CO_2 capture, storage and conversion in The Netherlands

ENLENS Future of Energy Seminar October 2024

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HOMKAT

SOLE$_2$CAT

Motivation

Real waste feedstocks

vs.

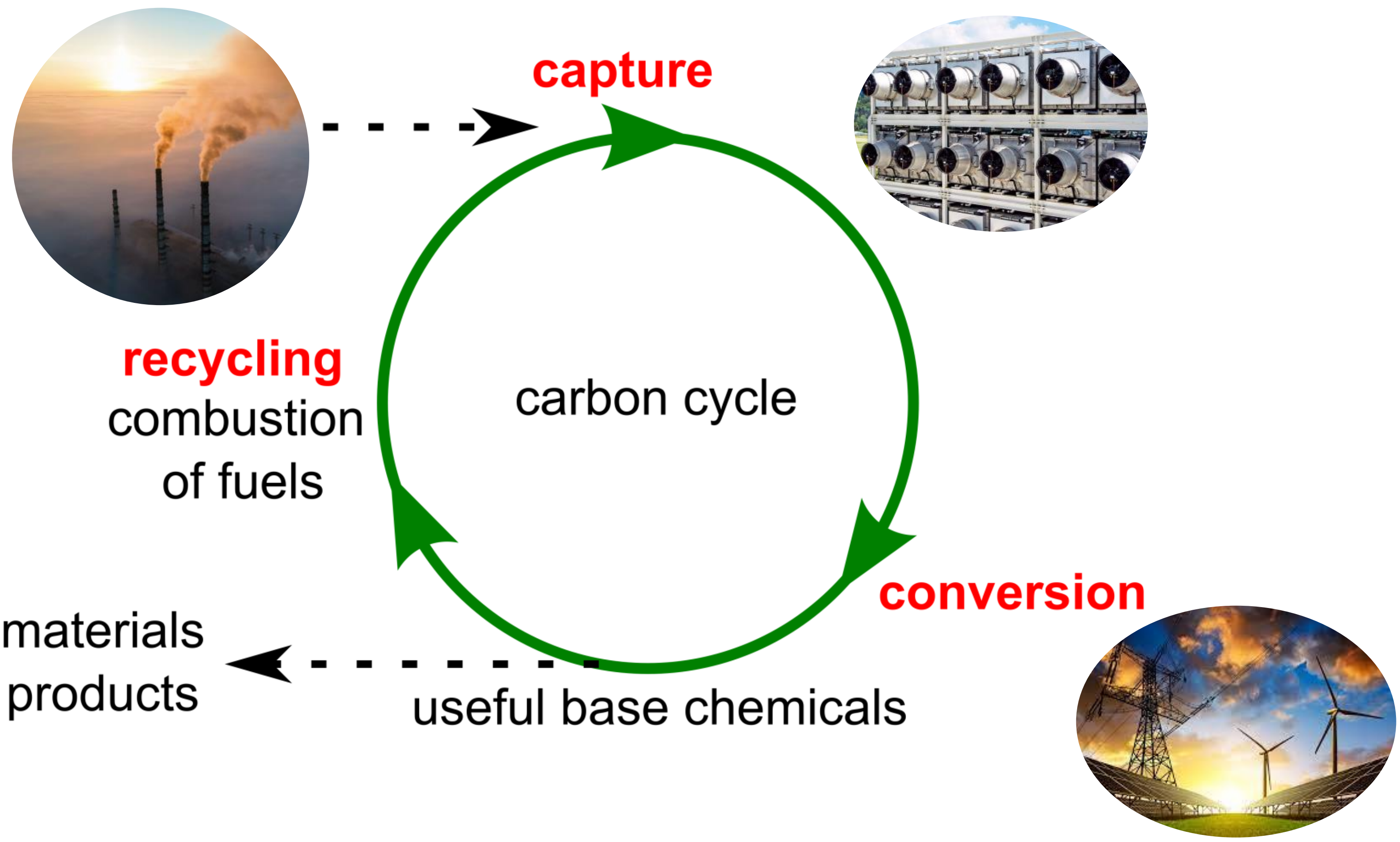
Catalysis today

- Create highly selective and robust catalysts
- Deal with **impure** reaction mixtures
- Make catalysts work with **dilute** substrate concentrations

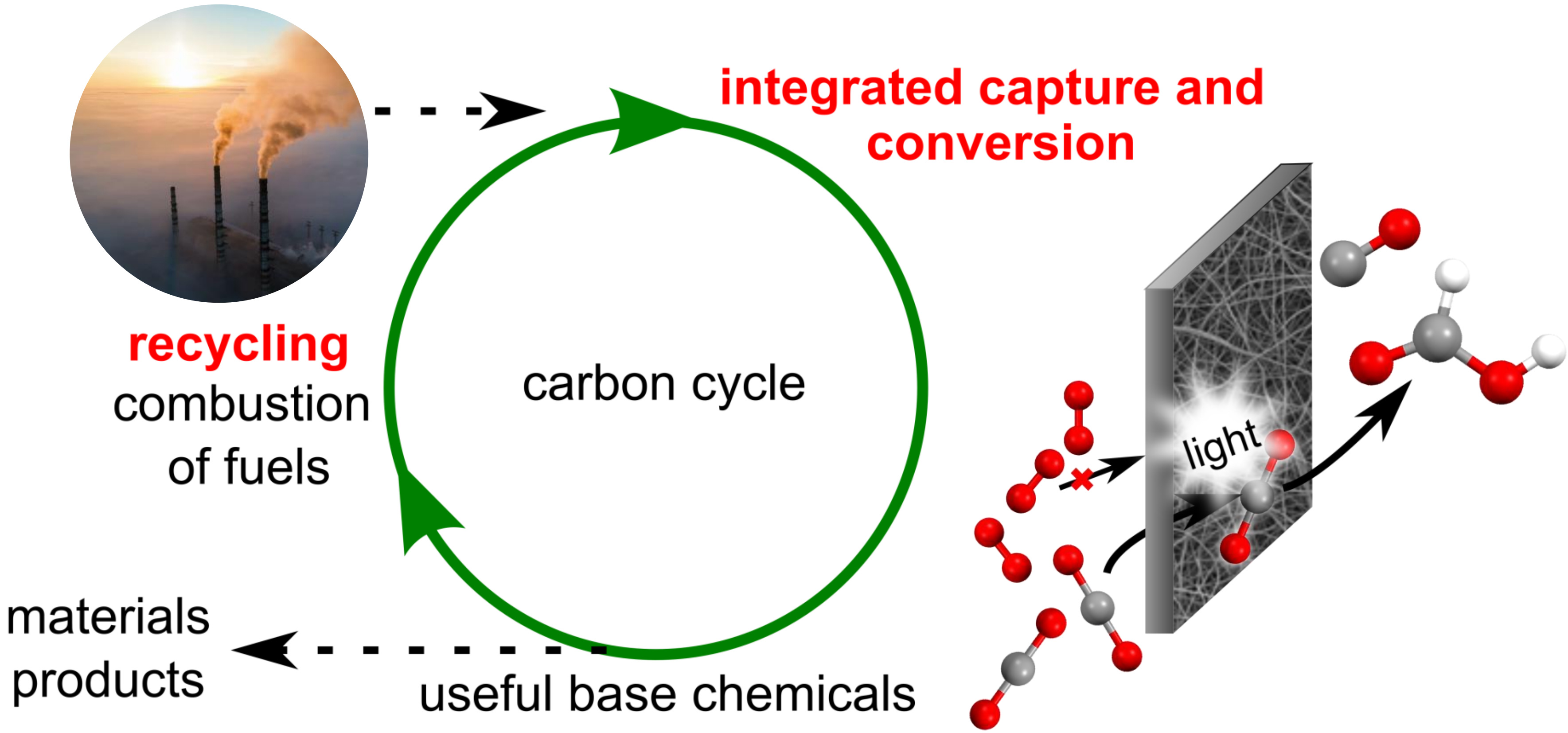
-> Paradigm shift from pure, concentrated feedstocks to real waste!

