Extracting carbon from seawater

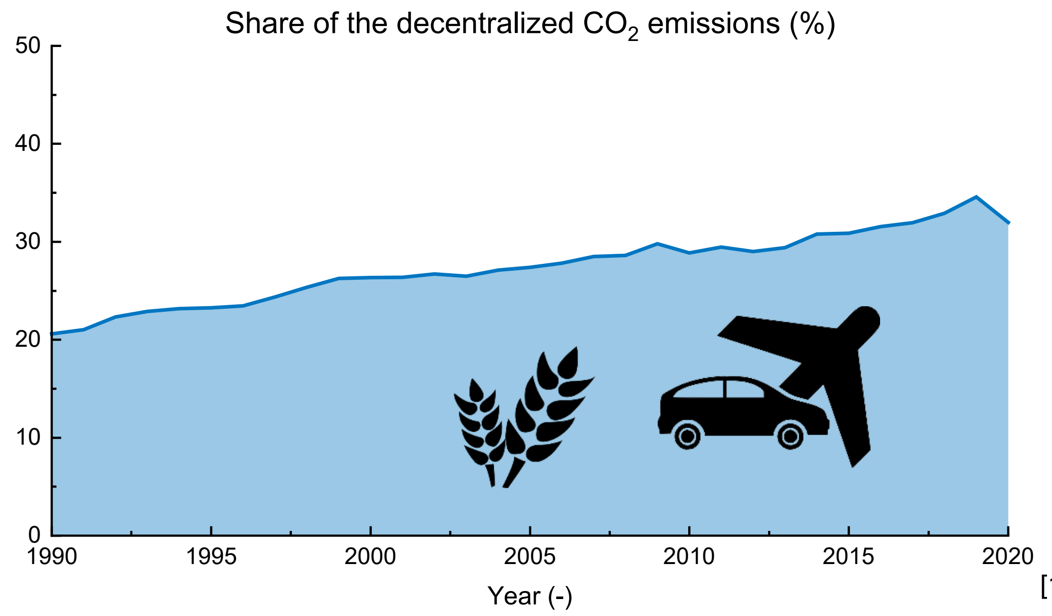
Indirect CO_2 capture

Vojtech Konderla

David Vermaas

15th December 2022

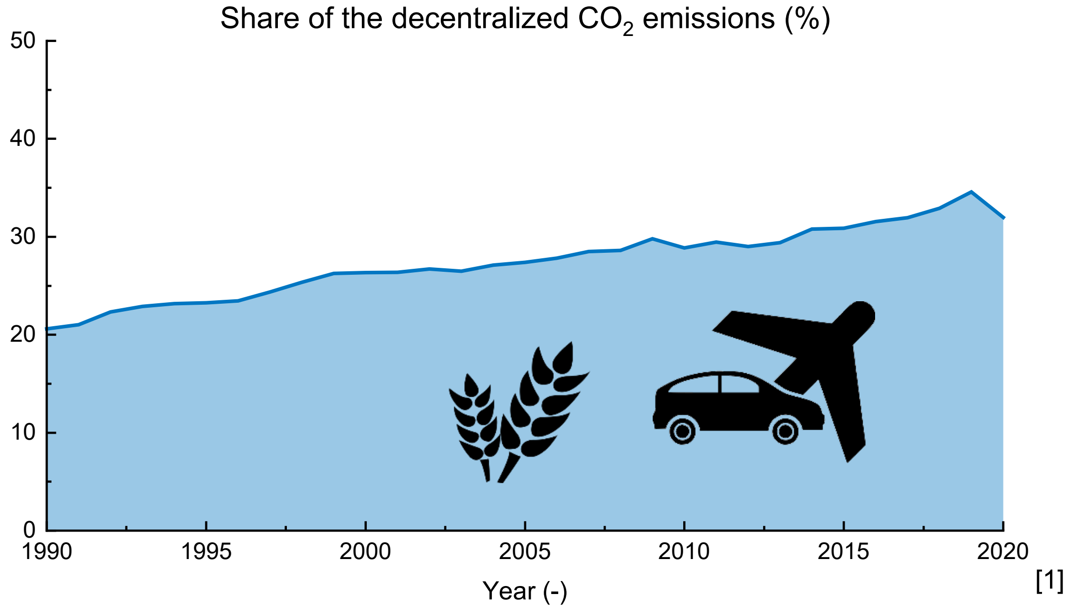
Driving force



[1]

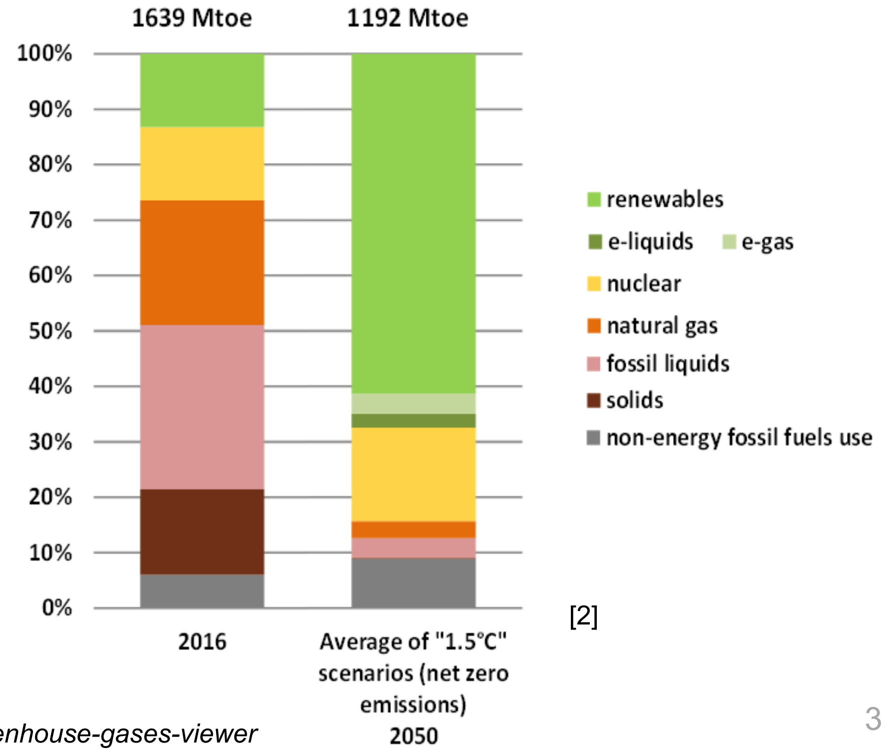
How can we decarbonize decentralised sources of CO_2?

Driving force



How can we decarbonize decentralised sources of CO_2?

How can we reach carbon-neutral society when we are still using fossil fuels?



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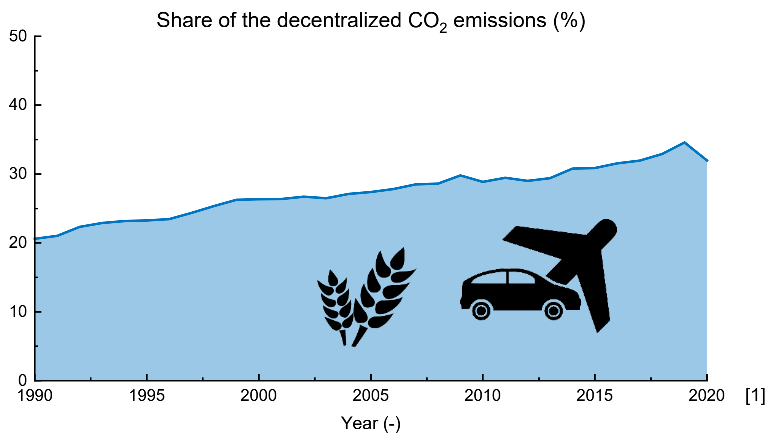
[1] European Environment Agency, https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer
[2] EU vision on 'Going Climate-neutral in 2050

Driving force

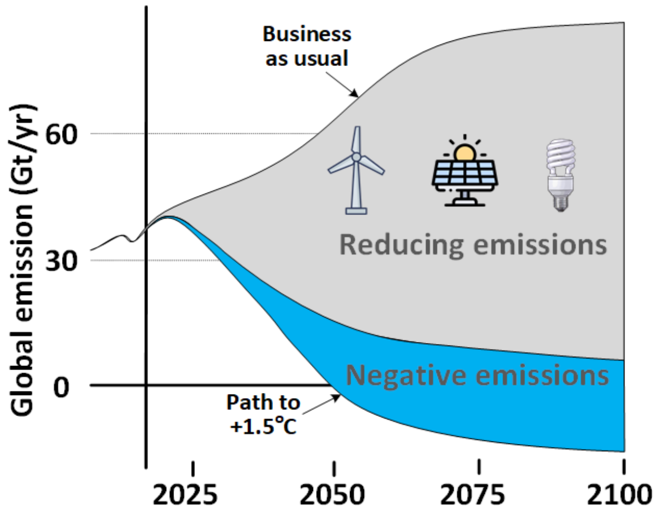


How can we decarbonize decentralised sources of CO_2?

Batteries instead of jet fuel? Biomass instead of petrochemicals?

