No. A-2-1E

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

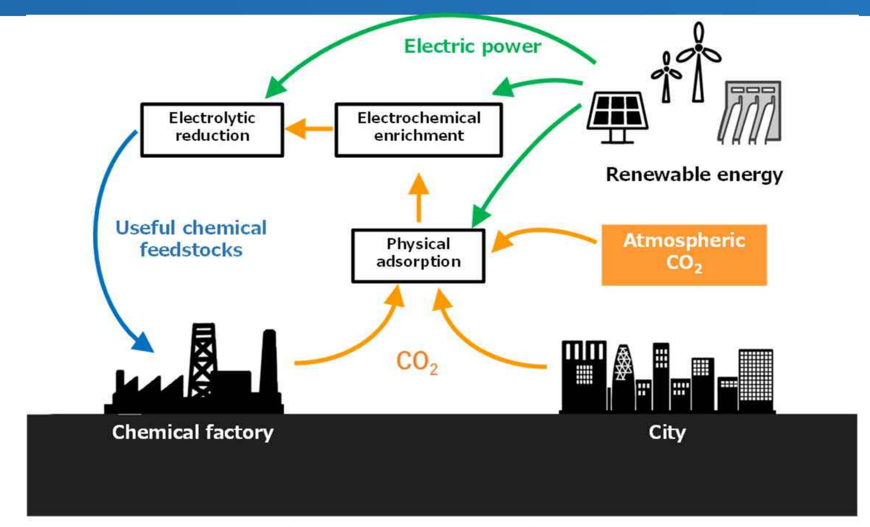
Theme：Project Overview

Organization : The University of Tokyo

Contact : sugiyama@enesys.rcast.u-tokyo.ac.jp / ebe@enesys.rcast.u-tokyo.ac.jp

1. Research Outline

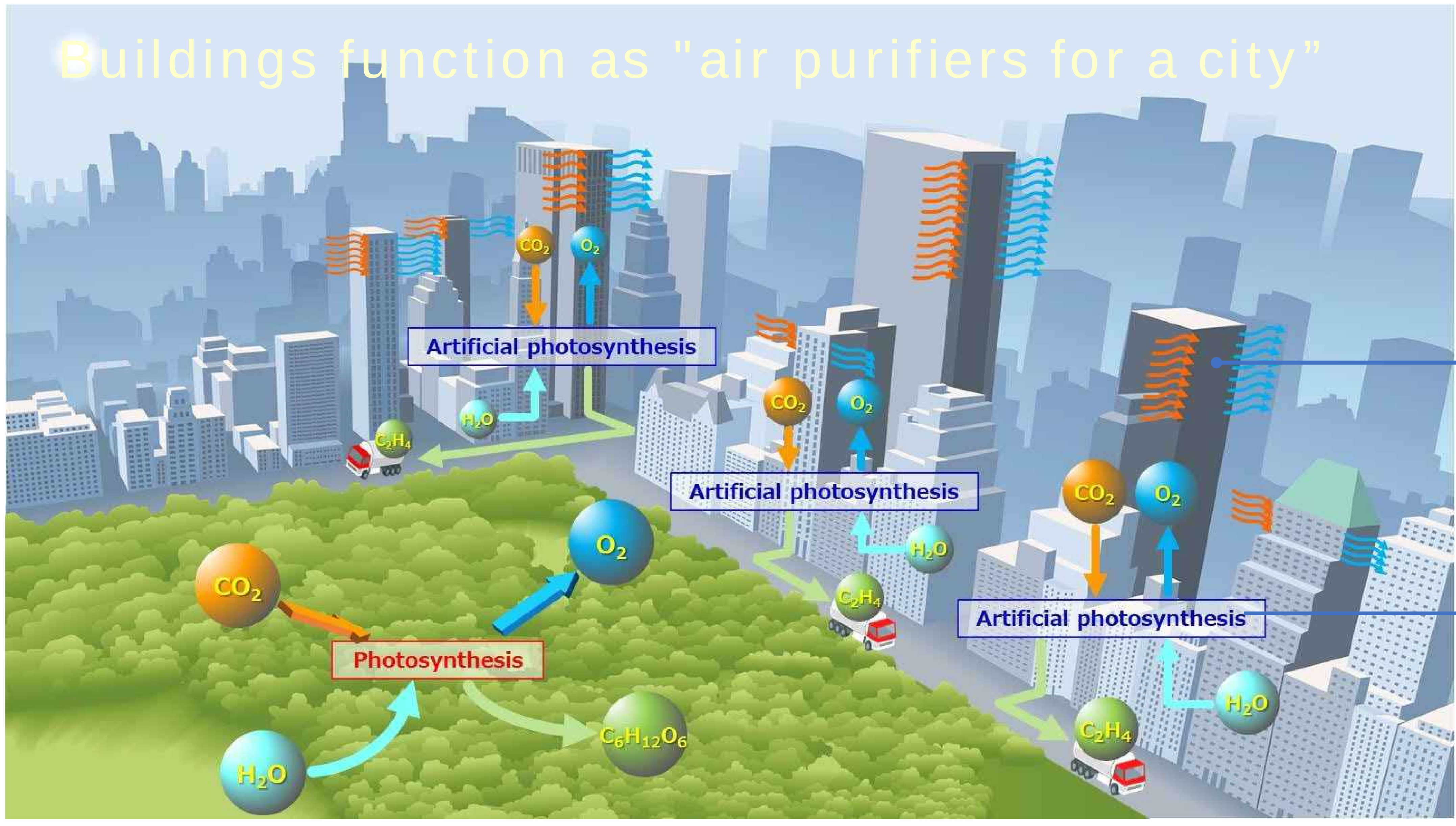
- ☐ Development of a system to convert atmospheric CO_2 into useful chemical feedstocks based on electrochemical processes.
- ☐ Proposal for a compact and decentralized urban infrastructure for CO2 recycling taking advantage of scalable electrochemical processes.

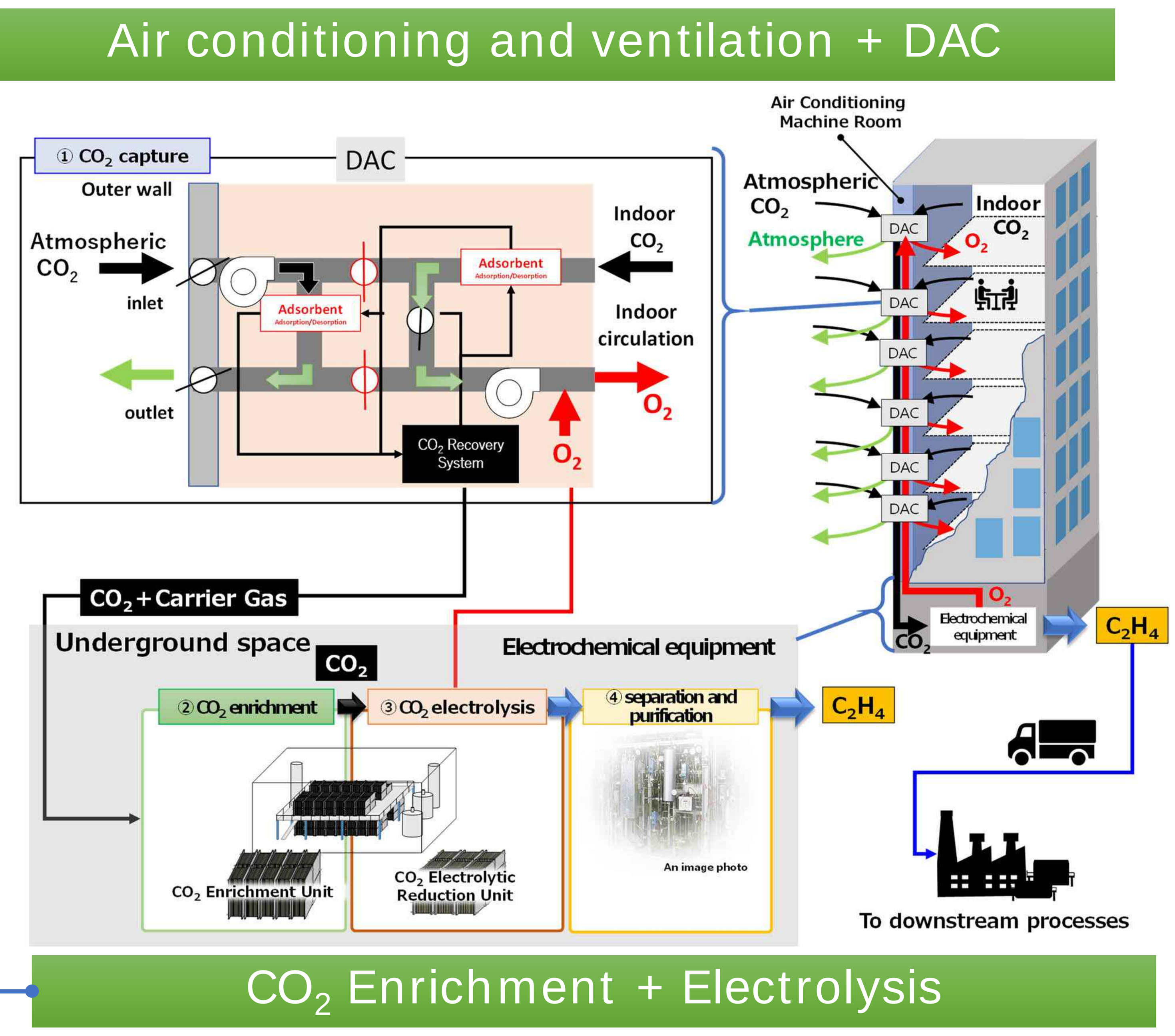


Achievement of carbon cycle based on electricity which is a platform of future energy system

