

What to do with CO₂ ?

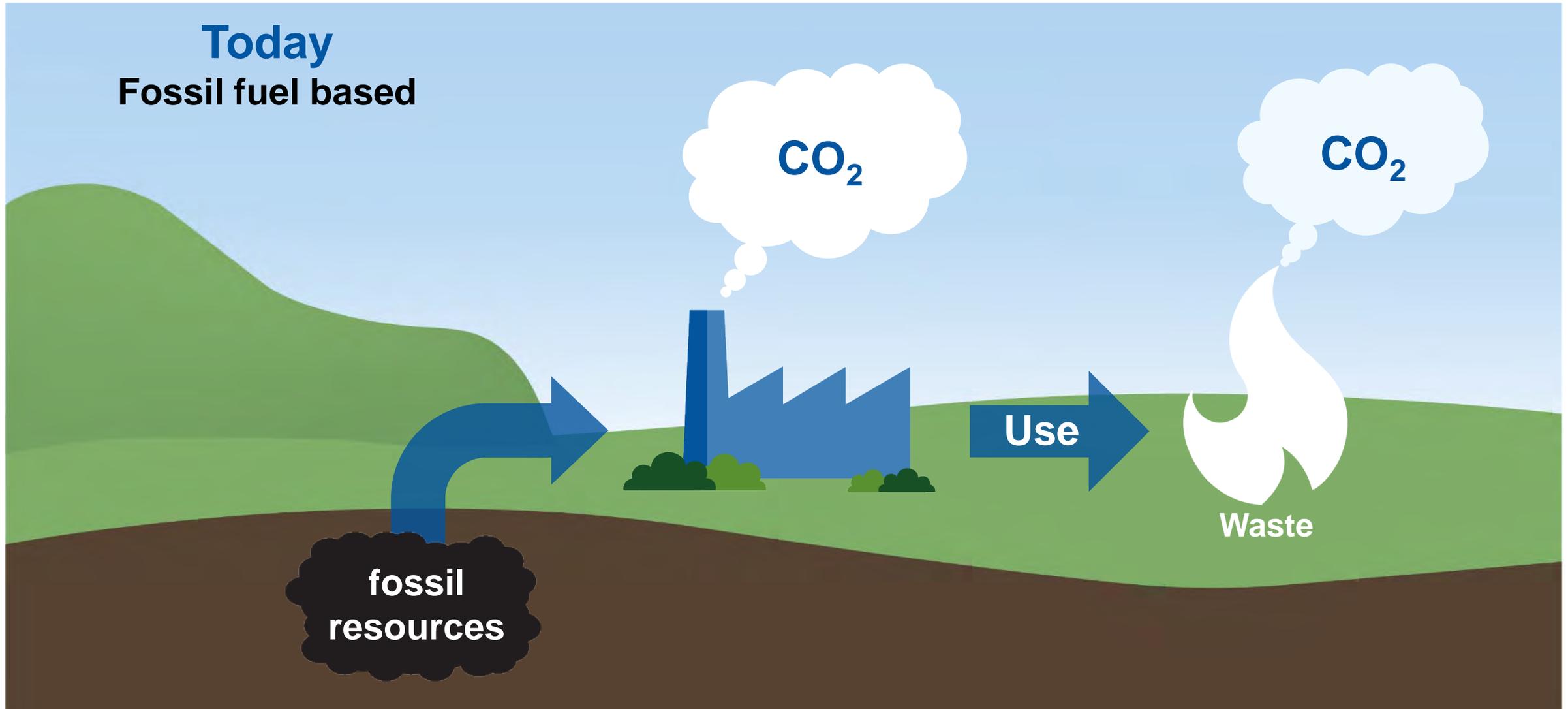
Möglichkeiten & Grenzen der CO₂-Nutzung

André Bardow
ETH Zurich

VBSA-Fachtagung
Dienstag, 6. Dezember 2022, Hotel Arte, Olten



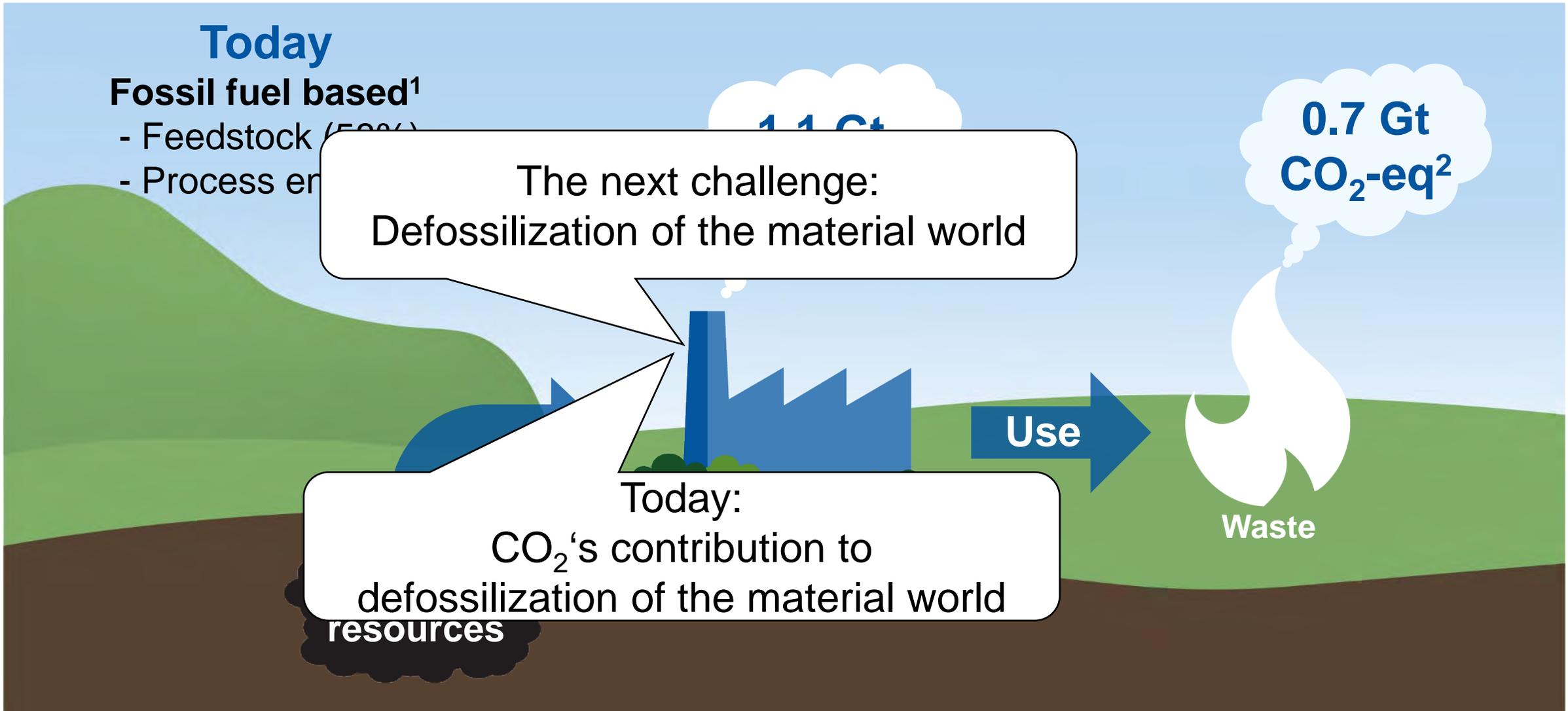
The current linear fossil-based carbon economy



¹ IEA, DECHEMA, ICCA (2013), Technology Roadmap

² Zheng and Suh. *Nature Climate Change*. 2019. <https://doi.org/10.1038/s41558-019-0459-z>

The Fossil-based Chemical and Plastics Industry



¹ IEA, DECHEMA, ICCA (2013), Technology Roadmap

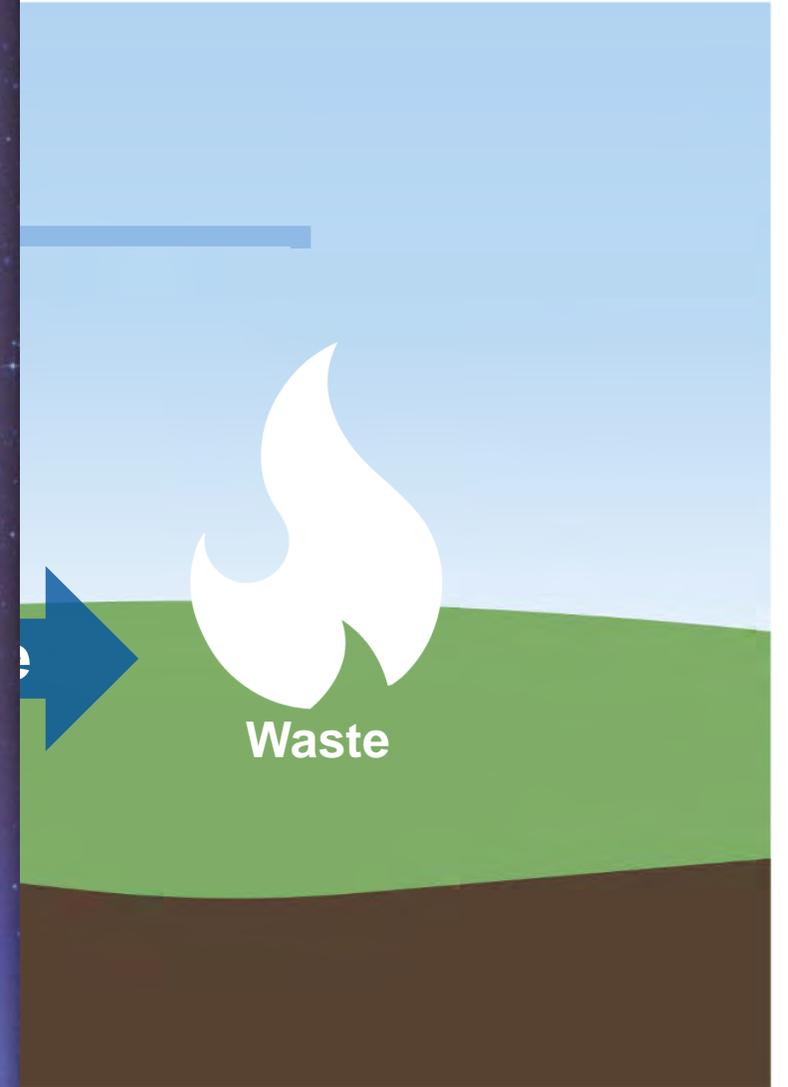
² Zheng and Suh. *Nature Climate Change*. 2019. <https://doi.org/10.1038/s41558-019-0459-z>