We need negative CO_2 emission technology

Renewable energy sources and process intensification are both not good enough



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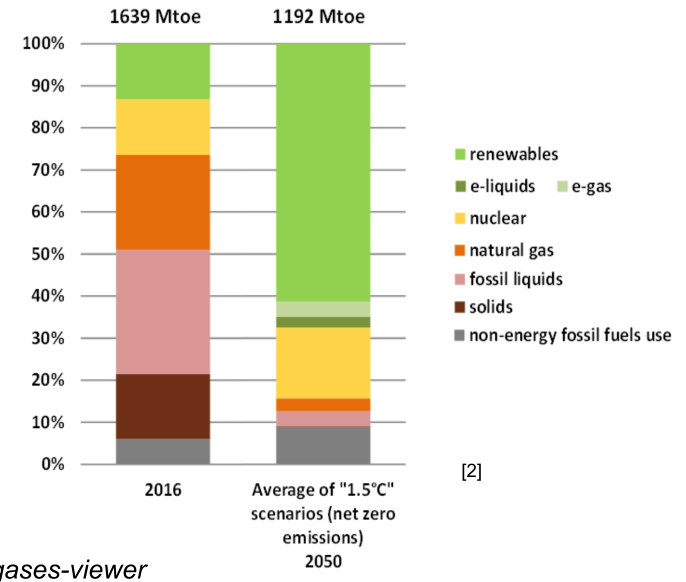

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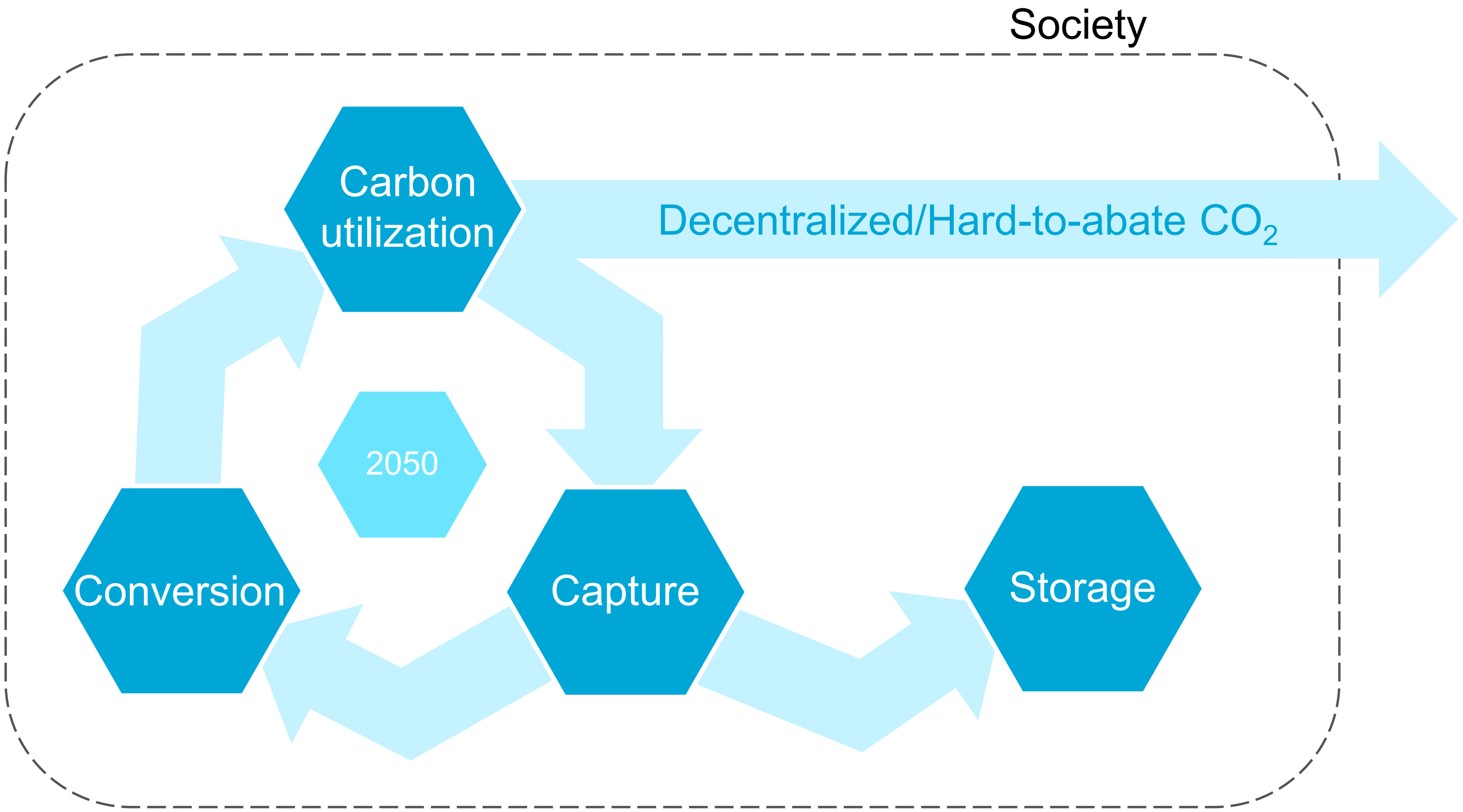
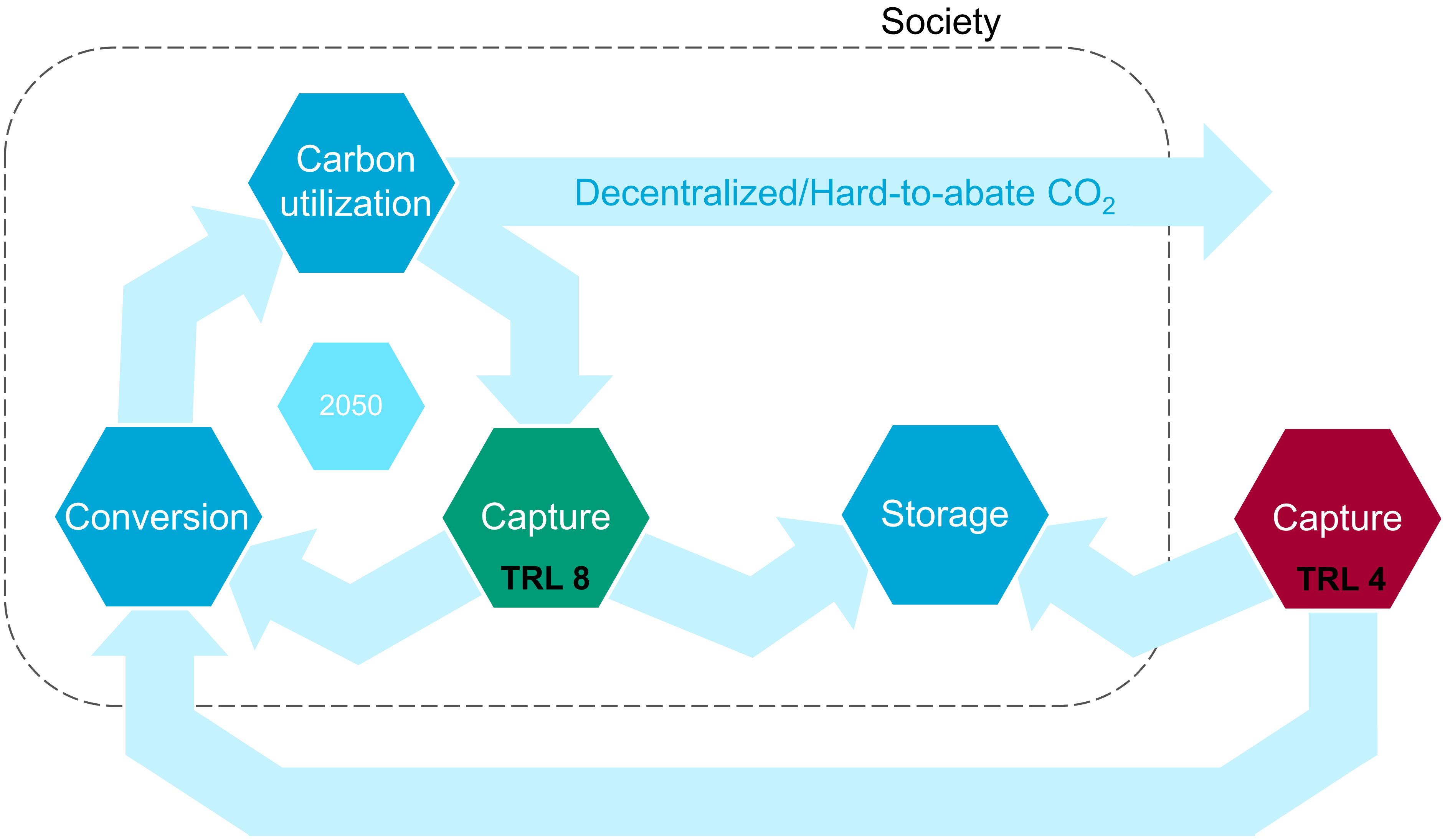
Carbon cycle



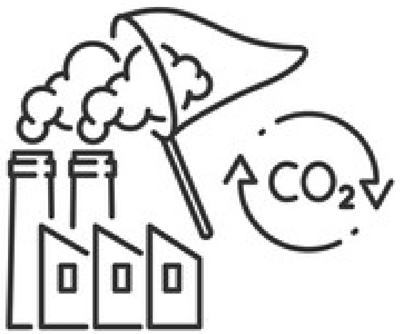
Hard-to-abate emissions disable to achieve net zero emission

