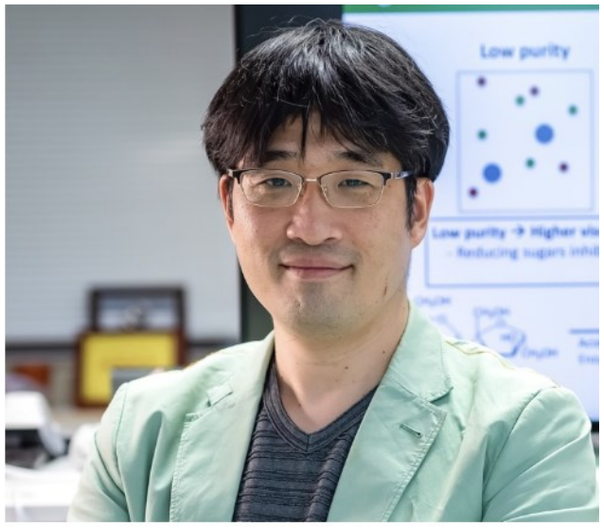
Development of Combined Carbon Capture and Conversion (quad-C) Systems for the Utilization of Atmospheric CO_2

Presenter： Dr. FUKUSHIMA Yasuhiro (Tohoku University)



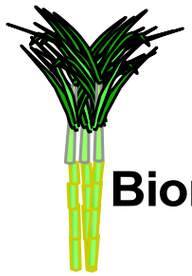
PM： Dr. Fukushima Yasuhiro
Tohoku University

Implementing Organizations：
Tohoku University
Osaka City University
Renaissance Energy Corporation

Target and Strategies

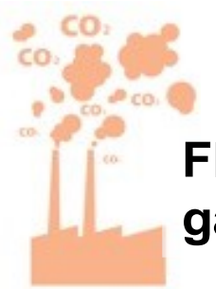
- **Production of Chemicals under Carbon Neutral Society**
  - **Energy Saving**
  - **Hydrogen Saving**

Strategy 1
Produce chemicals that includes **Carbonyl Group** in its structure
→ potentially energy saving



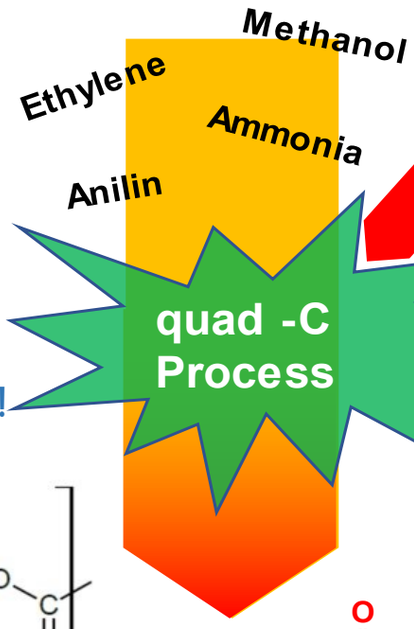
Biomass

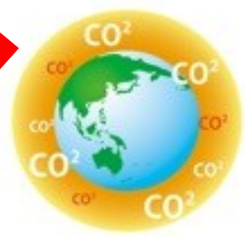
Recycled Materials



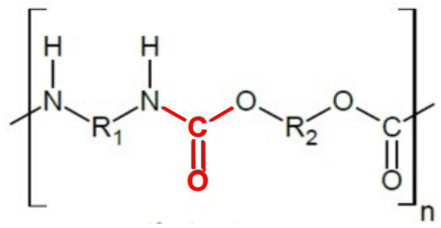
Flue gas

Insert CO_2 as a carbonyl group in product chemicals
→ Highly energy-saving (non-reductive) route !!

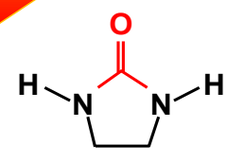




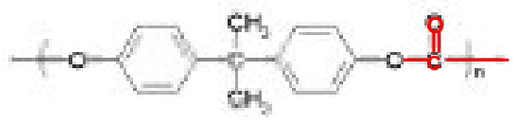
Air



Polyurethane



Urea Derivatives



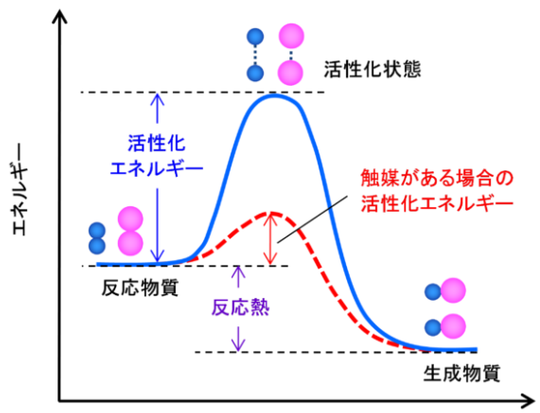
Polycarbonate

Target and Strategies

Strategy 2
Feed CO_2 to the conversion reaction system using
elements of reaction