Idea: CIRCULAR ind



PETER ATKINS
**FOUR
LAWS**
THAT DRIVE THE
UNIVERSE

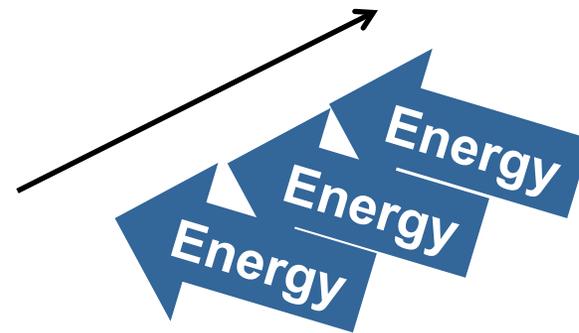
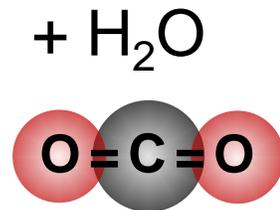
'This book is a joy to read.'
PAUL DAVIES



Thermodynamics of CO₂ conversion:

1. Inverting combustion

Energy



Chemicals & fuels

ETH zürich

Separation Processes
Laboratory



La logistique du CO₂

Pauline Oeuvray

Doctorante à l'EPF de Zürich

6 décembre 2022, séminaire ASED, Olten

The PrISMa Platform – Rapid screening of CO₂ capture technology

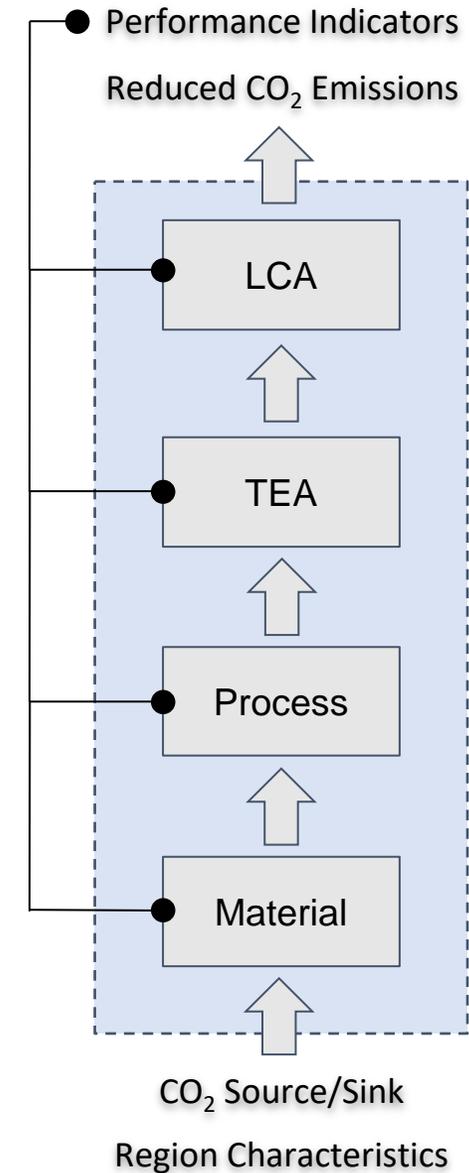
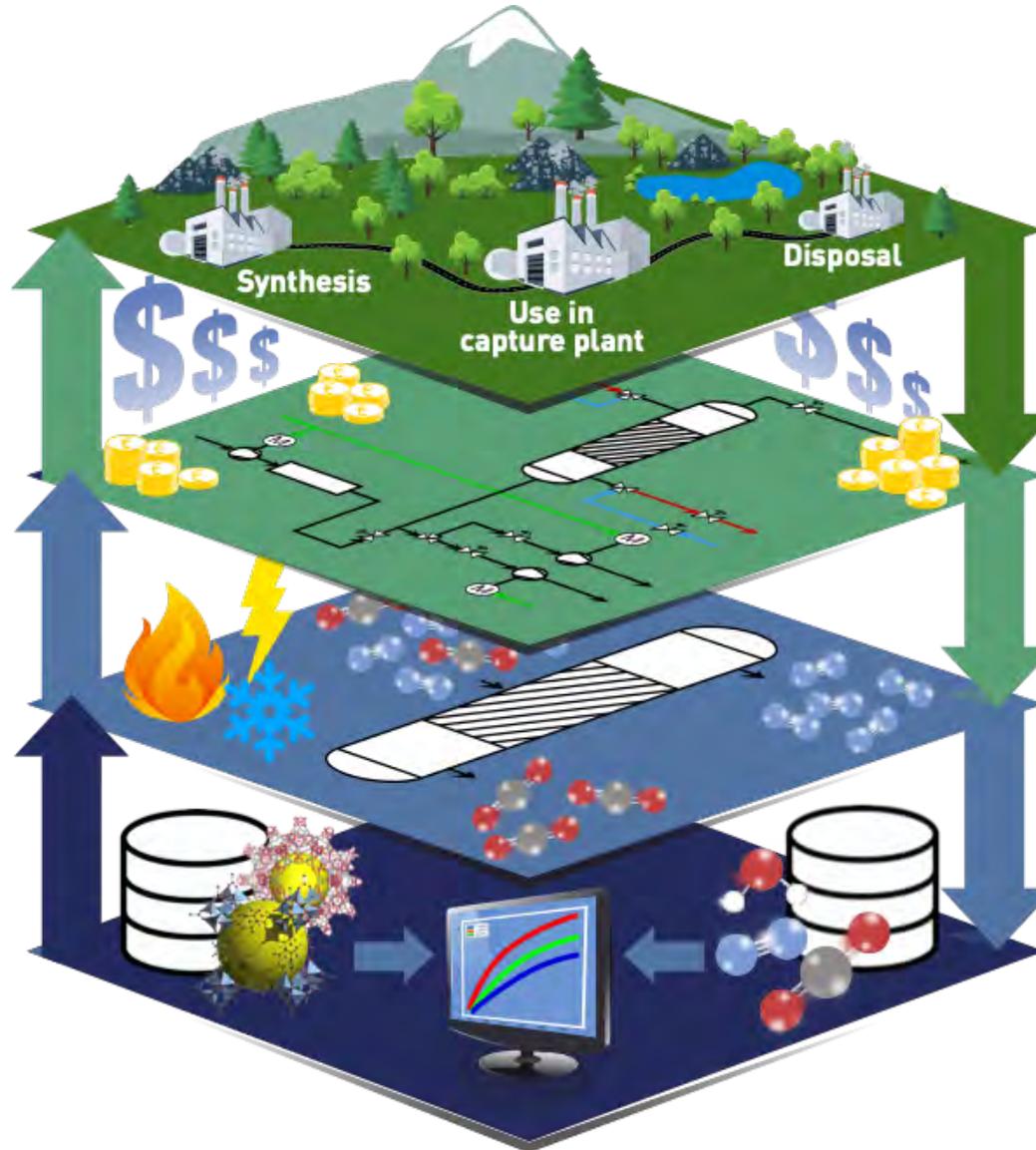
The Platform Core Team:

ETHZ: Johannes Schilling,
André Bardow

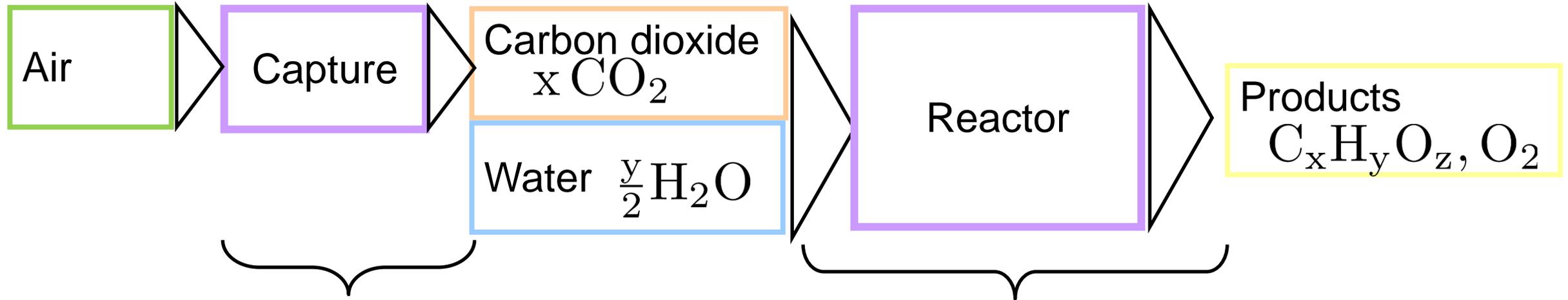
Solverlo: Eva Sanchez
Fernandez

Heriot-Watt: Charithea
Charalambous, Jinyu Wang,
Laura Herraiz-Palomino,
Susana Garcia

EPFL: Elias Moubarak, Kevin
Jablonka, Berend Smit



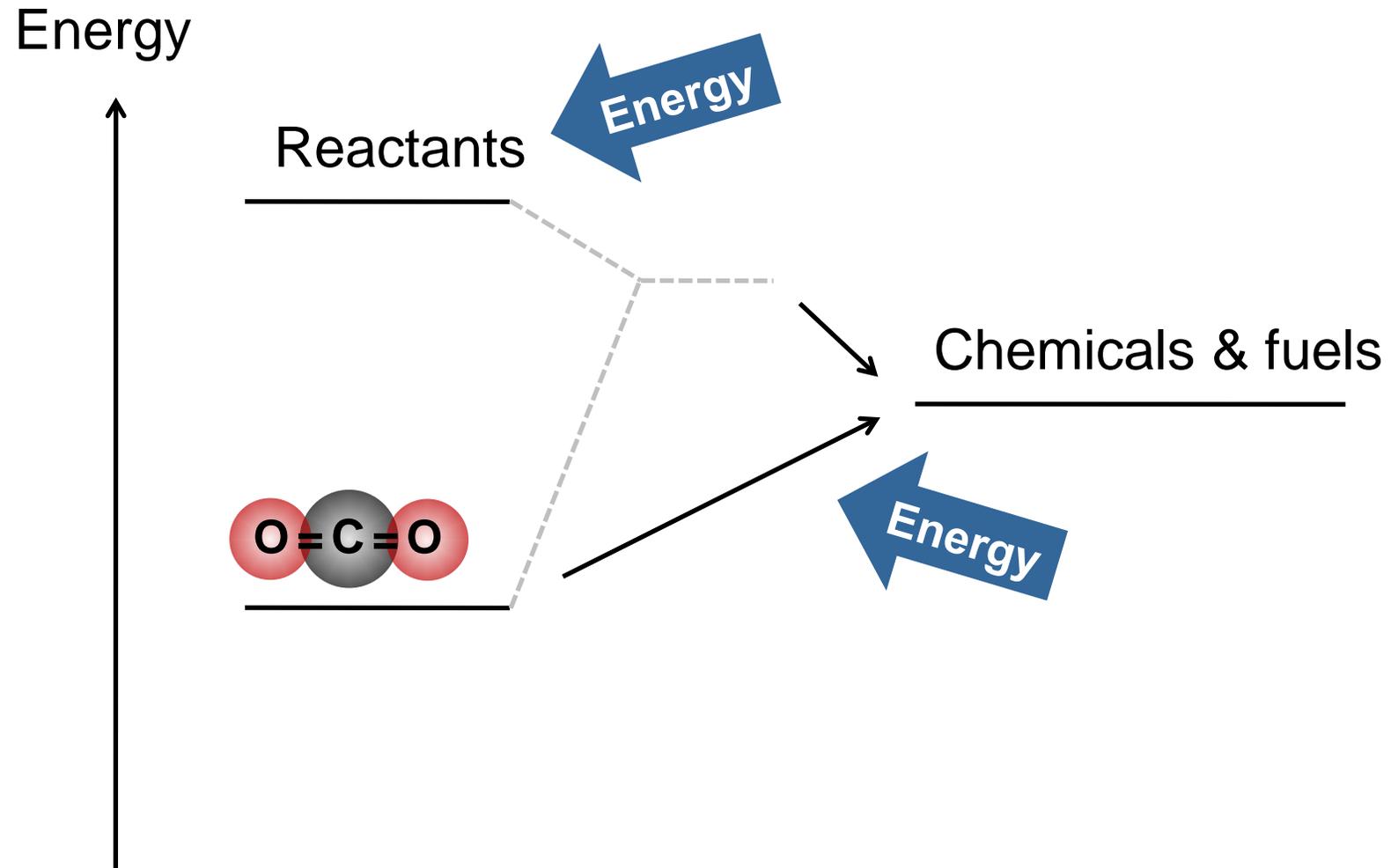
Thermodynamics of CO₂ conversion: Supply Chain



