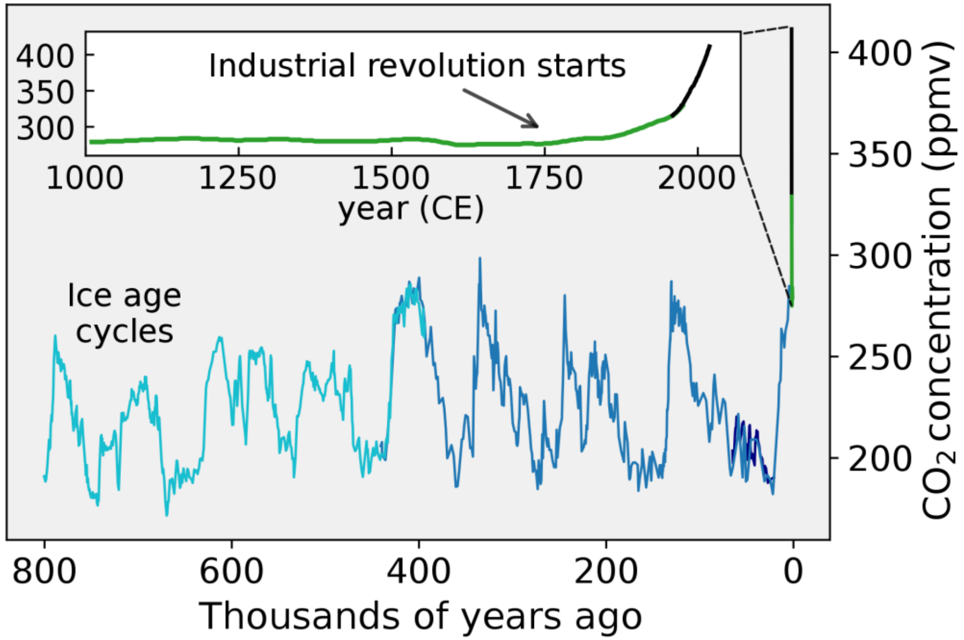
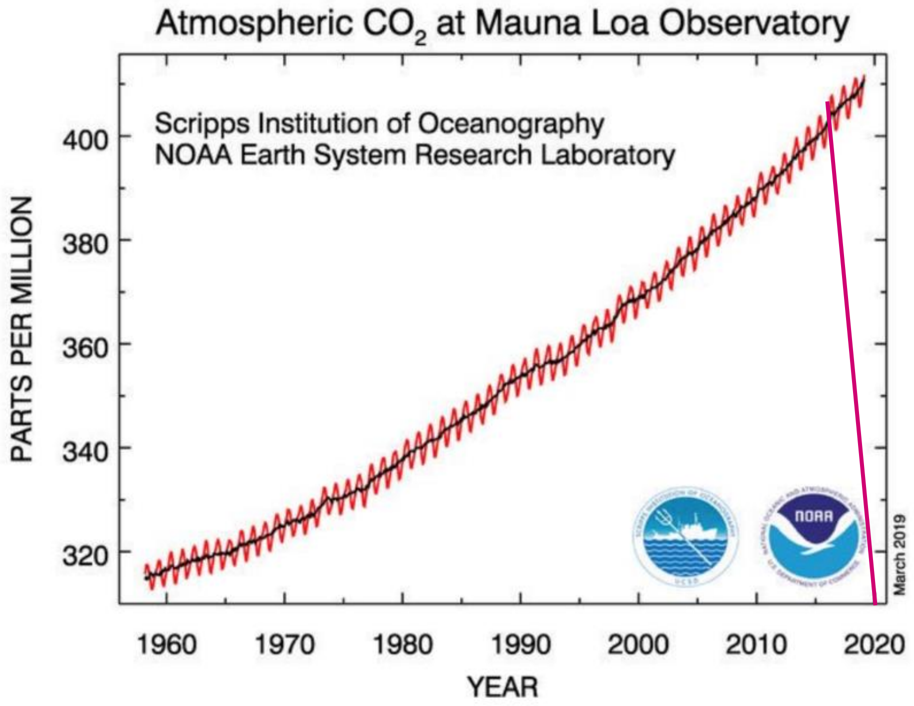
Negative Emission Techniques (NET) or Carbon Dioxide Removal (CDR)

Albert van den Berg – Climate Centre – University of Twente

FLUCTUATIONS VS TREND

Atmospheric CO_2





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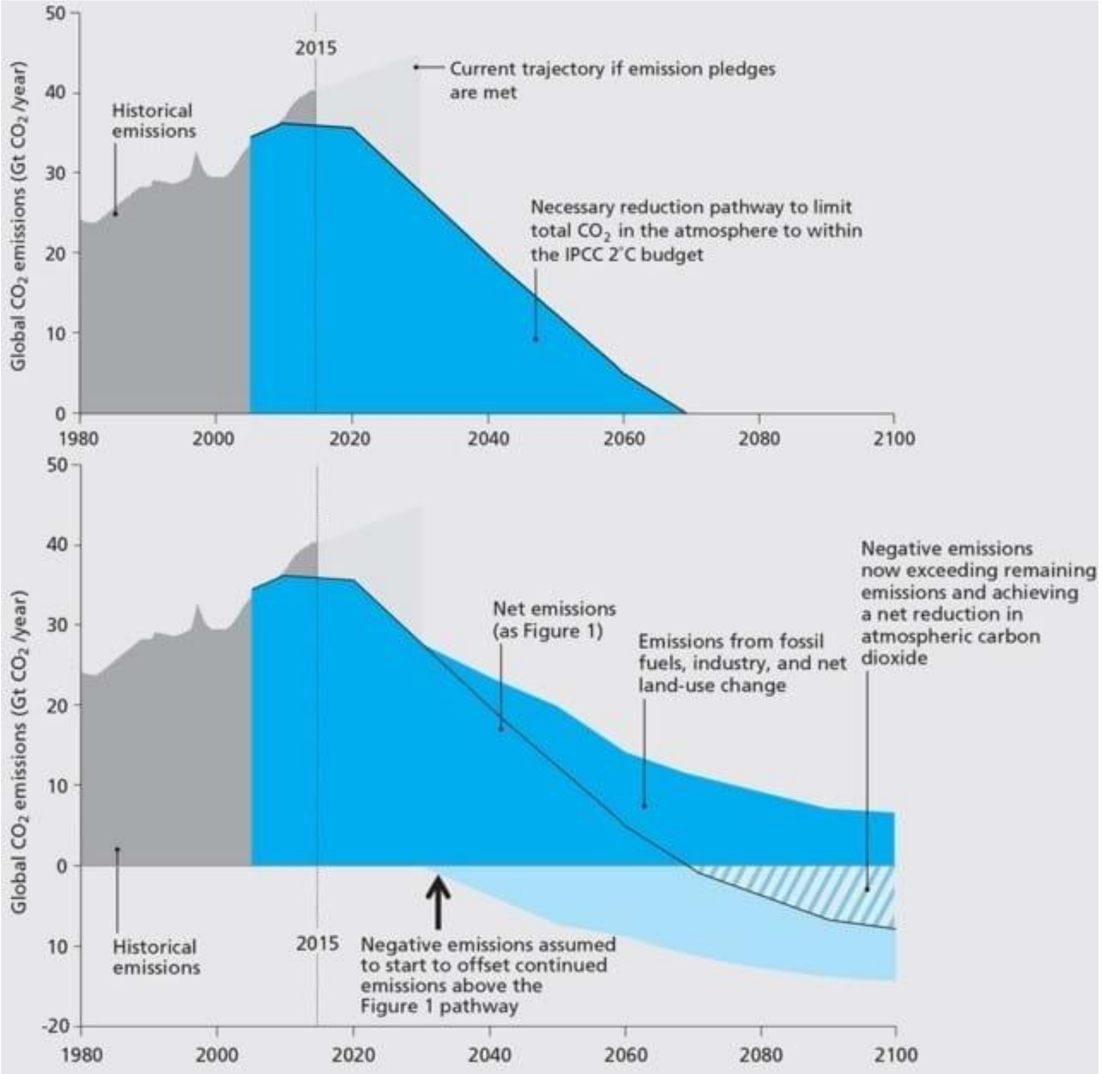
EMISSION REDUCTION ALONE IS NOT ENOUGH

