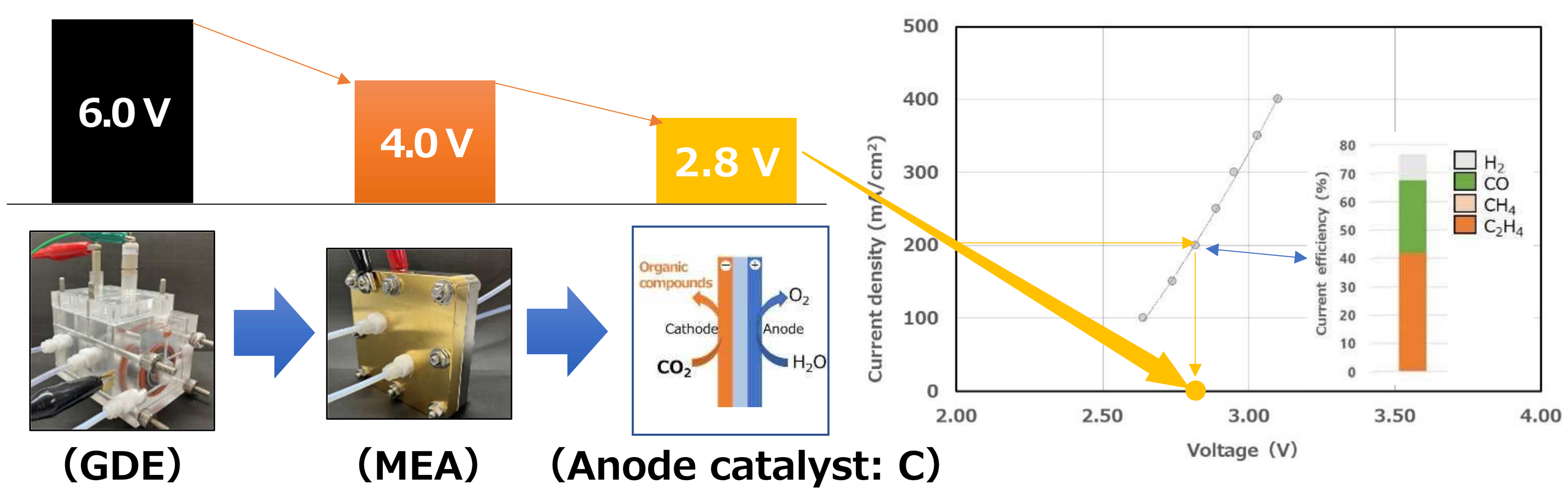
☐56% of FE (C_2H_4) was achieved at the 3.4 V of operation voltage (MEA).

☐Operation voltage of 2.8 V (@200 mA/cm²) was achieved.

※FE : faradaic efficiency



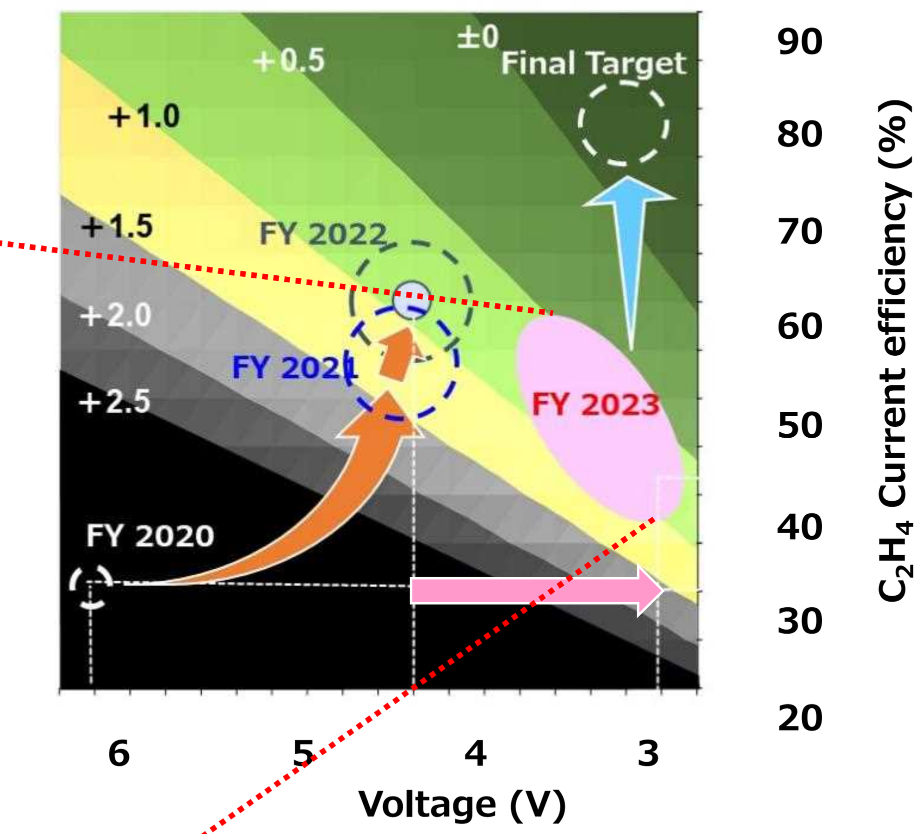
Added metal species (Cathode)