～ Toward 100 million ton/year reduction of CO_2 emissions @ 2050 ～

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

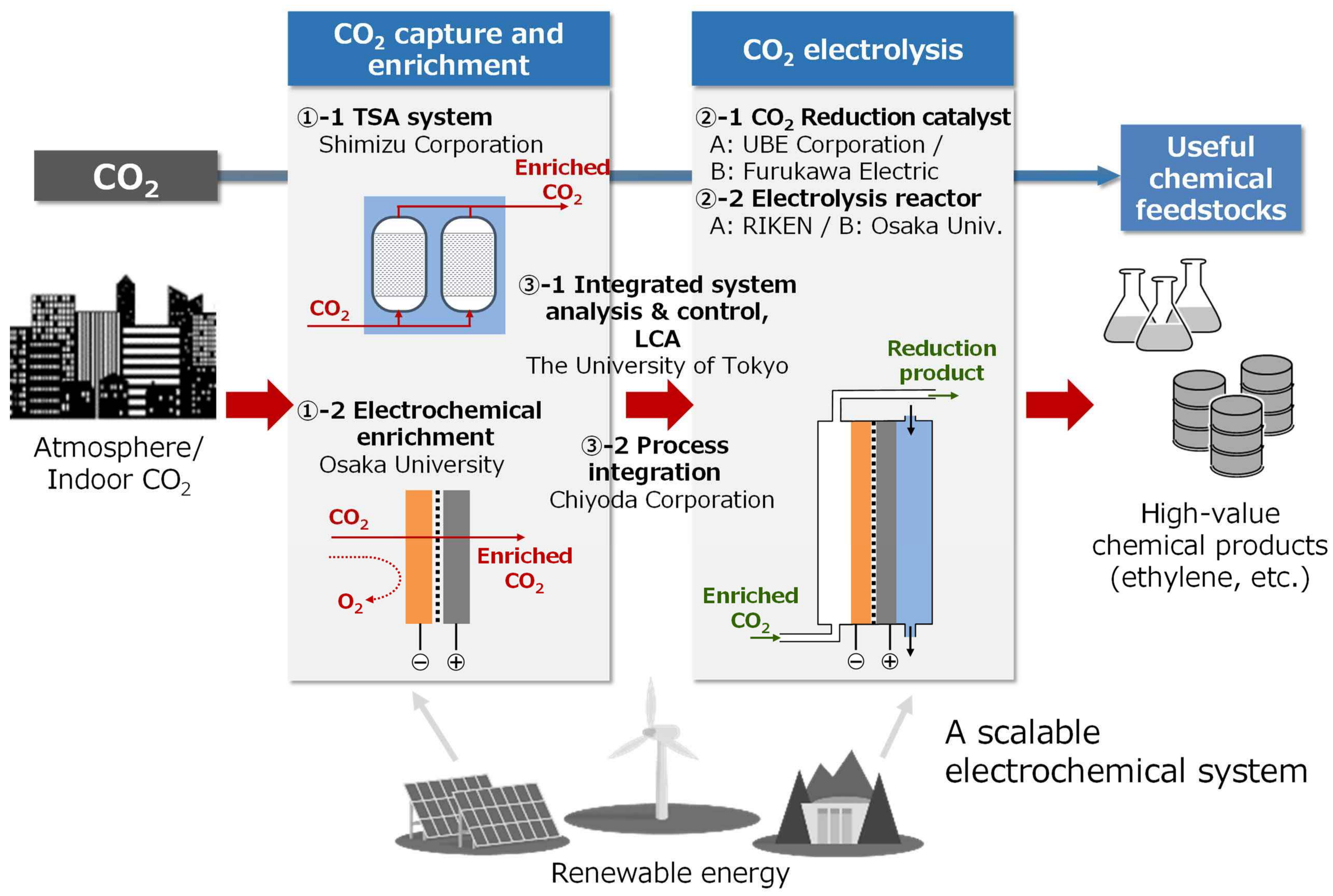




Urban DAC-U system to capture and recycle CO_2 from inside and outside of buildings

- ☐ 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 (Cu-based catalyst, Functional Substrate)	Substrates	OSU	UBE
			Cu-based materials		FKW
		Gas-Diffusion Electrode (GDE)			Collaborative member
		MEA-based reactor	Membrane	RIKEN	Collaborative member
			Reactor		New member
		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

Poster No.	Theme	Major Results	Future Works
A-2-2E	CO_2 Capture and Enrichment	・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	・High current density (2,000 mA/cm^2) at the 80% of FE (for C2+ products) was achieved. ・60% of FE (for C_2H_4) was achieved at the operation voltage of 4V.	・Preparing electrodes that satisfy all the required factors simultaneously (i.e., high FE, high current density, and high 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

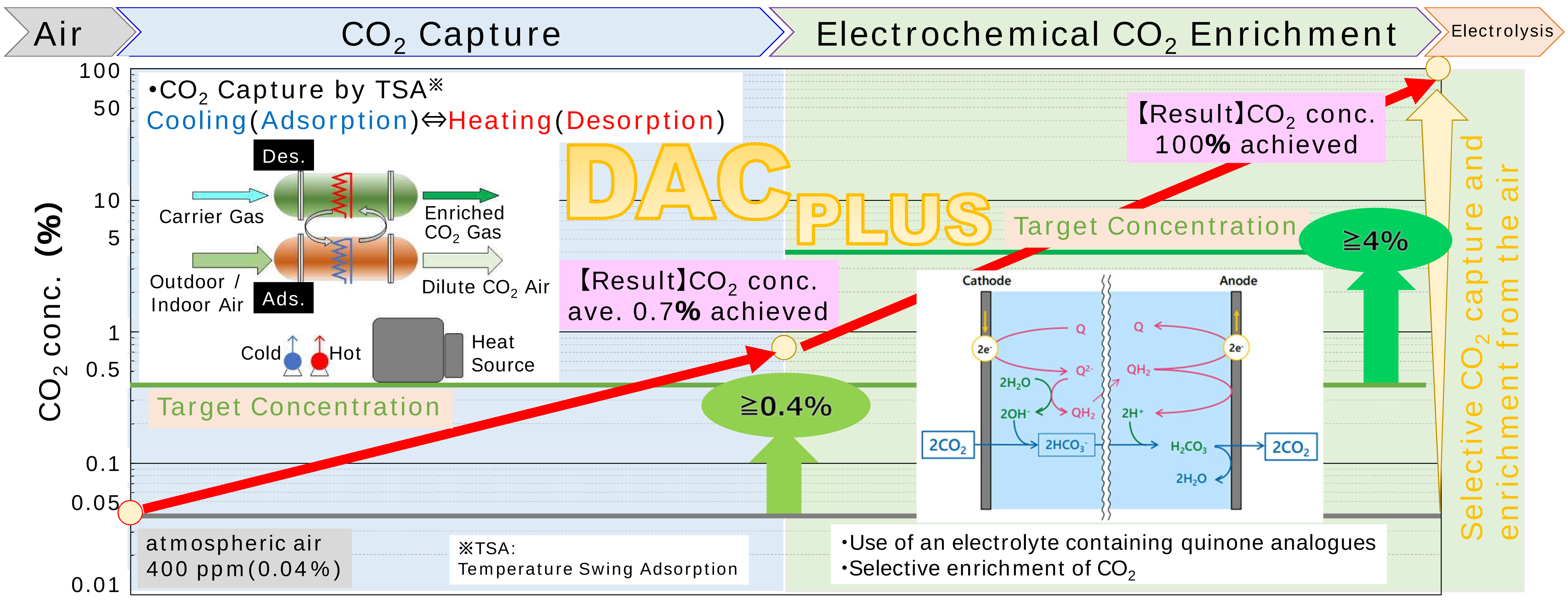
東大先端研 大阪大学 OSAKA UNIVERSITY RIKEN UBE Corporation SHIMIZU CORPORATION CHIYODA CORPORATION FURUKAWA ELECTRIC

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

Theme : CO_2 Capture and Enrichment

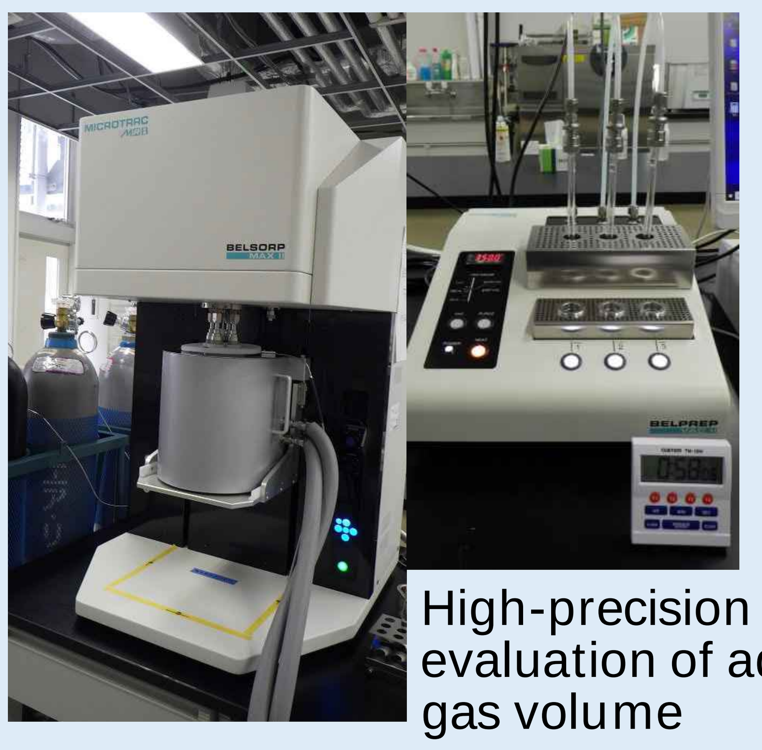
Organization : Osaka University / Shimizu Corporation
Contact : nakanishi.shuji.es@osaka-u.ac.jp / yukinori.fuse@shimz.co.jp