Carbon cycle



Negative CO_2 emissions

Flue gas



- Negative emission in combination with biomass

Negative CO_2 emissions

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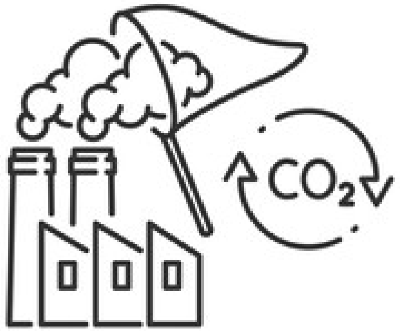
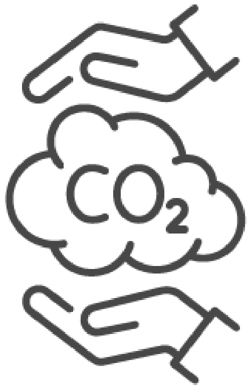


- Negative emission in combination with biomass

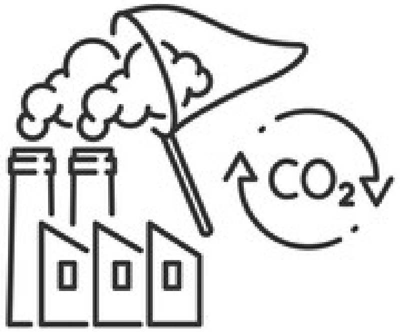
Air



- Needs to filter full atmosphere each 35 years

Negative CO_2 emissions

Flue gas



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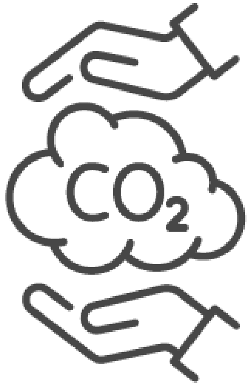

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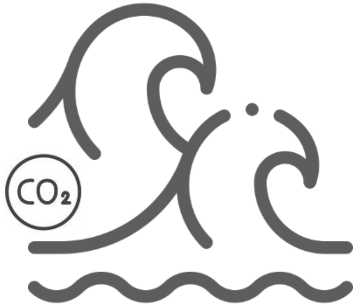
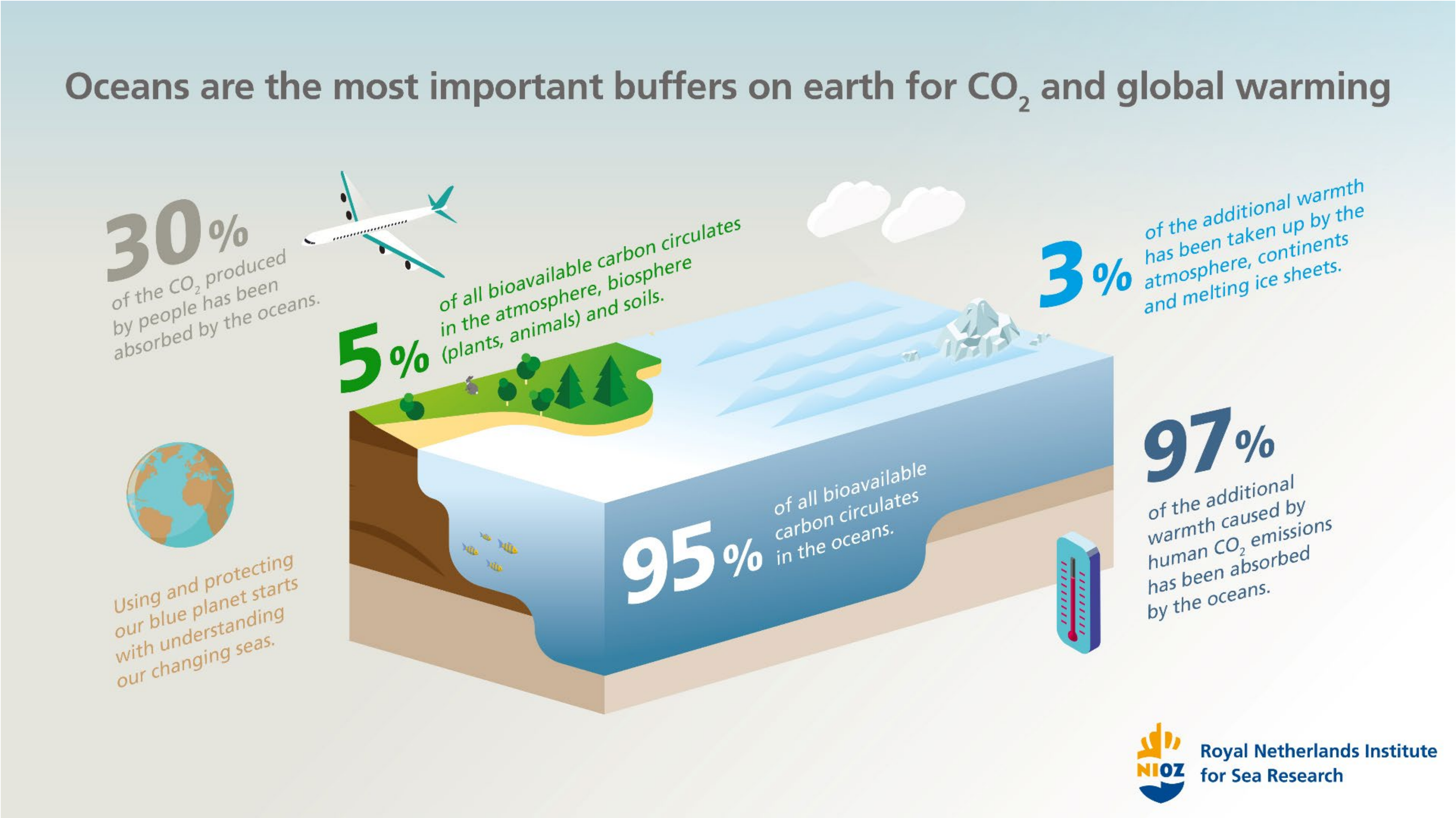
Seawater



- Concentration 150x higher than in air
- Lower TRL than air capture

Where is our CO_2?

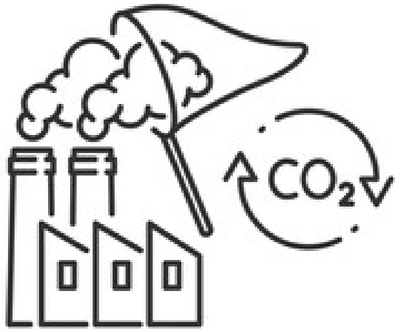


[1]

[1] https://www.nioz.nl

Negative CO_2 emissions

Flue gas



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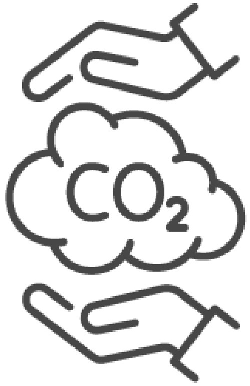

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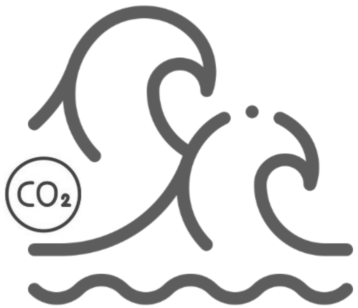