Negative emission technologies are required to meet Paris climate agreement



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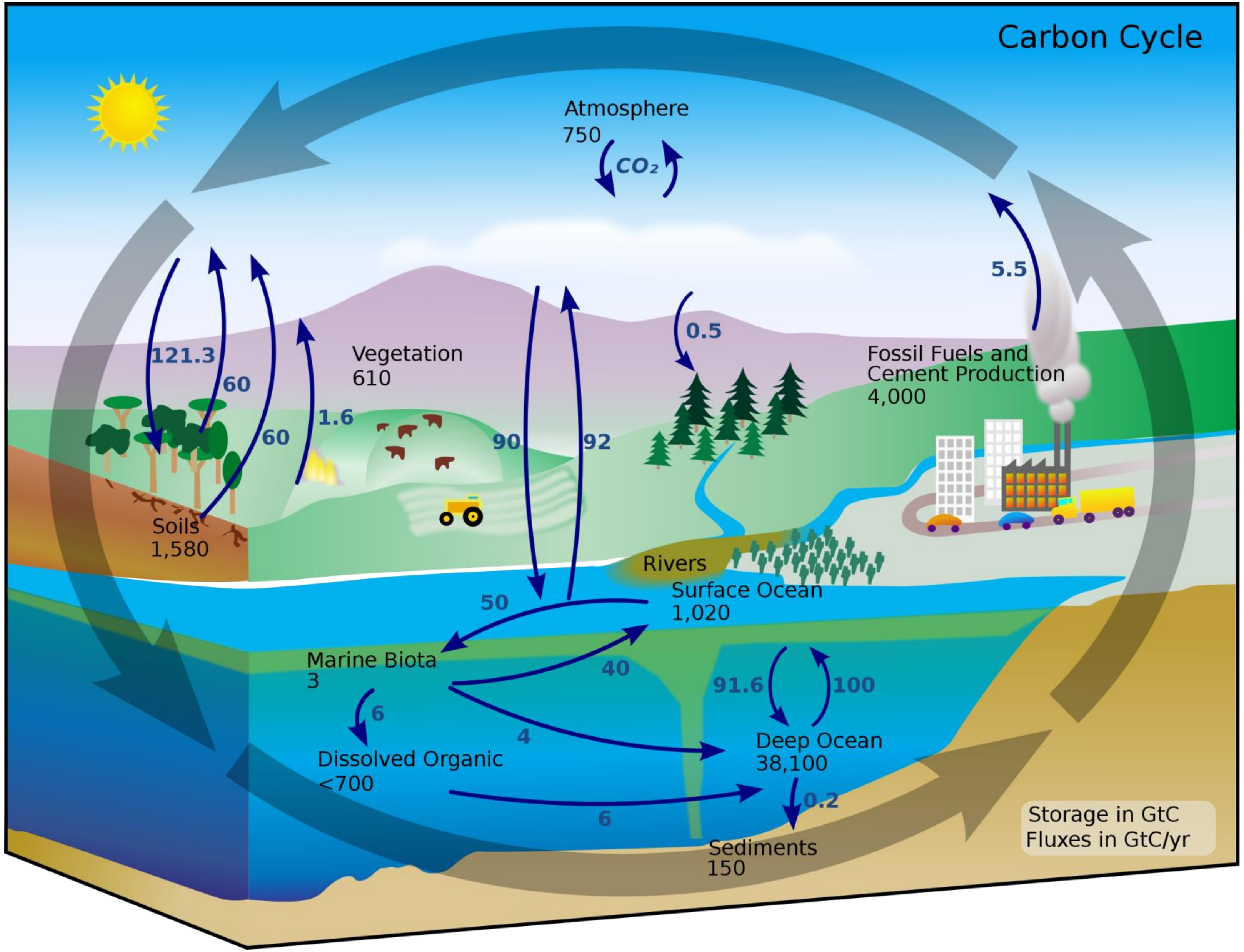
CARBON CYCLE ON EARTH



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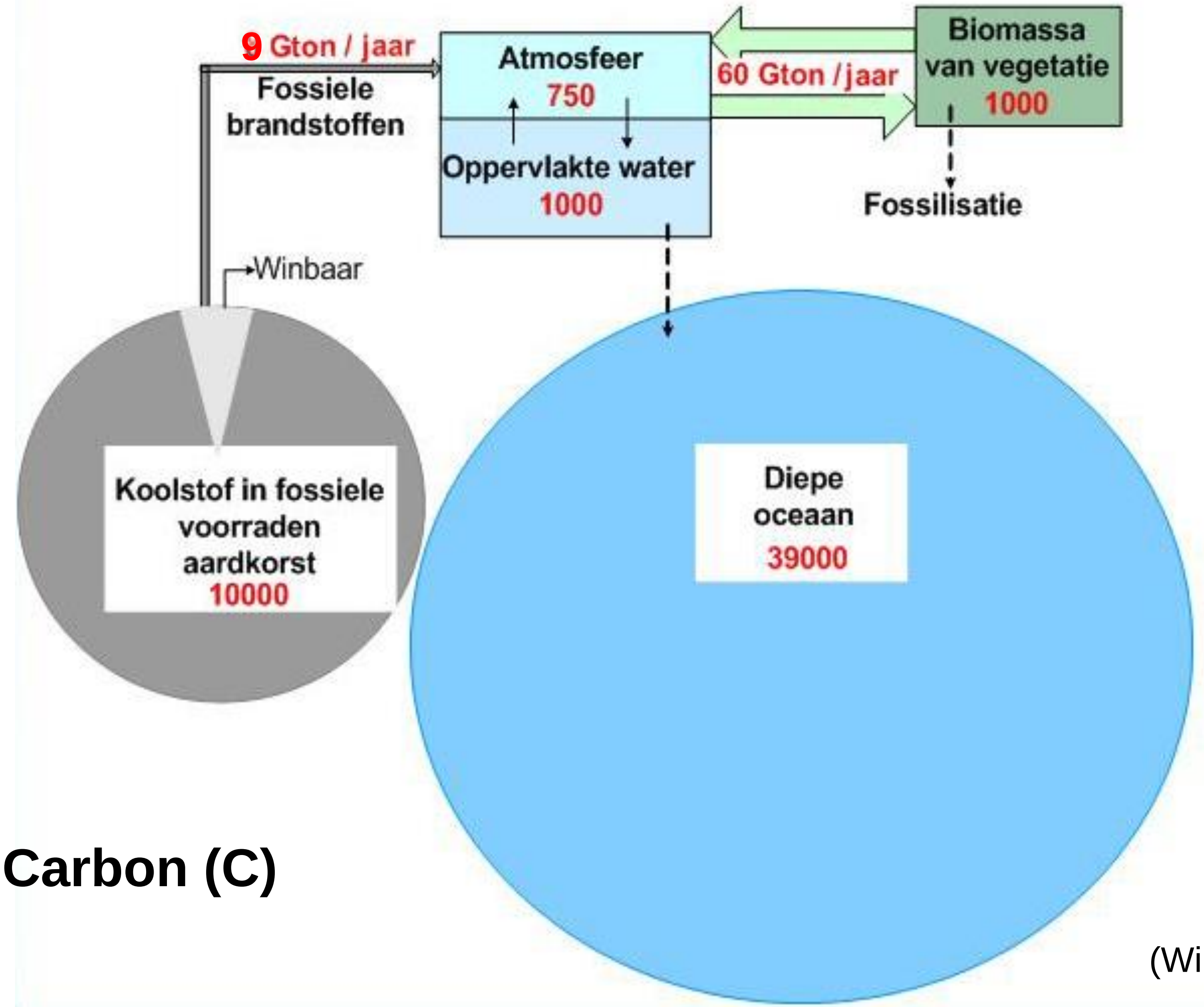
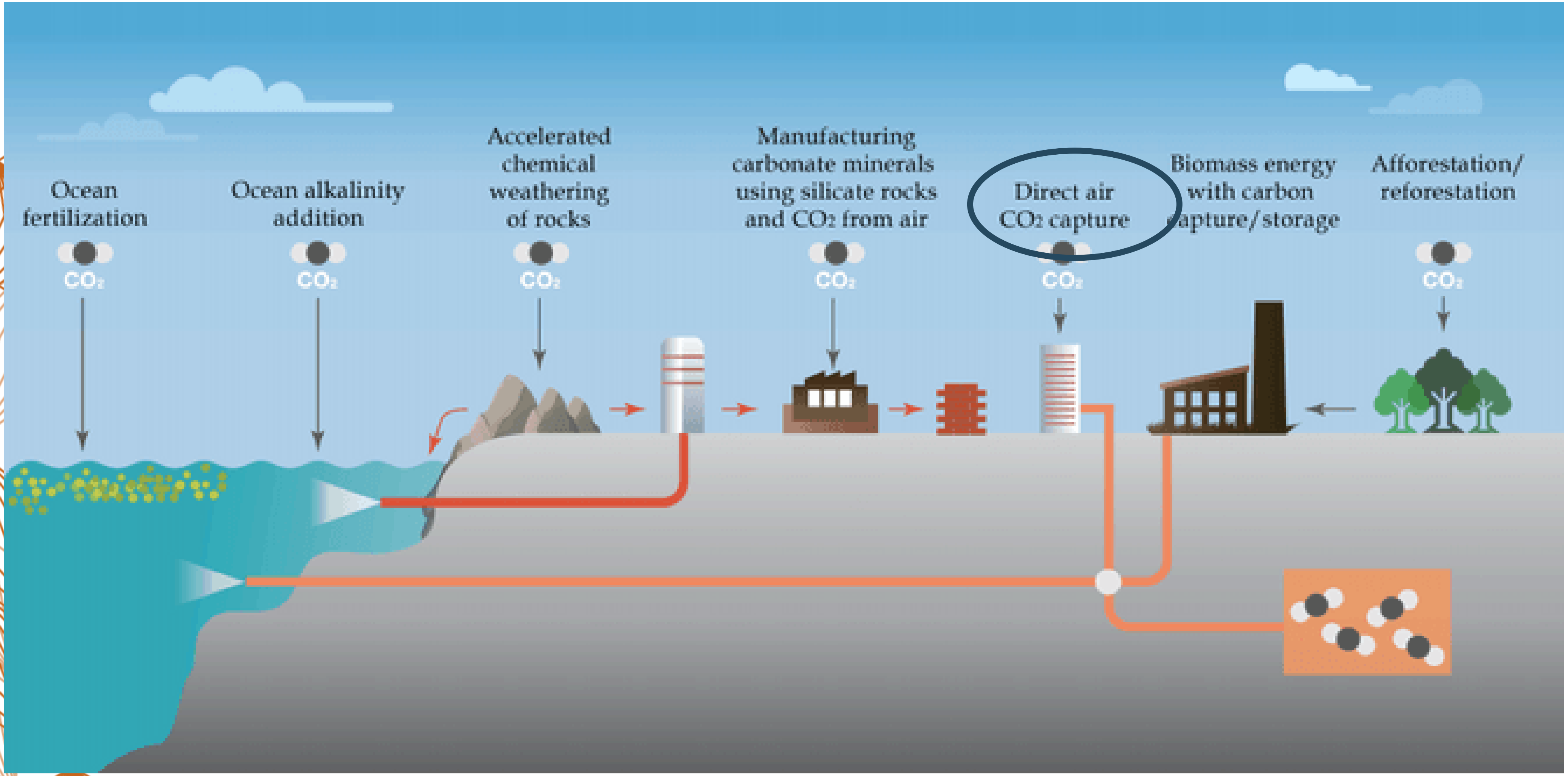
SIMPLIFIED:



Gigaton Carbon (C)

(Wim van Swaaij, 2019)

OPTIONS NEGATIVE EMISSION TECHNOLOGIES



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DIRECT AIR CAPTURE
(WIM BRILMAN)

Direct Air Capture (DAC)

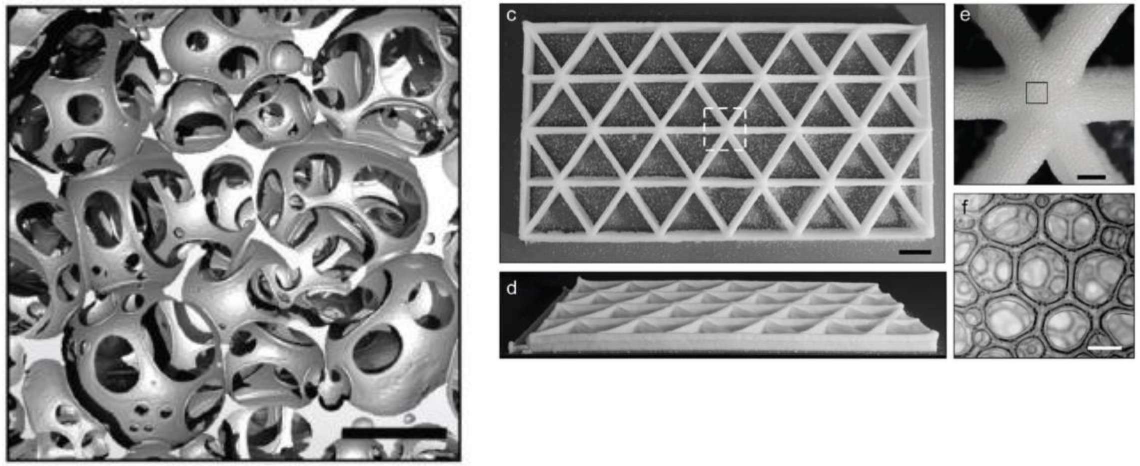
Challenge 1: Low ΔP for treating large volumes of air

Challenge 2: Low ΔE materials (low desorption energy)

Challenge 3: Integration caption & conversion

Challenge 4: Water

Challenge 5: SCALE UP to Gigatons



Visser, C. W. et al., Continuous High-Throughput Fabrication of Architected Micromaterials via In-Air Photopolymerization. *Adv. Mater.* 2021, 33, 2006336; Architected Polymer Foams via Direct Bubble Writing. *Adv. Mater.* 2019, 31, 1904668.

vito

Direct Air Capture commercial Suppliers – Solid sorbents

CLIMEWORKS

global thermostat
a carbon negative solution

skytree

ANTECY

Supplier	Carrier/shape	sorbent	process	$T^{desorption}$
Climeworks	Pellets	Aminated nanocellulose fibers	TSA + vacuum (TVS)	120
Global Thermostat	Honeycomb	Aminated inorganic	Vapour Swing Adsorption	65 and more
Skytree	Beads	Aminated polymer beads	TSA + sweep	80-90
Antecy	Honeycomb	Salt on (in)organic honeycombs	TSA + vacuum	<80

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Technologies For CO_2 Capture and separation

	TRL 2-4	TRL 5 -7	TRL 8 - 9
TECHNOLOGIES	Ionic liquids Encapsulated solvents Catalytic membrane Ceramic membranes …	Polymer membranes Chilled ammonia Solid sorbents	Absorption by amines Alkali carbonate Cryo
COST * (€/Ton CO2)	30	40	50 - 75
TIME TO MARKET	2035 - 2040	2025 - 2030	Commercialised