1. Research Outline

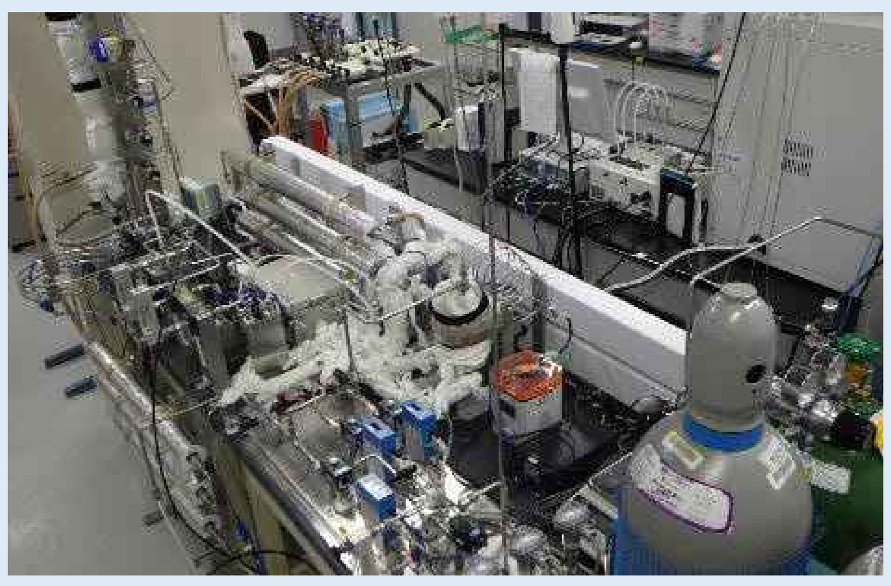


2-1. Progress

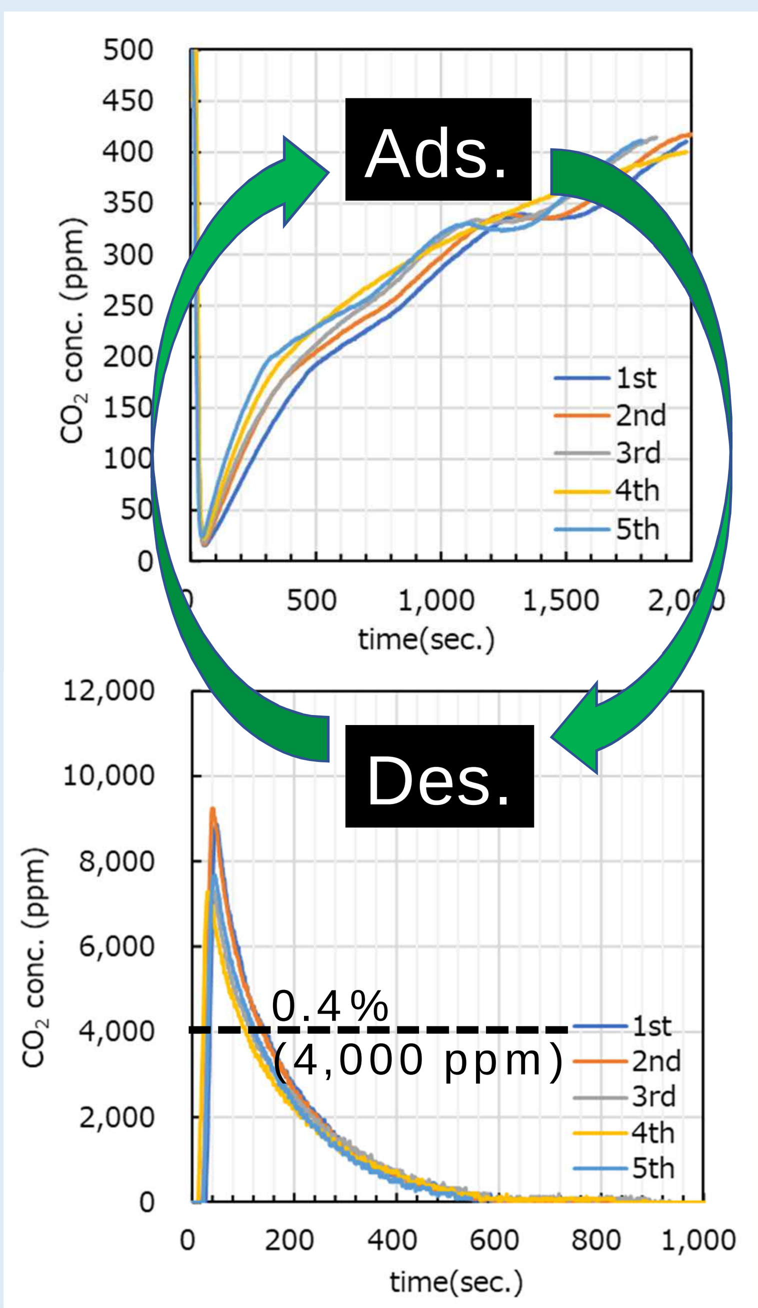
- ☐ Selection of effective adsorbents
- ☐ 10-fold enrichment of atmospheric CO_2
- ☐ Adsorption/desorption cycle performance



High-precision evaluation of adsorbed gas volume



System for evaluating adsorption/desorption cycle performance



Ex.) Outlet CO_2 conc. upon repeated adsorption/desorption
Adsorption : 15℃ CO_2 400ppm
Desorption : 90℃

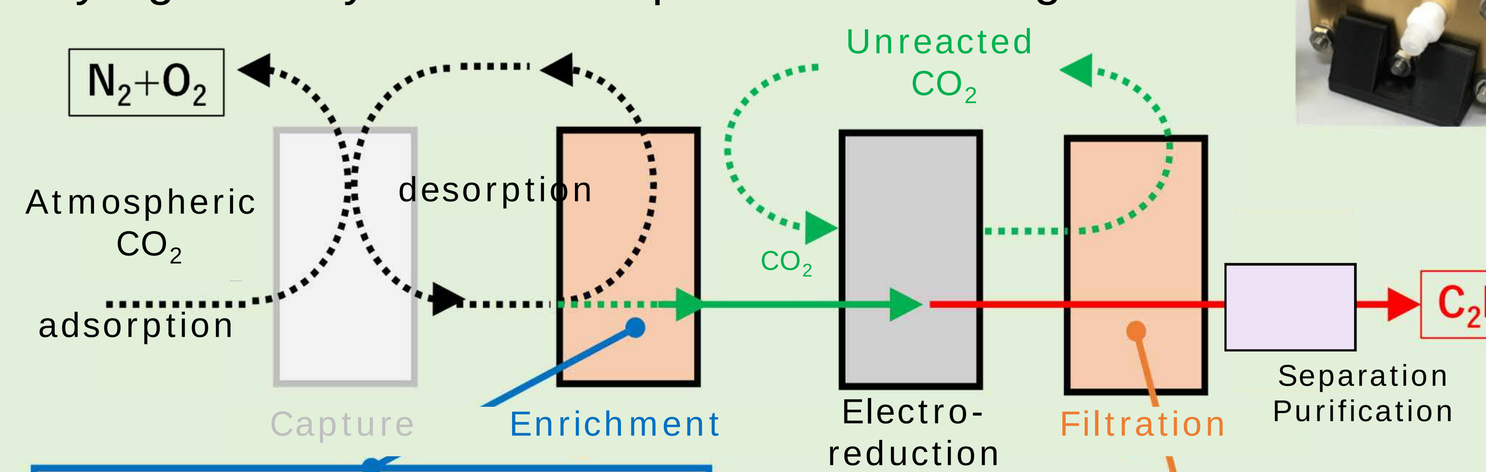
3-1. Future Works

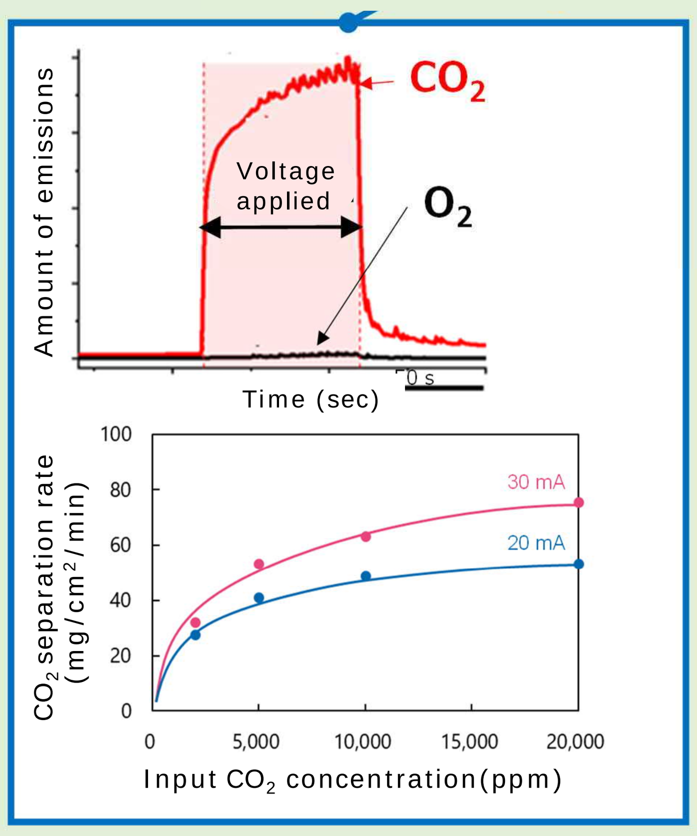
- ☐ Design of a prototype system
- ☐ Appropriate selection of humidity-tolerant adsorbents
- ☐ Optimization of the adsorption/desorption cycles
- ☐ Development of high-efficiency heat sources (eg. heat pump)
- ☐ Design of the interface compatible with downstream processes

Prototype (image)