Update of the reactor

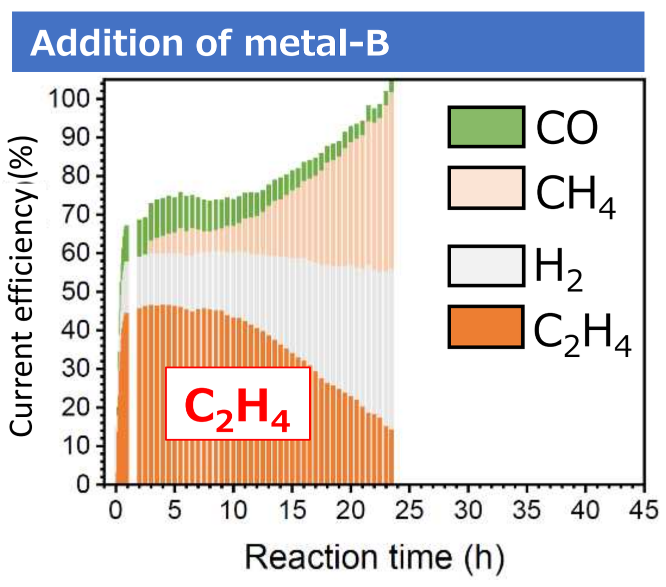
Structural improvement of the anode

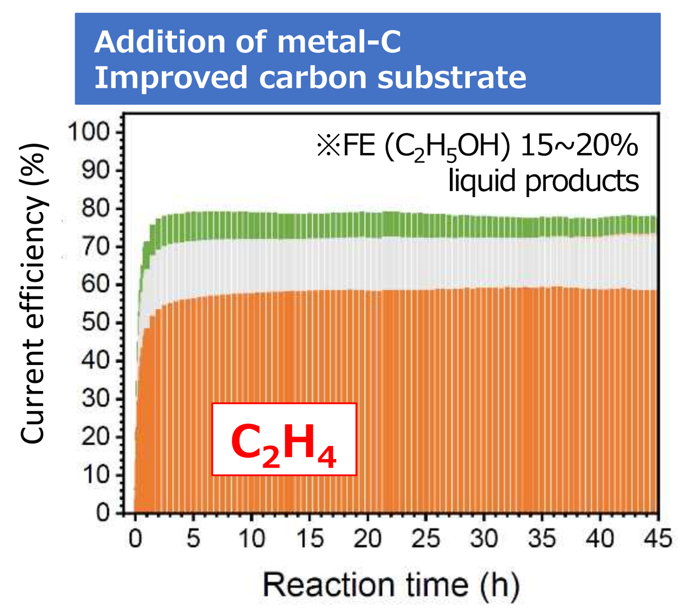
Reduction of Operation Voltage

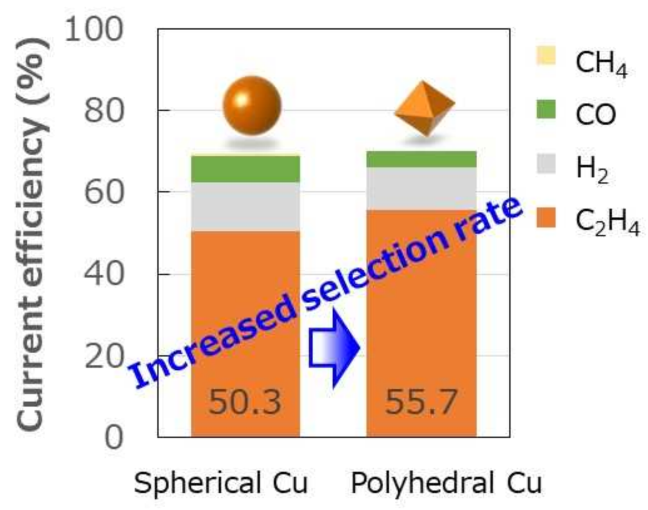


Total CO_2 emission (t-CO_2/t-C_2H_4)

2) Attaining both high faradic efficiency and high stability

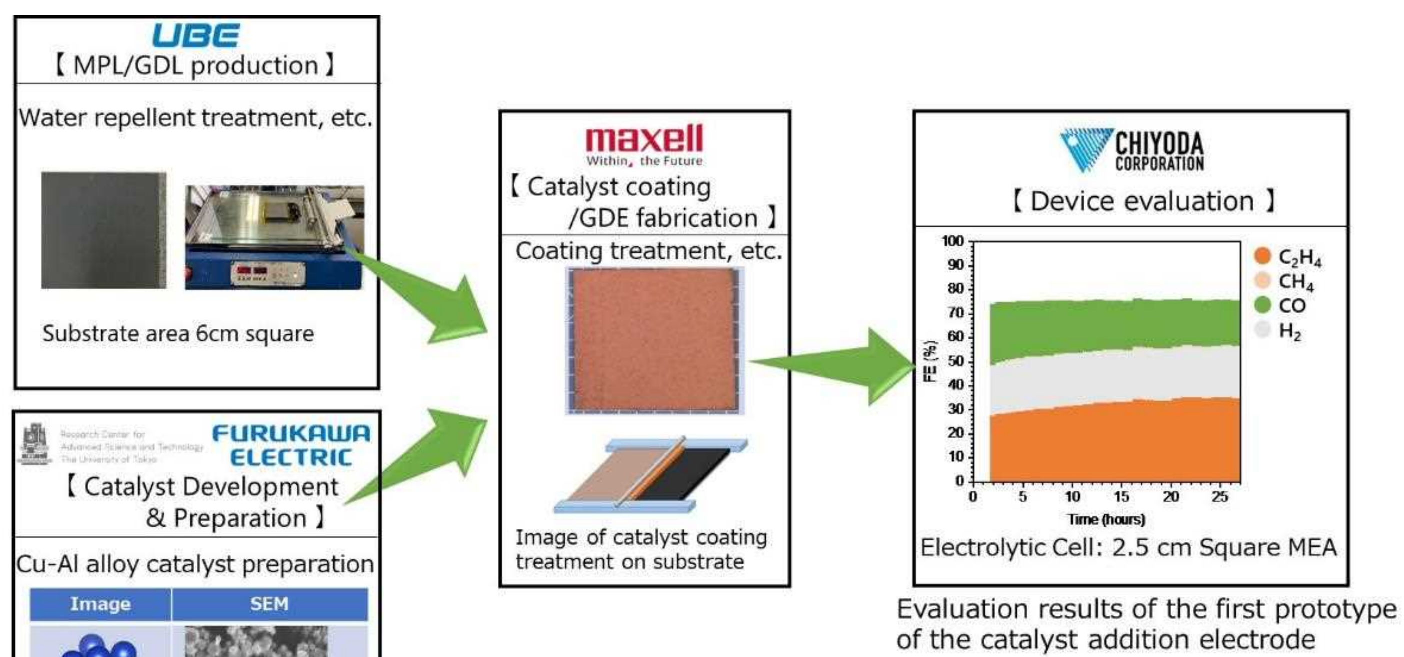






☐ Improvements of electrocatalysts and electrode substrate.
☐ Design guideline was obtained through the identification of critical factors.