$A + CO_2 \rightarrow P + B$

Substrate　Product　Byproduct



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ホームページより

$A + CO_2 \rightleftharpoons P + B$

Substrate
Reactant converted to yield the product

Catalyst
Accelerates the reaction

Conversion Enhancer
Removes byproduct, shifts the equilibrium

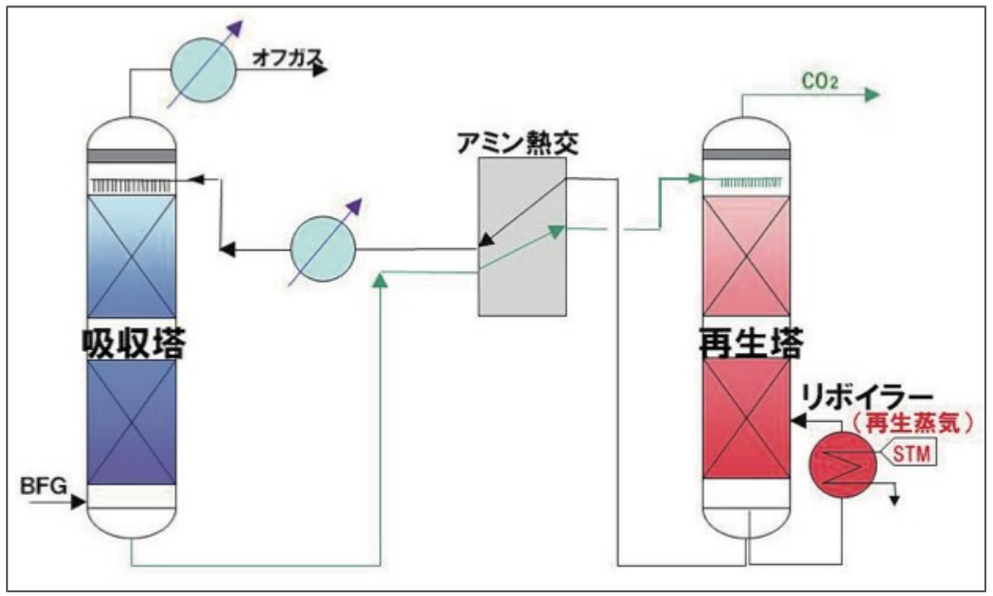
Dual Function Materials (DFMs)

amines: absorbent + Substrate
CeO_2: Adsorbent + Catalyst
LDH: Adsorbent + Conversion Enhancer (+ Catalyst)

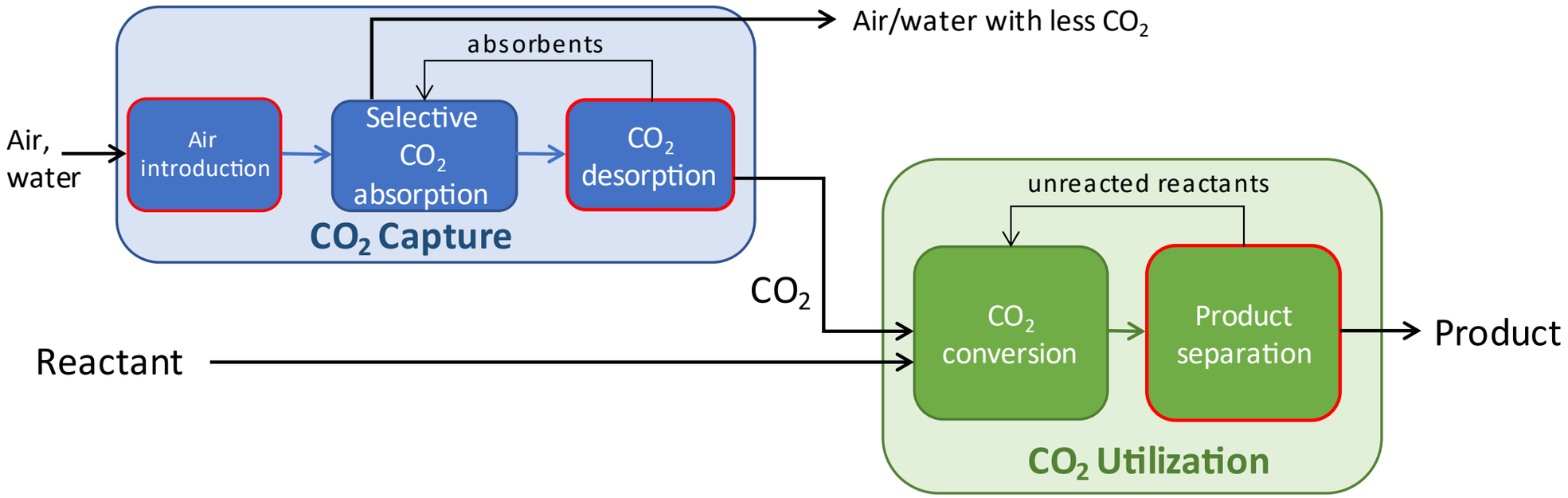
2020-2022 : Understand characteristics of various DFMs.
Explore process structures to unleash the potential of process systems intensification realized by the DFMs.