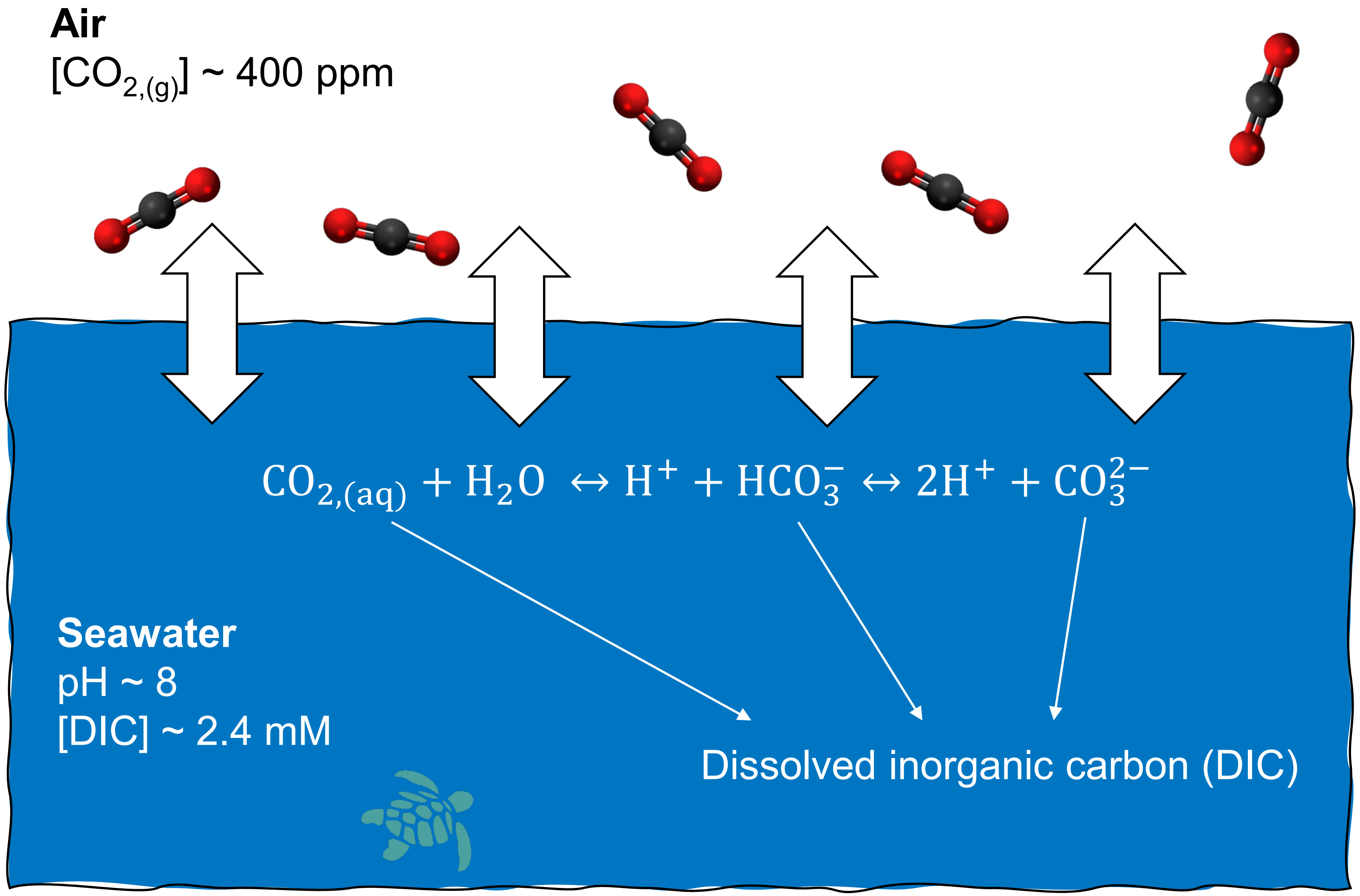
- Concentration 150x higher than in air
- Lower TRL than air capture

using:

Electrochemical methods

- Direct use of electricity
- Modular
- Isothermal

Atmosphere and ocean are in equilibrium



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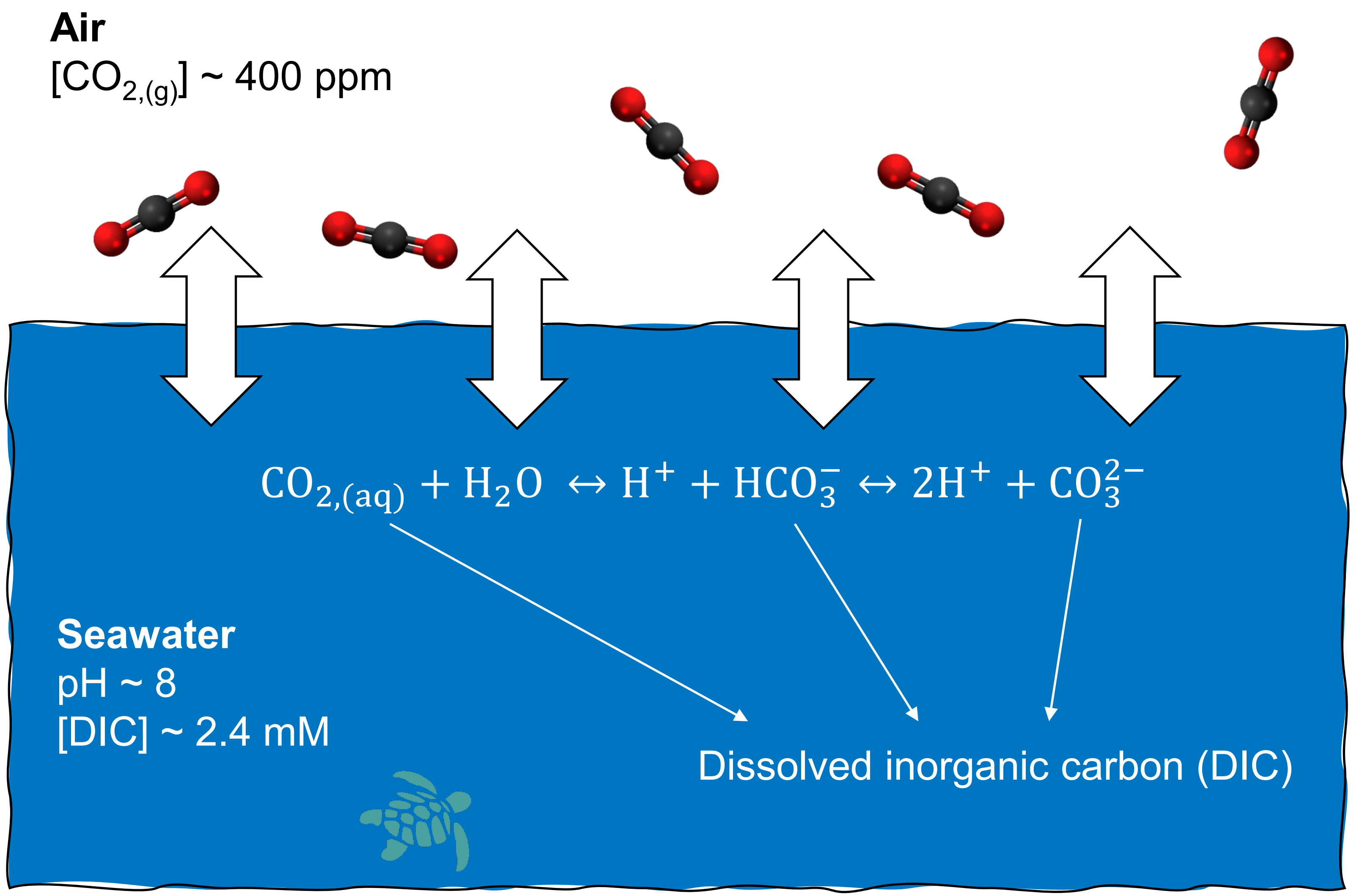
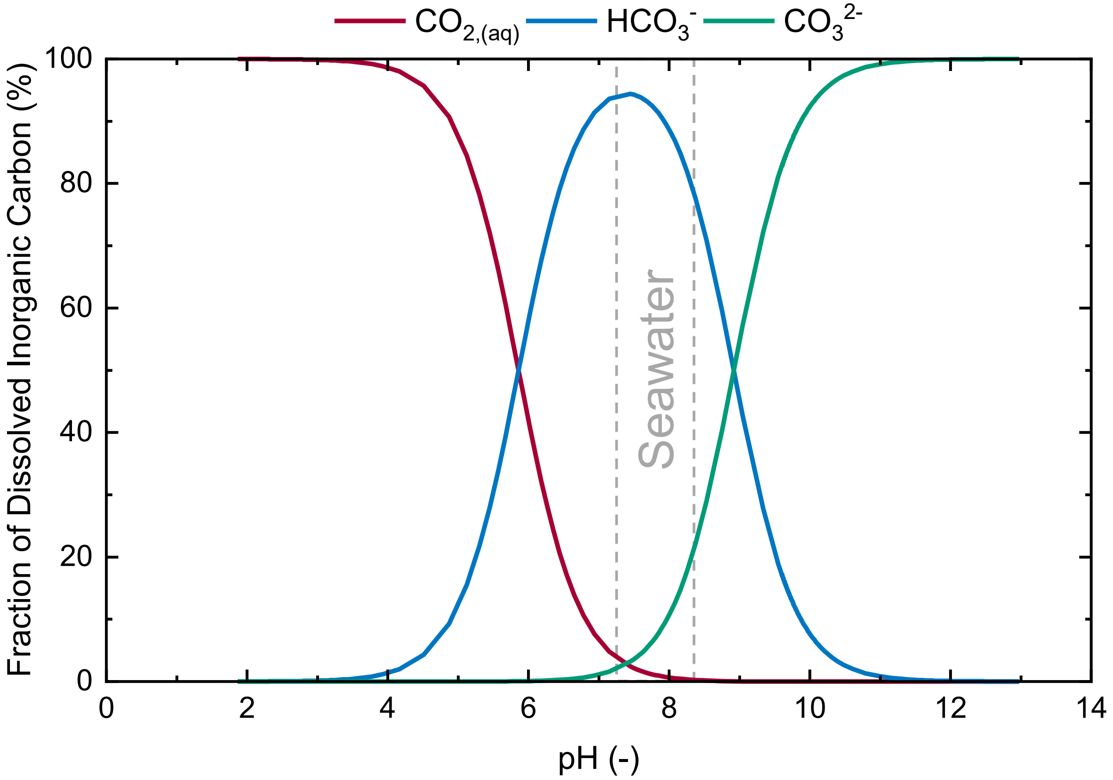


*Removing CO_2 from the **ocean** means removing CO_2 indirectly from the **air***