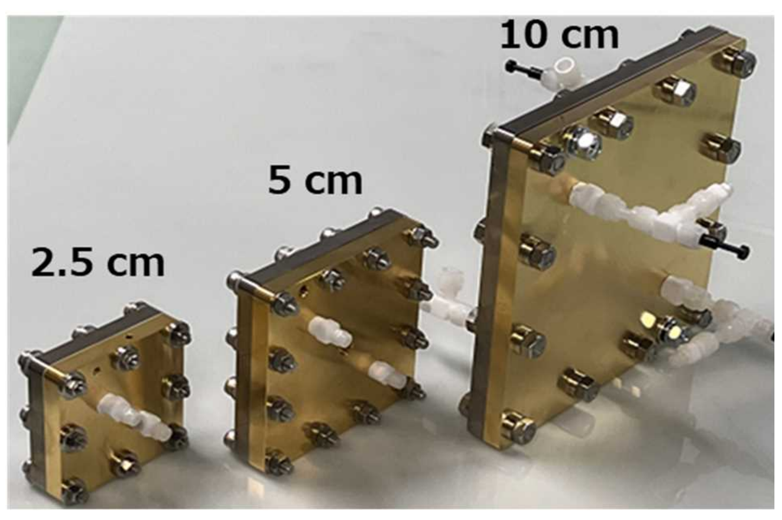
3) Team-based development of industrial scale electrode

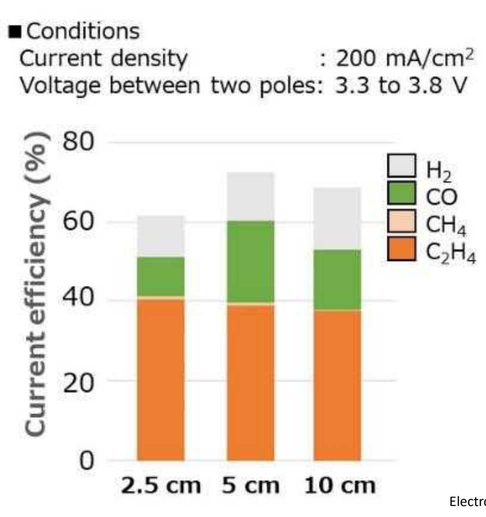


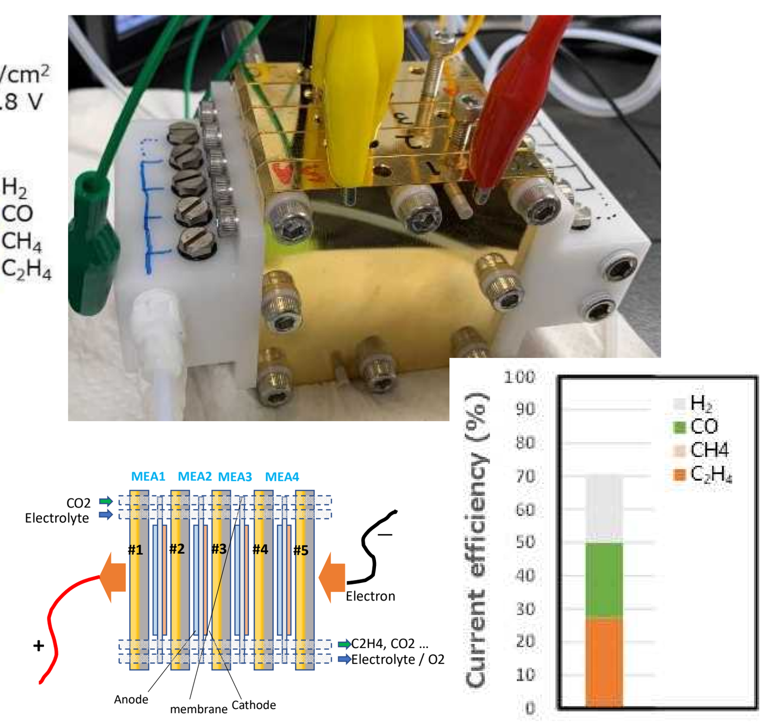
Evaluation results of the first prototype of the catalyst addition electrode

☐ Trial manufacture of electrodes through institutional collaboration started for demonstration of large-area electrodes.