Reference DAC/CCU process

https://www.theguardian.com/environment/2018/feb/04/carbon-emissions-negative-emissions-technologies-capture-storage-bill-gates



Mimura et al. 新日鐵エンジニアリング技報, Vol.3 (2012), pp.25-30



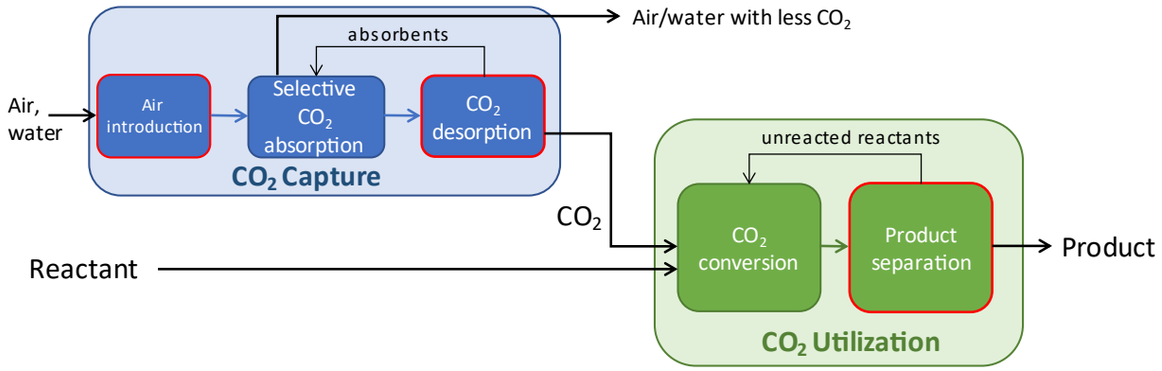
A double effect distillation plant, Wikipedia commons, CC 3.0

Processes in red are known to be energy intensive!

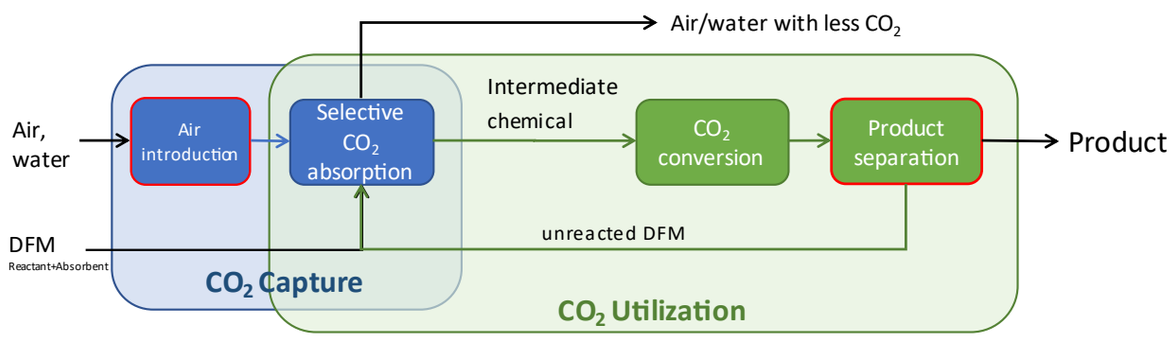
quad-C: Combined Carbon Capture and Conversion

