



What to do with CO₂ ?

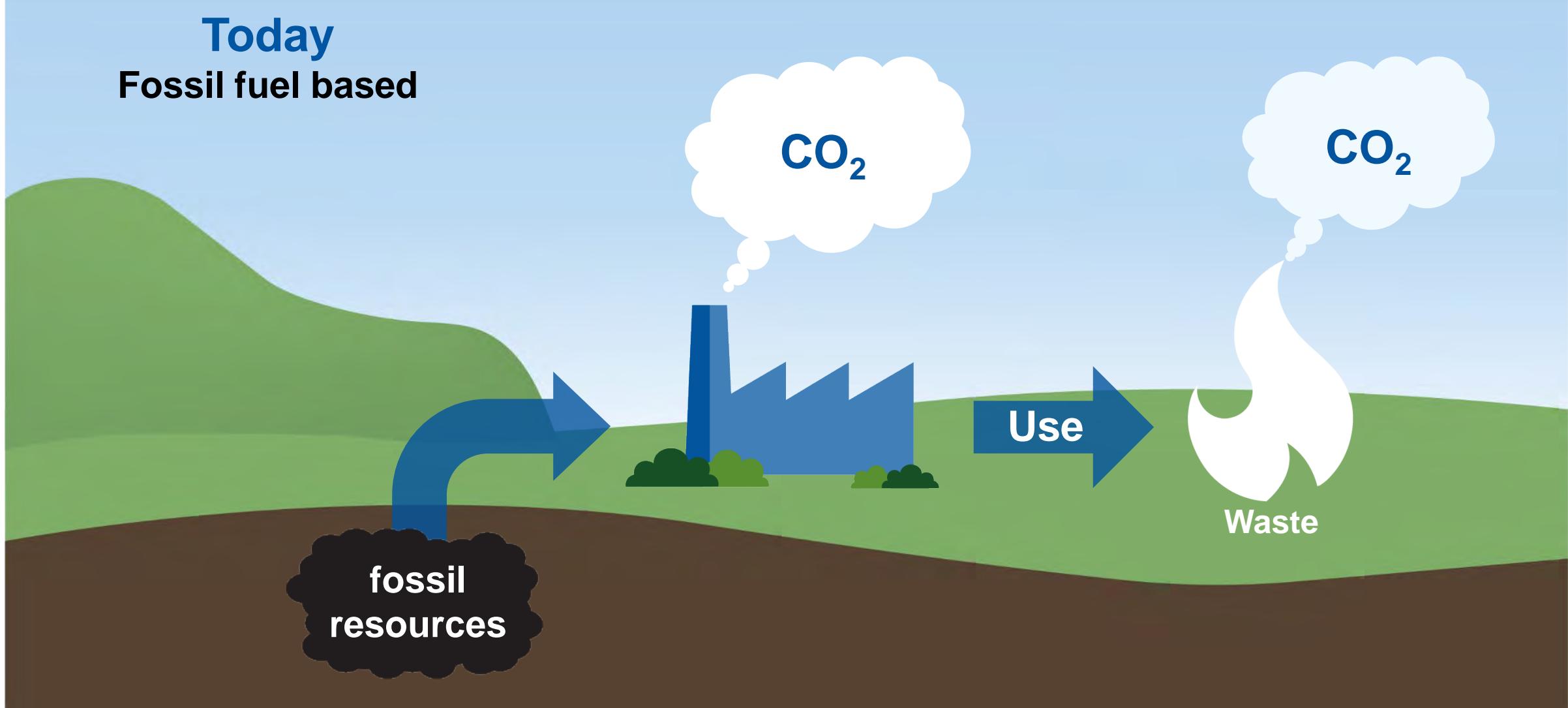
Möglichkeiten & Grenzen der CO₂-Nutzung

André Bardow
ETH Zurich

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