$$4 - 5 \times \Delta_{DAC}G = \Delta_R G$$

CO₂ conversion starting from CO₂ + water
= 4-5 times the minimal energy demand of direct air capture

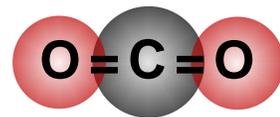
Thermodynamics of CO₂ conversion: 2. More efficient chemistry



Thermodynamics of CO₂ conversion:

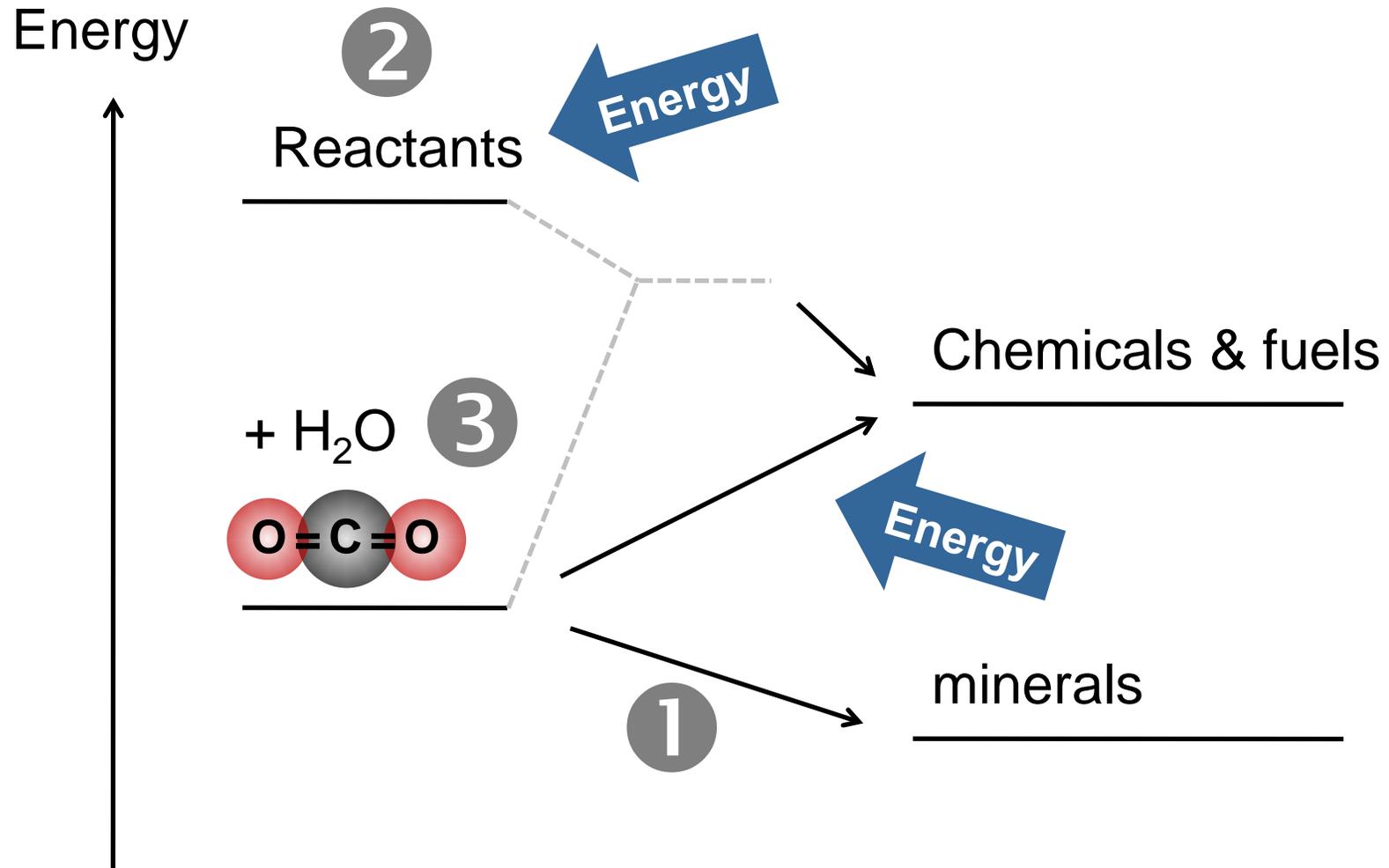
3. Mineralization

Energy



minerals

Thermodynamics of CO₂ conversion



The Team



Niklas von der Assen André Sternberg Arne Kätelhön Nils Baumgärtner Johanna Kleinekorte Marvin Bachmann Lorenz Fleitmann



Raoul Meys Sarah Deutz Hesam Ostovari Benedikt Winter Tim Langhorst David Shu Christiane Reinert