DFMs allow integration of Capture and Conversion processes, eliminating Desorption process

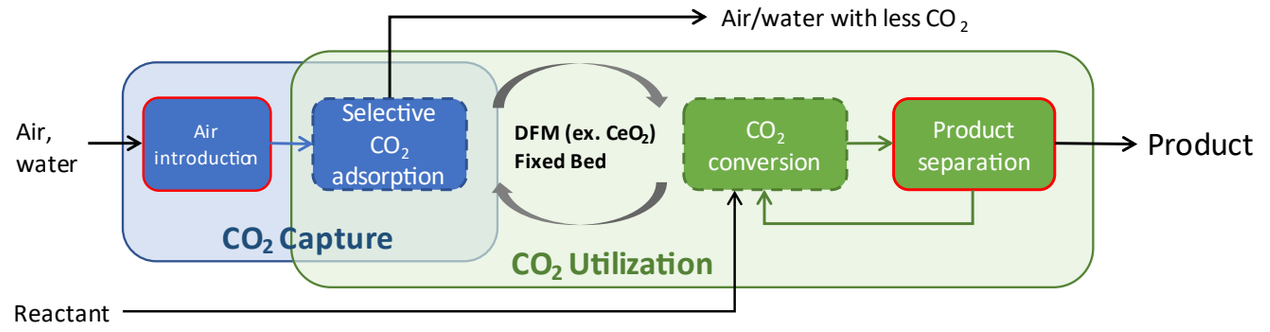
Reference process



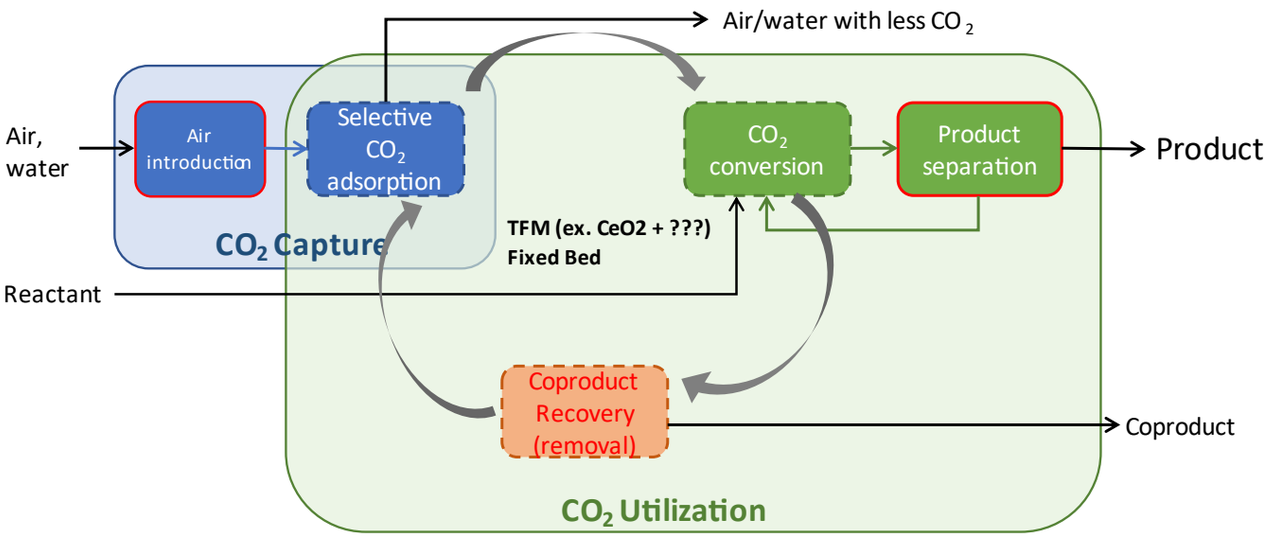
Type I: Amines and Alcohols as DFM (Substrate + Absorbent)



Type II: Metal oxides as DFM (adsorbent + catalyst)



Type III: Adsorbent, Catalyst, and Conversion Enhancer



Work items and current achievements

Exploration of reactants and catalysts (ERC)

- ✓ Various substrates （Amines, Alcohols）
- ✓ Yield enhancement, reaction rates, control over selectivity
- ✓ Influence of impurities, degradation of catalysts
- ✓ CO_2 sorption mechanisms（quantity, stability）, reactivity, desorption of products in relation to various conditions/procedures

Prof. Tomishige
Tohoku University

Prof. Yabushita
Tohoku University

Prof. Tamura
Osaka City University

Successfully yield urea derivatives by feeding catalysts with various amines and alcohols that chemically absorbed CO_2.