Example: CO_2 recycling

Goal: net zero CO_2 emissions by 2050!



Example: CO_2 recycling



Outline

- Brief explanation of chemical principles CO_2 capture
- Possibilities for large scale storage
- Potential ways to valorize
- Discussion points

Carbon-neutral power (at least 10 TW required by 2050)

Capture and Storage of CO_2

SMART NEWS

World's Largest Carbon Capture Plant Opens in Iceland

'Orca' will use geothermal energy to pull thousands of metric tons of carbon dioxide out of the atmosphere and pump it underground

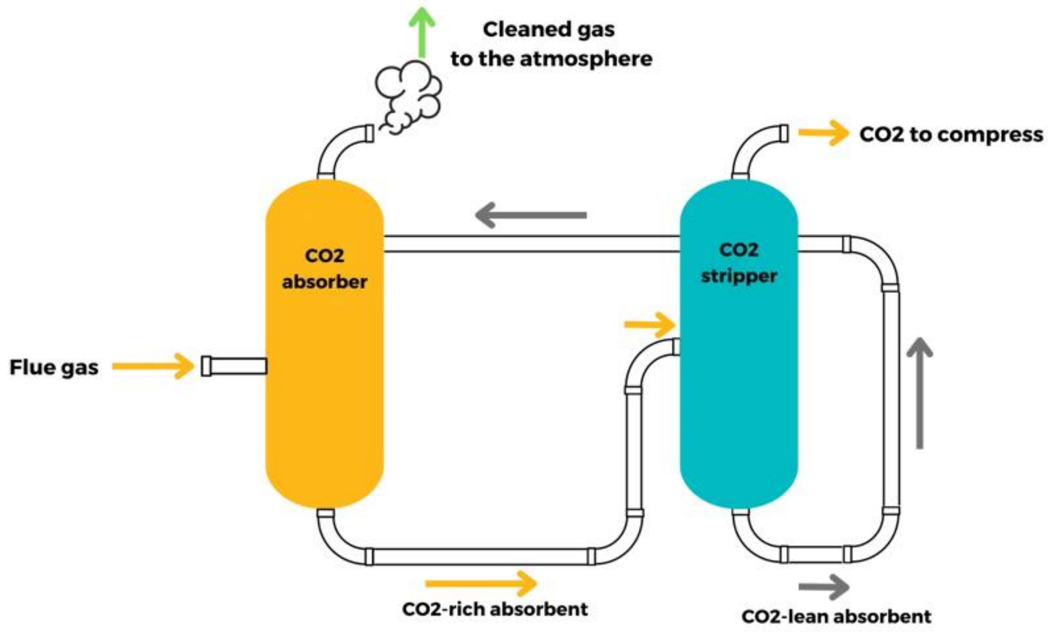
Ben Panko

September 9, 2021

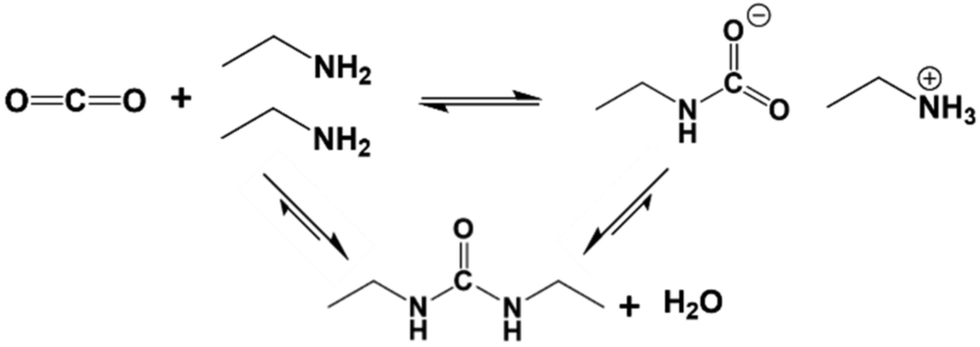
powered by geothermal power plant
capacity of **4,000 tons CO_2** / year
= annual emissions made by **790 cars**

Amine scrubbing

Amine capture + concentration



Amine scrubbing process

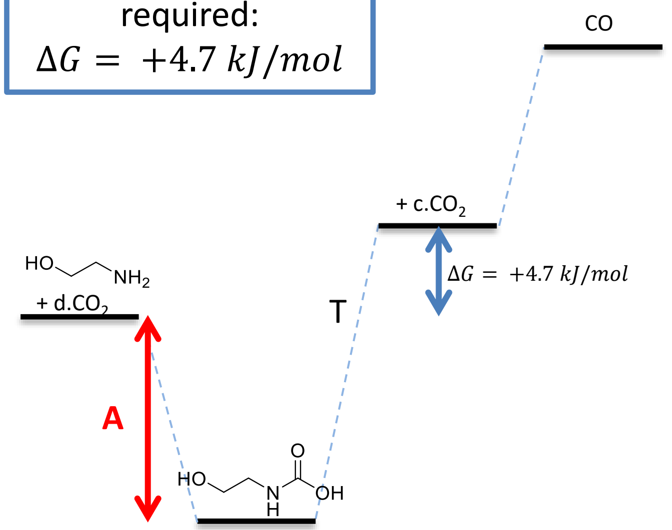


Chem. Rev. **2023**, *123*, 8069. J. Am. Chem. Soc. **2022**, *144*, 14161. ChemCatChem **2023**, *15*, 1.