4) Scaling up of the reactor

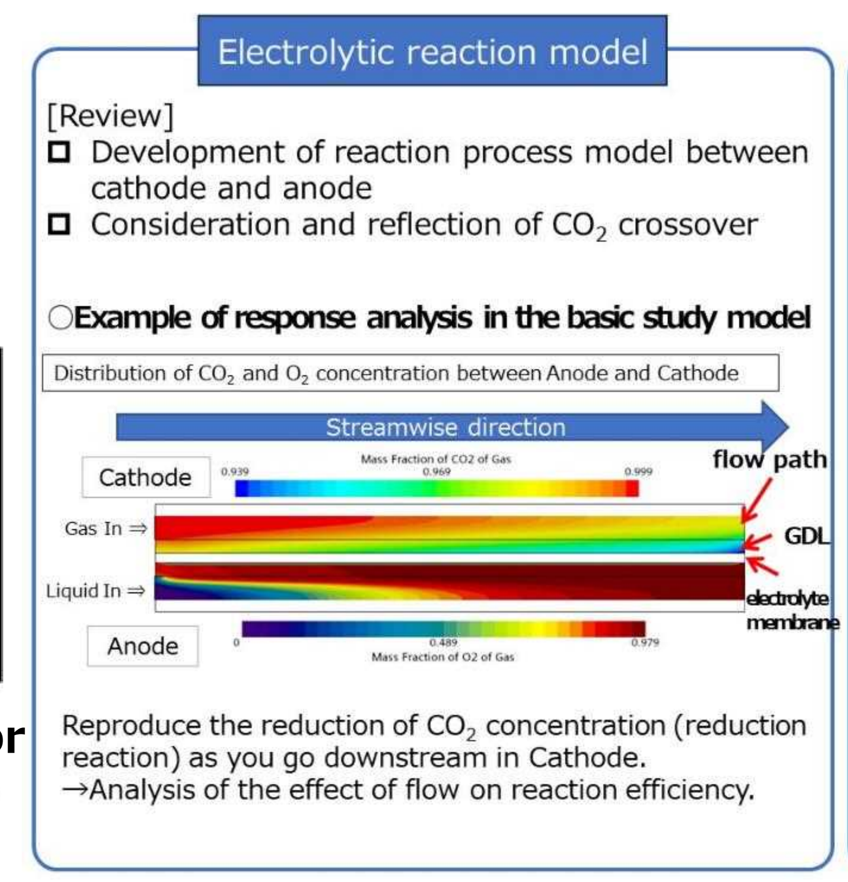


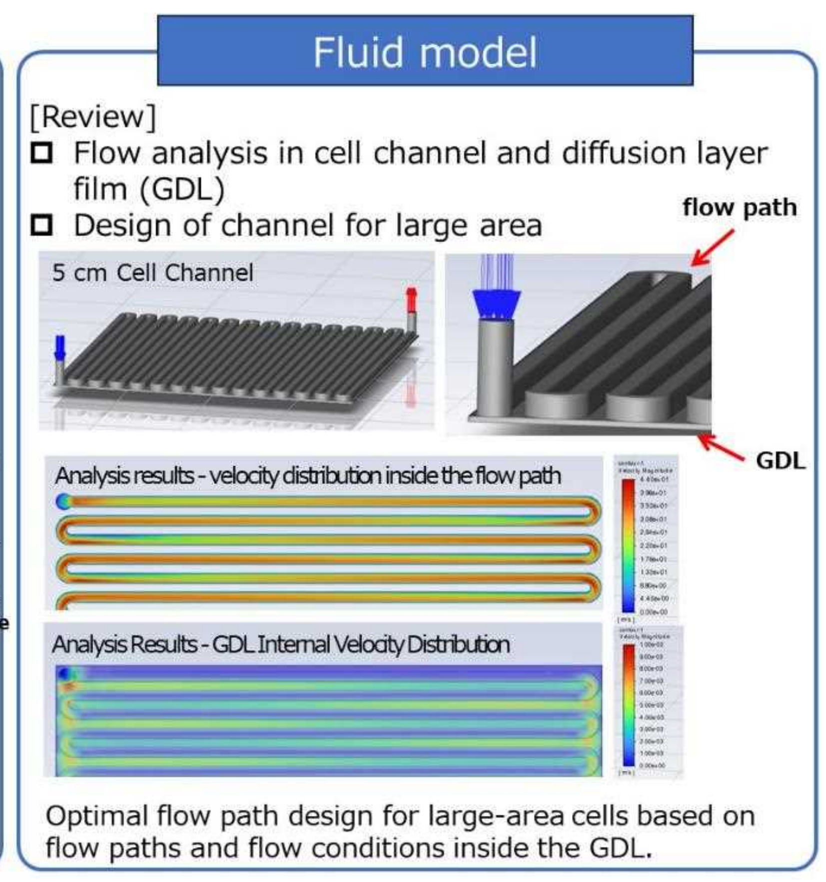




2.5 cm square x 4 stacks reactor (Ethylene production confirmed)

☐ 10 cm square scale reactor was successfully developed.
☐ Key factors for the scaling up the reactor were identified.
☐ Started to study stacking. Ethylene production was confirmed.
☐ A skeleton model for simulating mass transfer in





3. Future Works

☐ Further improvements of the performance of the CO_2 electrolysis reactors.
☐ Developing electrodes and reactors that satisfy all the requirements for higher FE, current density, and stability.
☐ Developing scalable MEA-based cell stacks. (MEA: membrane electrode assemblies)

No. A-2-4E

PJ : Integrated Electrochemical Systems for Scalable CO_2 Conversion to Chemical Feedstocks

Theme : System Integration / LCA

Organization : The University of Tokyo / Chiyoda Corporation
Contact : ebe@enesys.rcast.u-tokyo.ac.jp / takeda.dai@chiyodacorp.com

1. Research Outline

■Reaction process development / Process integration（Chiyoda Corporation）

- ☐ Co-operative developments with the project members. Evaluation of CO_2 reduction catalysts.
- ☐ Process integration from CO_2 capture, through enrichment, to electrolytic reduction
- ☐ Design of a pilot-scale plant
- ☐ Development of process concepts for industrialization

■Characterization and Control of integrated systems LCA of the system（The University of Tokyo）

- ☐ Optimal operating conditions for each process
- ☐ Developing integrated process control methods
- ☐ LCA evaluation of the entire system

【Consideration of system integration from the early stages of R&D】

① Analyze gaps between current and ideal systems
② Efficient PDCA cycle between technology and system development
③ Clarify directions and issues for technological development
④ Review of systems in response to technological developments