Improved understanding on:

- How CO_2 is adsorbed on the surface
- How stable is the adsorbed CO2
- How can we control the structure of adsorption

Work items and Current Achievements

Reaction processes (RP)

Type I

- ➢ Membrane (Gas/Gas)
  → Avoid loss of DFM
- ➢ Membrane (Gas/Liquid)
  → Drive separation by reaction with DFM on permeate side

✓ Discovery of mechanisms
- Selective sorption of CO_2
- Release of CO2 on permeate side

Type II, III

- ➢ Capture from air or water using solid DFM, remove by feeding substrate to cause reaction

✓ Exploration of DFMs and Evaluate the correlation between:
- Capacities：sorption, catalyzing, repetitive use, durability
- Conditions：CO_2 conc., Temp., LDH preparation、LDH pelletization, moisture, reactants

Establish foundations for high performance modules

Module development (MD)

Type I

- ➢ Membrane fabrication
- ➢ Optimization (thickness, etc…)
- ➢ Simulation

Type II, III

- ➢ Parameters to design the column
- ➢ Continuous column experiments with varied scales
- ➢ Simulation

Process for feeding the substrates with CO_2
Acquire original data for connecting the modules

Work items and Current Achievements

Reaction processes (RP)

Type II, III

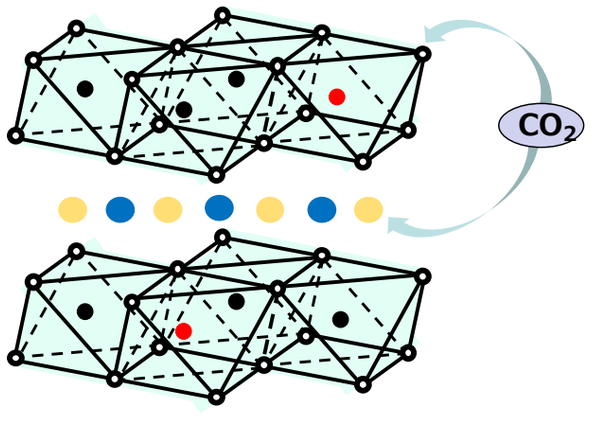
- ➢ Capture from air or water using solid DFM, remove by feeding substrate to cause reaction
- ✓ Exploration of DFMs and Evaluate the correlation between:
  - Capacities：sorption, catalyzing, repetitive use, durability
  - Conditions：CO_2 conc., Temp., LDH preparation、LDH palletization, moisture, reactants

Prof. Kameda
Tohoku Univ.

Adj. Prof. Uchida
Tohoku Univ.

CO_2 sorption and desorption

Desorption at which T for which adsorption type？



CO_2 recovery rate and ratio at low concentration？

Influence of moisture?

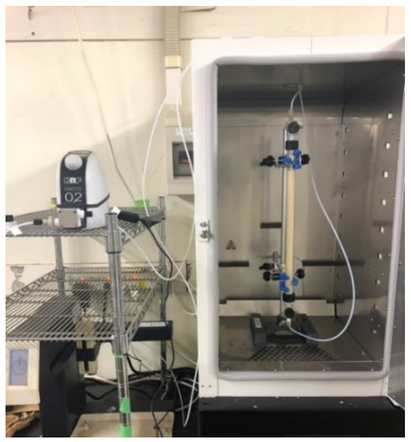
Confirmed and quantified intermediate substance produced when CO_2-adsorbed-LDH is fed by the substrate.

Work items and Current Achievements

Module development (MD)