Energy efficiency of capture with amines

Amine capture + concentration

Flue-gas (15% CO_2)
Minimum energy required:
$\Delta G = +4.7\ kJ/mol$



Limited efficiency achievable
Current heating demand at scale $\geq 100\ kJ/mol$
→ $\eta < 5\%$

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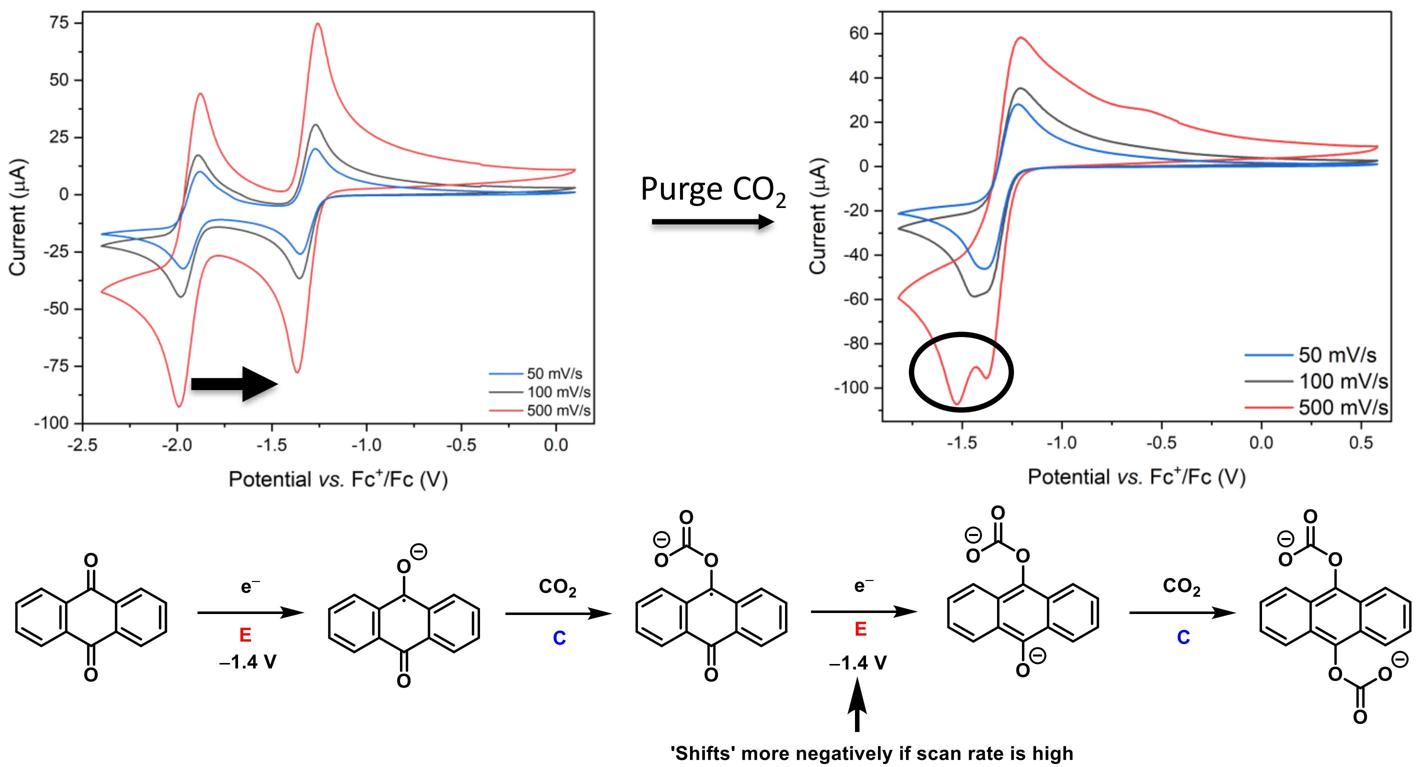
Electrochemical CO_2 capture



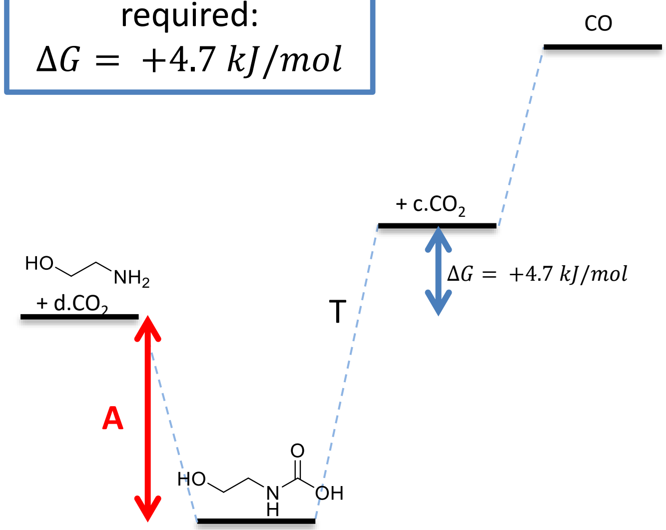
WE = GC, RE = Ag/AgCl, CE = Pt wire
0.1 M $TBAPF_6$ in dry MeCN, 5 mM AQ

Forse, A.C., *J. Phys. Chem. C.*, **2022**, 14163.; Hatton, T.A. *J. Phys. Chem. C.*, **2022**, 1389. Hatton. T.A., *Nature Commun.*, **2020**, 1.