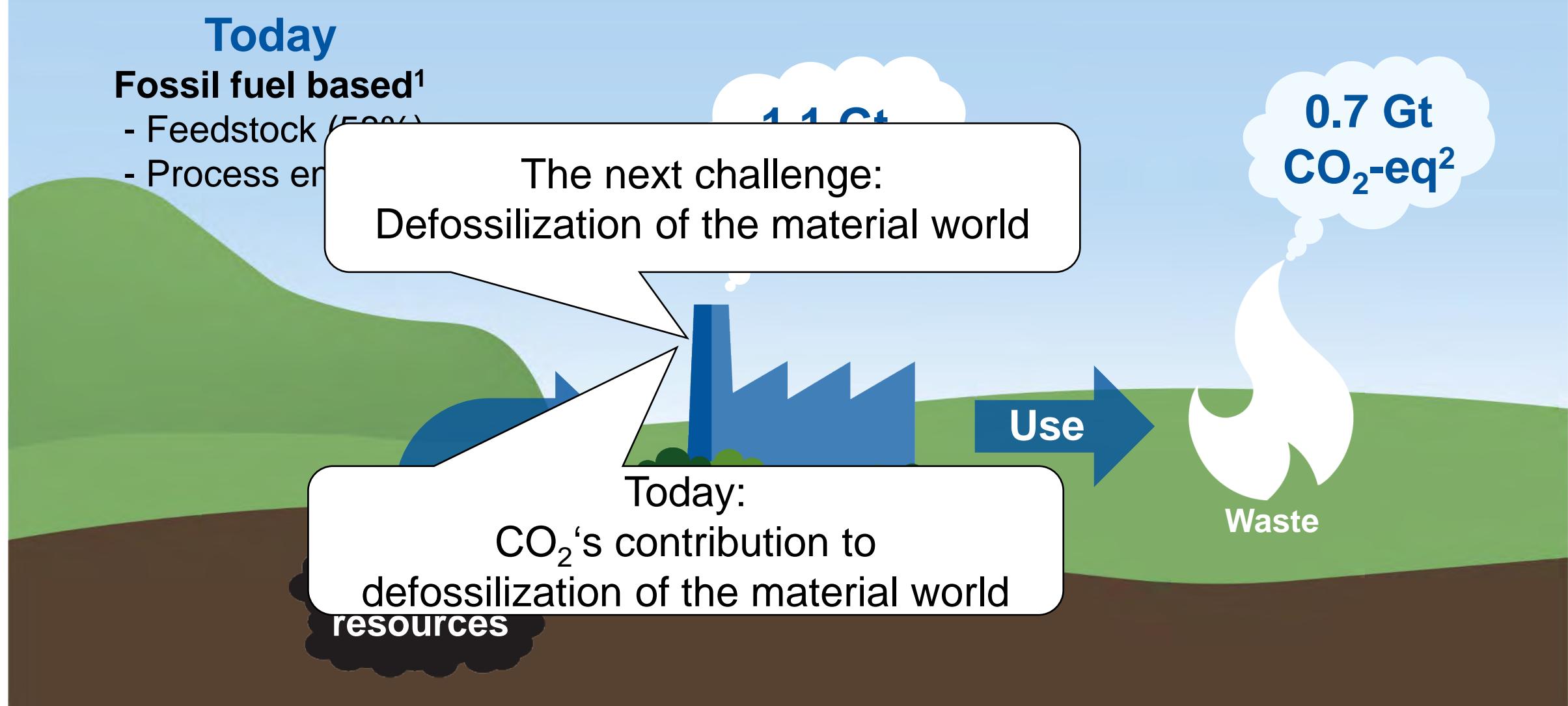


The current linear fossil-based carbon economy



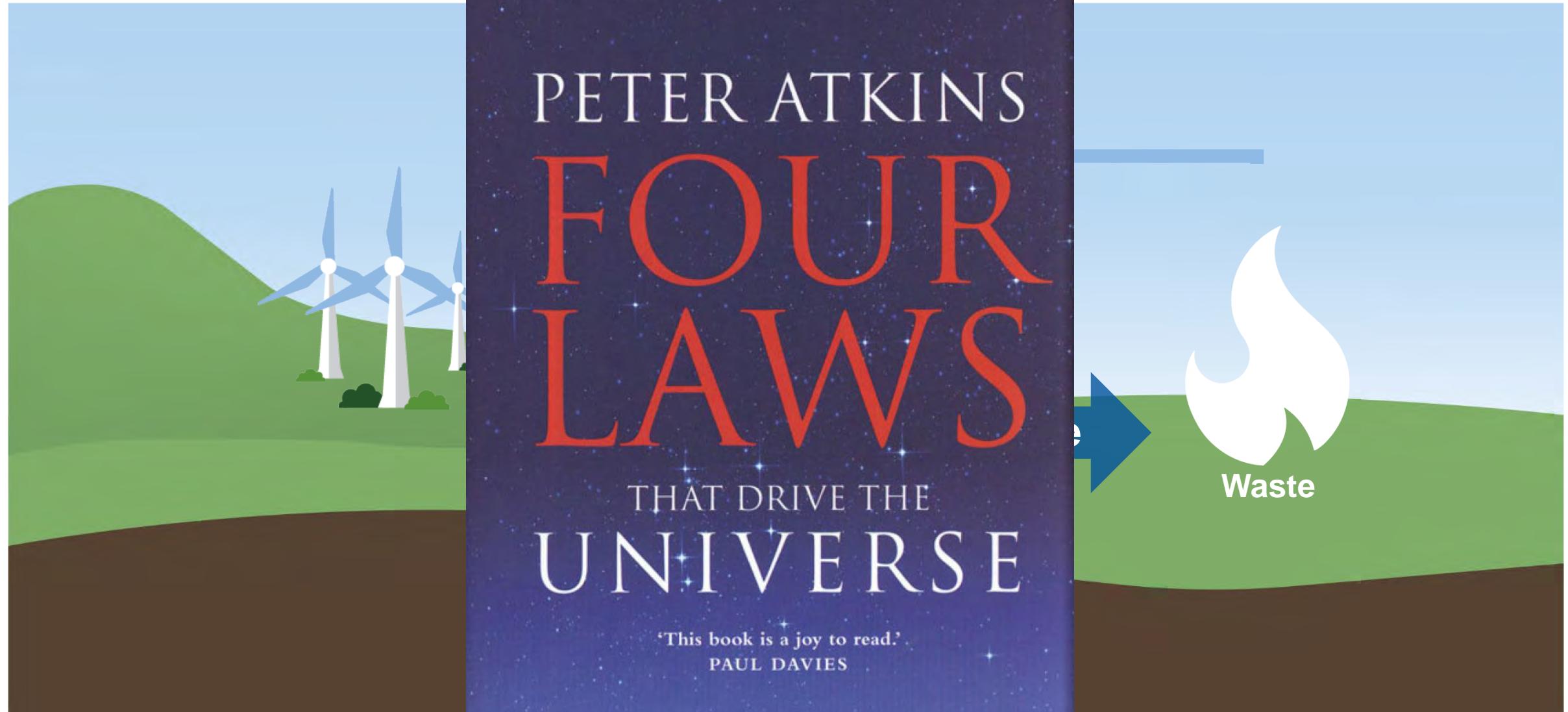
¹ IEA, DECHEMA, ICCA (2013), Technology Roadmap