Type II, III

- Data for column system design
- Experiments with varied scale
- Simulation



Prof. Kitakawa
Tohoku University

Prof. Takahashi
Tohoku University

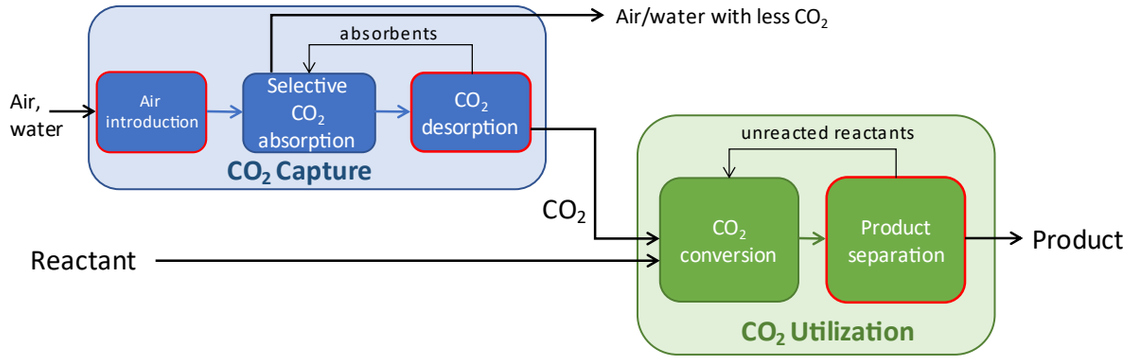
Prof. Hiromori
Tohoku University

Prof. Nakagaki
(Waseda University)

Work items and Current Achievements

Process simulation and Technoeconomic assessment (PSTEA)

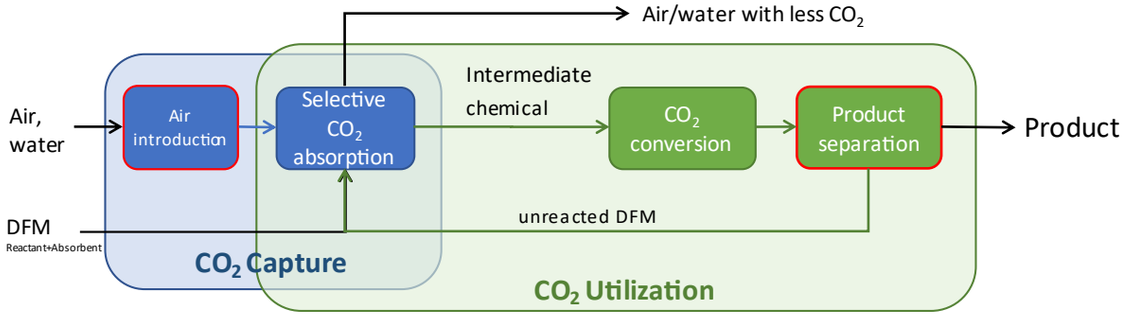
Reference Process



DAC using Mg oxides

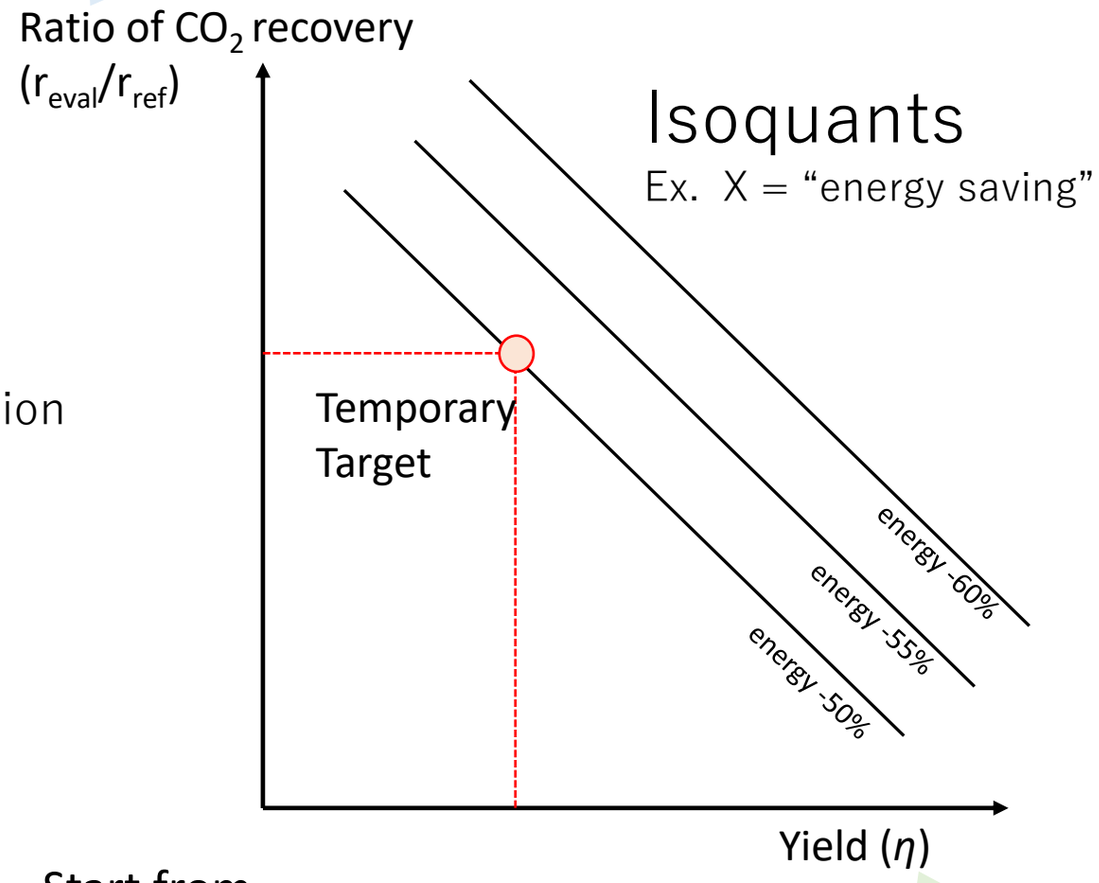
Homogeneous conversion (AIST process)