Seawater carbon capture – pH swing



$$DIC = [CO_{2,(aq)}] + [HCO_3^-] + [CO_3^{2-}]$$

$$H^+ + HCO_3^- \leftrightarrow CO_2 + H_2O$$

$$HCO_3^- + OH^- \leftrightarrow CO_3^{2-} + H_2O$$

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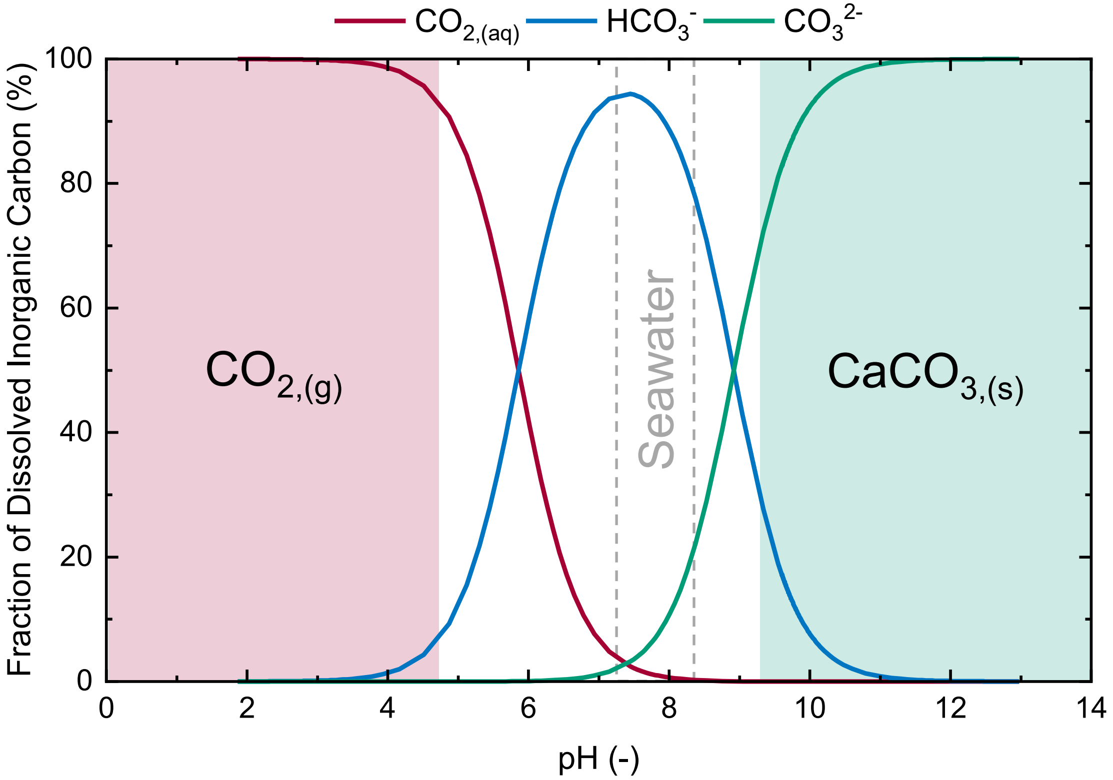
Seawater carbon capture – pH swing



$$\mathrm{DIC} = \left[\mathrm{CO_{2,(aq)}}\right] + \left[\mathrm{HCO_3^-}\right] + \left[\mathrm{CO_3^{2-}}\right]$$

pH swing can be achieved by

- Water electrolysis
- Redox active carriers
- Bipolar membranes
- ...

$$\mathrm{H^+ + HCO_3^- \leftrightarrow CO_2 + H_2O}$$

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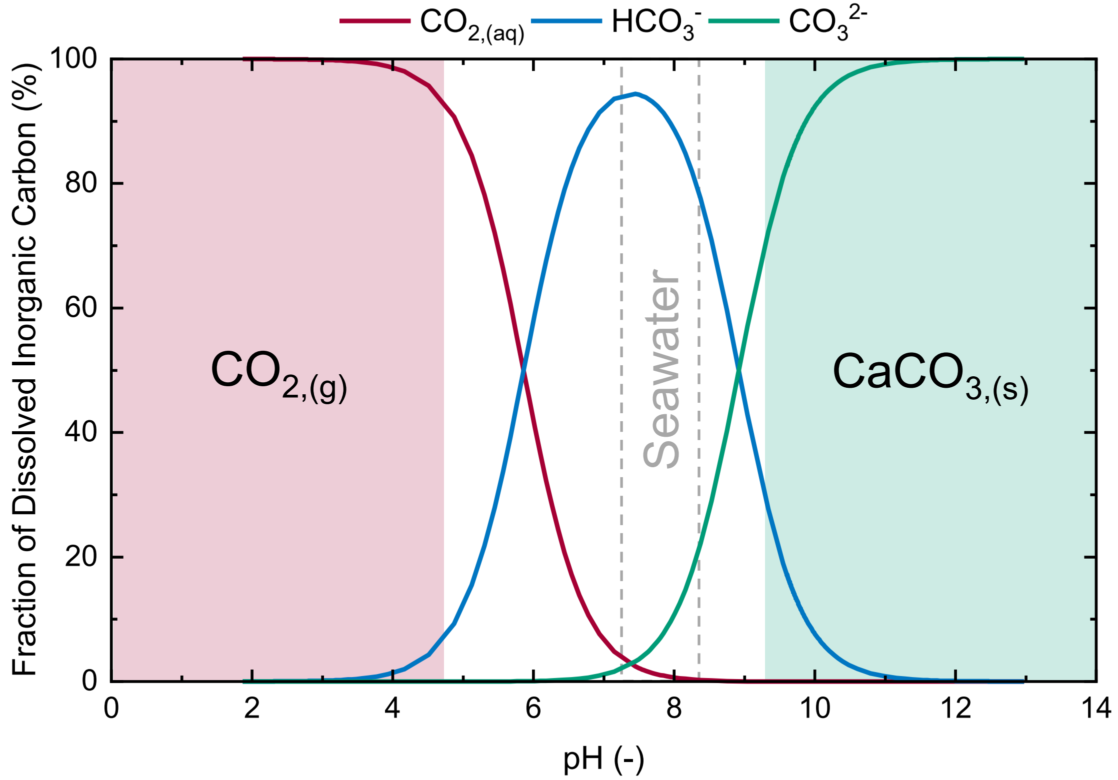

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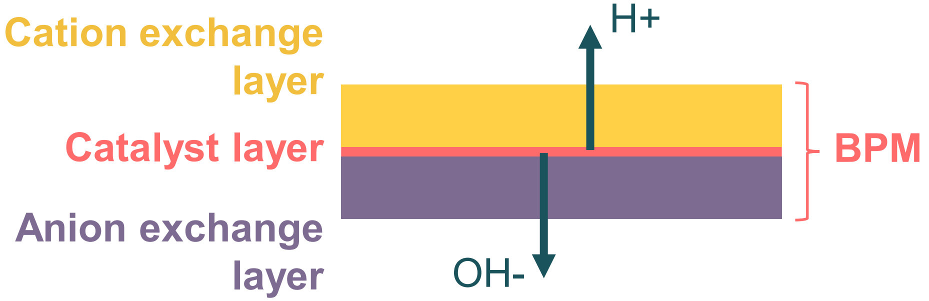
- Bipolar membranes



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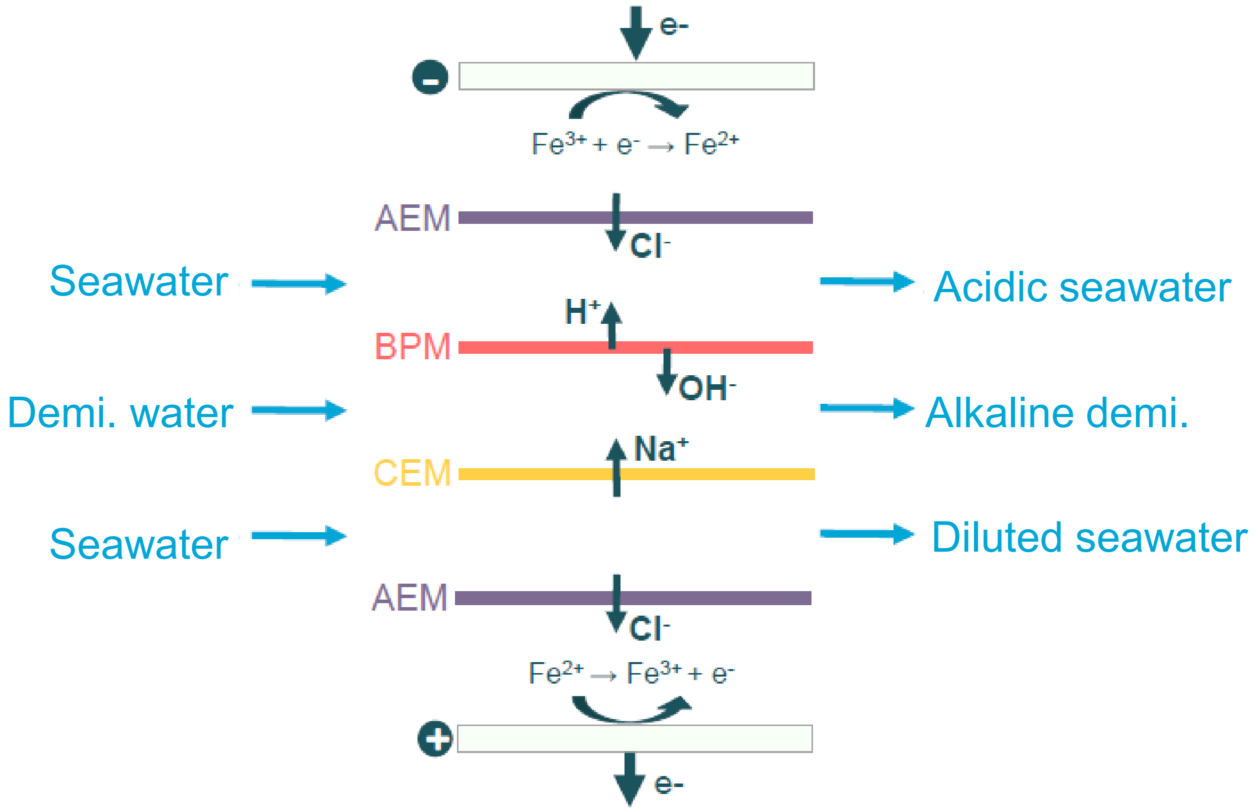
3 compartment Bipolar Membrane Electrodialysis (BPMED)