2. Progress

System study / Conceptual design

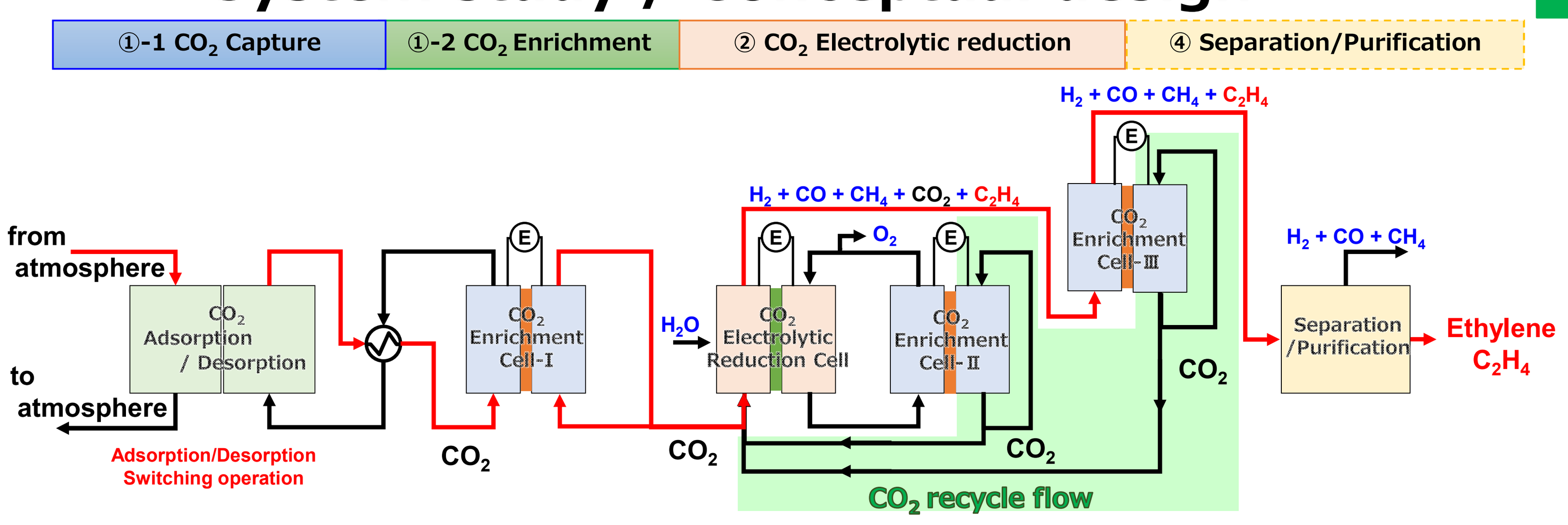


Figure 1. Design of an integrated system

☐ introduction of CO_2 recycling flow using CO_2 enrichment cells (**Fig. 1**)

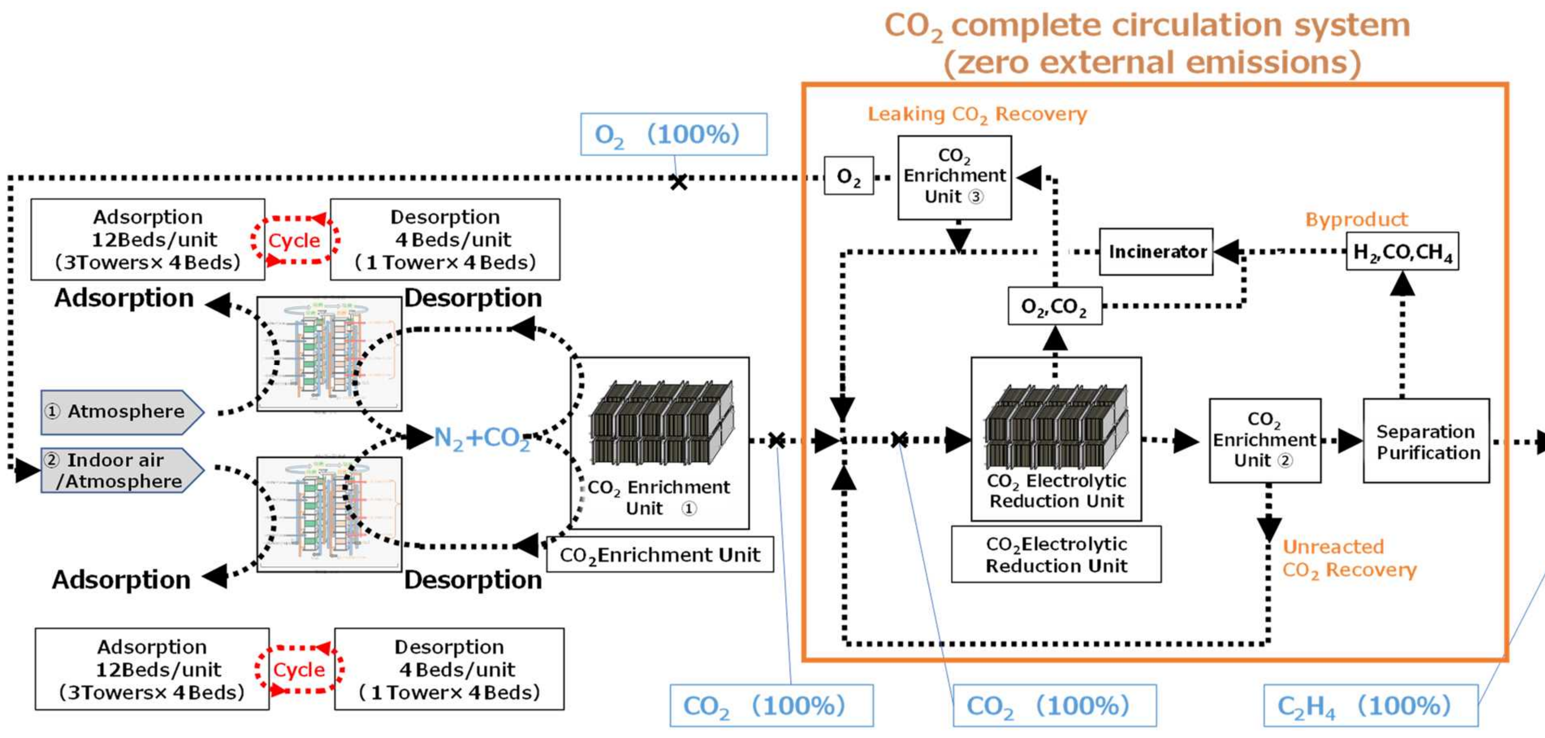


Figure 2. System diagram (excerpt)