* Future estimated CO_2 capture costs based on Concawe report, 2020

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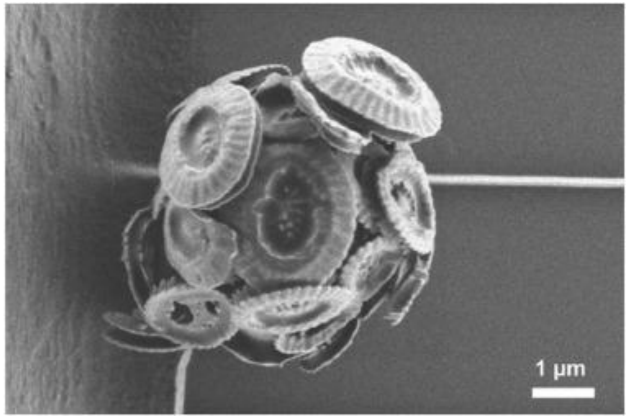
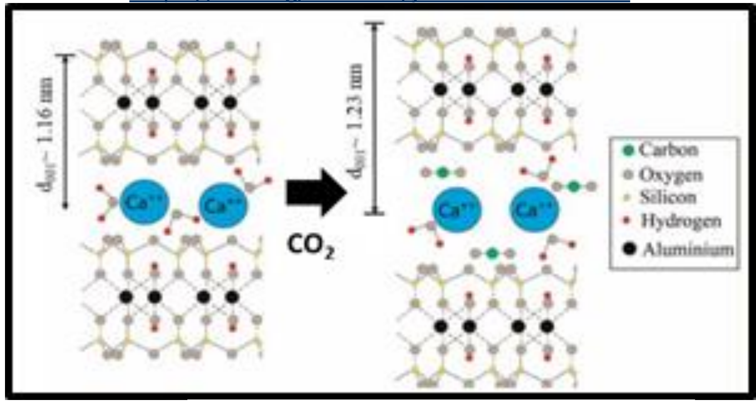
Towards carbonates

TOWARDS CARBONATES

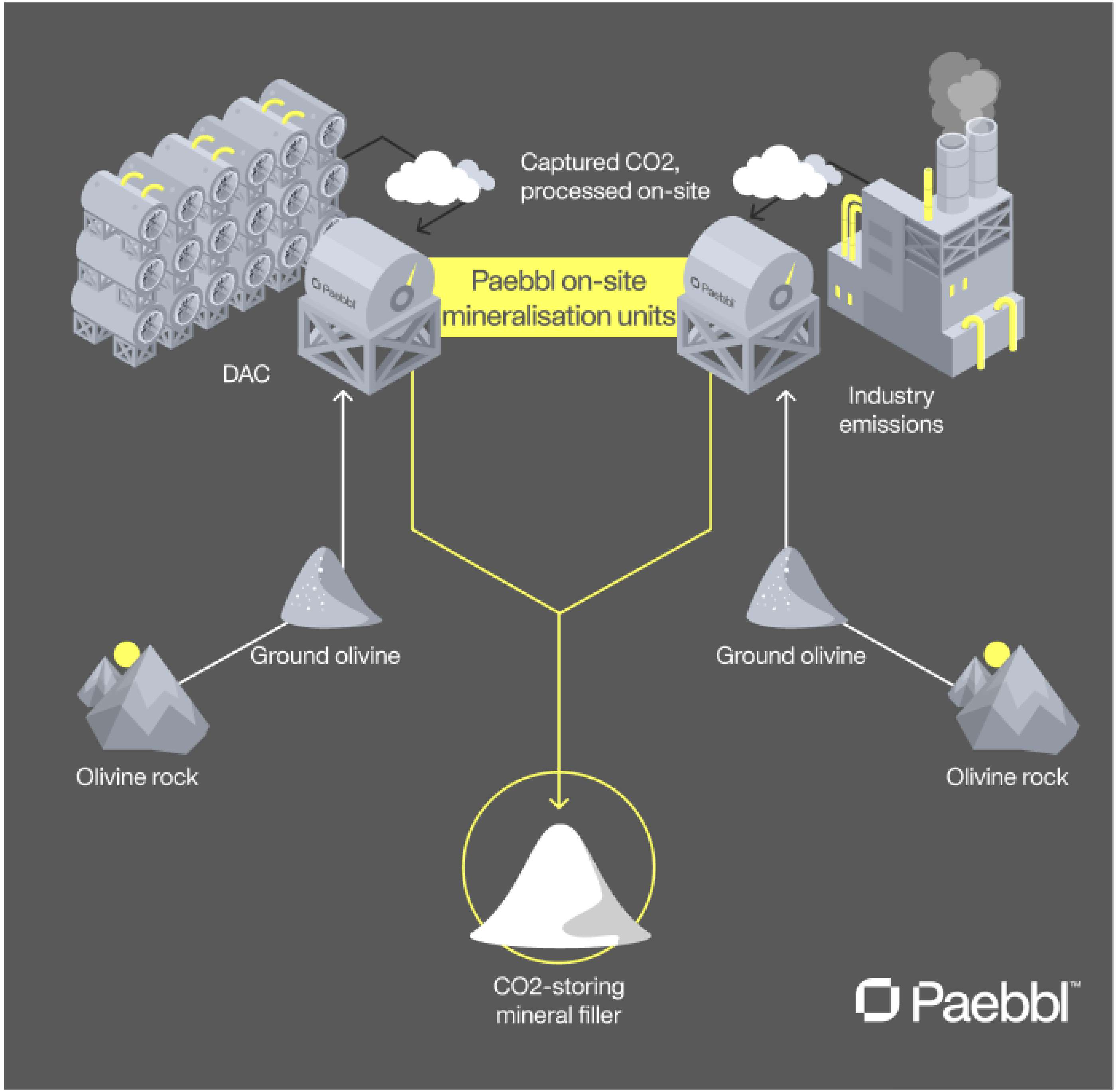
- Energetically ‘cheapest’ route
- Weathering of minerals (olivine)
- Storage in clays (Mugele)
- Algae routes
- Products for construction industry: cut out the emissions of concrete- and cement production and replace with carbon storing solutions



Calcifying algae on a microfluidic chip
https://doi.org/10.1016/j.bios.2020.112808



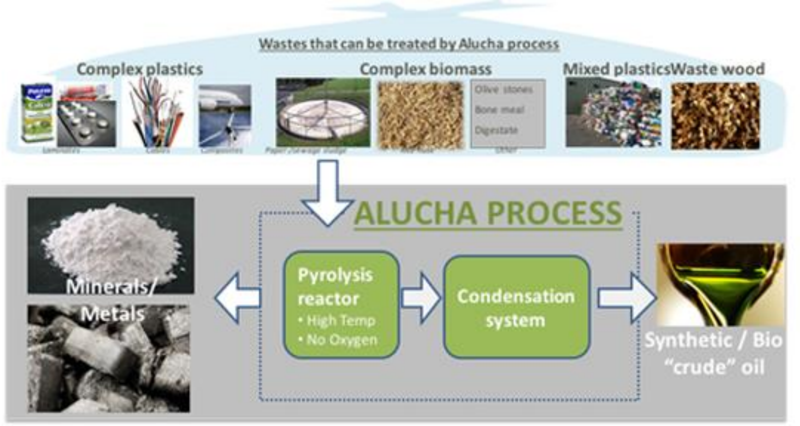
Clay materials

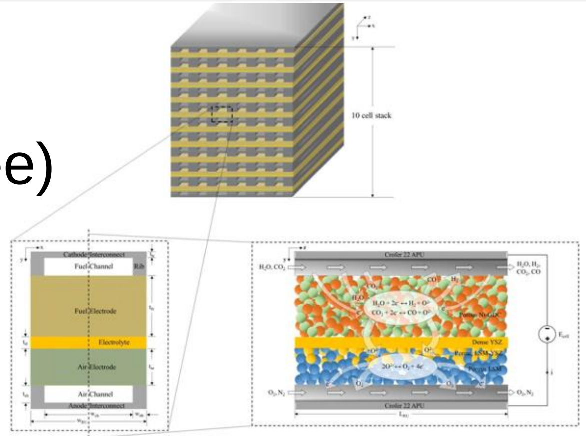

Captured CO2,
processed on-site
Paebbl on-site
mineralisation units
DAC
Industry
emissions
Ground olivine
Ground olivine
Olivine rock
Olivine rock
CO2-storing
mineral filler
Paebbl™