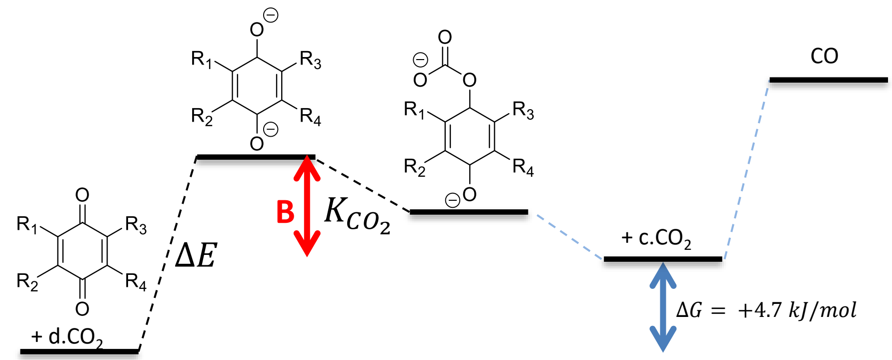
Energy efficiency of capture with amines vs. quinones

Amine capture + concentration

Flue-gas (15% CO_2)
Minimum energy required:
$\Delta G = +4.7\ kJ/mol$



Quinone capture + concentration



Limited efficiency achievable
Current heating demand at scale $\geq 100\ kJ/mol$
→ $\eta < 5\%$

Using $\Delta G = -nFE_{cell}$ & $E^{cap} = E^0 - \frac{RT}{nF} ln(K_{CO_2})$
Example of $E_{cell} = 220\ mV \rightarrow \Delta G = +21.2\ kJ/mol$
→ $\eta = 26\%$

Chem. Rev. **2023**, *123*, 8069. *J. Am. Chem. Soc.* **2022**, *144*, 14161. *ChemCatChem* **2023**, *15*, 1.

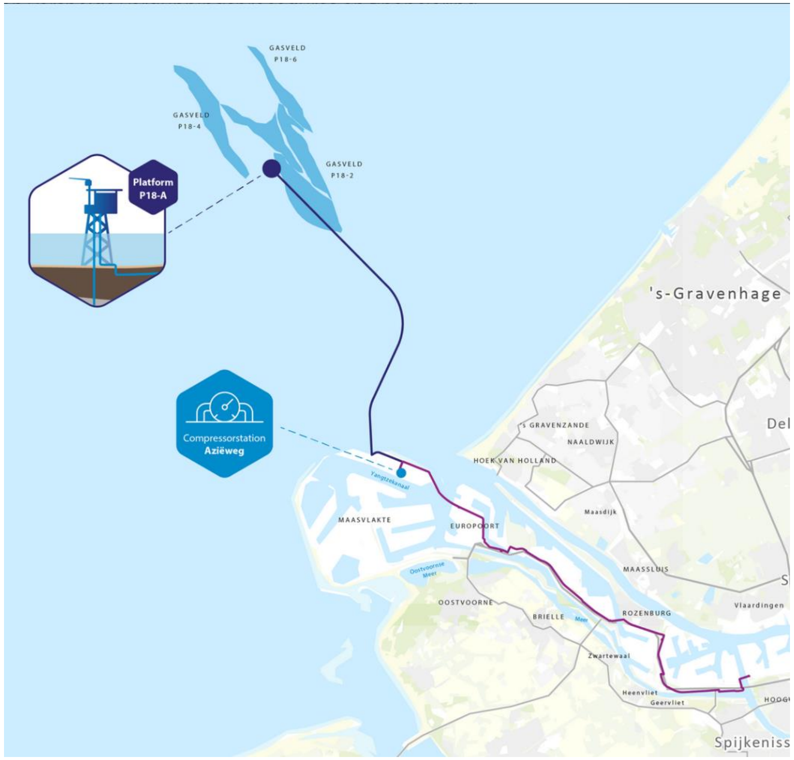
Porthos project

Planned storage of about 37 Mton CO_2 (2.5 Mton CO_2 /year for 15 years)

October 2023 – definitive investment decision

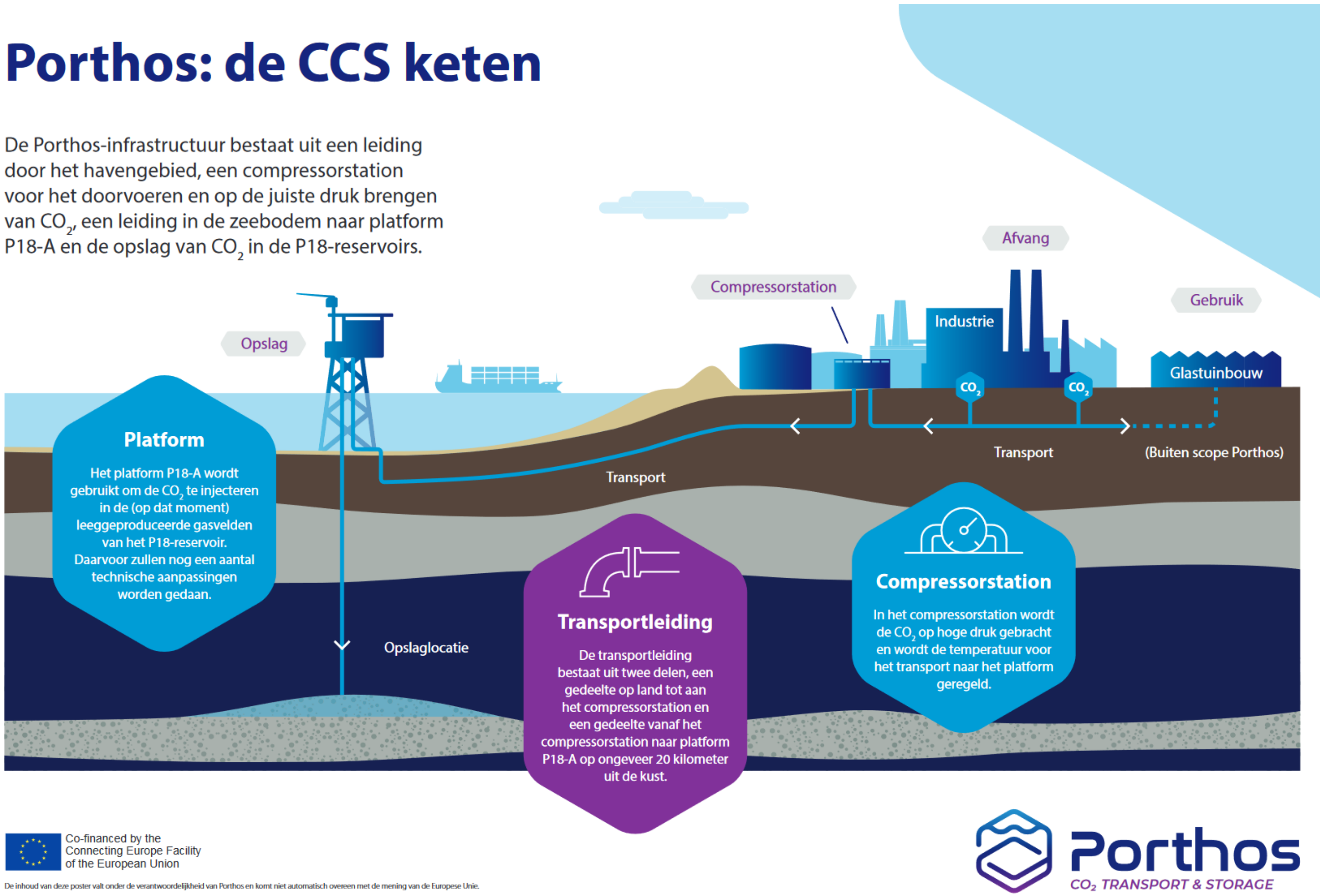
Beginning 2024 – start building infrastructure