Type I: Amines and Alcohols as DFM (Substrate + Absorbent)



Our Process

Ex. of Target set for RP Team



Start from
- Target set from the profession point of view

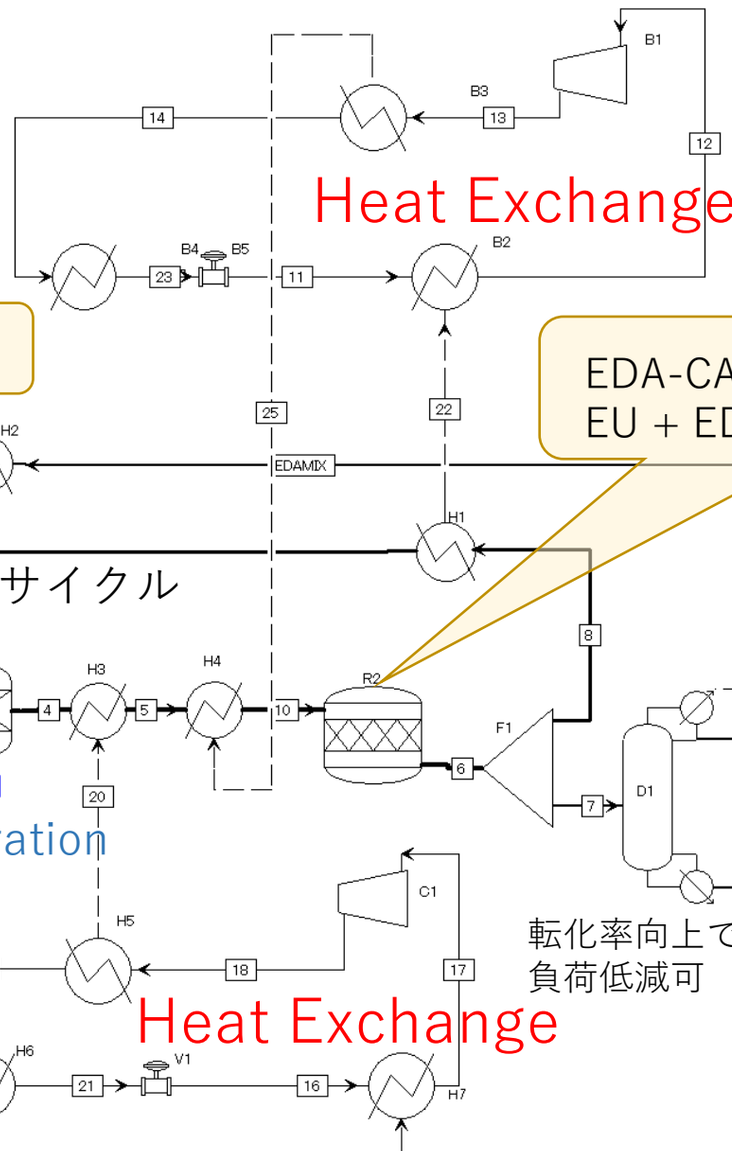
… and shift to
- Target deduced from the required systems performance

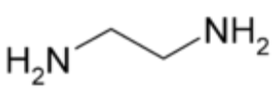
Ex. of Target set for ERC teaam

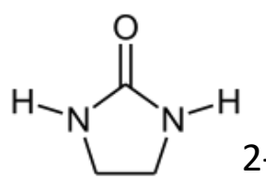
Prof. Fukushima
Tohoku University

Prof. Ni
Tohoku University

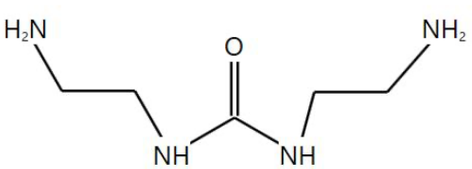
Adj. Prof. Matsuda
Tohoku University
(Yamagata University)