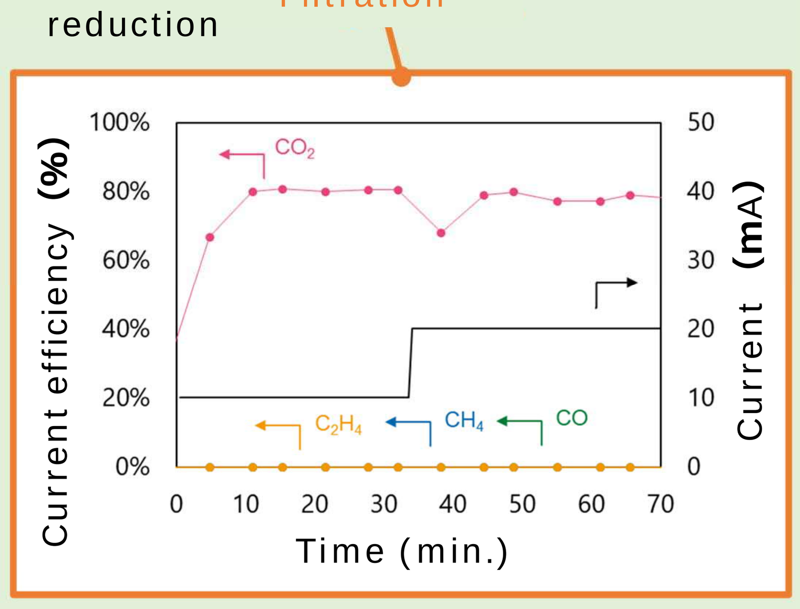
2-2. Progress

- ☐ 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
- ☐ Reducing the cell voltage by improving the electrode and reactor structures
- ☐ Identifying the key factors for performance degradation





CO_2 enrichment from CO_2/O_2 mixture



Selective separation of CO_2 from the mixture of CO_2/C_2H_4

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
Aqueous electrolyte, upgraded (Electrodes are physically attached to the separator)	2.1 V (Target : 1.1 V)	Low voltage	Low durability

3-2. Future Works

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

No. A-2-3E

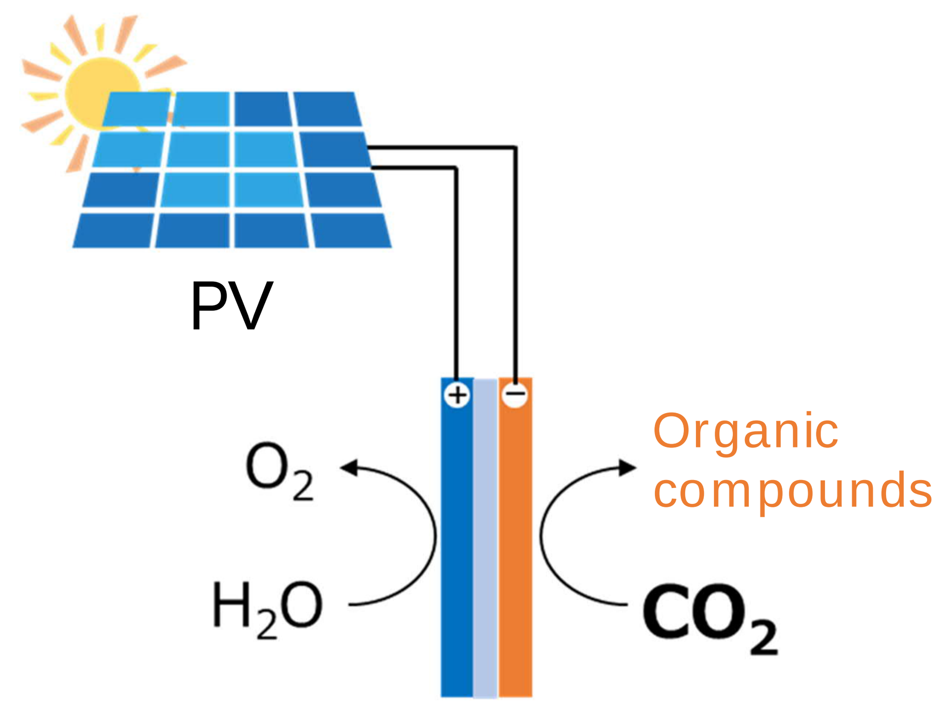
PJ : Integrated Electrochemical Systems for Scalable CO_2 Conversion to Chemical Feedstocks

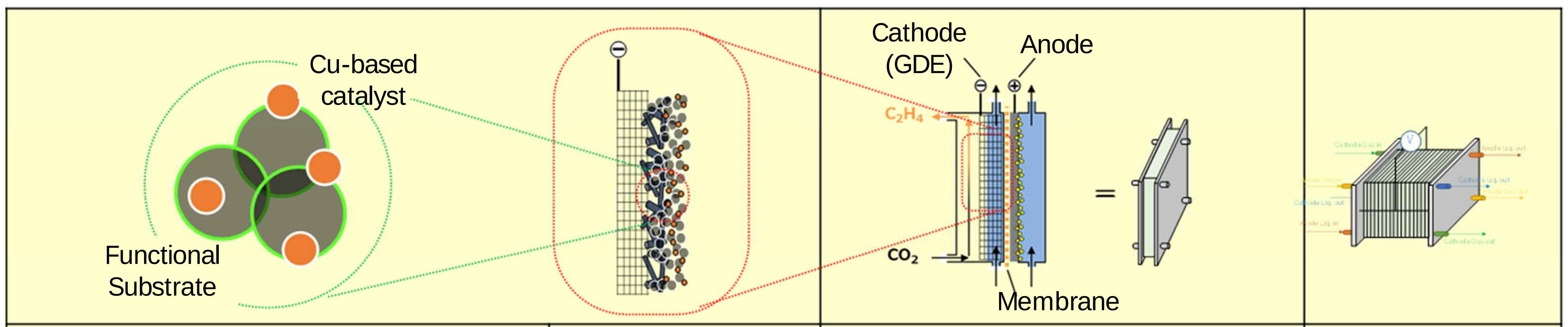
Theme : CO_2 Electrolysis

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

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

1. Research Outline





Catalyst		Gas-Diffusion Electrode (GDE)	MEA-based reactor		Stack
Substrate	Cu-based materials		Reactor	Membrane	
UBE	Furukawa Electric	Osaka University	RIKEN	Collaborative member	New member

2. Progress

1) Ultra-high rate electrolysis

- High current density (2,000 mA/cm²) at the 80% of FE (for C2+ products) was achieved.

2) High FE and low operation voltage

- 60% of FE (C_2H_4) was achieved at the 4 V of operation voltage.