From 2026 – anticipated system to be operational



https://www.porthosco2.nl/project/

CO_2 capture



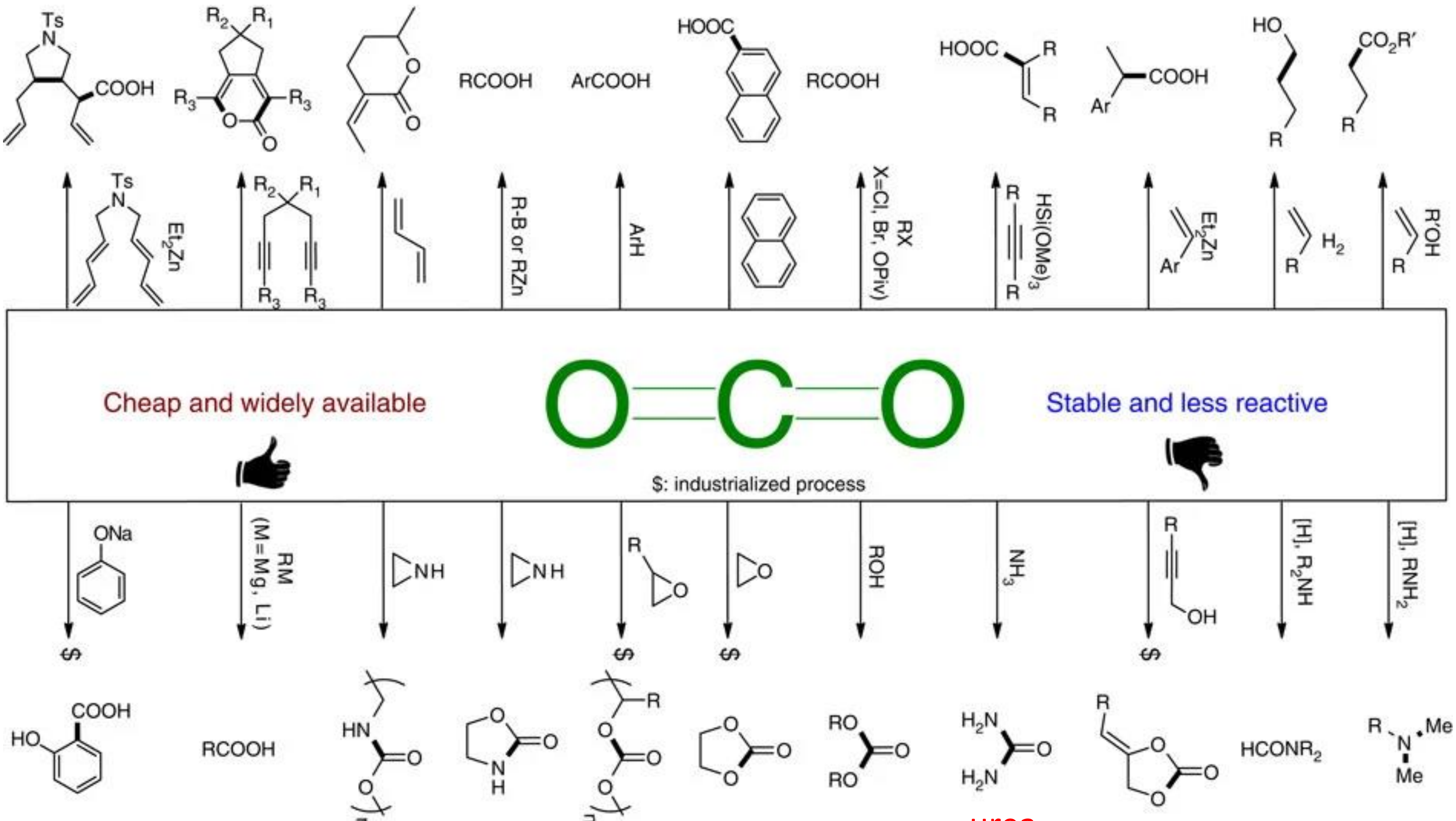
https://www.porthosco2.nl/project/

Potential ways to valorize

dry ice

green houses