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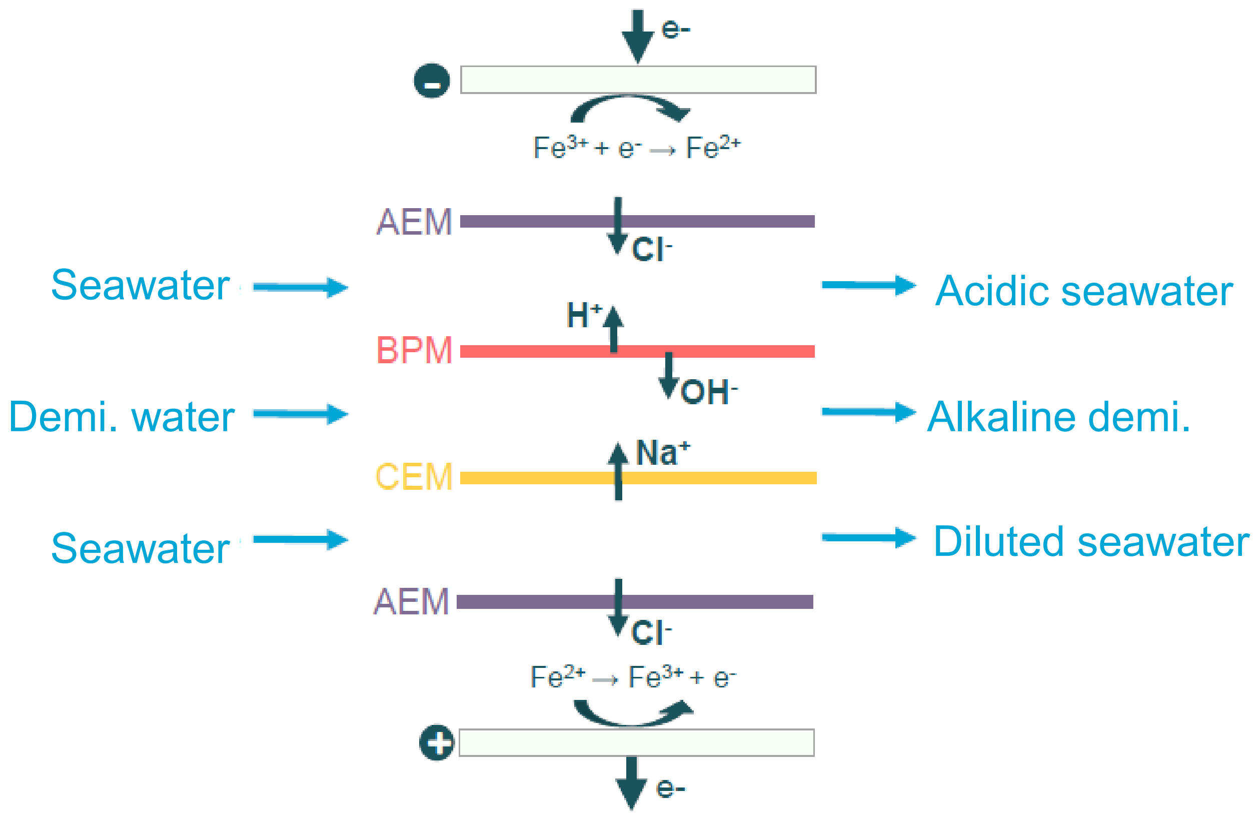

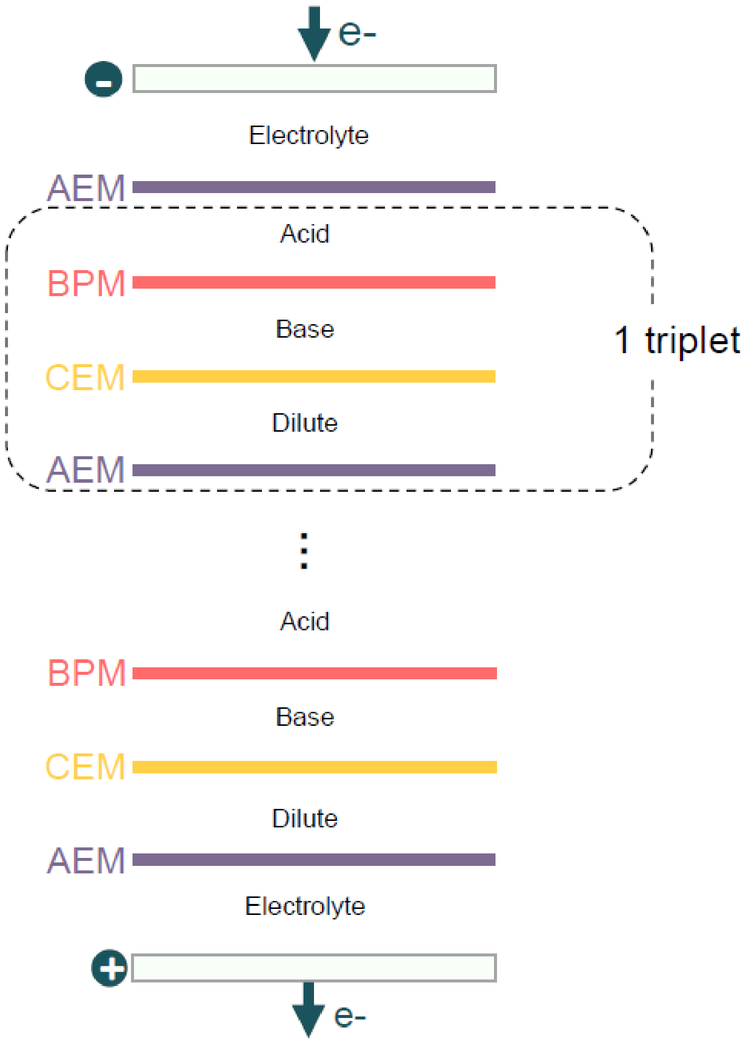

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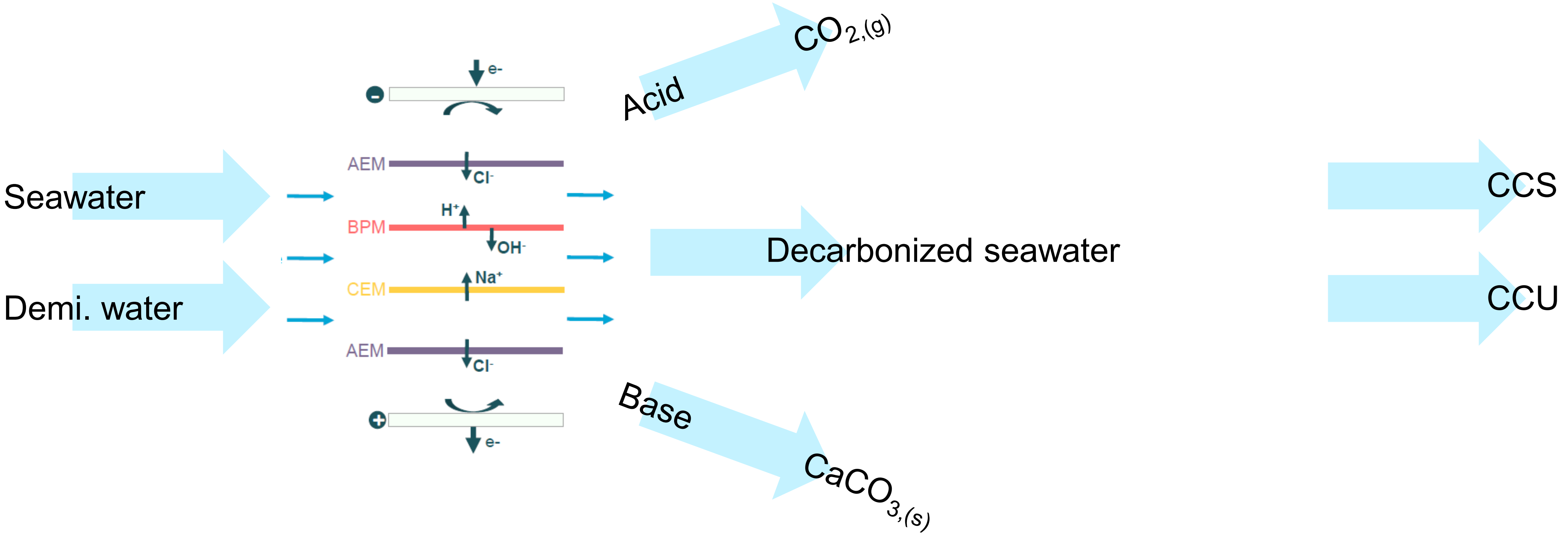
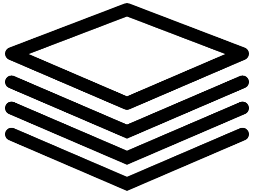