TOWARDS CARBON

Towards carbon

- Energetically expensive route
- Products: C, O_2, H_2
- Applications of C
  - Fillers in rubbers (Dierkes/Blume)
  - C in materials (high-tech, moderate volumes)
  - Soil enhancement in agriculture
- Technologies
  - Electrochemical high/low T (Mul, Mei, Lohse, Banerjee)
  - Pyrolysis/torrefaction (Brem, Kersten)
  - Catalysis + Plasma (Lefferts)
  - High-T solar (direct decomposition of CO_2)





Banarjee et al., Applied Energy 2018 230 996-1013
Hierarchical modeling of solid oxide cells and stacks…

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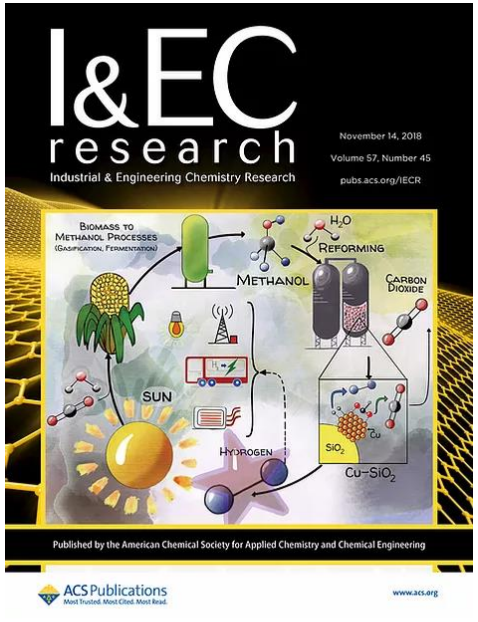
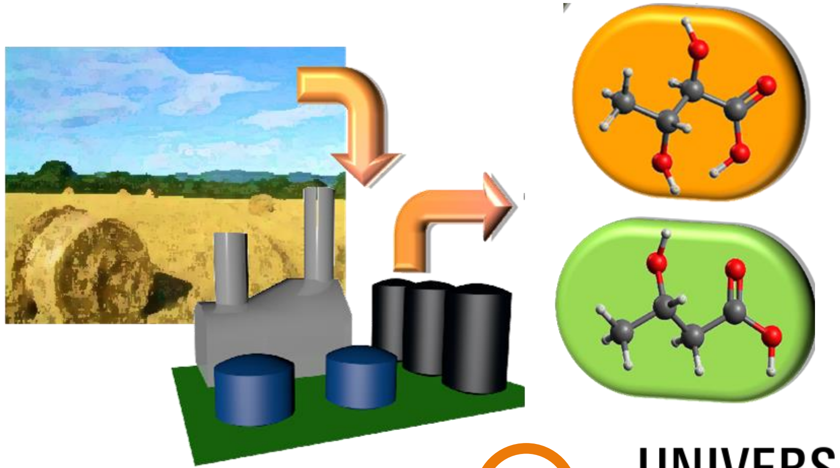
TOWARDS CHEMICALS AND POLYMERS

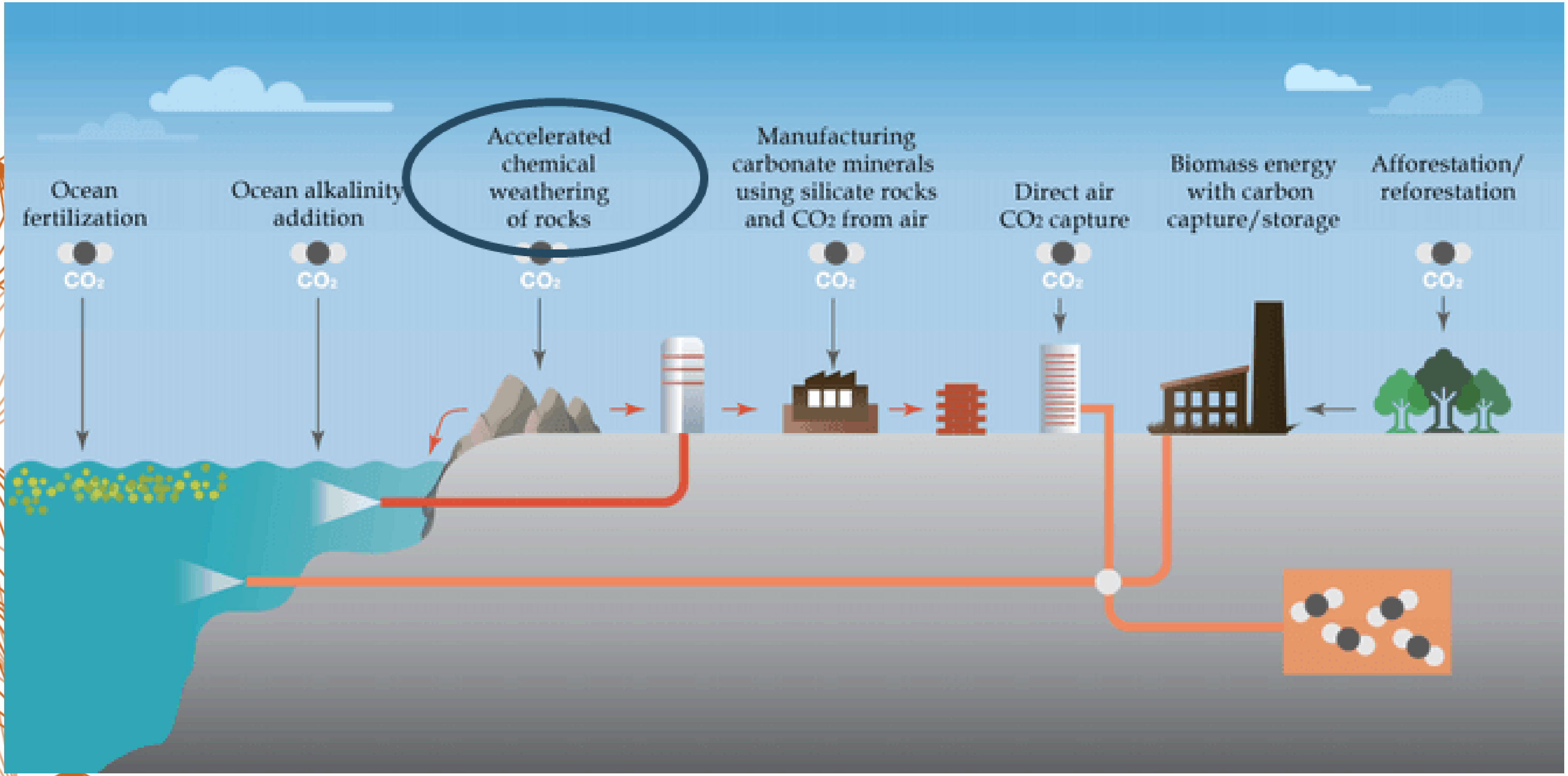
- Sources are biomass and CO_2
- Oxygen-rich products
- Not fully “NET”, but surely circular
- Carbonate based polymers (Wurm, de Beer, Faria)
- Base materials (Schuur)
  - DMC and other carbonates
  - Crotonic acid (Schuur)
  - Alcohols, MeOH, DME (Brilman, Lefferts)





Jimmy Faria c.s., Angew. Chem. Int. Ed., 59 (2020), 1-6, 9, 11, (2019).