Chemical reactions with CO_2



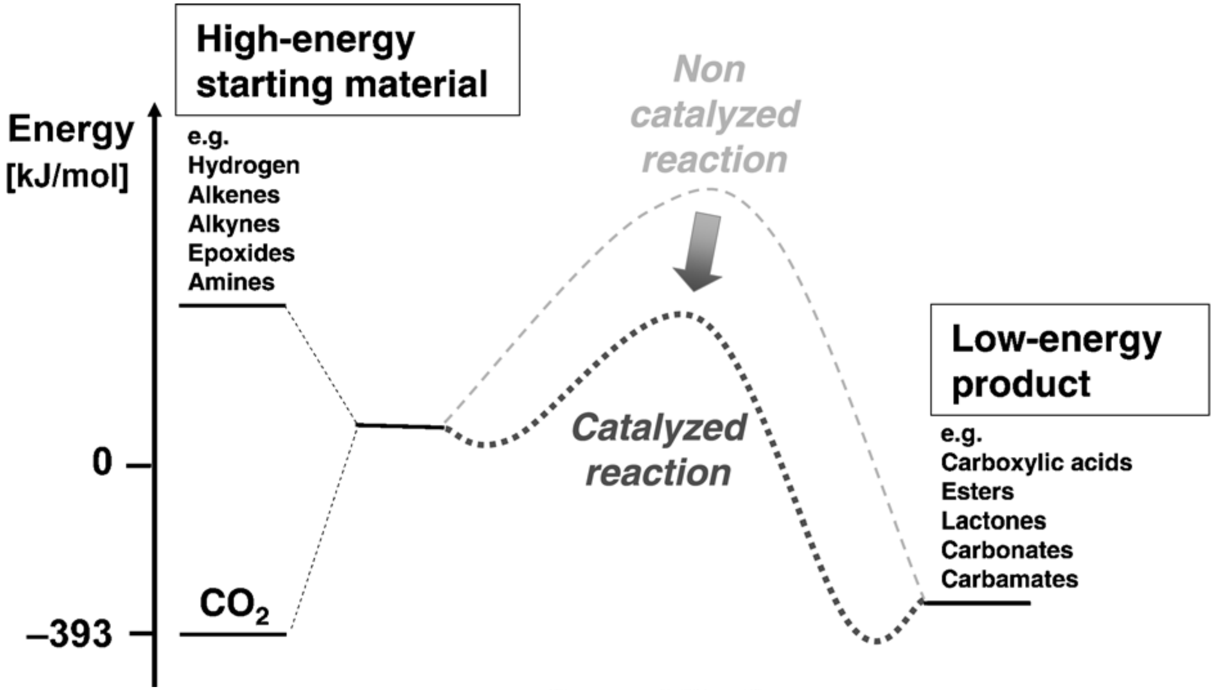
salicylic acid

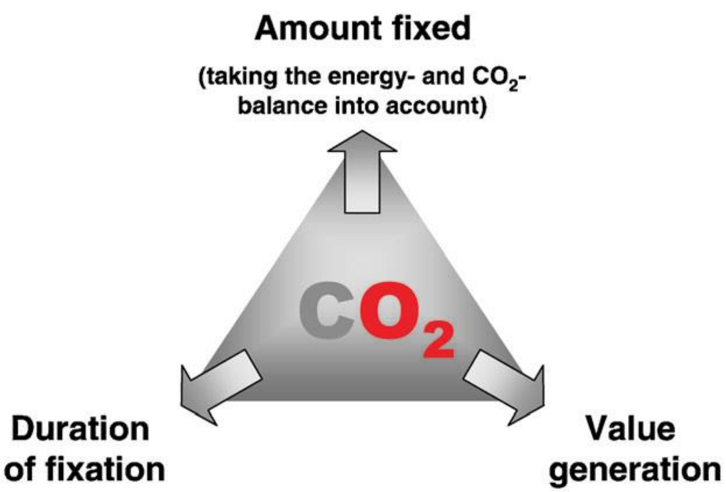
urea

cyclic carbonates

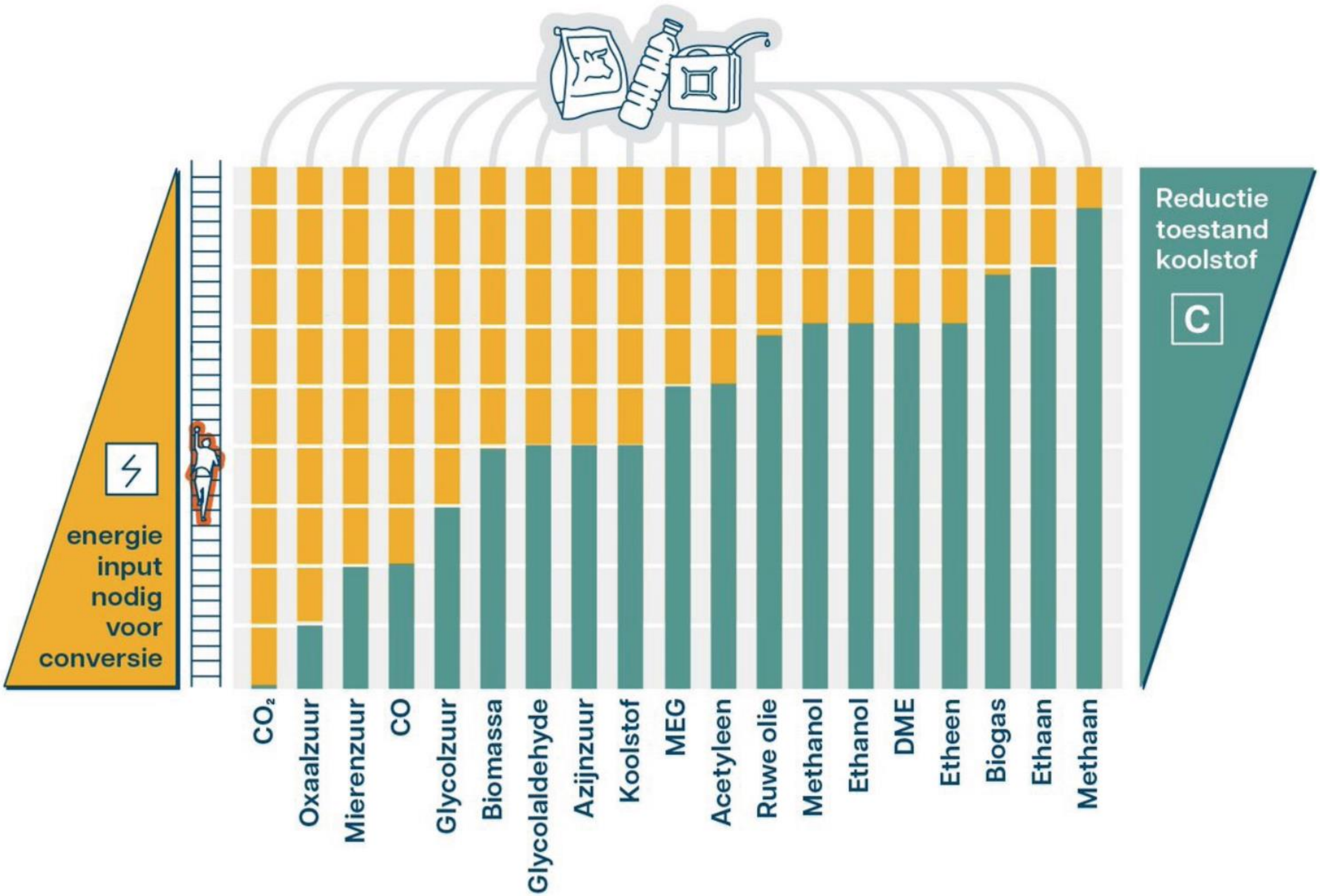
Liu *et al. Nat. Commun.* **2015**, *6*, 5933.