Aspen modeling results

- Results are scaled up for the size of the desalination plant ~ 137 kg/h CO_2, 177 kg/h $CaCO_3$

Power consumption



Production rate

Product purity

Lifetime

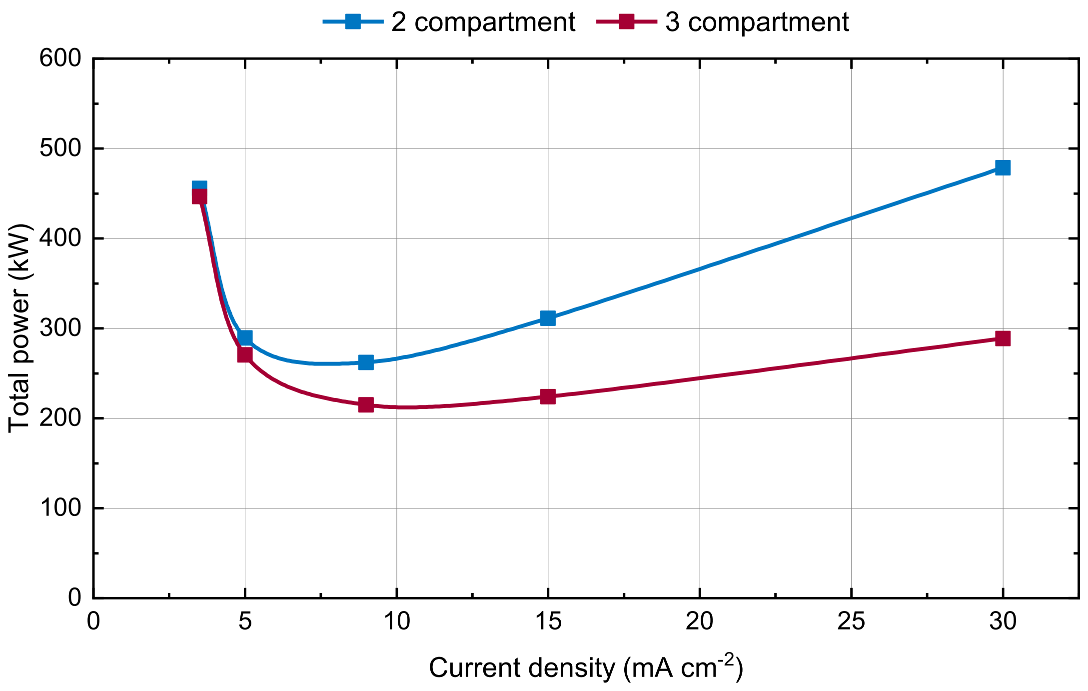
Aspen modeling results

- Results are scaled up for the size of the desalination plant ~ 137 kg/h CO_2, 177 kg/h calcite

Power consumption
=f(current density)

Number of stacks
=f(current density)

Total power consumption



- Sum of the electrochemical and pumping power

CO_2 energy consumption:

- **3 comp.:** 249 kJ/mol
- **2 comp.:** 303 kJ/mol
- Digdaya *et al.* 2020: 155 kJ/mol[1],*
- Eisaman *et al.* 2012: 242 kJ/mol[2],*

CO_2 & $CaCO_3$ energy consumption

- **3 comp.:** 158 kJ/mol
- **2 comp.:** 193 kJ/mol

- Results are scaled up for the size of the desalination plant ~ 137 kg/h CO_2, 177 kg/h $CaCO_3$

** Does not include pumping power, considers regular seawater*

*[1] Digdaya, I.A., Sullivan, I., Lin, M. et al. A direct coupled electrochemical system for capture and conversion of CO_2 from oceanwater. Nat Commun **11**, 4412 (2020)*
[2] Eisaman, M. & Parajuly, Keshav & Tuganov, Alexander & Eldershaw, Craig & Chang, Norine & Littau, Karl. (2012). CO2 extraction from seawater using bipolar membrane electrodialysis. Energy Environ. Sci.. 5. 10.1039/C2EE03393C.

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CO_2 & $CaCO_3$ energy consumption

- **3 comp.:** 158 kJ/mol
- **2 comp.:** 193 kJ/mol

- **Natural gas:** 400 kJ/mol *electricity/CO_2*
- **Thermodynamic minimum:** 20 kJ/mol

- Results are scaled up for the size of the desalination plant ~ 137 kg/h CO_2, 177 kg/h $CaCO_3$

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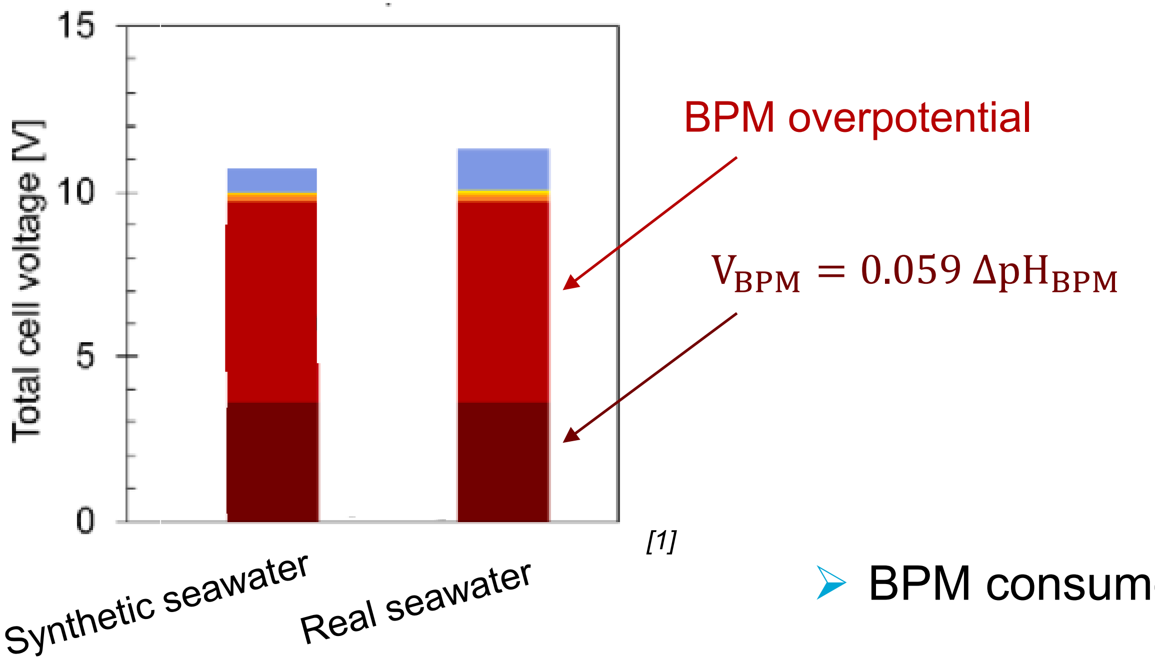
BPM limits the energy consumption

- BPM thermodynamic voltage: $V_{BPM} = 0.059\ \Delta pH_{BPM}$, however, in practice water splitting starts only at 0.6V

In-situ $CaCO_3$ mineralization using 2 compartment BPMED with 10 BPMs



[1]

➢ BPM consumes approximately 90% of the electrical energy

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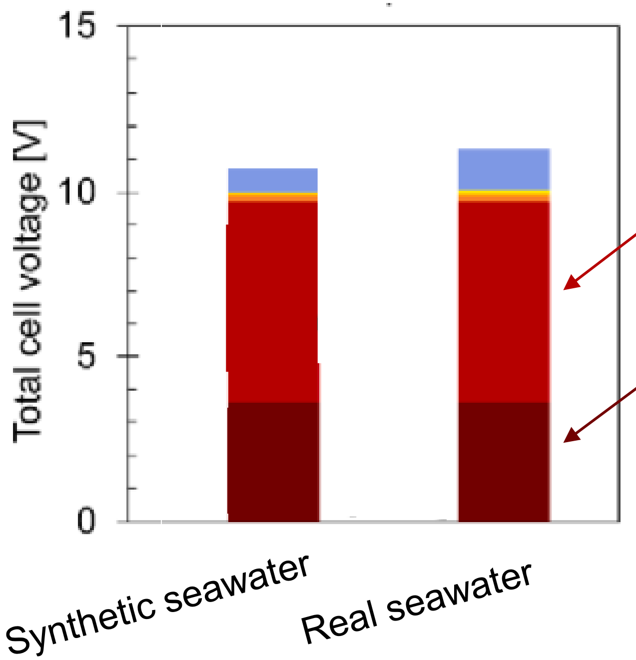
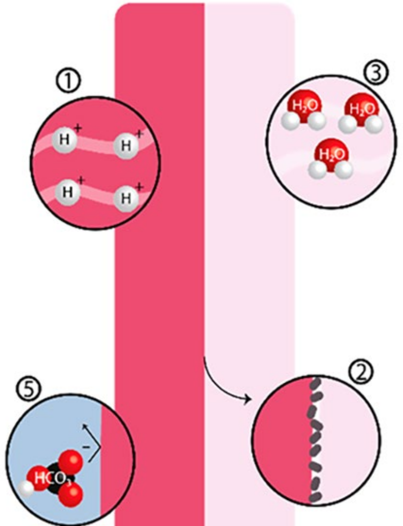