☐ System study including material balance, heat balance, etc. (**Fig. 2**)

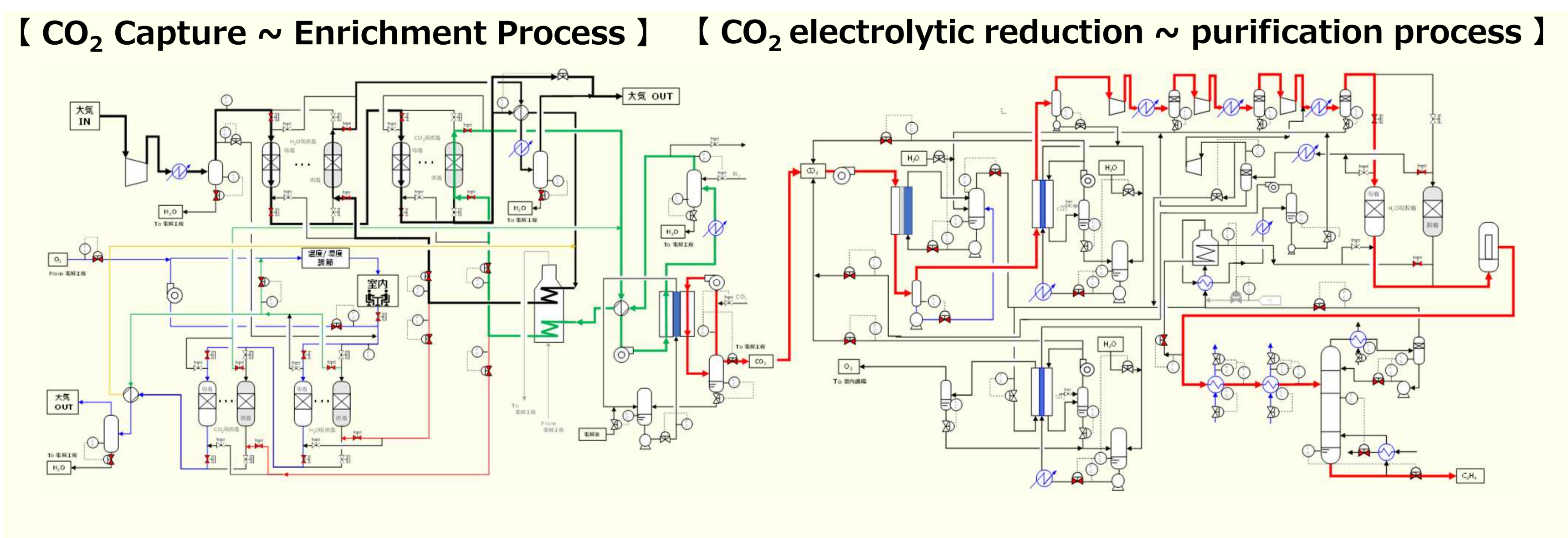


Figure 3. Process flow diagram (Conceptual design)

☐ Conceptual design from atmospheric CO_2 capture to ethylene production (**Fig. 3**)

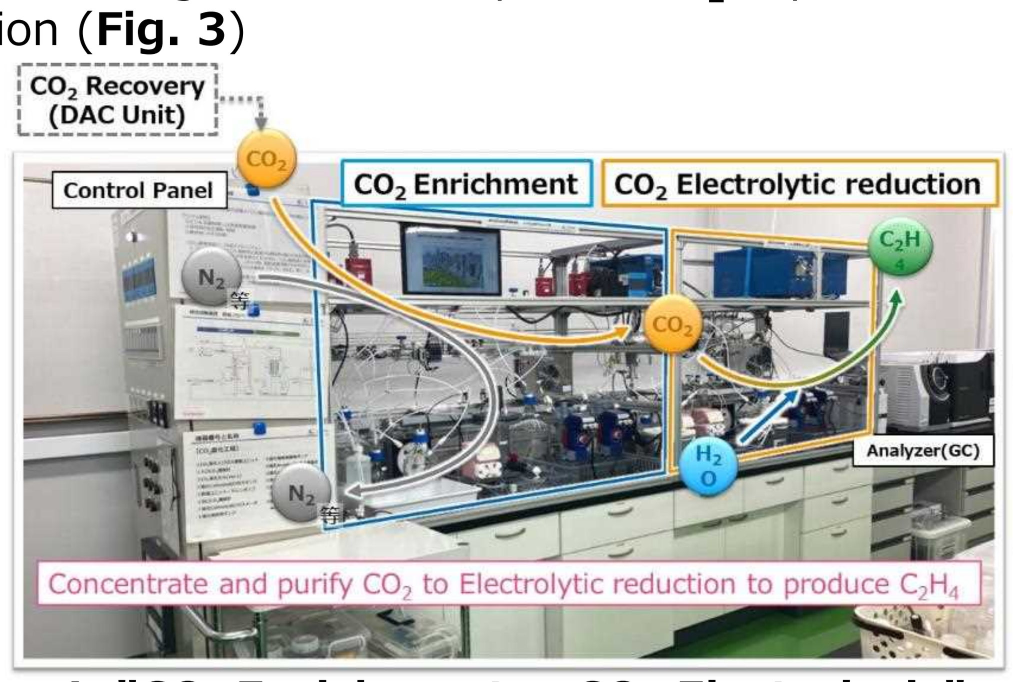
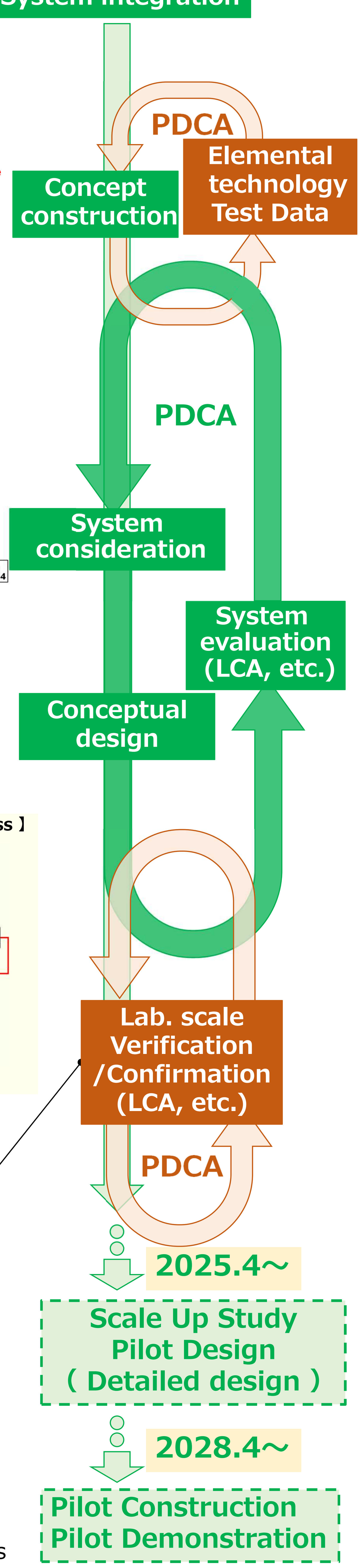