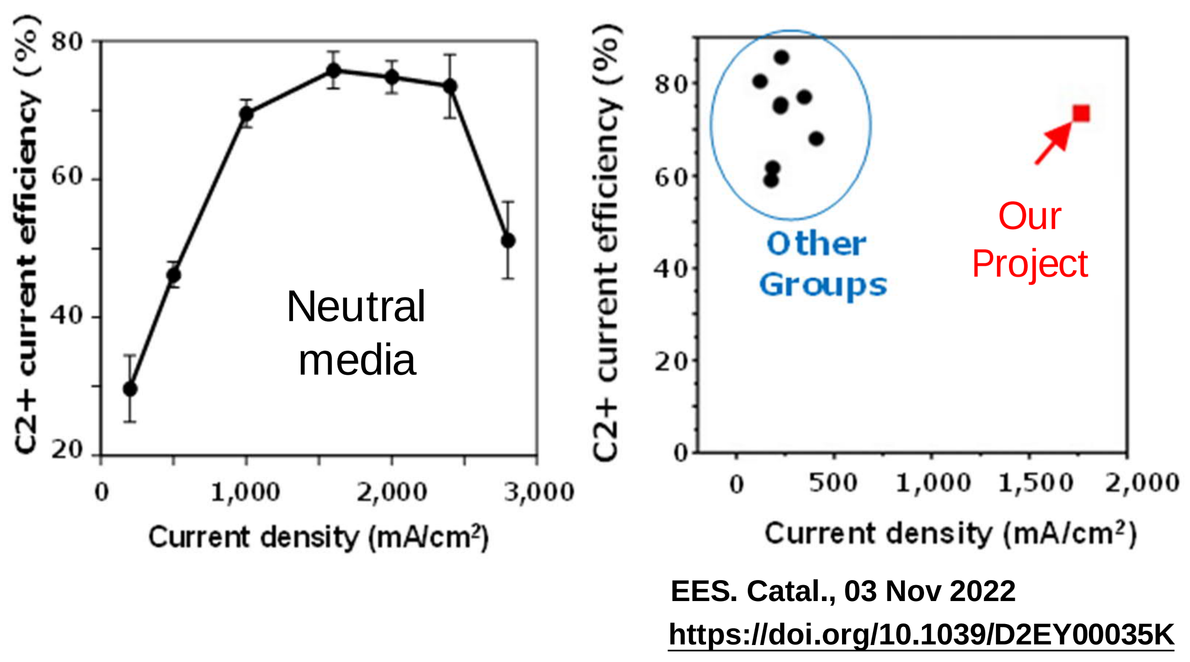
※FE : faradaic efficiency

The world record

FY22 target cleared 100 mA/cm²

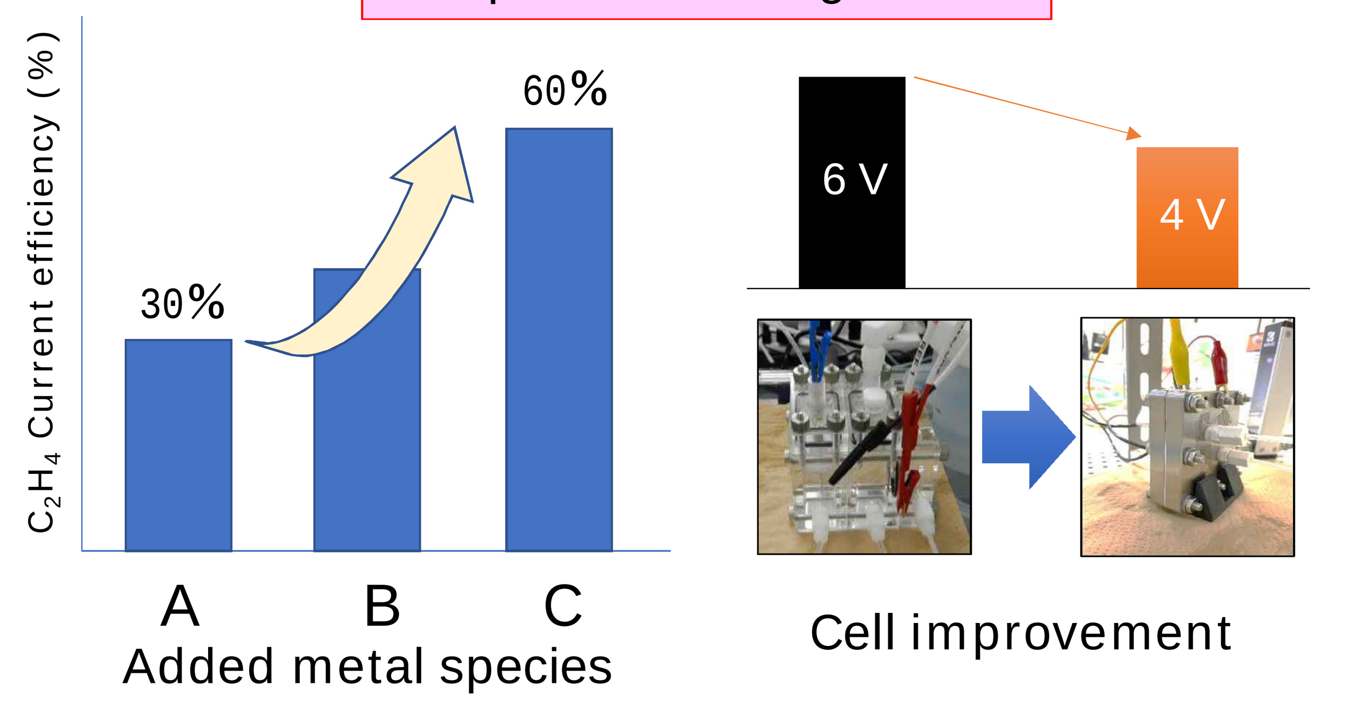
FY24 KPI target cleared CO_2 emission (t-CO_2/t-C_2H_4) +0.5〜+1.0

- FE for C2+: **80%**
- Current density: 2,000 mA/cm²



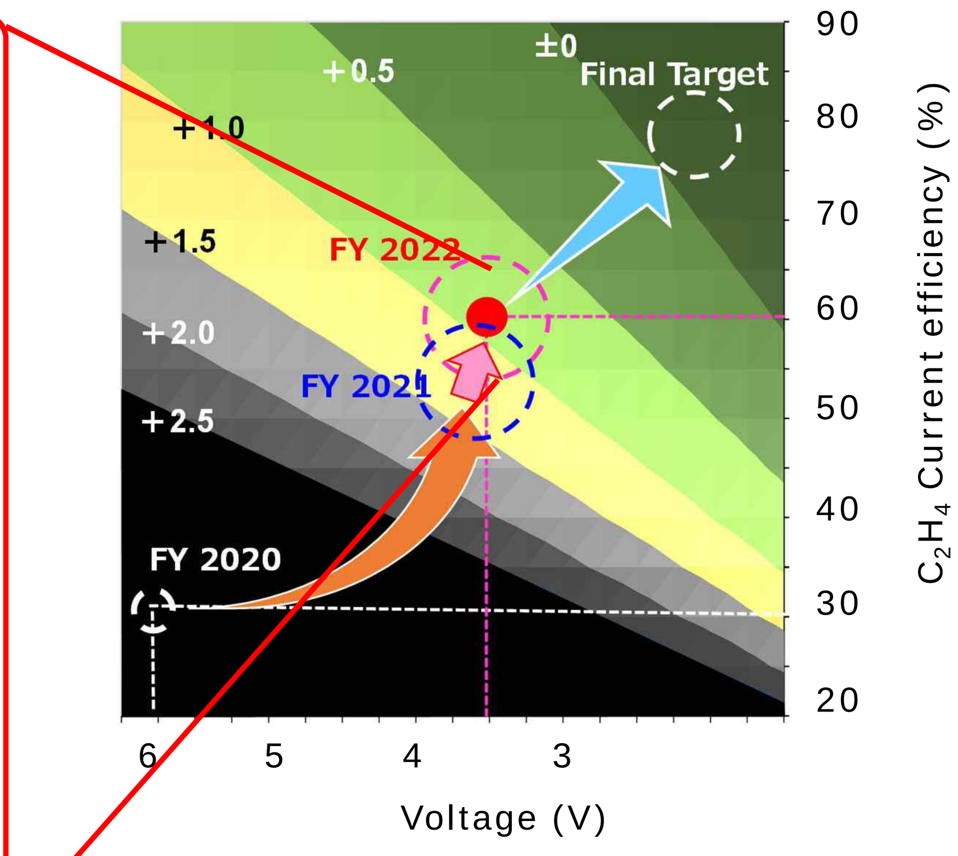
Achievement of both high FE and high current density

- FE for C_2H_4: **60%**
- Operation voltage: **4** V



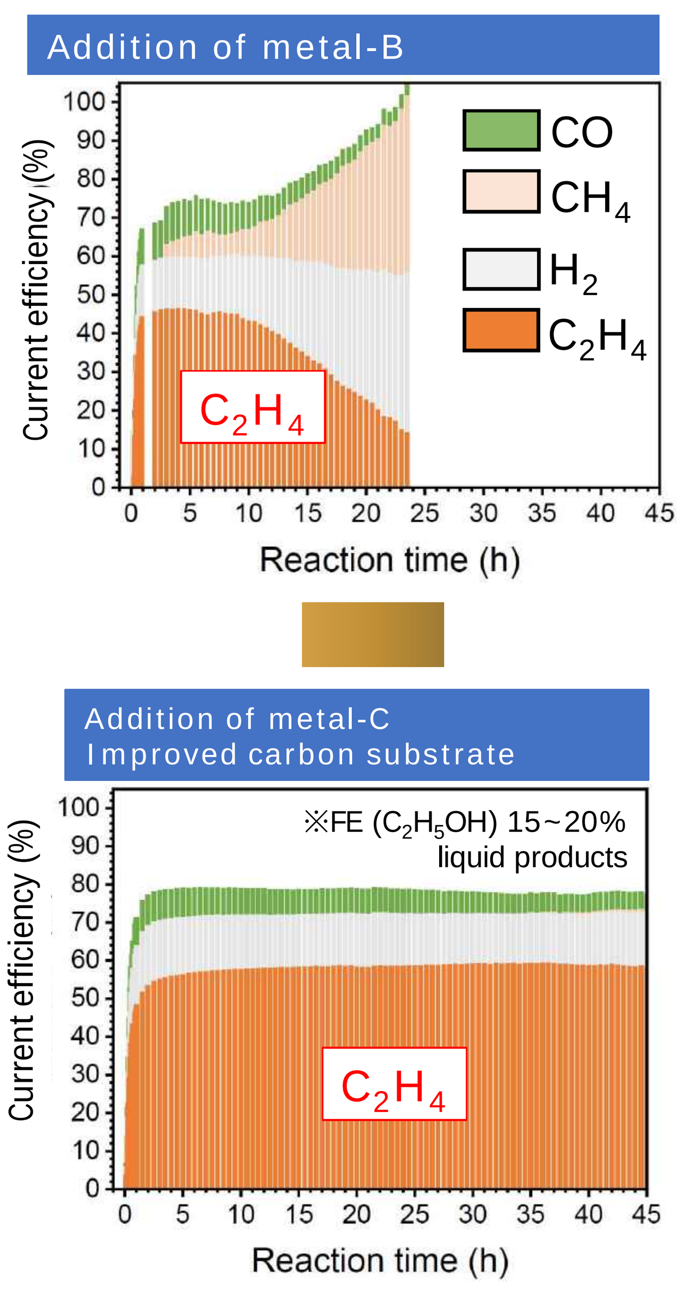
Improved reaction selectivity

Reduced operation voltage



CO_2 emissions from the whole system (t-CO_2/t-C_2H_4)

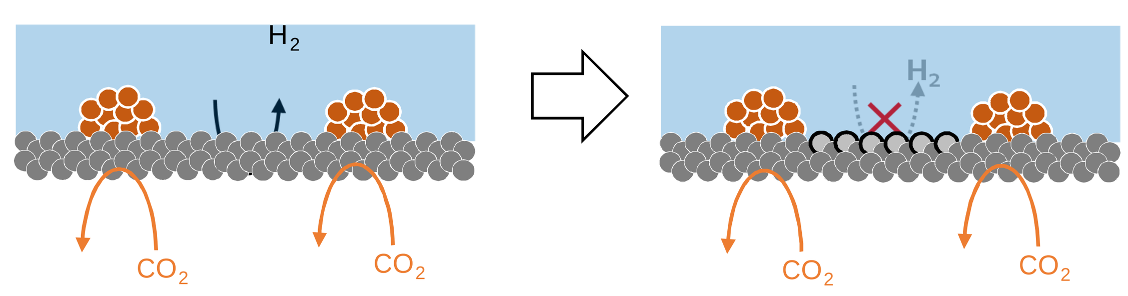
3) Achievement of both FE (for C_2H_4) and stability