Funding

GEFÖRDERT VOM



Bundesministerium
für Bildung
und Forschung



Our Project Partners

- Walter Leitner
- Thomas Müller
- Stefan Pischinger
- Sangwon Suh



Competence
Center
Power to Fuel

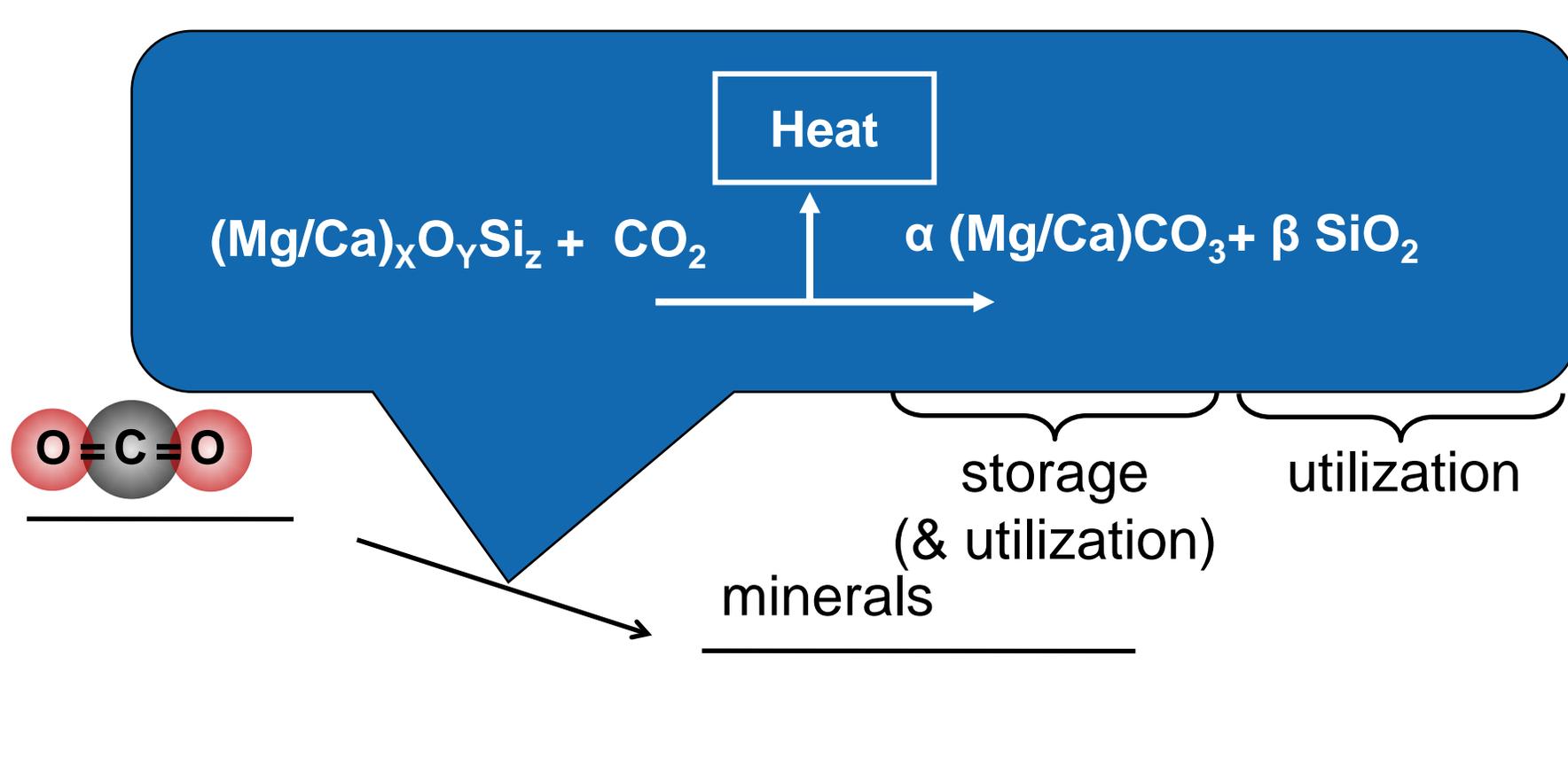


Thermodynamics of CO₂ conversion: 1. Mineralization



Hesam Ostovari

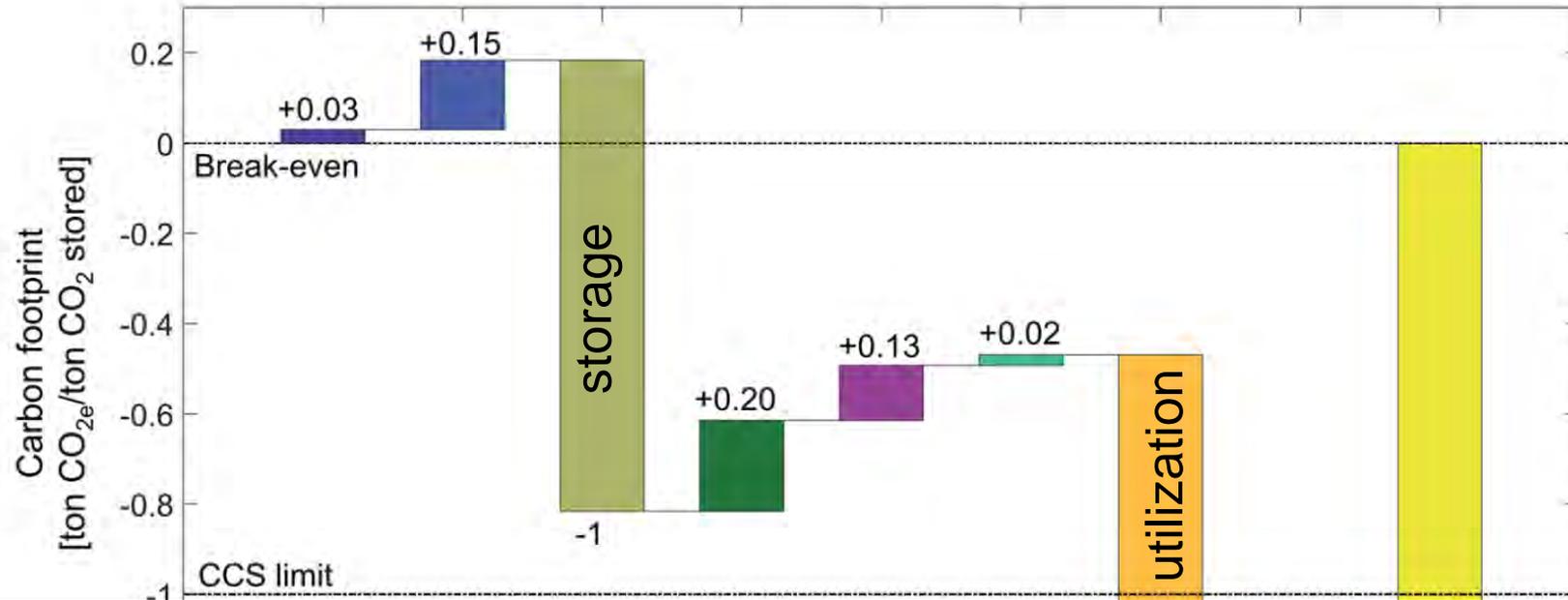
Energy





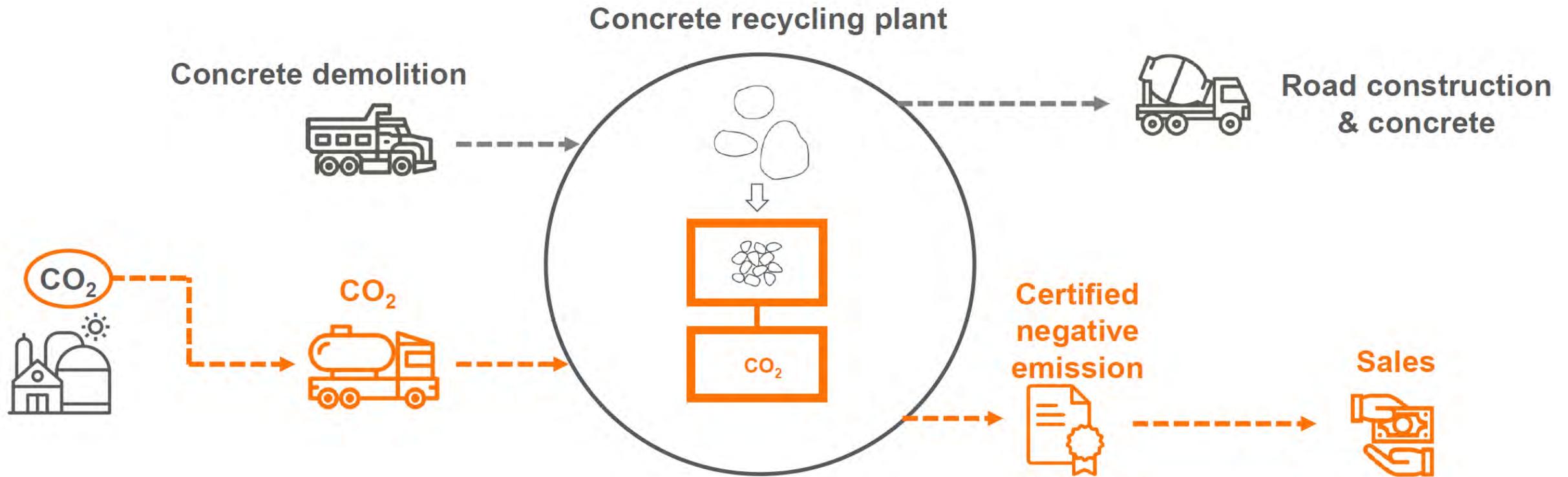
<https://doi.org/10.1039/D0SE00190B>

The carbon footprint of CO₂ mineralization to cement substitutes



- CO₂ mineralization combines storage + utilization
- GHG savings possible – even today !
- benefit from substitution of current materials
- product development crucial

ETH Spinoff on CO₂ mineralization: Neustark



<https://www.neustark.com/>

Status Quo:

- **Cement Market:**
4.5 Gt/year
- **CO_{2e} emissions:**
3.6 Gt CO_{2e}/year



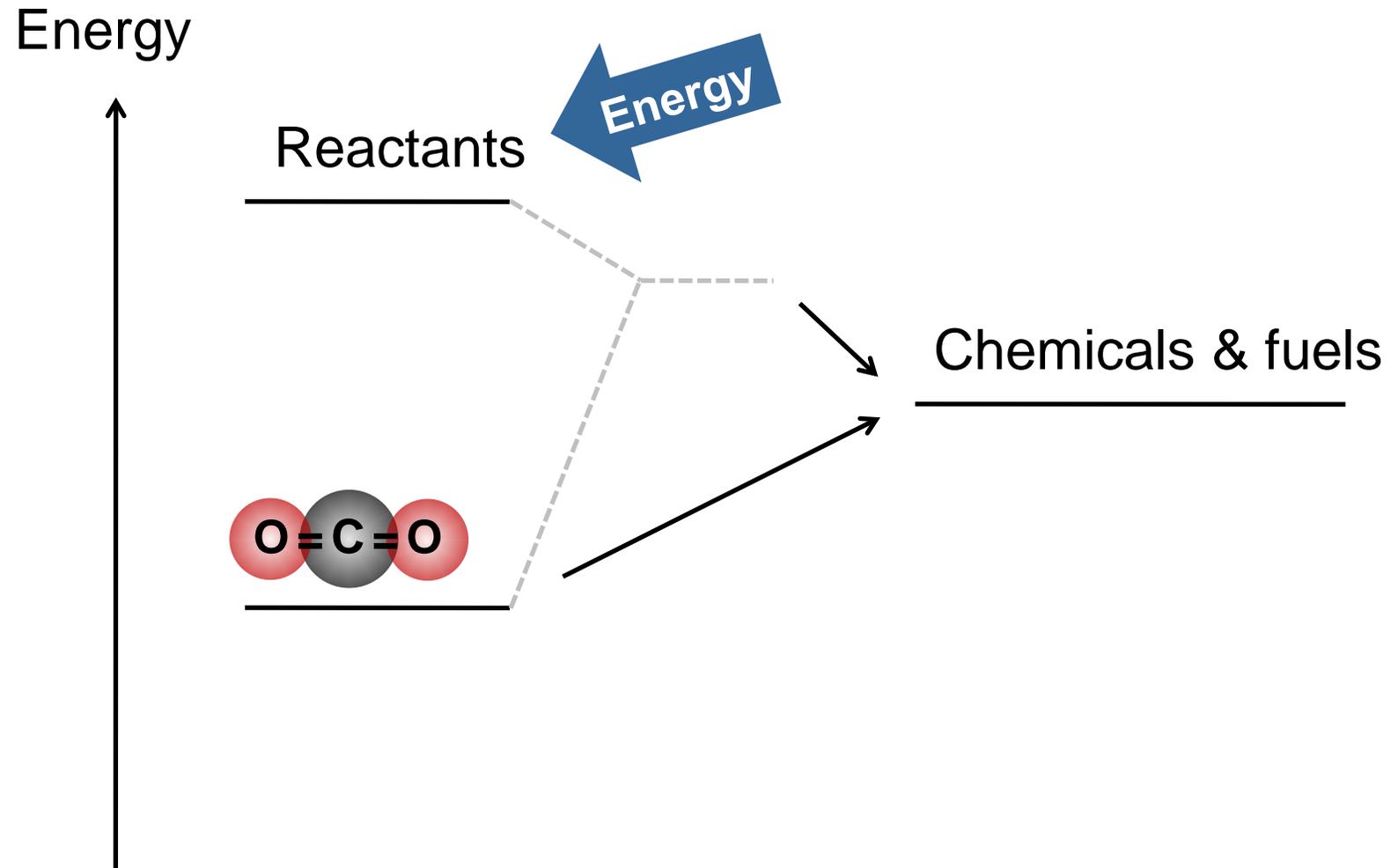
The potential for integrated CO₂ mineralization:

- **62% CO_{2e} reduction**
= 2.3 Gt CO_{2e}/year
- **Energy demand:**
4.37 GJ/ton CO₂

Miller, Vanderley Pacca, Horvath, (2018):
Cement and Concrete Research 114, 115–124.