OPTIONS NEGATIVE EMISSION TECHNOLOGIES



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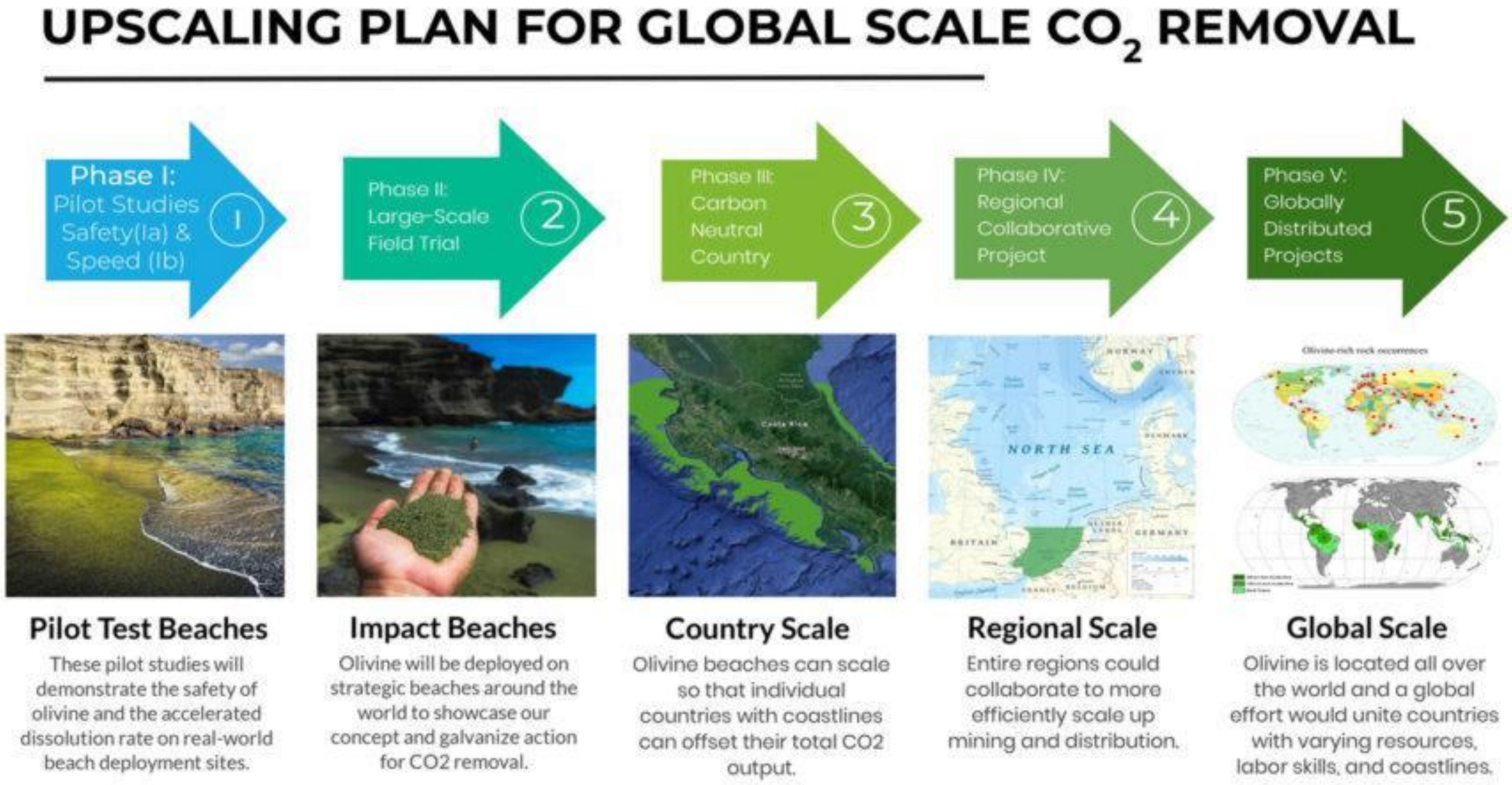
Project Vesta



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Van Oord dredging

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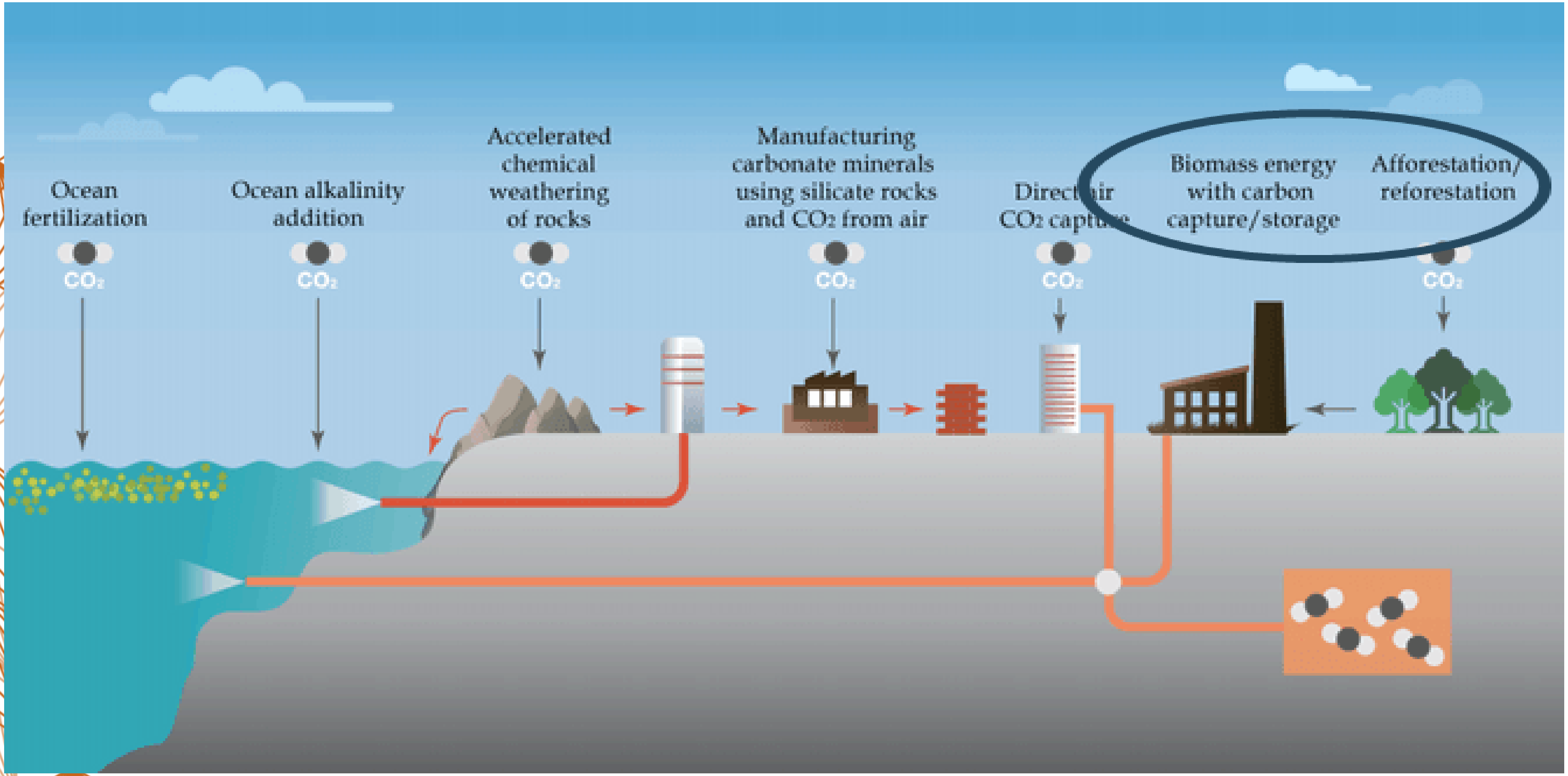
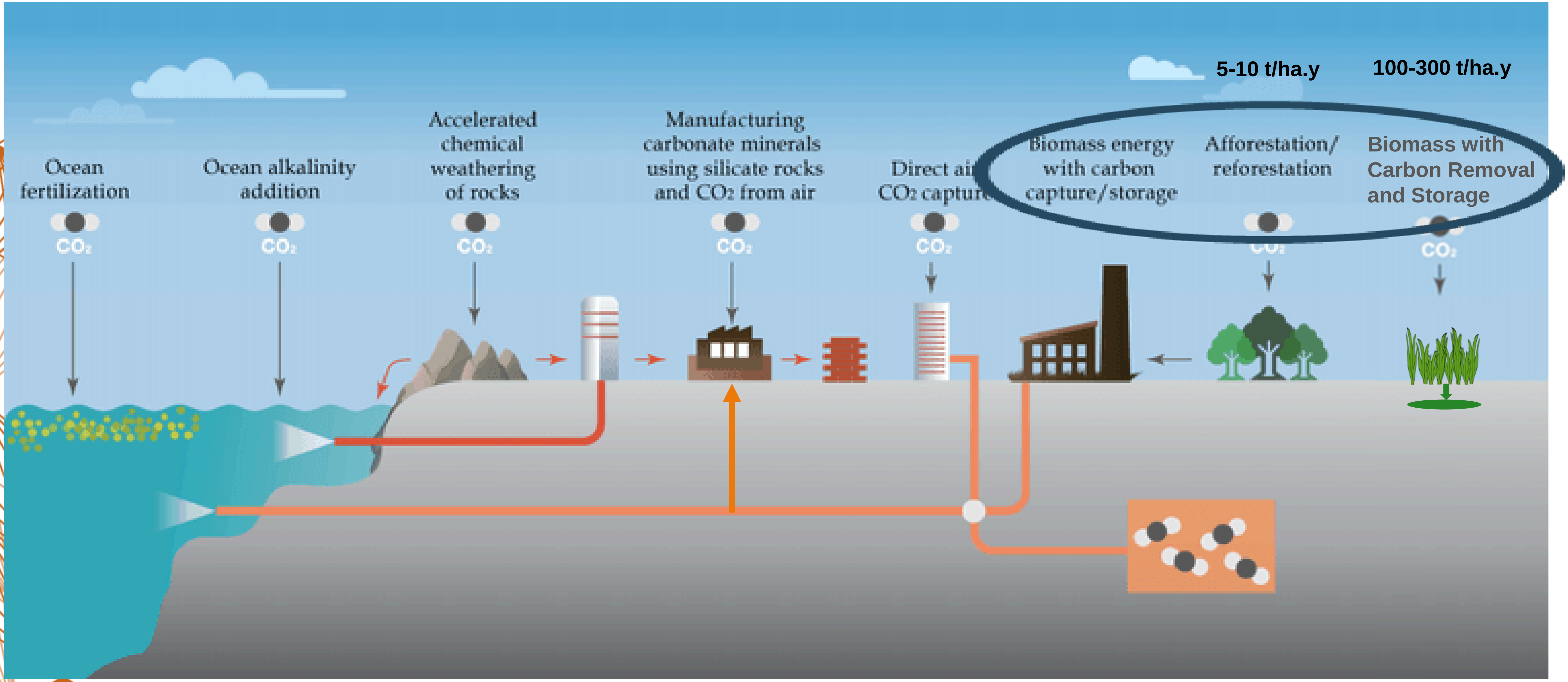
OPTIONS NEGATIVE EMISSION TECHNOLOGIES