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



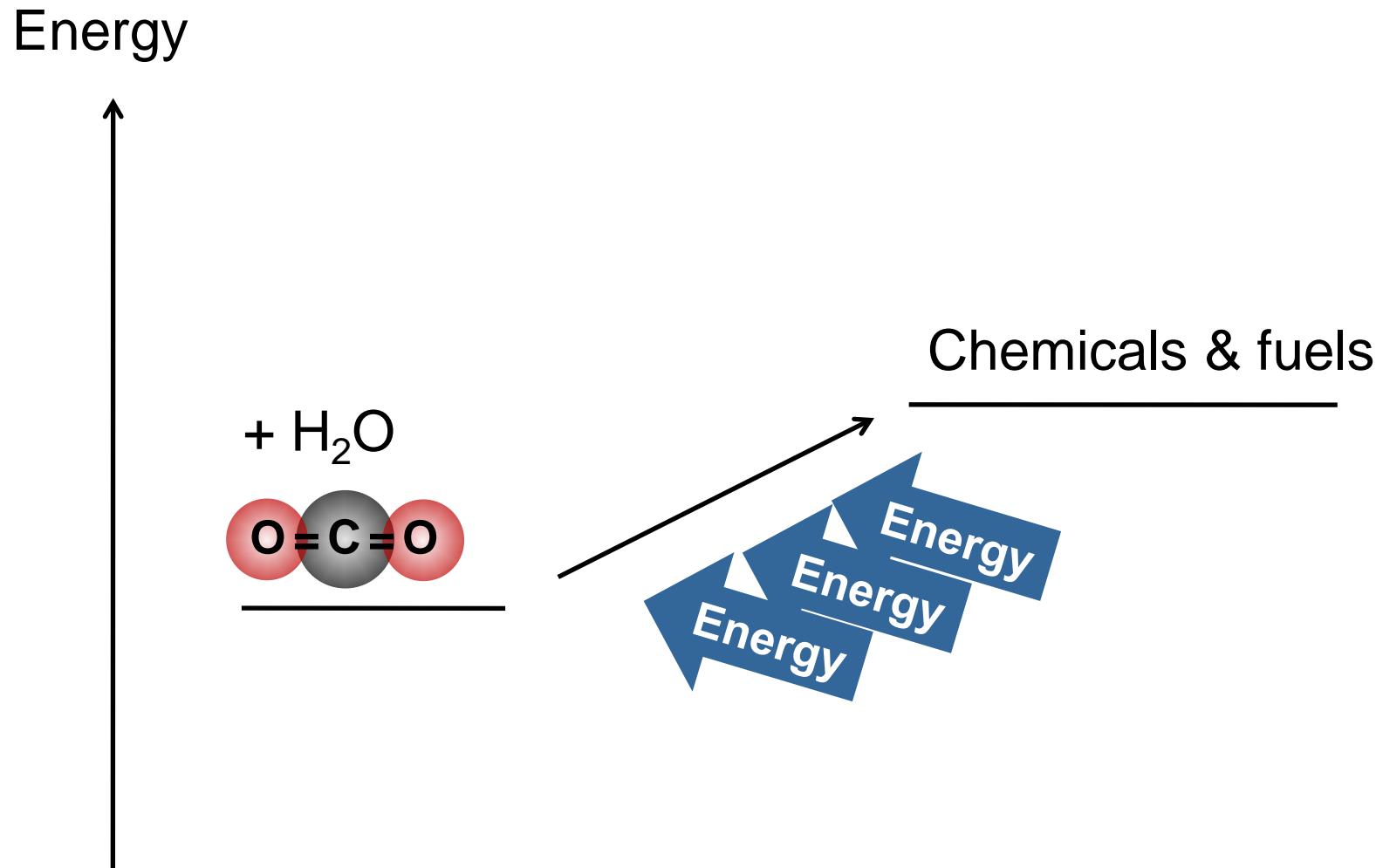
¹ IEA, DECHEMA, ICCA (2013), Technology Roadmap

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Thermodynamics of CO₂ conversion:

1. Inverting combustion





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

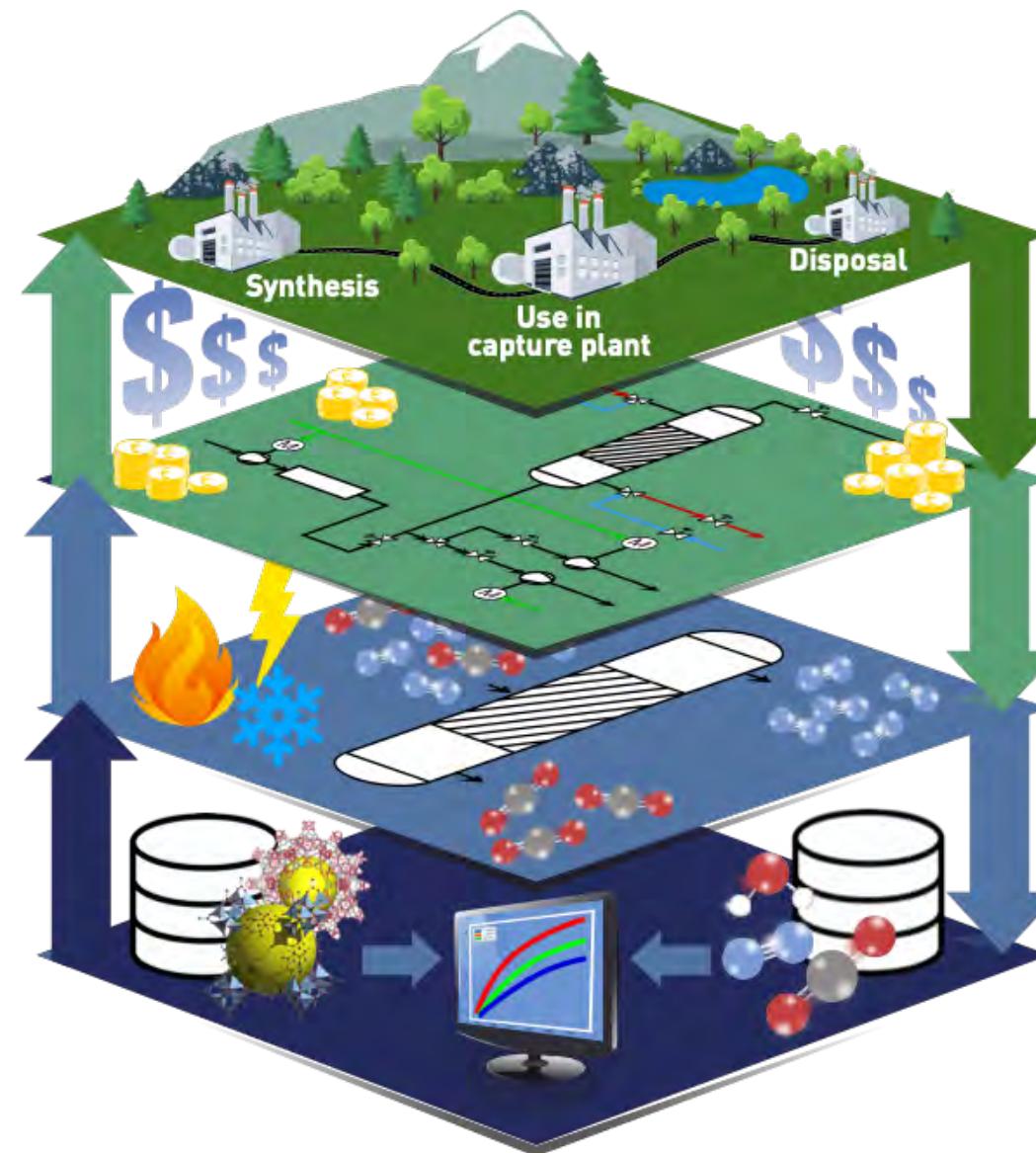
The Platform Core Team:

ETHZ: Johannes Schilling,
André Bardow

Solverlo: Eva Sanchez
Fernandez

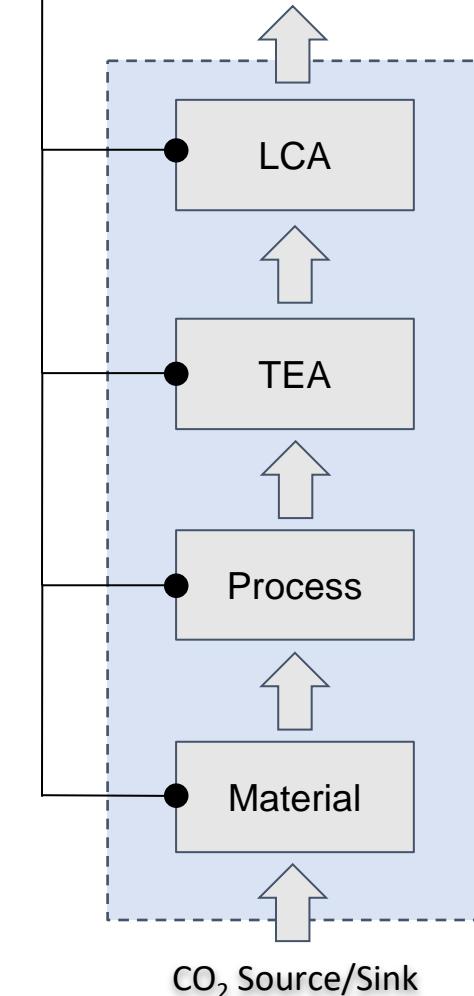
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EPFL: Elias Moubarak, Kevin
Jablonka, Berend Smit