Thermodynamics of CO₂ conversion:

2. More efficient chemistry



CO₂-based polymers: Project “Dream Production“



Niklas von der Assen



Scrubbing and supply of CO₂

VORWEG GEHEN



Process development and conversion of CO₂



Bayer Technology Services



Production and testing of polyurethanes with CO₂



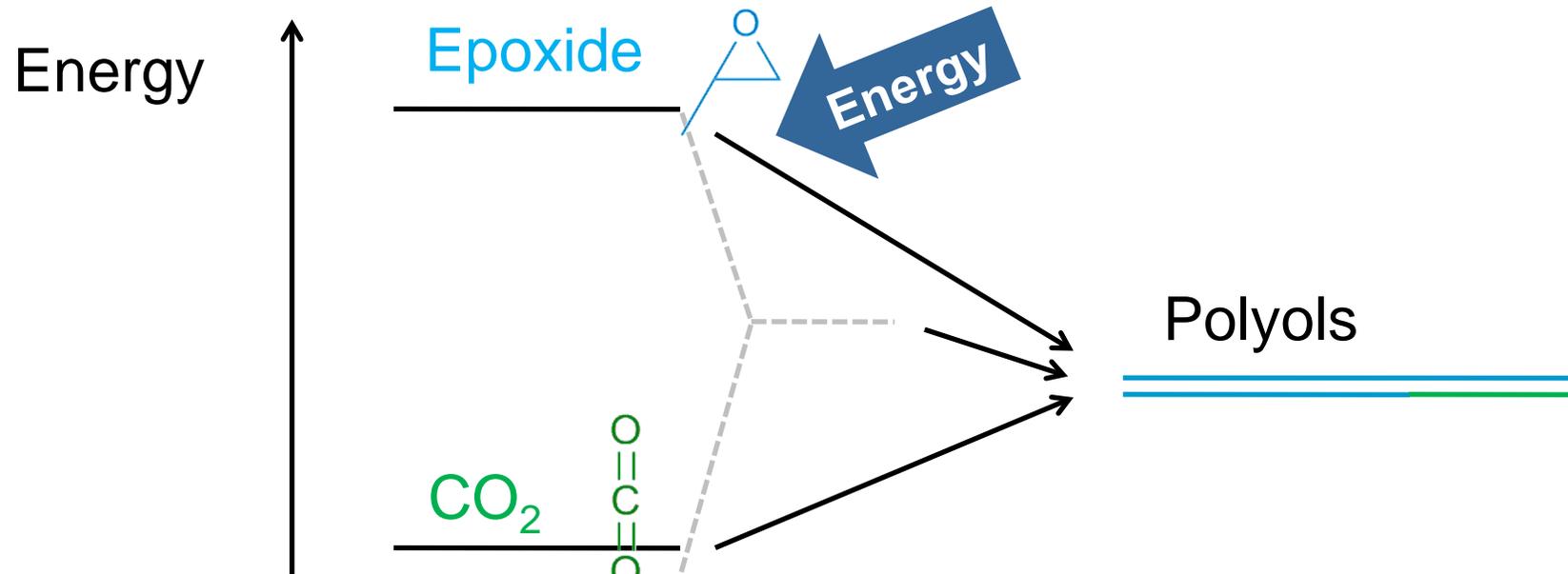
Bayer Material Science



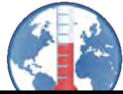
Life Cycle Assessment

Fundamental research

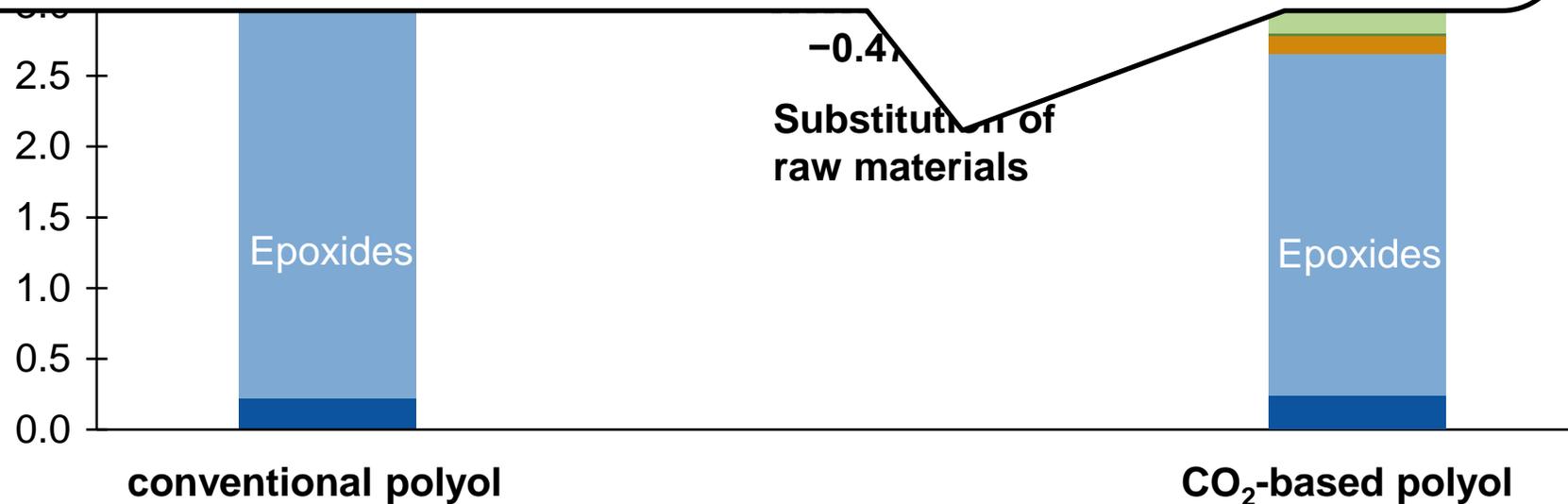
von der Assen, Bardow, *Green Chem.*, 2014, 16, 3272



- CO₂ replaces part of epoxides
- better catalysis & reaction engineering allows to produce the desired product properties



1 kg CO₂ as feedstock can avoid
3 kg of CO_{2,eq} emissions



Conclusions from CO₂-based polymers

- CO₂ can substitute fossil resources and thereby reduce GHG emissions today
- CO₂ *avoided* can exceed the amount of CO₂ *utilized*
- more CO₂-based polymers are becoming available (e.g. elastomers, see Meys, Kätelhön, Bardow, *Green Chem.*, 2019, 21, 3334)



Status Quo:

- polyurethane market:
33 Mt /year
- CO_{2e} emissions:
164 Mt / year



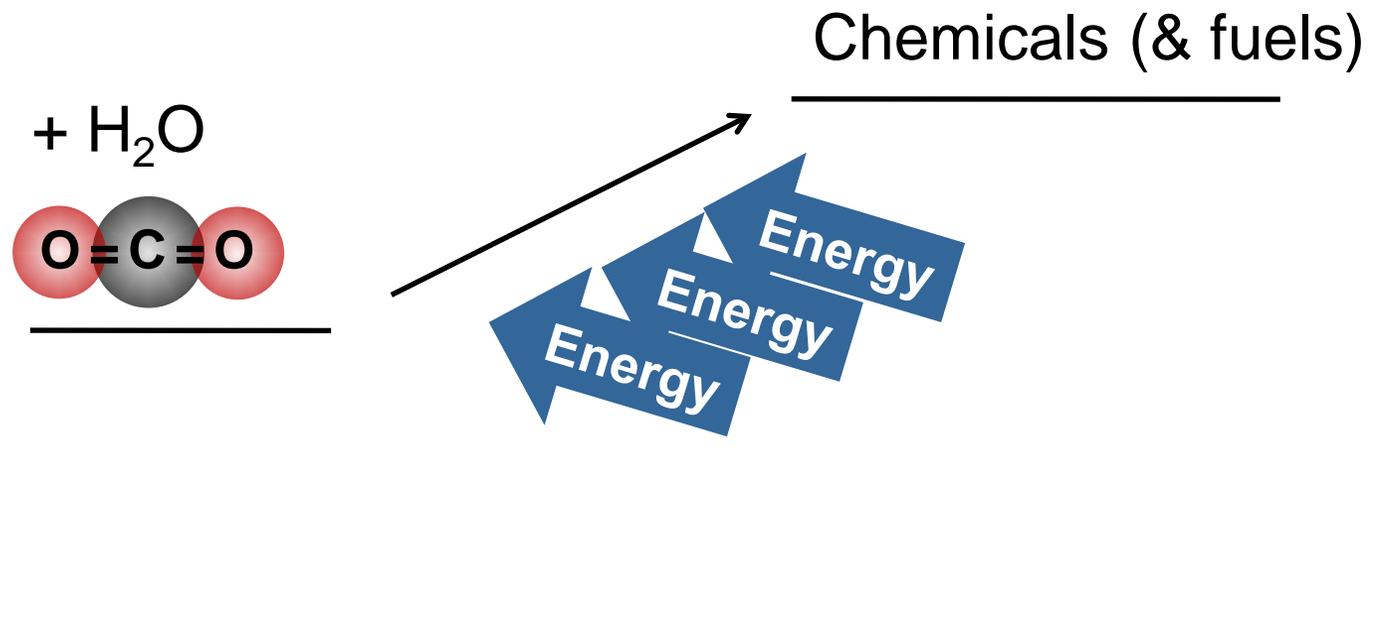
The potential for CO₂-based polyurethanes:

- 20% CO_{2e} reduction
= 33 Mt CO_{2e}/year

R Geyer, JR Jambeck, KL Law. Production, use, and fate of all plastics ever made. *Sci. Adv.*, 2017
Zheng, Suh, "Strategies to reduce the global carbon footprint of plastics." *Nature Climate Change* (2019)