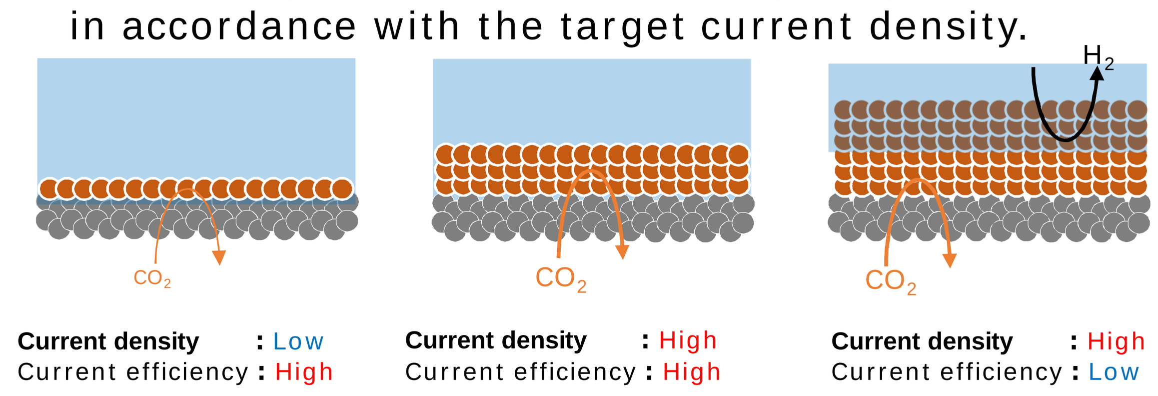
- Enhancement in C_2H_4 current efficiency & stability

4) Strategies for enhancing FE (for C_2H_4)

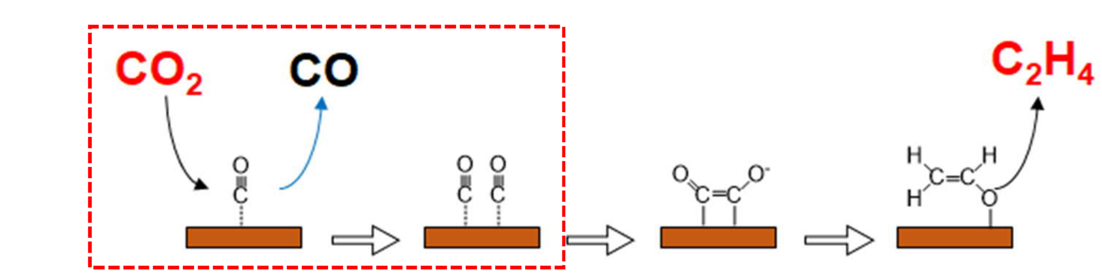
① Suppression of parasitic H_2 evolution by surface modification of a carbon substrate.



② Thickness optimization of the catalyst layer in accordance with the target current density.



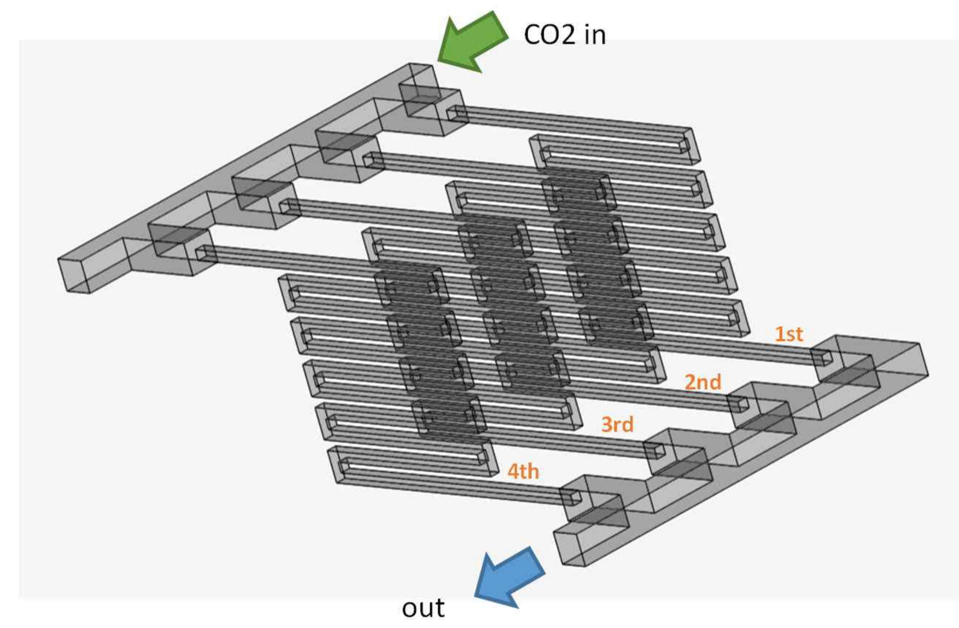
③ Increasing the local concentration of CO



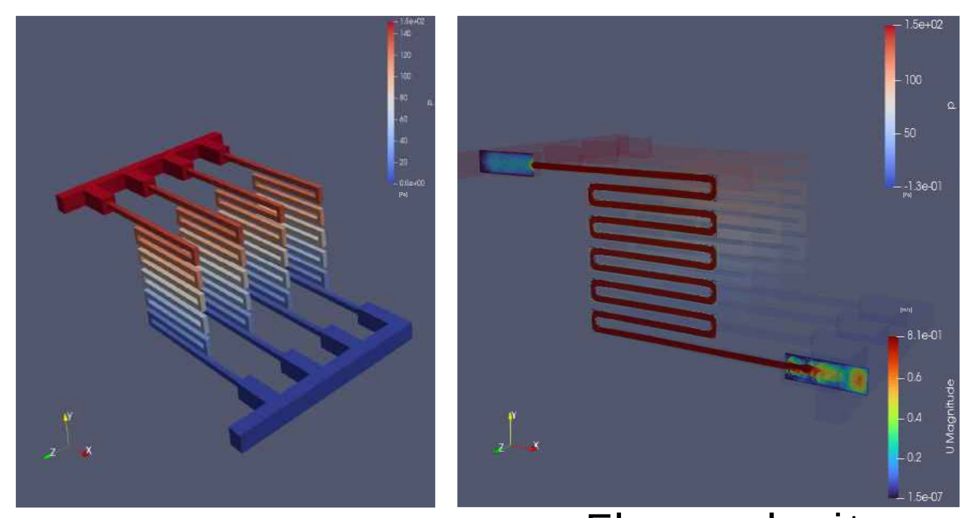
Promoting dimerization of CO

- CO dimerization is the key for the improvement of C_2H_4 generation
- Preparation of an appropriate porous electrode that allows to increase the local CO concentration

5) Development of cell stacks



CFD Results



Pressure distribution

Flow velocity distribution

- CFD evaluation of gas/liquid distribution with common inlet/outlet flow channels

3. Future Works

- Improving the FE (for C_2H_4) based on the mechanism of electro-catalytic reactions
- Preparing electrodes that satisfy all the required factors simultaneously (i.e., high FE, high current density, and high stability)
- Developing scalable membrane electrode assemblies (MEAs) that can be installed in cell stacks