Figure 4. "CO_2 Enrichment + CO_2 Electrolysis" Continuous Benchmarking Equipment

☐ Lab. scale "CO_2 Enrichment + CO_2 Electrolysis" coupled operation has been started for evaluation.(**Fig. 4**)

System integration



System evaluation (LCA, etc.)

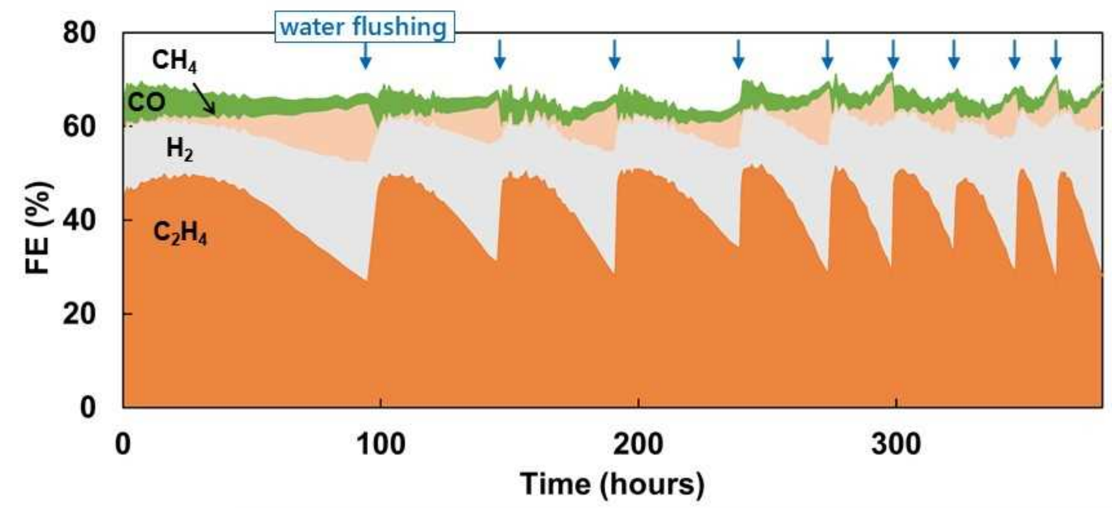


Figure 5. Stability improvement through system control

☐ System control for continuous operation (**Fig. 5**)
➡ Effectiveness of operation control is confirmed.