Thermodynamics of CO₂ conversion: 3. Inverting combustion

Energy



CO₂ Utilization in the Chemical Industry



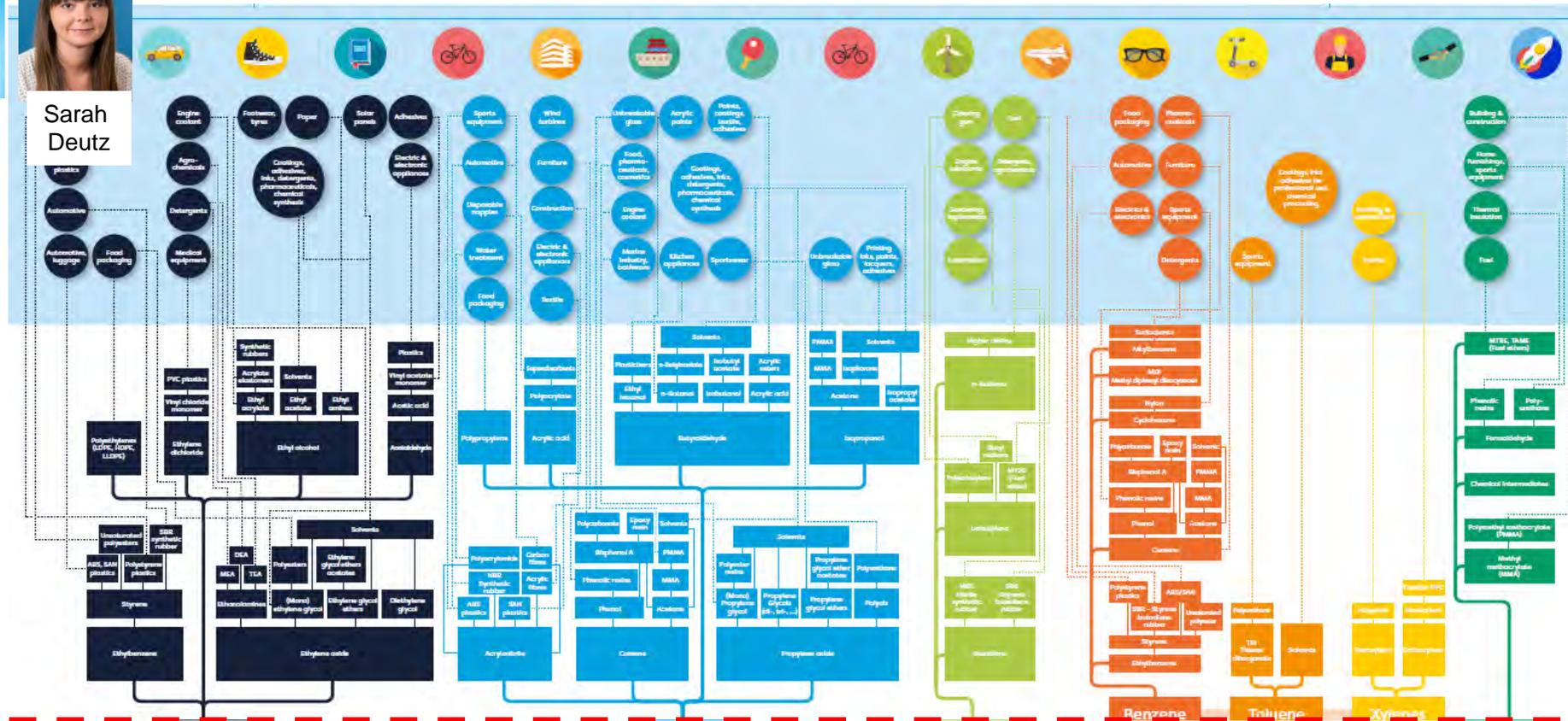
Arne Kätelhön



Raoul Meys

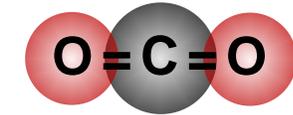
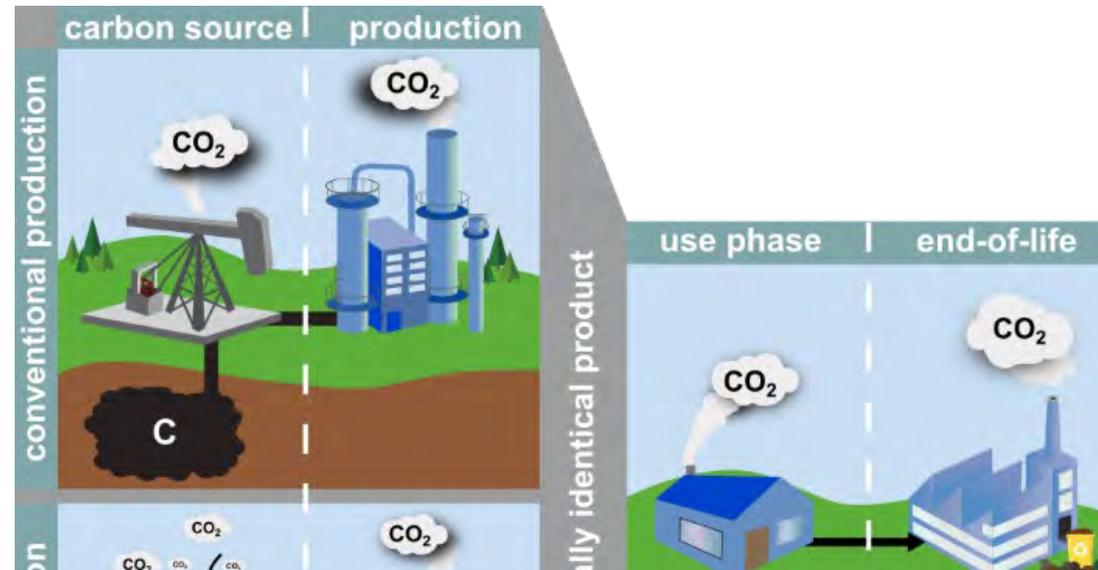


Sarah Deutz



What is the large-scale potential of CCU in the chemical industry ?
 ⇒ 20 basic chemicals = 75% of CO₂ emissions of chemical industry

Life cycle: Fossil-based vs CO₂-based chemical industry



Carbon storage possible

Chemically identical products

⇒ identical use phase and end-of-life

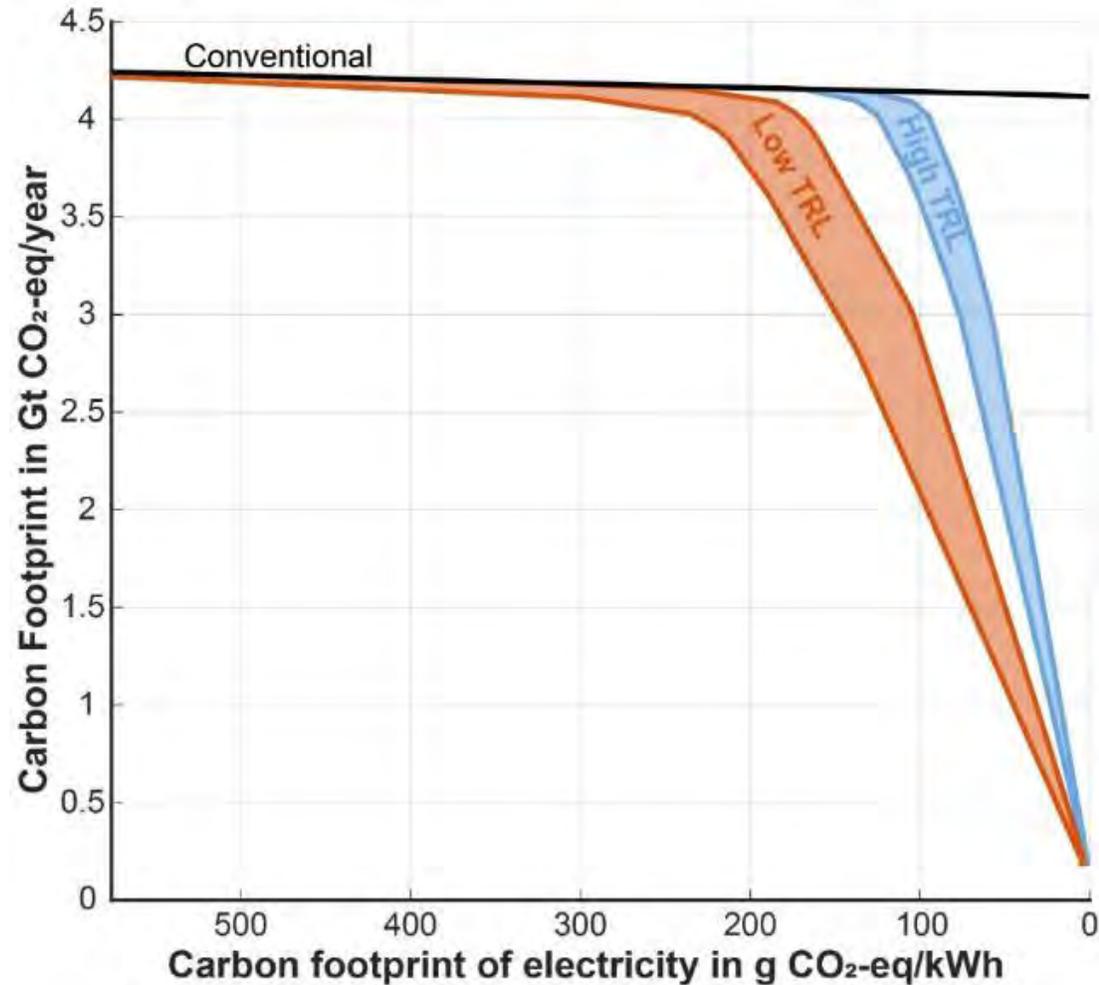
⇒ no benefit from temporary storage duration (!!!)

⇒ benefit from

change in raw materials & production

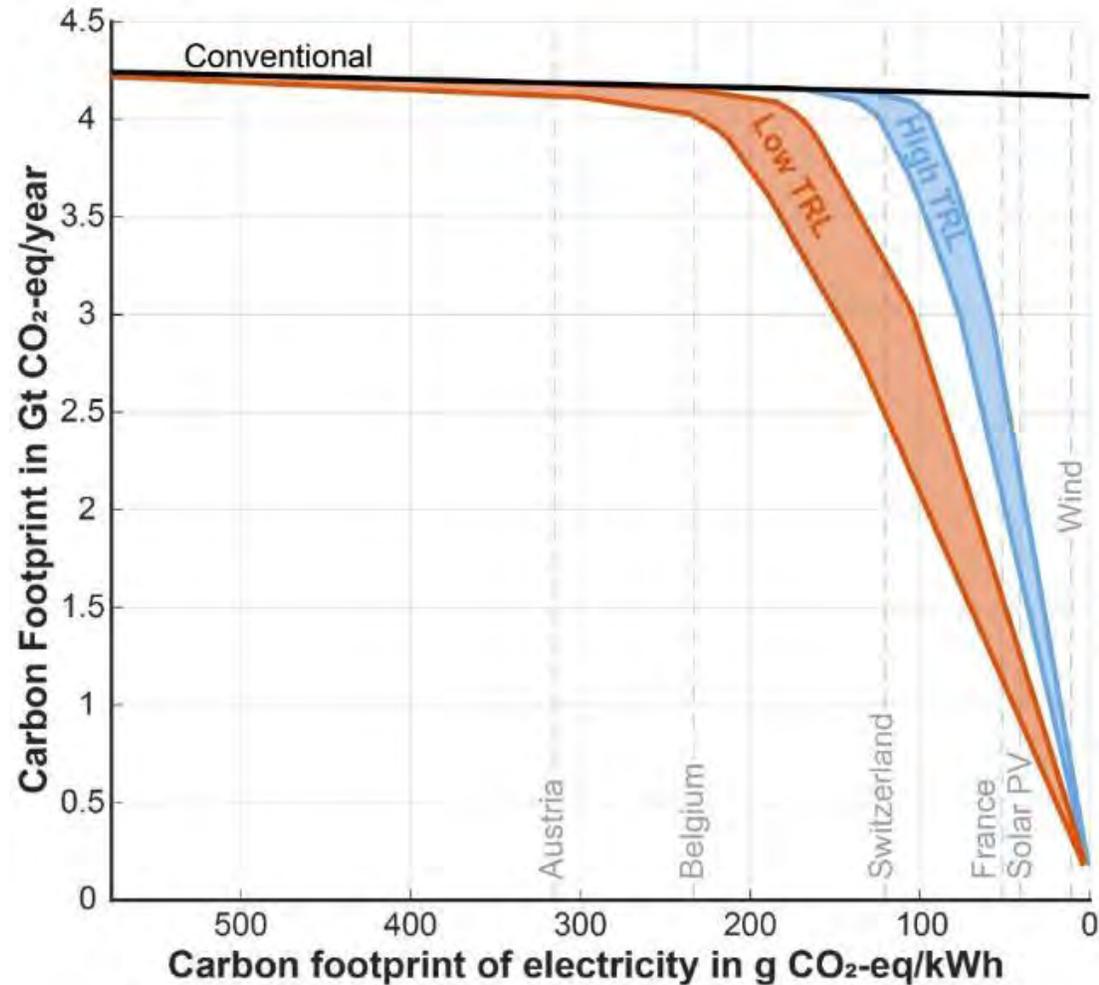
+ 1 time filling the carbon pool

ETHZ ⇒ usually no change at end of life = possibility to add CCS



- CCU can lead to practically carbon-neutral chemical industry
- GHG savings require low-carbon electricity