OPTIONS NEGATIVE EMISSION TECHNOLOGIES



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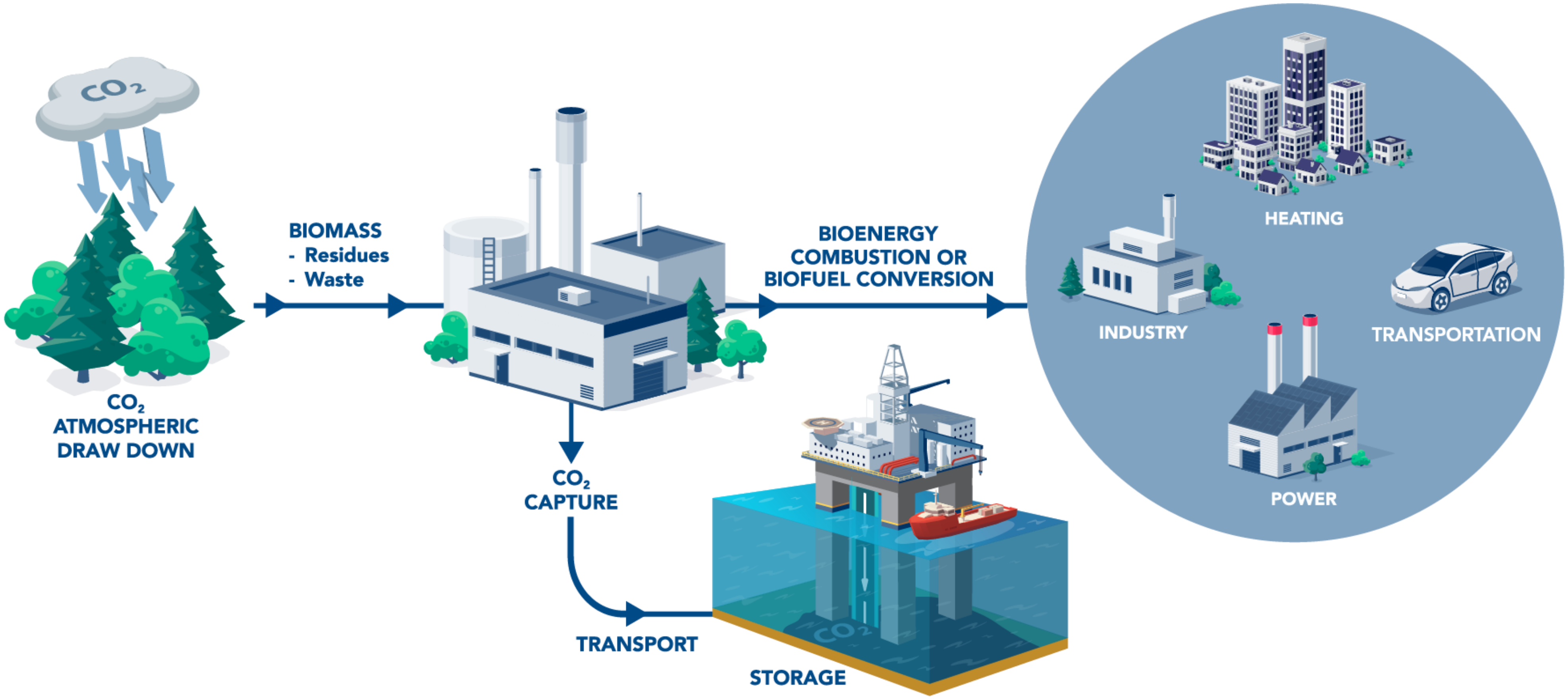
BECCS – BIOENERGY WITH CARBON CAPTURE AND STORAGE