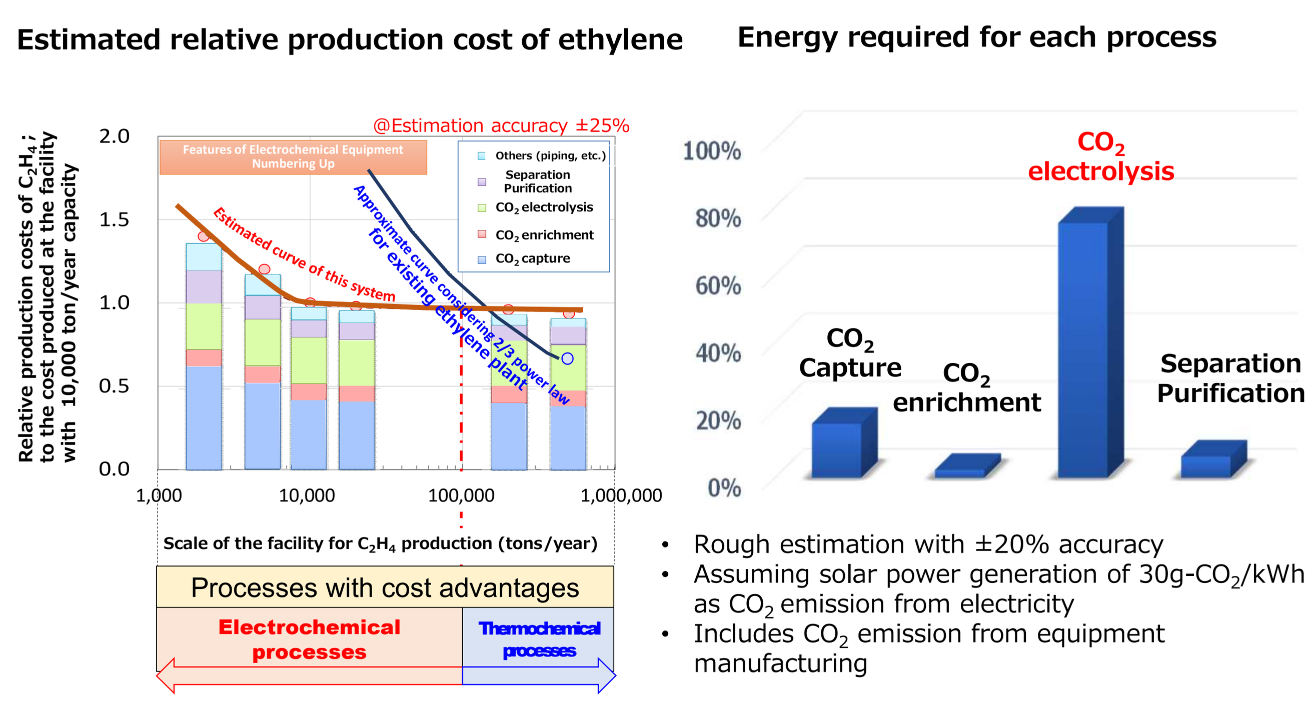


Figure 6. Scaling and energy demand for ethylene production plant

☐ Itemized an equipment list and estimated the scale of ethylene production facilities and the required energy for each process (**Fig. 6**).

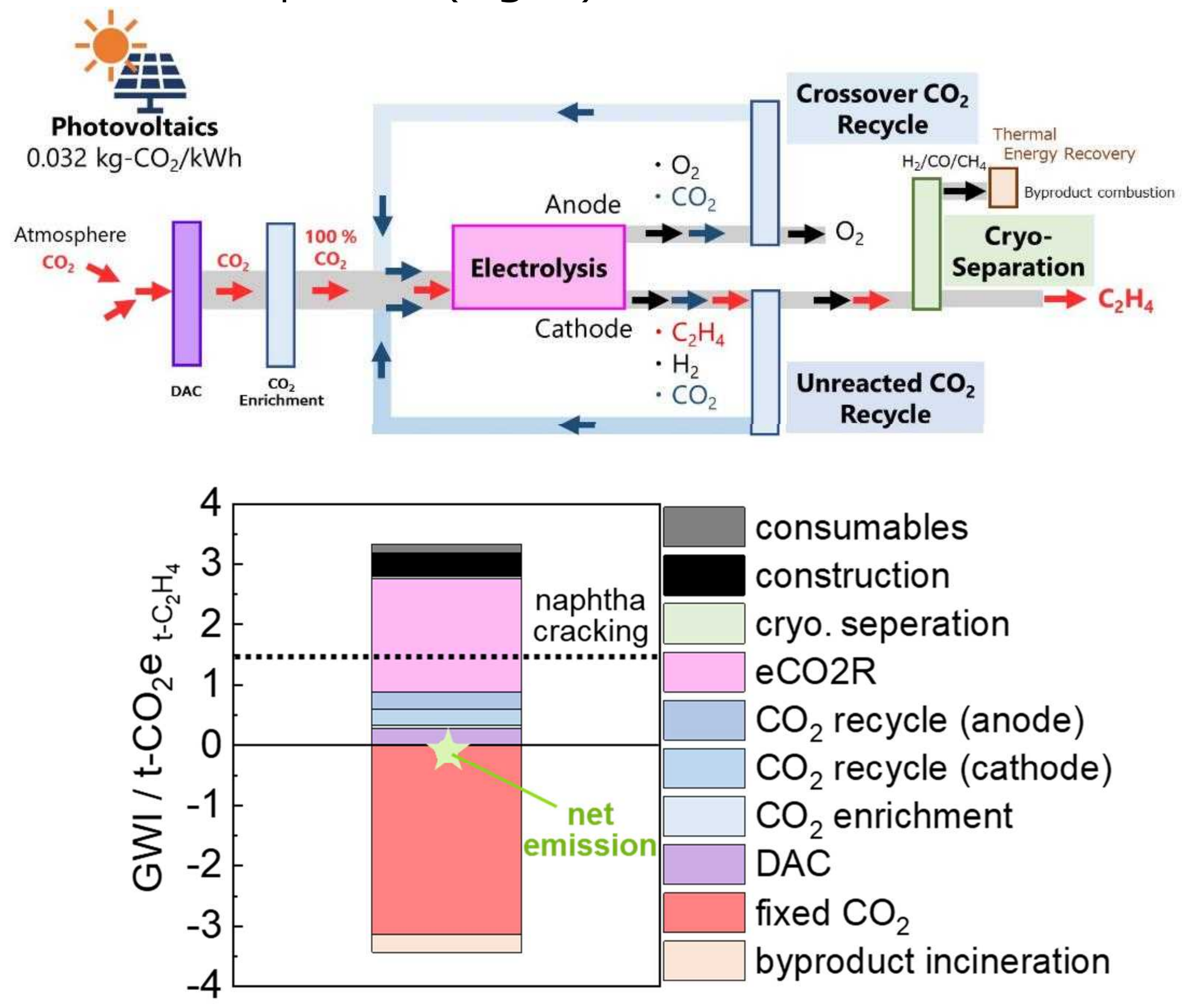


Figure 7. LCA evaluation for electrolytic reduction process (excerpt)

☐ Conduct basic study of LCA (**Fig. 7**)
➡ Study LCA for a system that reuses heat from combustion of by-products as heat for CO2 desorption from DAC

3. Future Works

- ☐ Verification and confirmation on a lab. scale using the "CO_2 Enrichment + CO_2 Electrolysis" continuous evaluation system (**Fig. 4**)
  ➡ Identification of issues／Implementation of 500 hours operation and forecast of 1000 hours operation (FY2024 target)
- ☐ Improving the accuracy of system evaluation (LCA, etc.)
- ☐ Review and optimization of systems in accordance with the progress of technological development
- ☐ Collaboration with various agencies (continued)