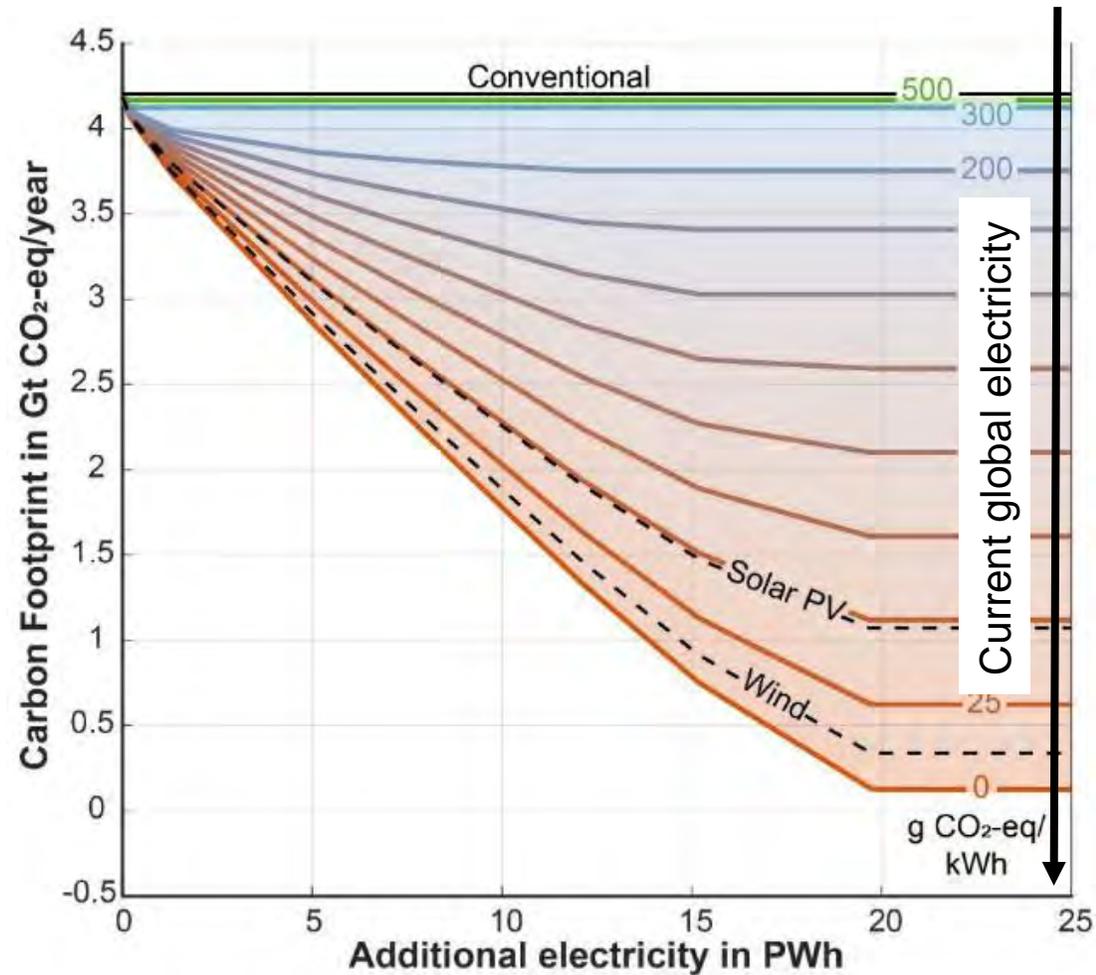
Kätelhön, Meys, Deutz, Suh, Bardow, *PNAS*, 2019



- CCU can lead to carbon-neutral chemical industry
 - GHG savings require low-carbon electricity
- ⇒ additional electricity

Kätelhön, Meys, Deutz, Suh, Bardow, *PNAS*, 2019

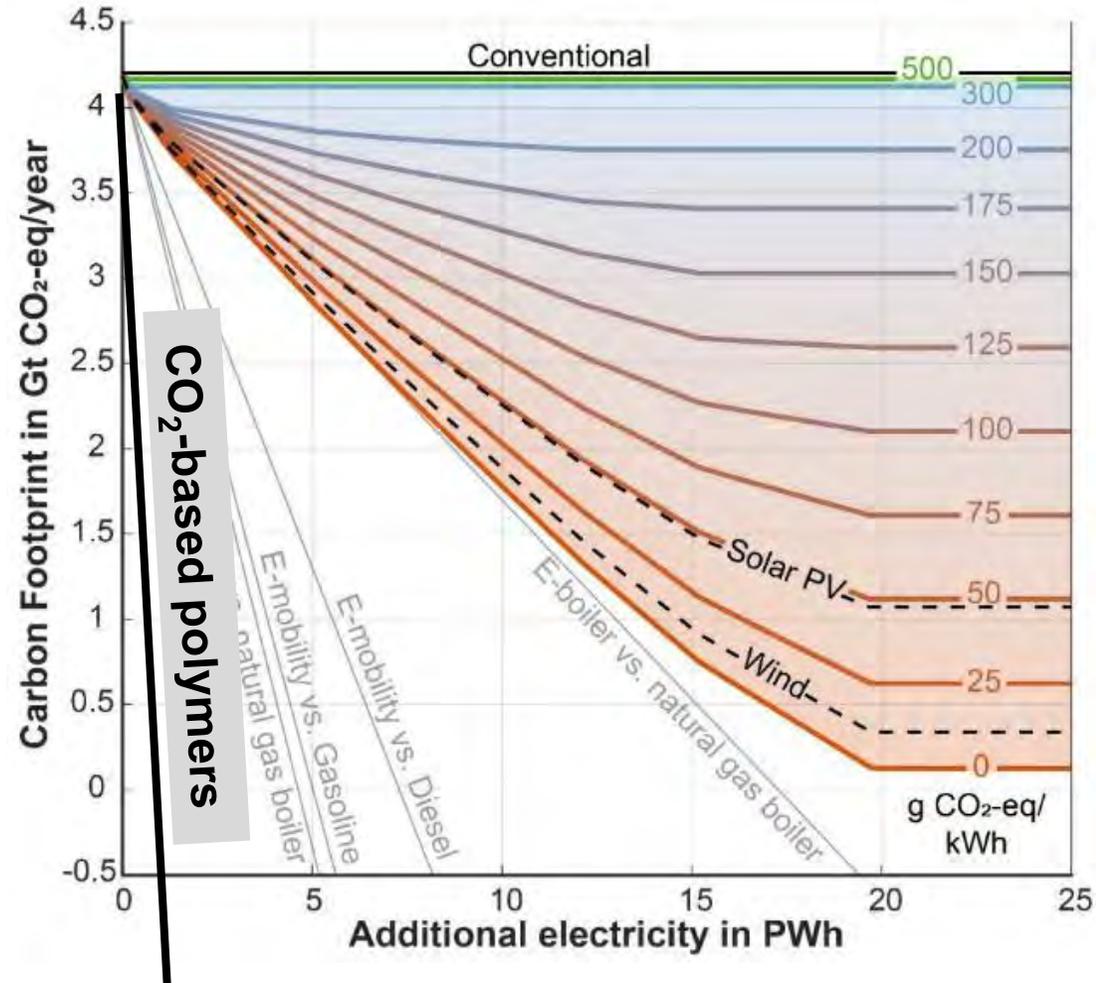
Electricity need for CCU in the Chemical Industry