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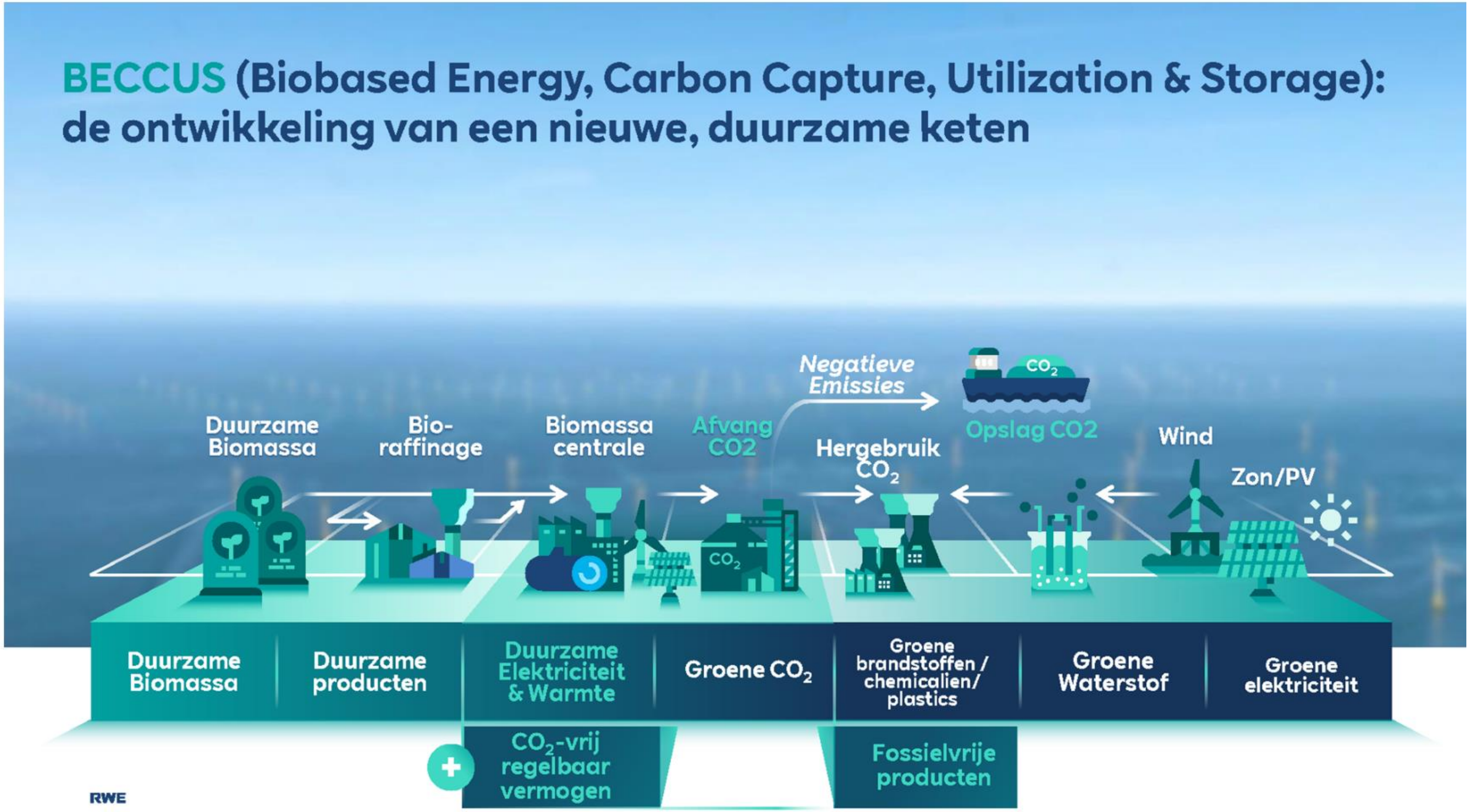
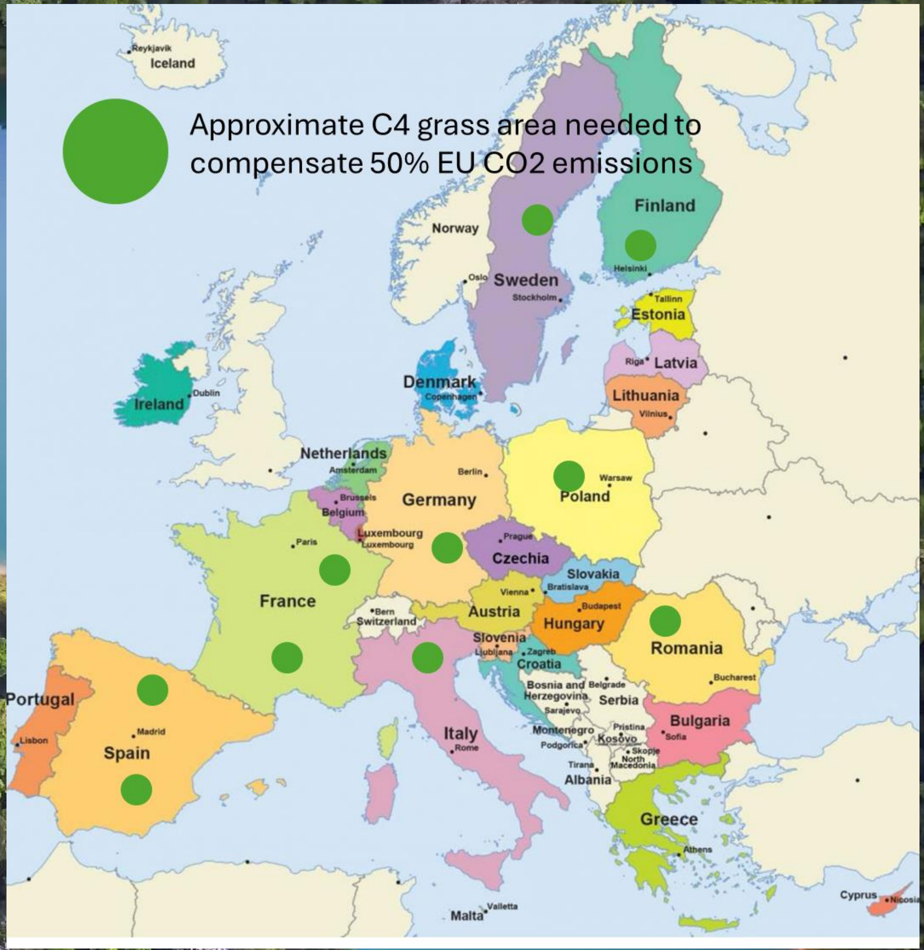
RWE INITIATIVE



Biomass Carbon Removal and Storage (BiCRS)



Carbon-ALERT

SOCIETAL DIMENSION

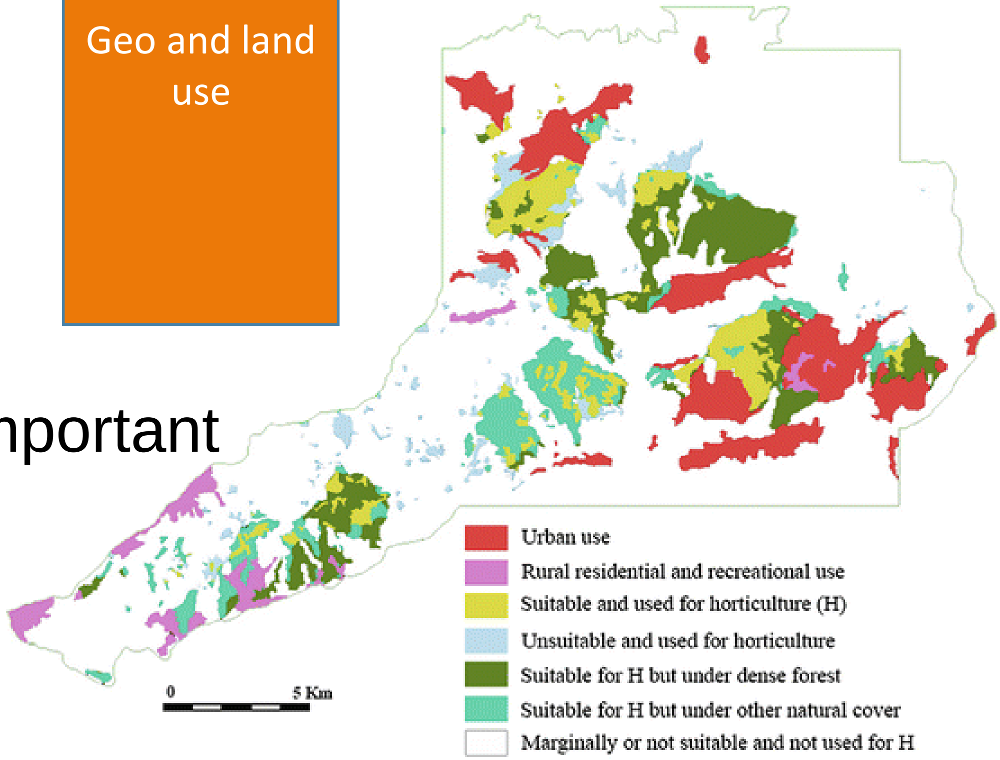
- Governance of the sociotechnical transition towards NET
- Ethical aspects of NET at various levels (normative aspects)
  - Citizen
  - Governmental
  - Geopolitical/geographical
- Legal & Regulatory
- Responsible Design of NET (e.g. competition with food production and energy use)
- Citizen Science
- Business model development & logistics

Societal dimension

GEO AND LAND USE

Geo and land use

- NET is global issue, scale is huge…
- Earth observation tools needed
- Geological and land use aspects are important
- Local land/weather conditions
  - Utilizing wind/natural convection
  - Using water co-absorption
  - Underground storage
  - Weathering (in situ and technological)
- Finding optimum location for each technology or combination of technologies is key



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