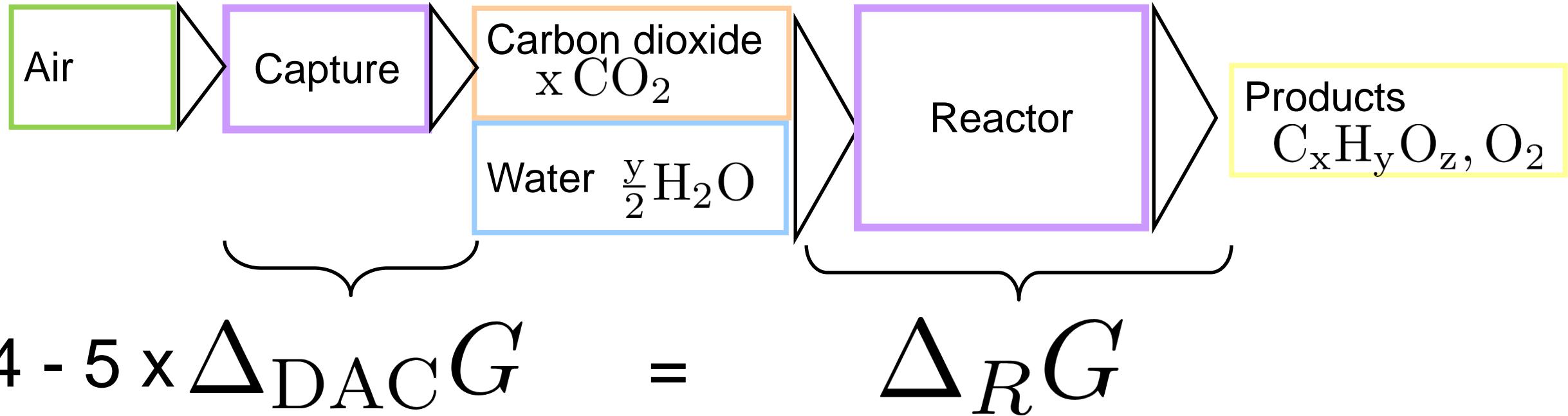


● Performance Indicators

Reduced CO₂ Emissions



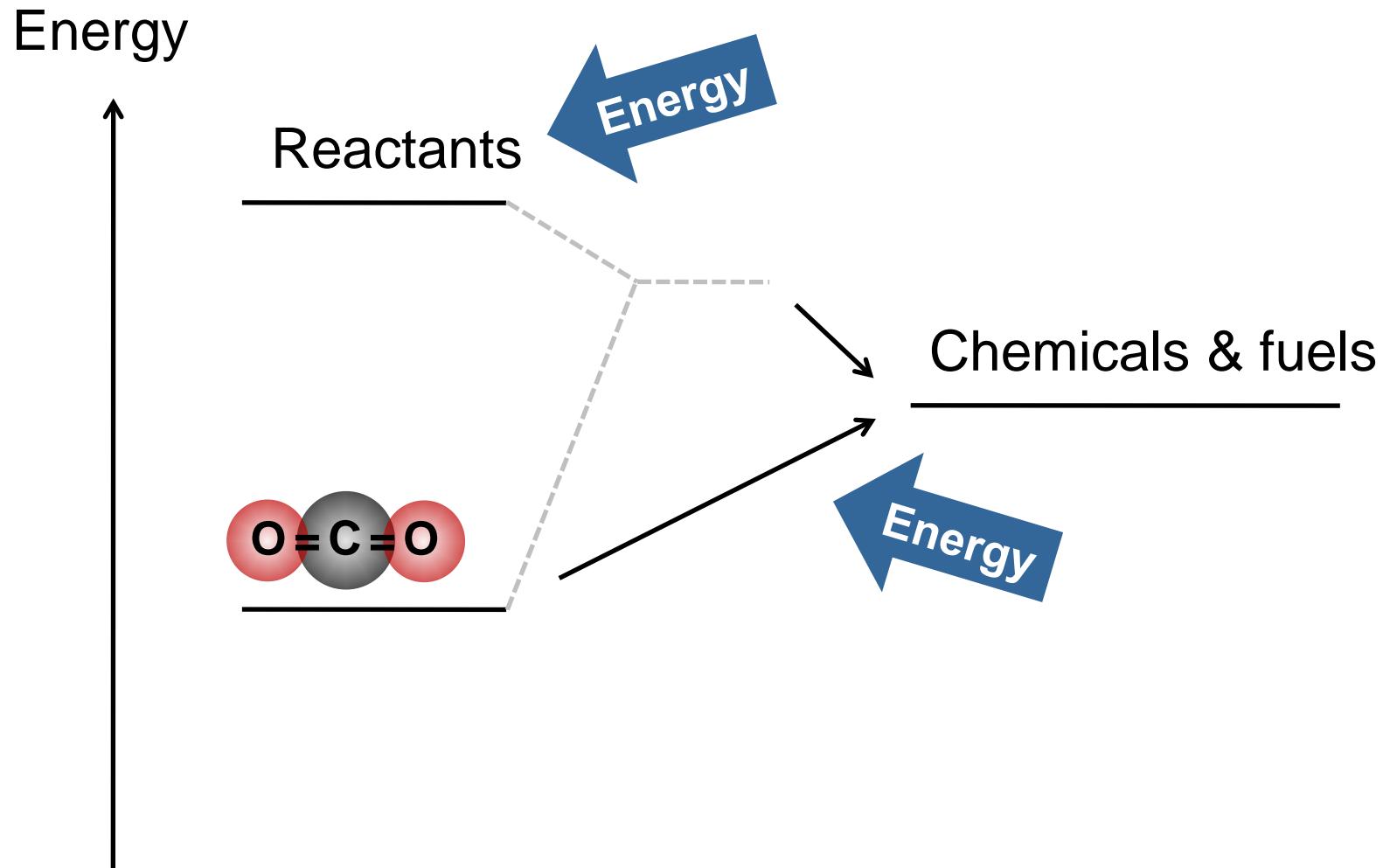
Thermodynamics of CO₂ conversion: Supply Chain



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

Thermodynamics of CO₂ conversion:

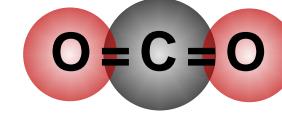
2. More efficient chemistry



Thermodynamics of CO₂ conversion:

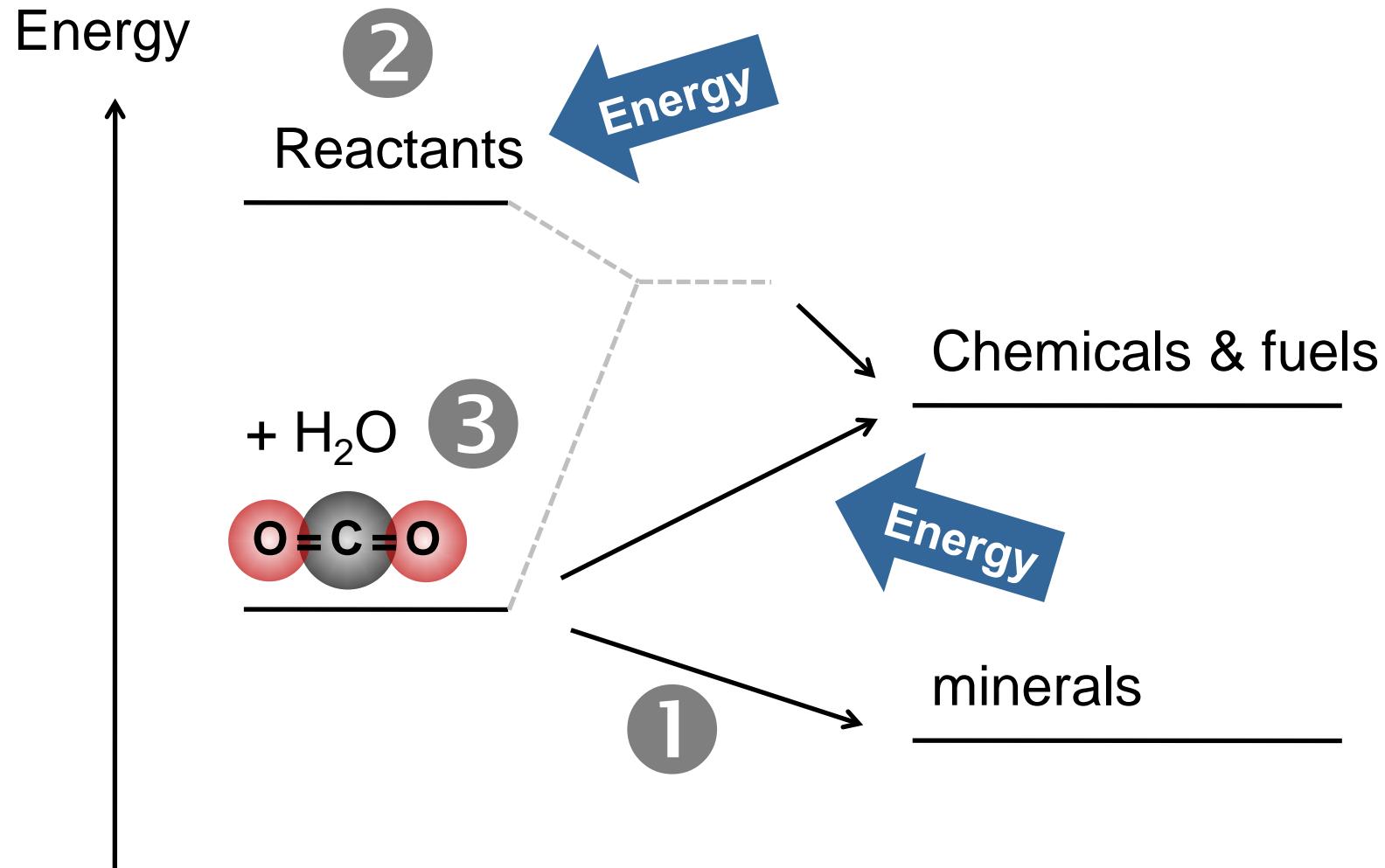
3. Mineralization

Energy



minerals

Thermodynamics of CO₂ conversion



Acknowledgments

The Team



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GEFÖRDERT VOM



Bundesministerium
für Bildung
und Forschung



Our Project Partners

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



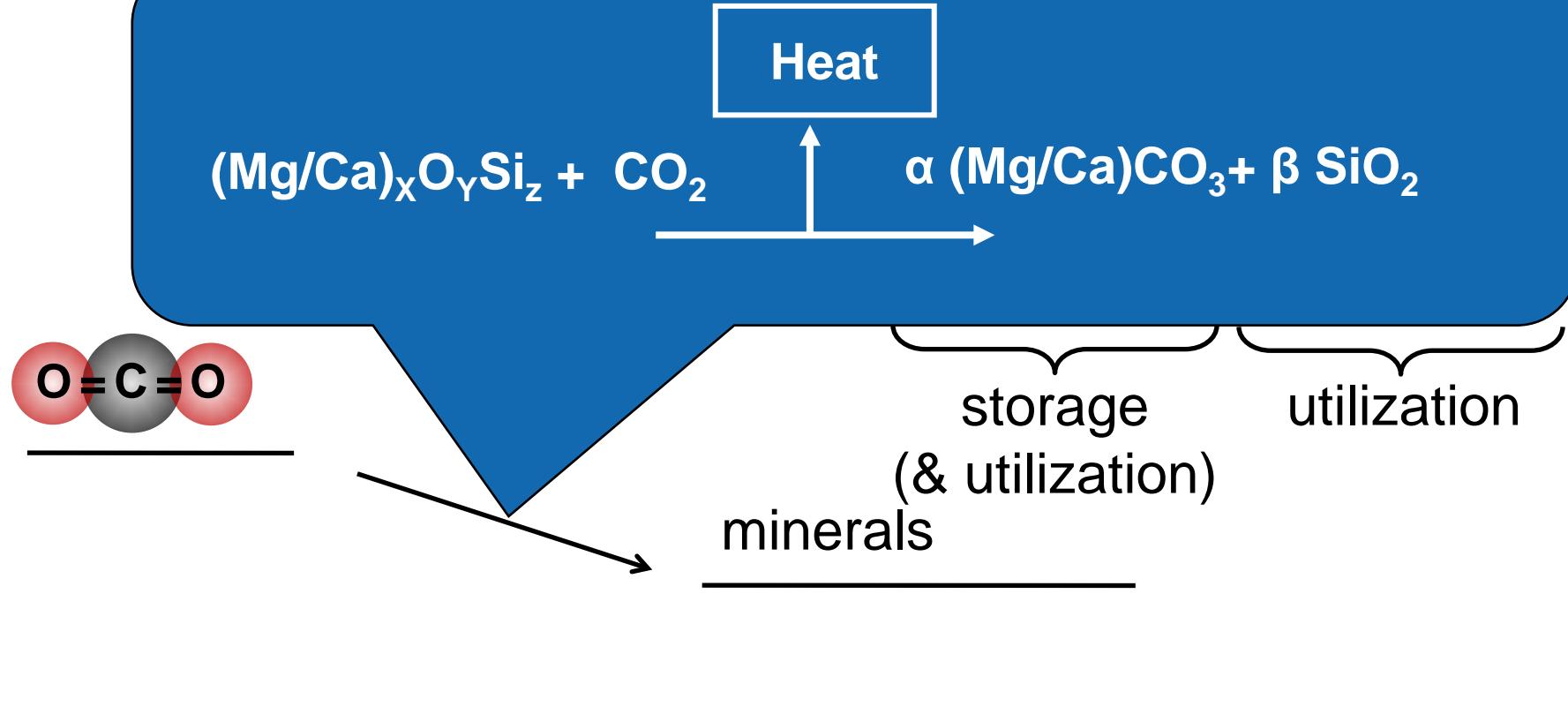
Thermodynamics of CO₂ conversion:

1. Mineralization



Hesam
Ostovari

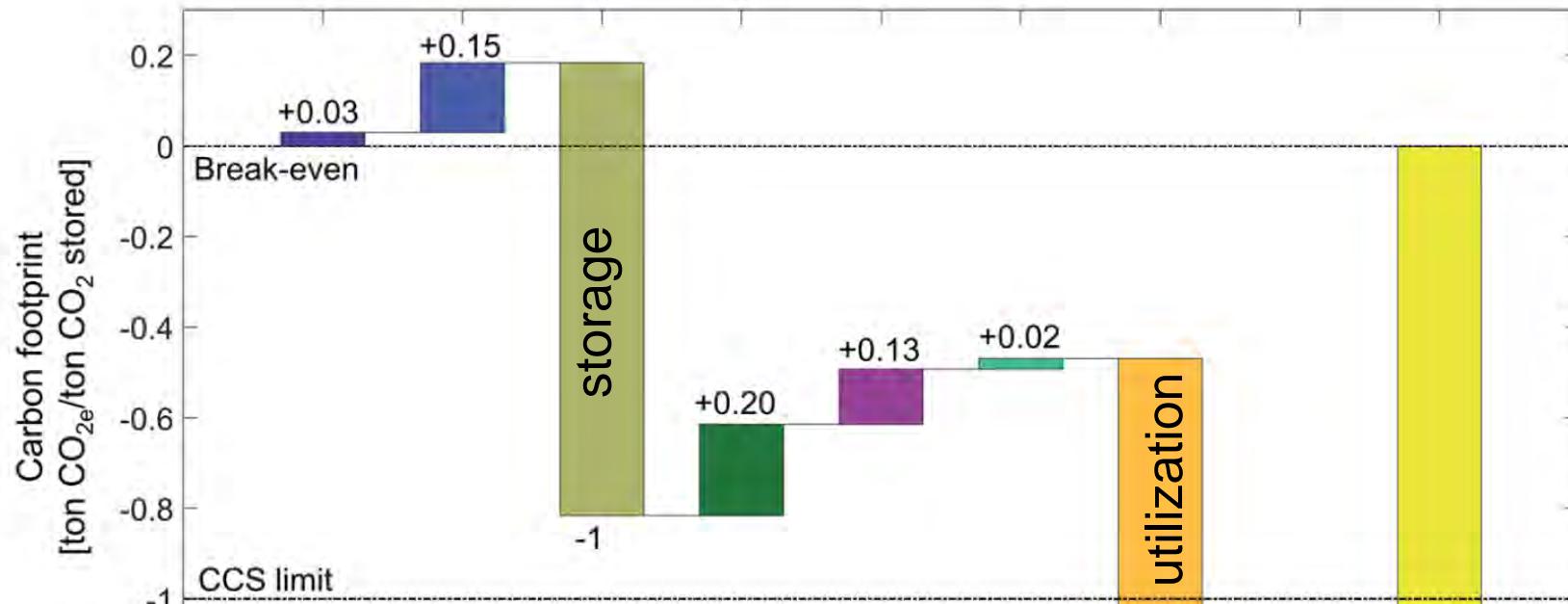
Energy



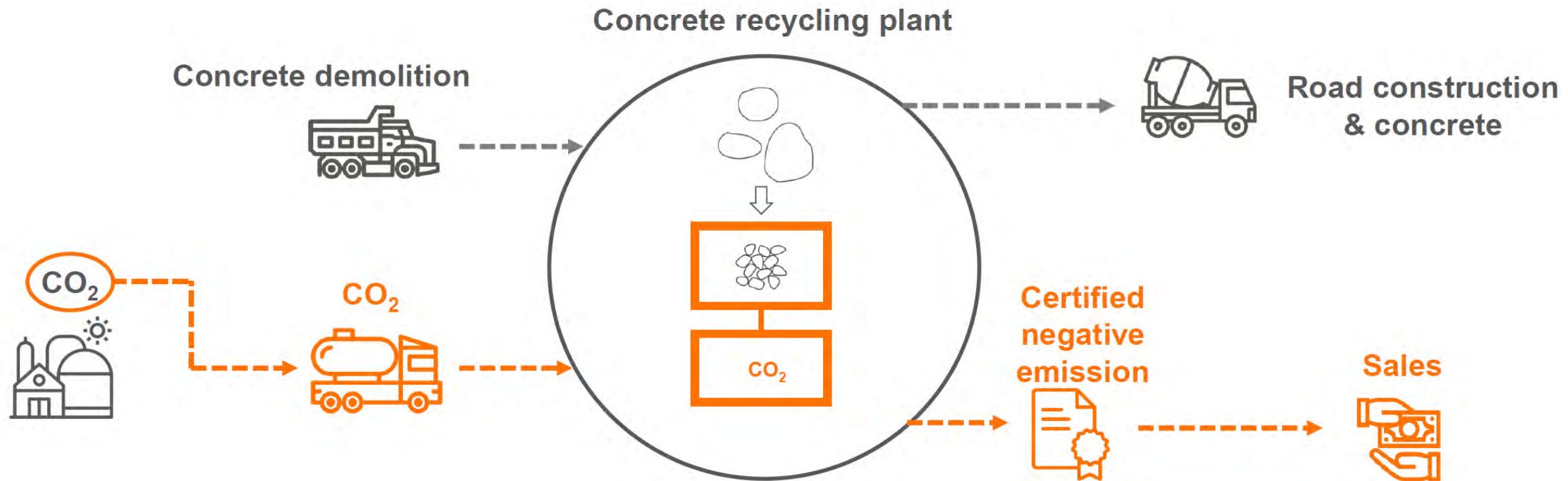


<https://doi.org/10.1039/D0SE00190B>

The carbon footprint of CO₂ mineralization to cement substitutes



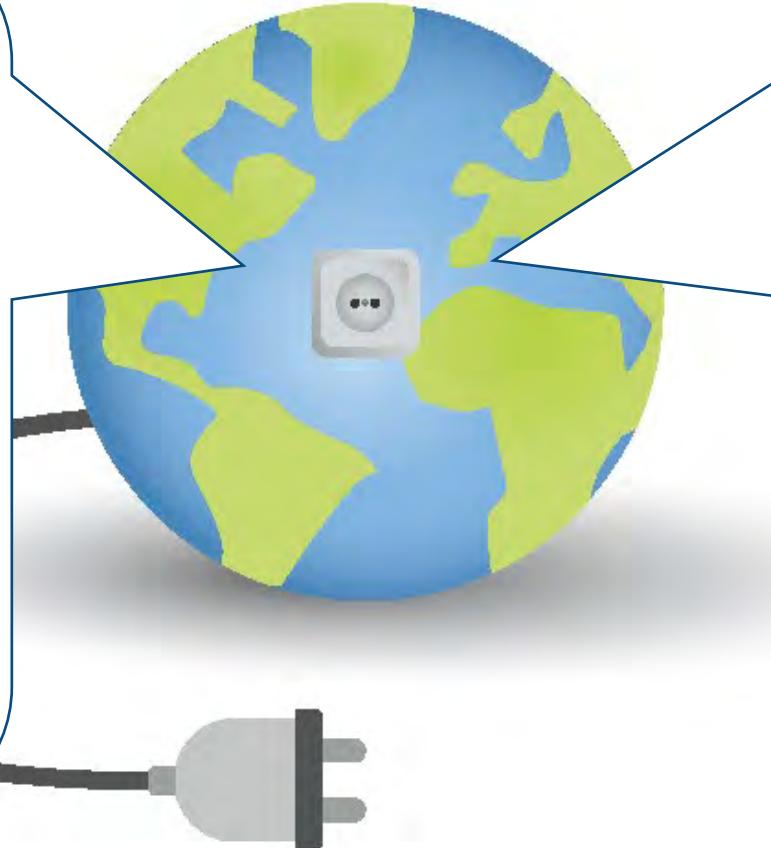
- CO₂ mineralization combines storage + utilization
- GHG savings possible – even today !