2-imidazolidinone

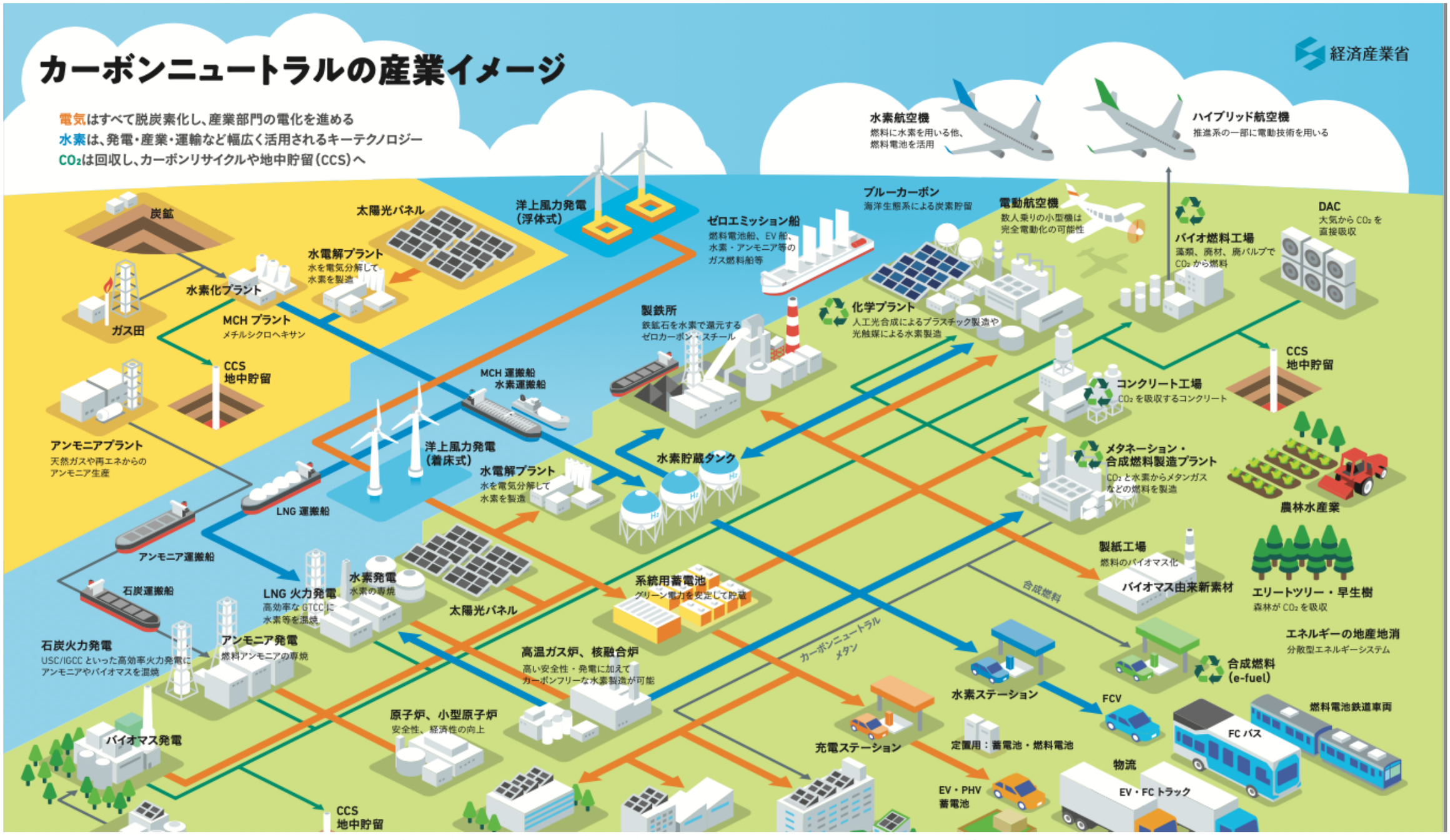


N,N′-bis(2-Aminoethyl)urea

Final Target (2029)

Construct Pilot Plant：

- Acquire data and process design that leads to commercialization for one or more carbonyl-containing compound with low energy consumption
- Set up foundation for experiments/simulation for designing other quad-C processes



https://www.meti.go.jp/press/2020/12/20201225012/20201225012-4.pdf

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