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

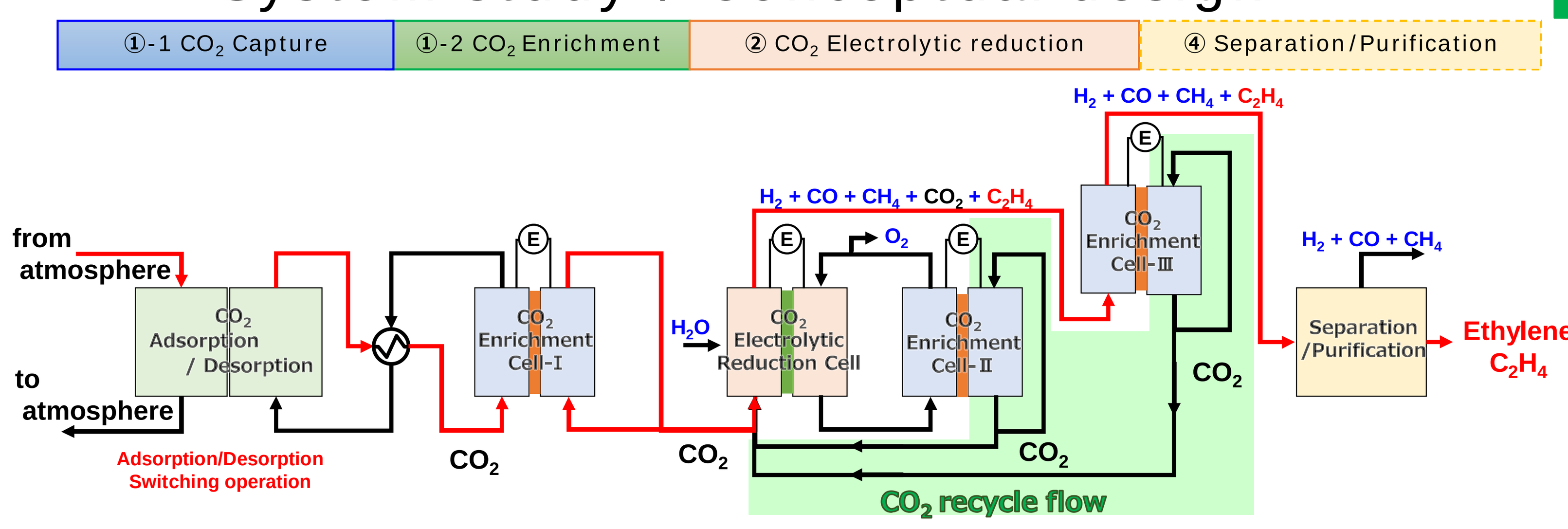


Figure 1. Design of an integrated system

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

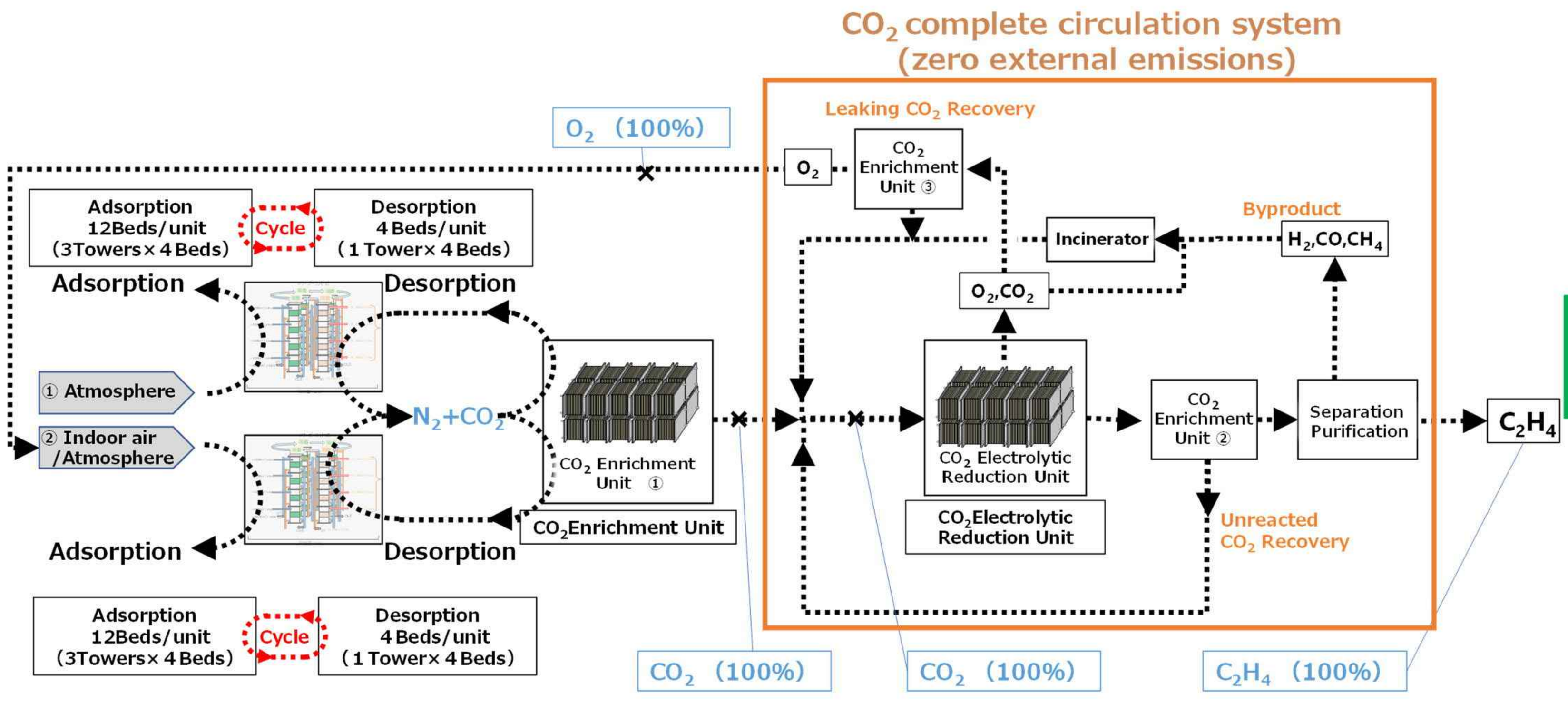


Figure 2. System diagram (excerpt)

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

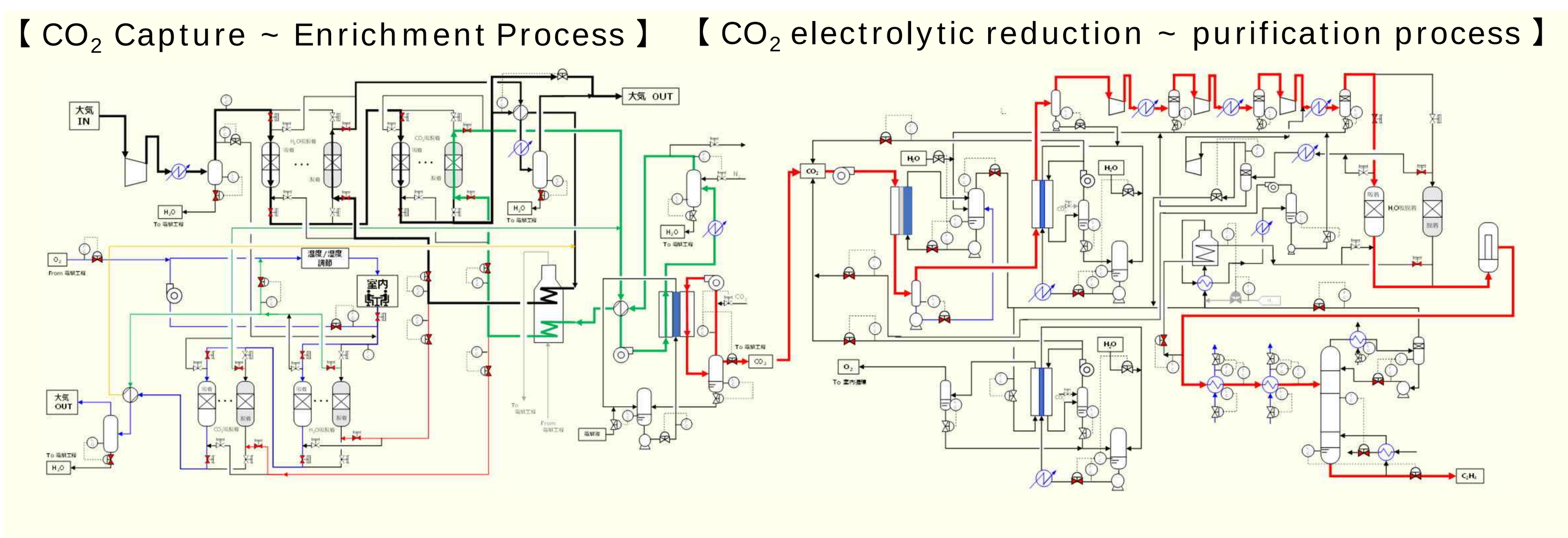


Figure 3. Process flow diagram (Conceptual design)

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

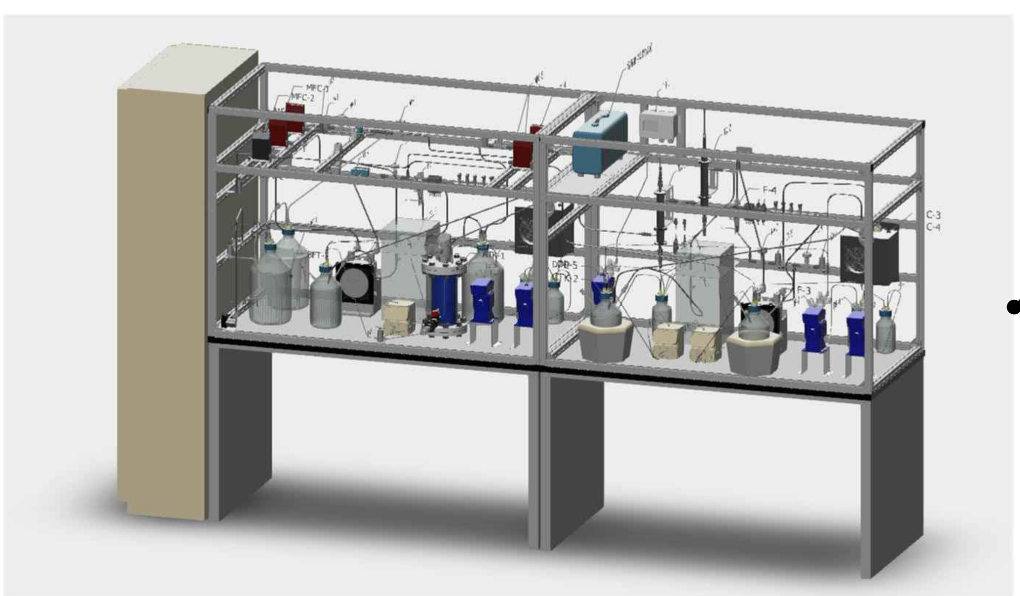
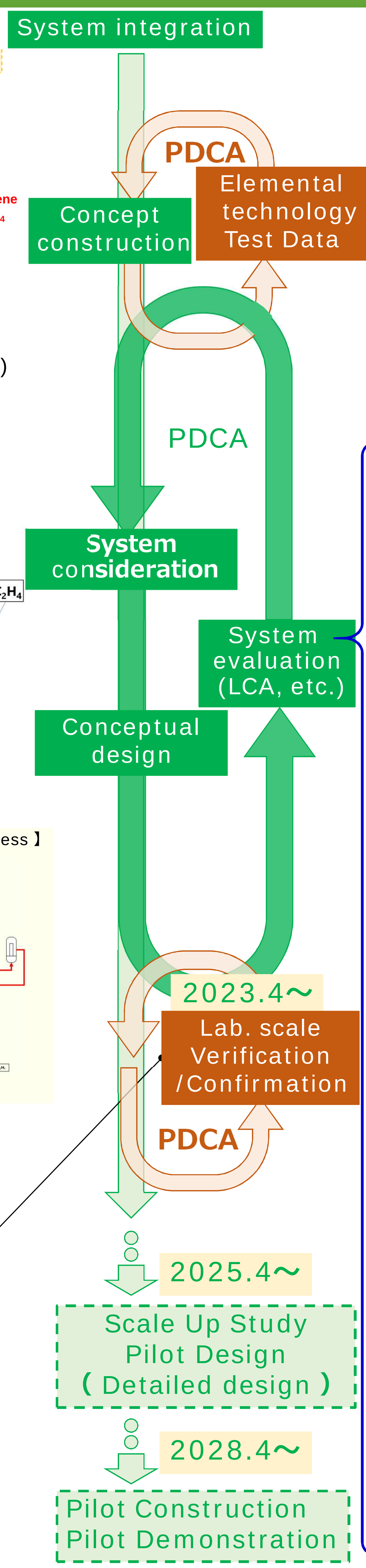


Figure 4. "CO_2 Enrichment + CO_2 Electrolysis" Continuous Benchmarking Equipment (scheduled for completion in February 2023)



System evaluation (LCA, etc.)