CO_2 as Feedstock





What product do we want to make?



FutureCarbon NL

CO_2 reduction potentials

Multi-electron reactions → difficult kinetic control → high overpotentials

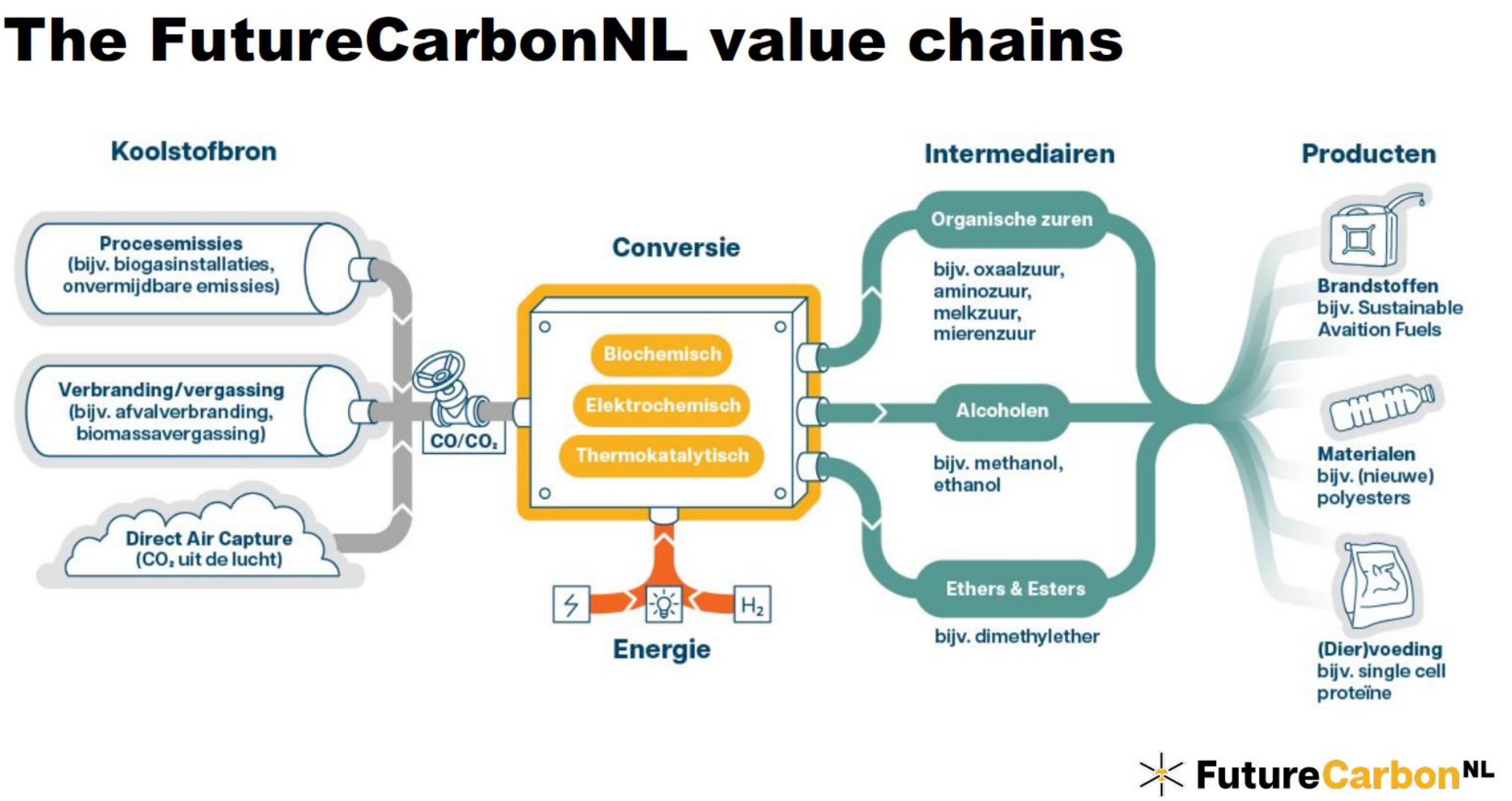
Values at pH 7!!

CO_2	$+ 2H^+ + 2e^-$	→	$CO + H_2O$	$E^0 = -0.53$ V
CO_2	$+ 2H^+ + 2e^-$	→	HCO_2H	$E^0 = -0.61$ V
CO_2	$+ 4H^+ + 4e^-$	→	$HCHO + H_2O$	$E^0 = -0.48$ V
CO_2	$+ 6H^+ + 6e^-$	→	$CH_3OH + H_2O$	$E^0 = -0.38$ V
CO_2	$+ 8H^+ + 8e^-$	→	$CH_4 + H_2O$	$E^0 = -0.24$ V
CO_2	$+ e^-$	→	$CO_2^{\bullet -}$	$E^0 = -1.90$ V

Why?

Further reduction of this radical feasible?

Potential ways to valorize



Potential ways to valorize

Thinking of CCU: What is needed?