BPM overpotential

$V_{BPM} = 0.059\ \Delta pH_{BPM}$

[1]

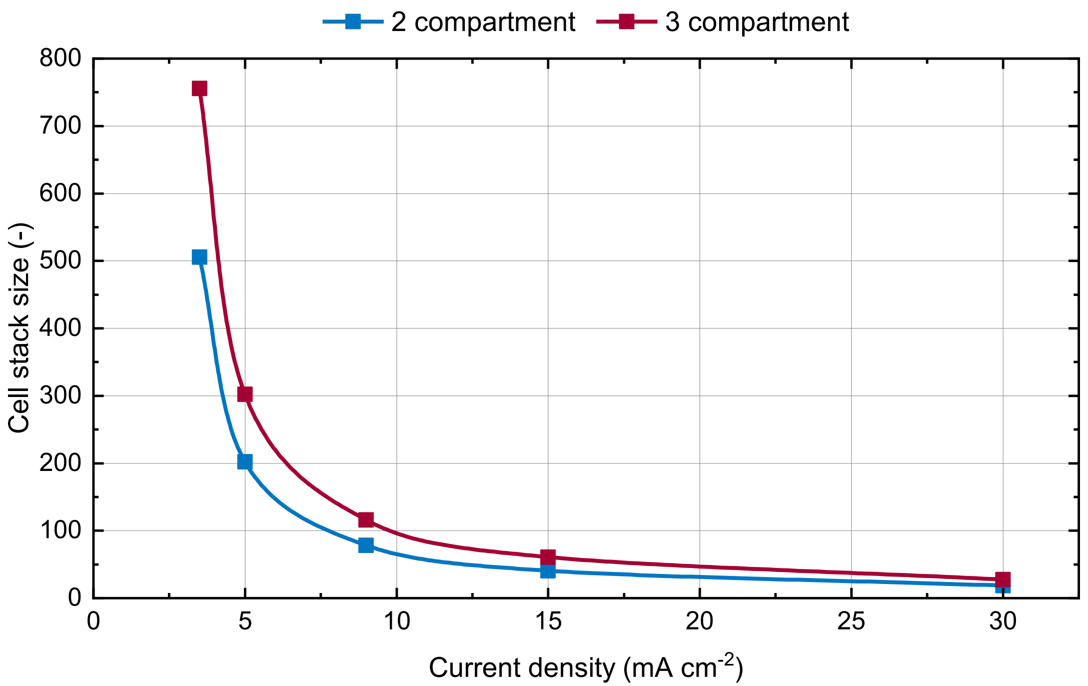


[2]

- ➢ BPM consumes approximately 90% of the electrical energy
- ➢ Market for BPMs is still in early stages
- ➢ Water splitting catalyst inside the BPM needs to be improved

[1] Sharifian, R., et al. "Oceanic carbon capture through electrochemically induced in situ carbonate mineralization using bipolar membrane." *Chemical Engineering Journal 438 (2022)*
[2] Blommaert, Marijn A., et al. "Insights and challenges for applying bipolar membranes in advanced electrochemical energy systems." *ACS Energy Letters* 6.7 (2021)

Number of BPMED stacks

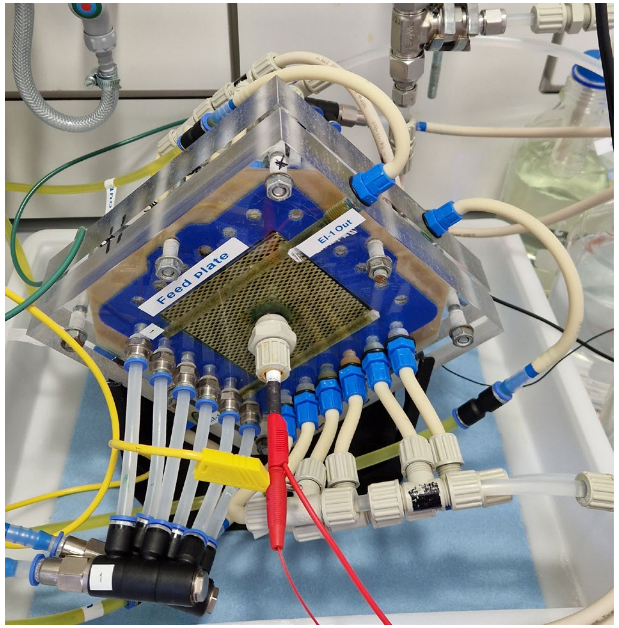


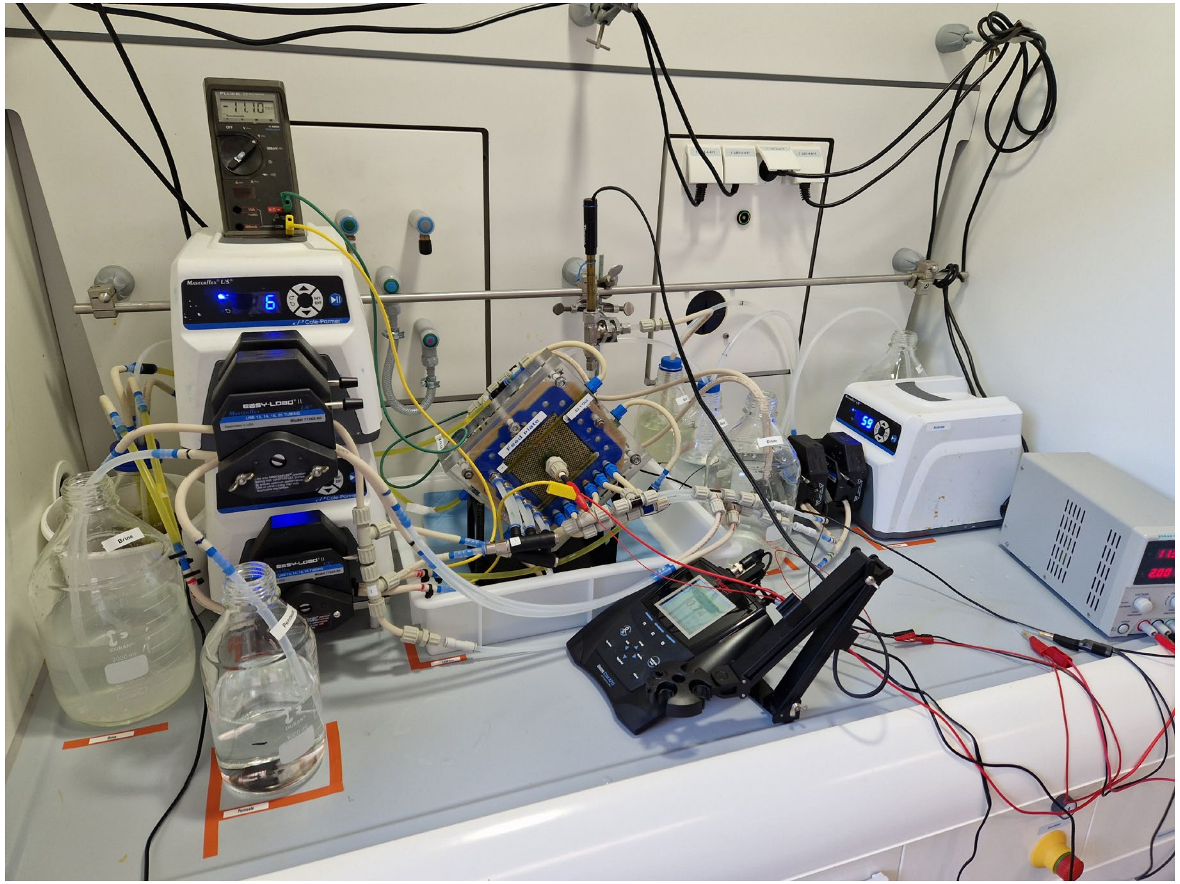
,where 1 cell stack contains 210 compartments with 0.5x0.5 m² active area

- **3 comp.:**
  - Design requires an additional dilute compartments
- 210 compartments stack corresponds to a pilot scale stack developed at AquaBattery

- Results are scaled up for the size of the desalination plant ~ 137 kg/h CO_2, 177 kg/h $CaCO_3$

3 compartment Bipolar Membrane Electrodialysis





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Conclusion – challenges to overcome

- Cost-efficient renewable electricity (Fluctuations are alright)
- Finding Suitable coastal location(s) : operation (ocean movements, carbon cycle) but also $CO_{2,(g)}$ storage
- Monitoring, reporting and verifying (MRV): Effect on ecosystem + geography
- Technology: fouling, pumping, pretreatment, low TRL, LCA
- Upscaling: Permit(s), Funding

TU Delft

Dutch Indirect Carbon Capture start-up

Ir. Vojtech Konderla
TU Delft Research engineer

Dr. Ir. David A. Vermaas
TU Delft associate professor

Ruben Brands (MBA & LL.M)
Business & corporate law

Dr. Ir. Rose Sharifian
Former TU Delft PhD

2023
$250tCO_2$

2035
$GtCO_2$

TRL 5 to 6

Upscaling and future view

https://capturacorp.com