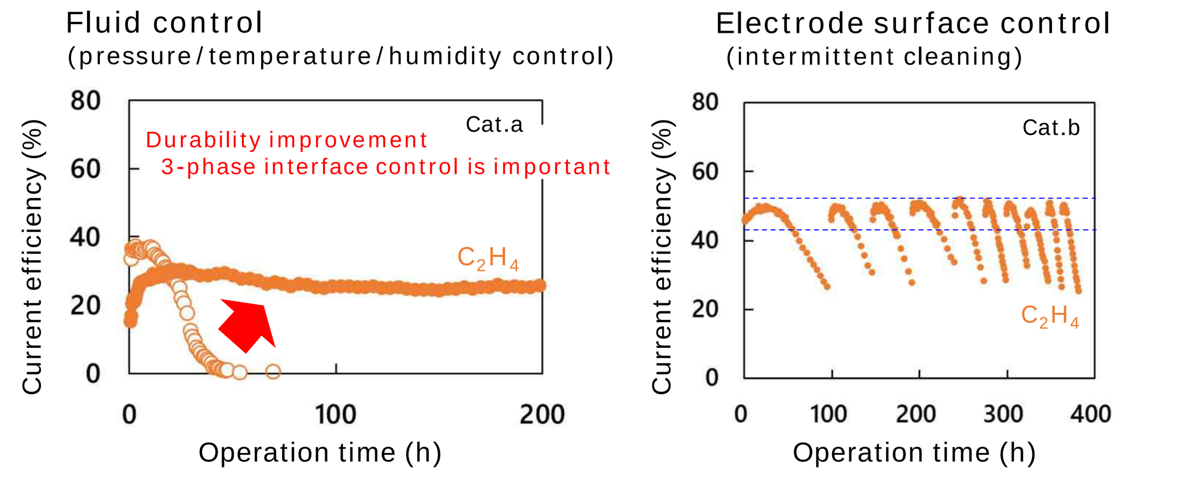


Figure 5. Evaluation of stability improvement through system control

☐ System control for continuous operation (Fig. 5)

➡ Effectiveness of operation control is confirmed.

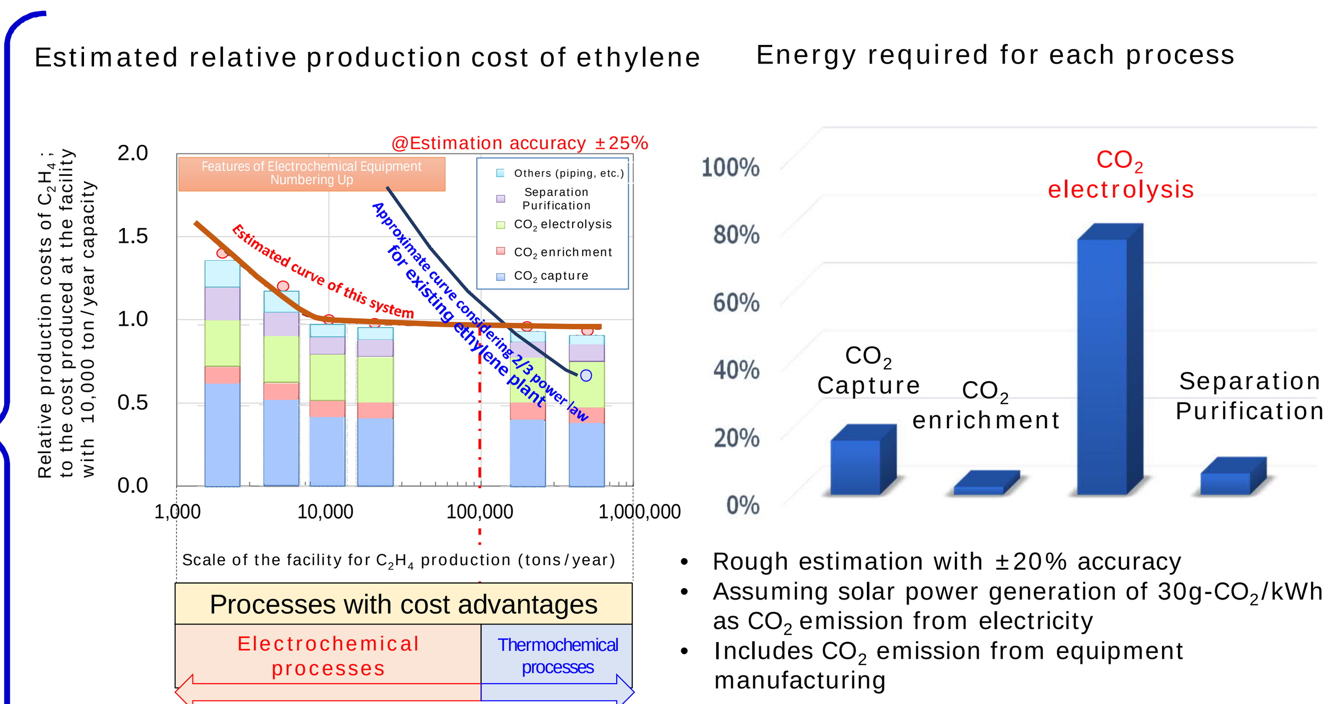


Figure 6. Scaling and energy demand for ethylene production plant

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

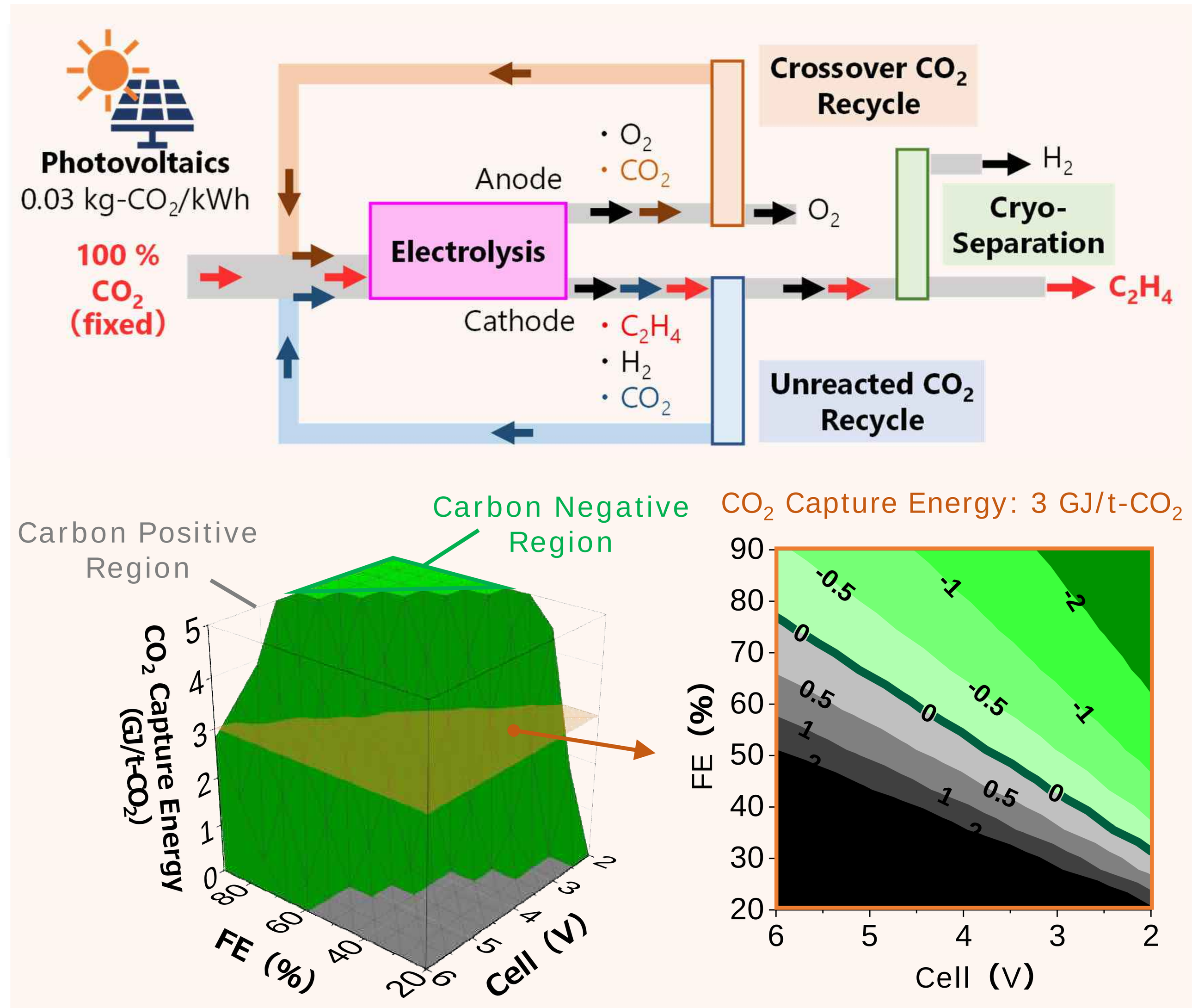


Figure 7. Evaluation of CO_2 emission in the electrolytic reduction process with CO_2 recycling

☐ Operating conditions necessary to achieve carbon negativity (emitted CO_2 < fixed CO_2) is identified (Fig. 7)

3. Future Works

- ☐ Verification and confirmation on a lab. scale using the "CO_2 Enrichment + CO_2 Electrolysis" continuous evaluation system (Fig. 4) in the following fiscal year and beyond ➡ Identification of issues
- ☐ 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)