- **New catalysts**
  - e.g. that can handle CO_2 gas streams with impurities
- **New reactors**
  - e.g. for electrochemistry
- **New energy-efficient processes**
  - e.g. by integrated capture and conversion
- **New value chains**
  - from CO_2 emitters, converters to product makers, …

"CCU technology"

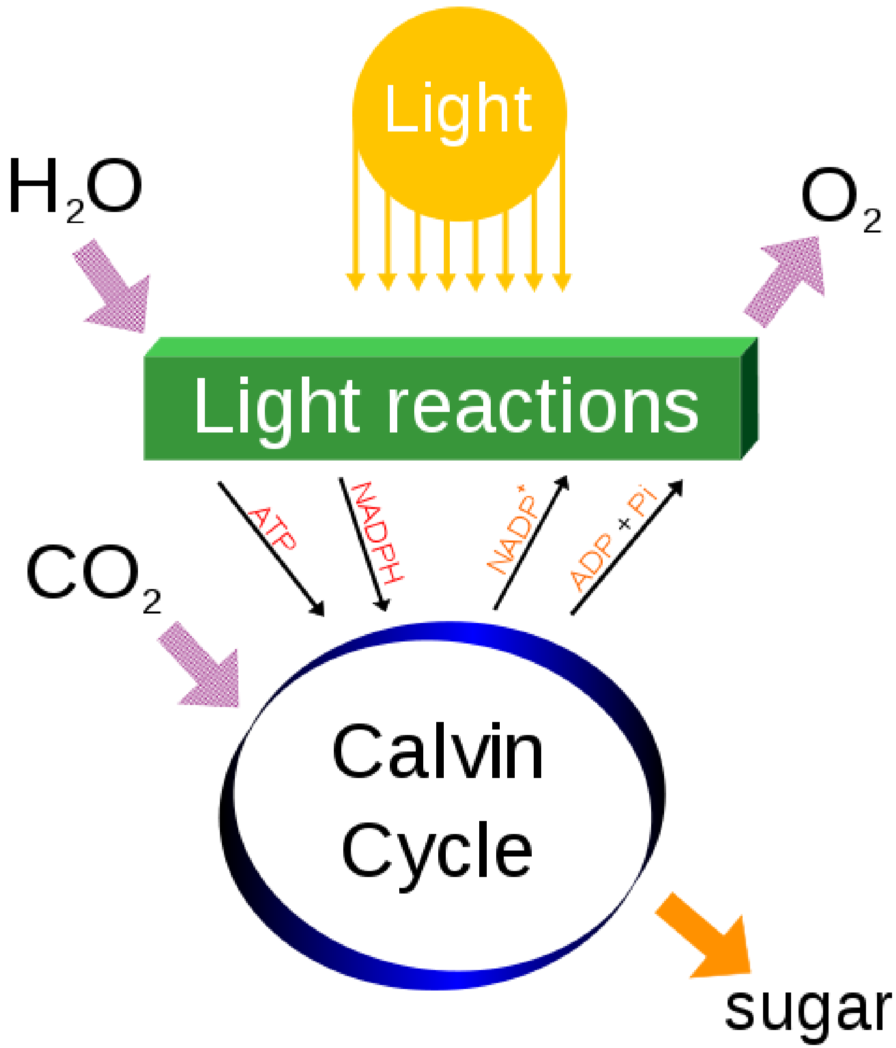
FutureCarbon NL

CCU technology

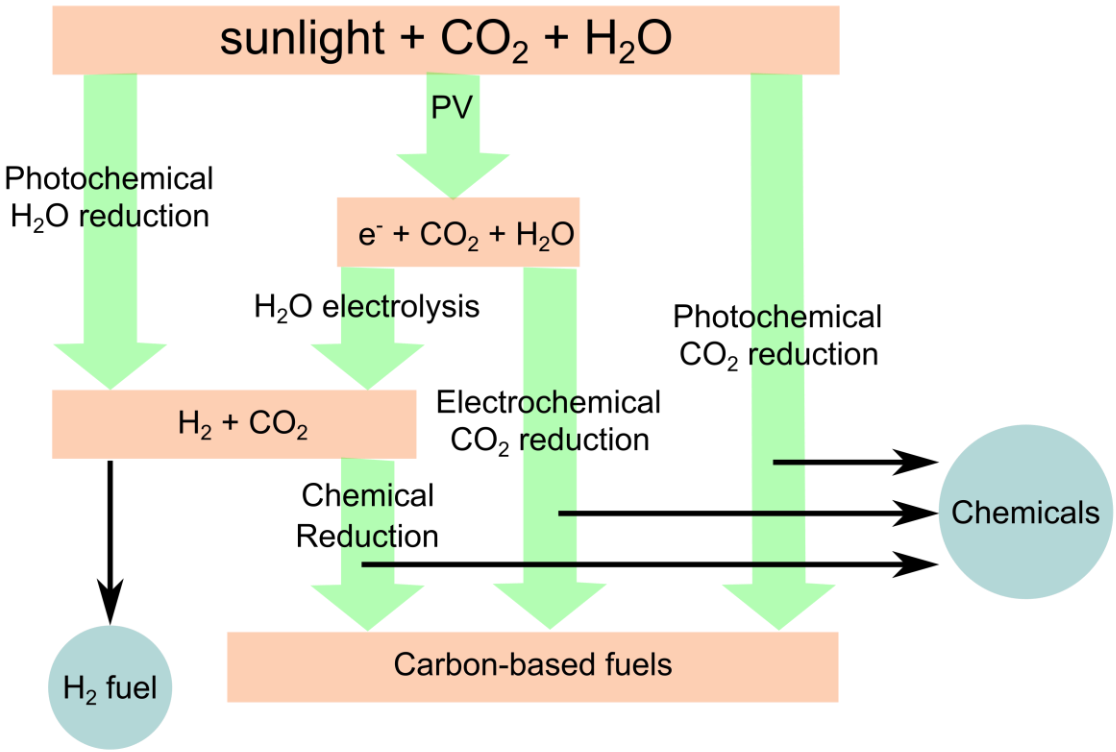
What is needed?

- New **catalysts** that can handle CO_2 gas streams with impurities
- New **reactors**, e.g. electrolyzers
- Energy efficient processes such as **integrated capture and conversion**
- New **value chains**: connecting CO_2 emitters with CO_2 converters and product makers

Natural Photosynthesis



Artificial Photosynthesis



Discussion points/Future Perspective

- Market analysis: production and use of each product
- Scale of emission (ca. **150** Mton/year) versus use
- Availability of technologies, technology readiness level

- We need it all!