- GHG savings require a lot of low-carbon electricity

Kätelhön, Meys, Deutz, Suh, Bardow, *PNAS*, 2019

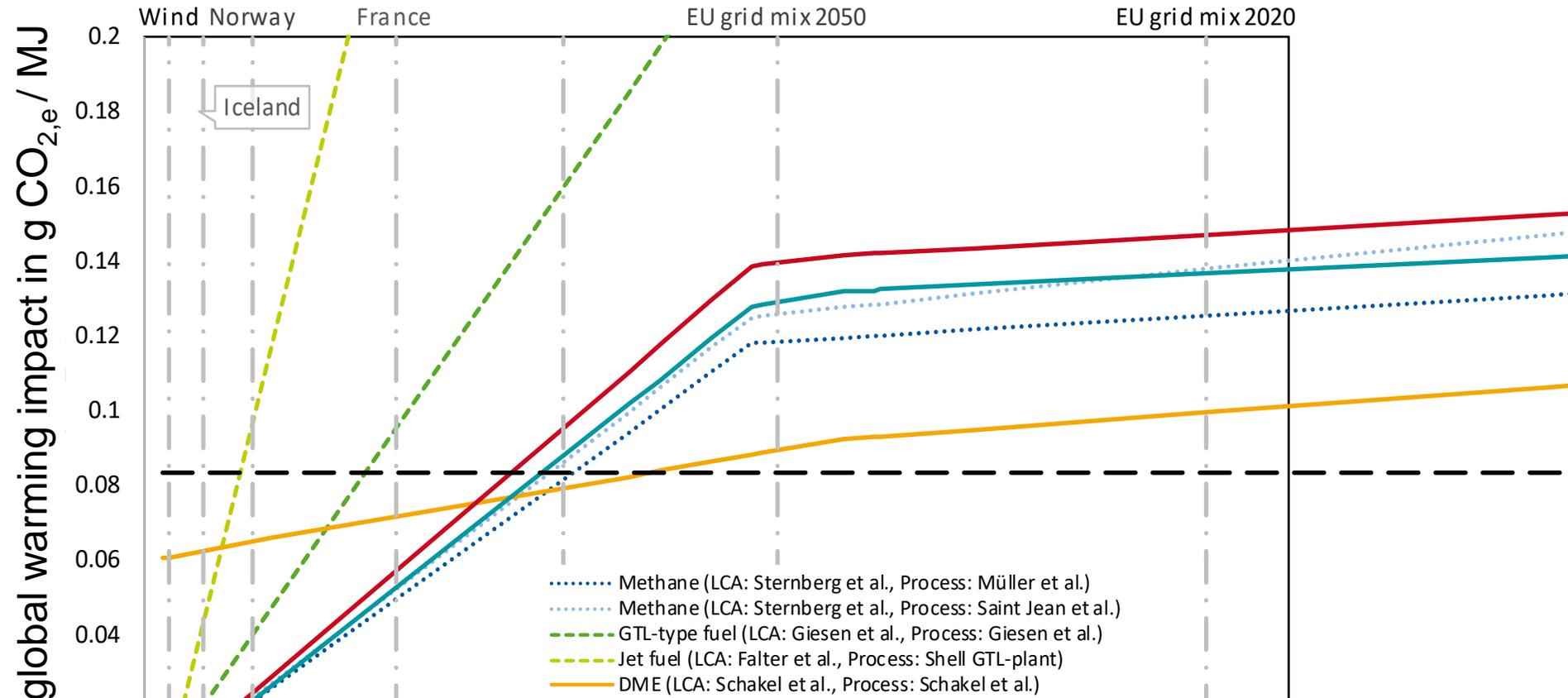
Power-to-Chemicals vs Power-to-X



- GHG savings require a lot of low-carbon electricity
- Declining efficiency
- Power-to-Chemicals often less efficient than Power-to-Heat and Power-to-Mobility
- but there are high efficiency opportunities

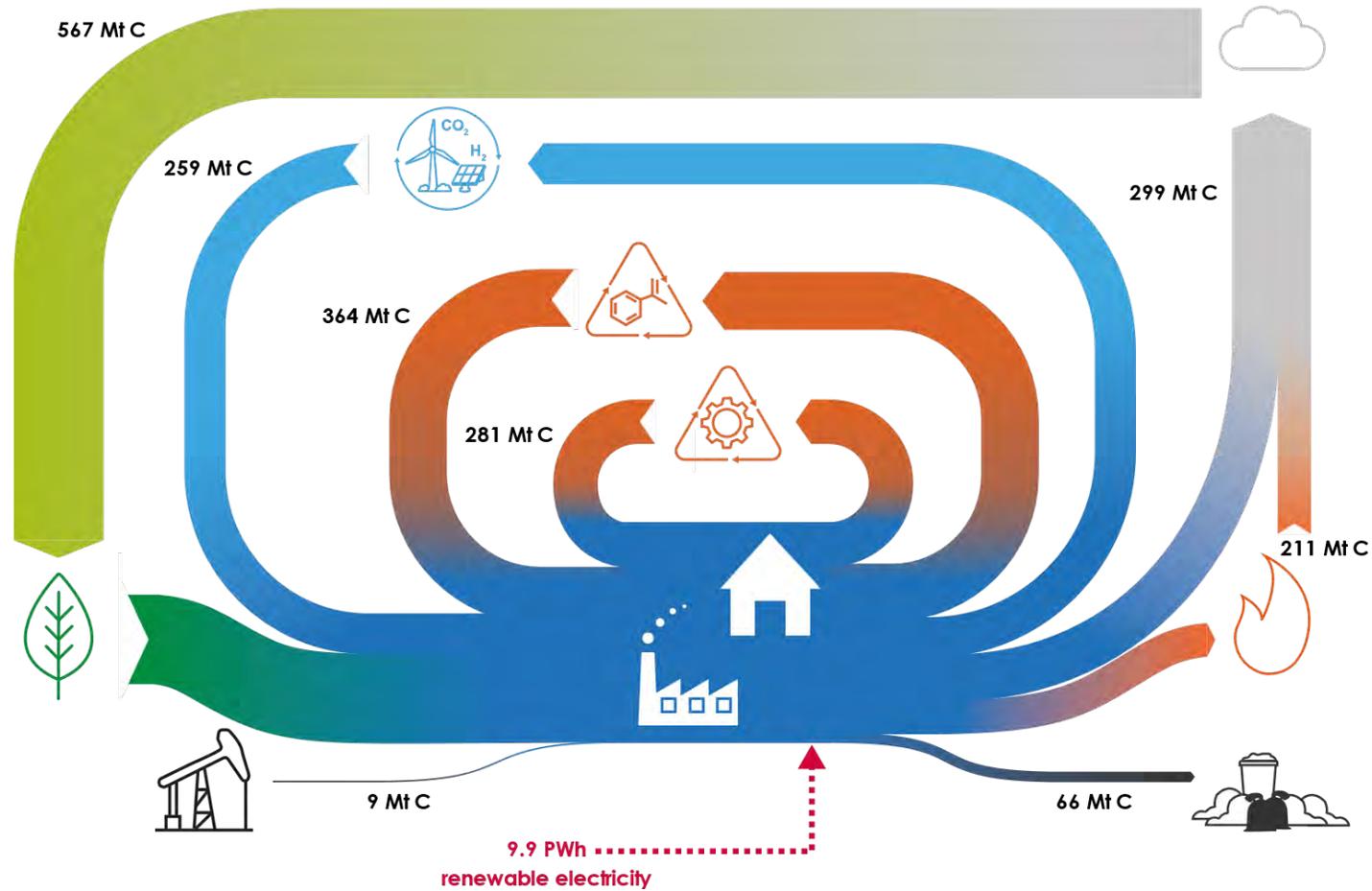
Kätelhön, Meys, Deutz, Suh, Bardow, *PNAS*, 2019
Sternberg, Bardow, *Energy Environ. Sci.*, 2015, 8, 389

Review of CO₂-based fuels



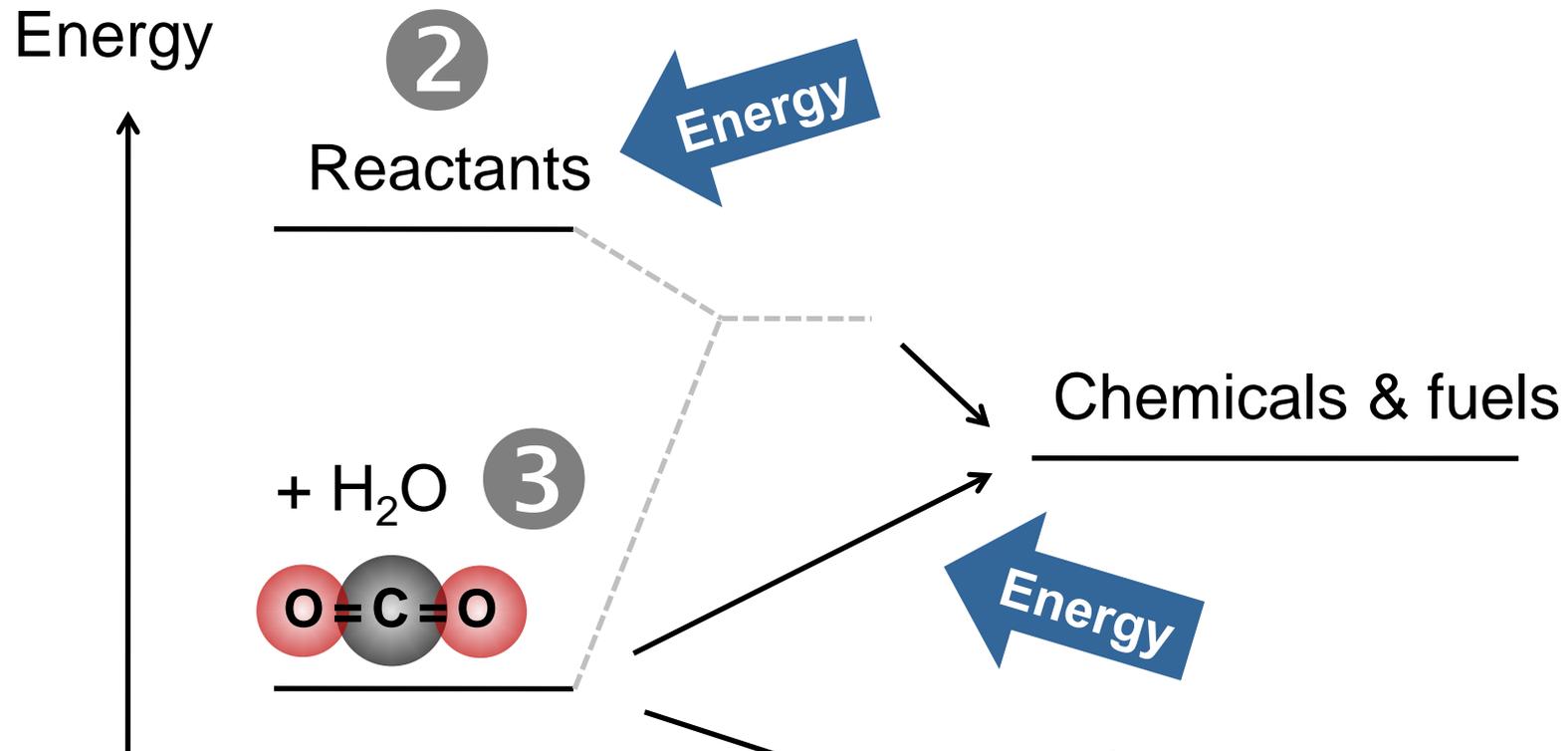
- All CO₂-based fuels require a lot of low-carbon electricity
- Employ CO₂-based fuels when no efficient alternatives exist (e.g., aviation)

CO₂ use as part of a circular carbon economy



Meys et al., *Science*, 2021

Combining CO₂ with all circular technologies achieves carbon-neutral plastics* using less energy than linear fossil-based benchmark.



- CO₂ utilization can provide many services
- CO₂ utilization *can* reduce GHG emissions



A sustainable world needs:

1. clean electricity
2. a lot of clean electricity
3. seriously, an awful lot of clean electricity

- Invest clean electricity where most efficient
- CO₂ use is often not first choice to solve climate change but CO₂ provides a sustainable carbon feedstock with potential climate benefits:
 - ⇒ Identify markets for products from CO₂ mineralization
 - ⇒ Identify CO₂-based chemicals with high benefits
 - ⇒ Exploit benefits of CO₂-utilization beyond climate change
 - ⇒ Explore synergies with biomass & other carbon cycles

Prof. Dr.-Ing. André Bardow

abardow@epse.ethz.ch

ETH Zurich

Energy & Process Systems Engineering

CLA F 19.1

Tannenstrasse 3

8092 Zürich

www.epse.ethz.ch