- benefit from substitution of current materials
- product development crucial



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

Status Quo:

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



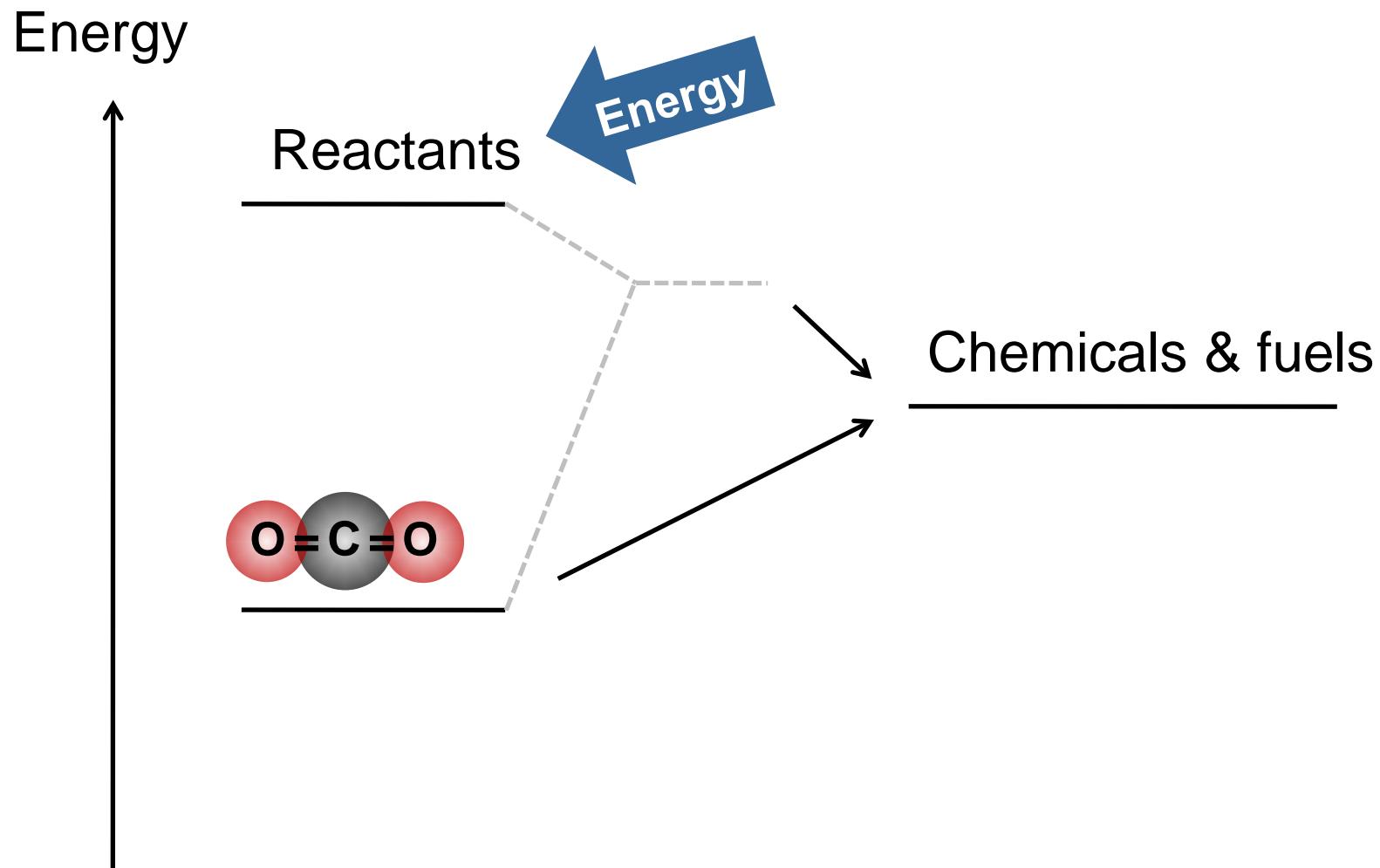
The potential for integrated CO₂ mineralization:

- 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



Fundamental research



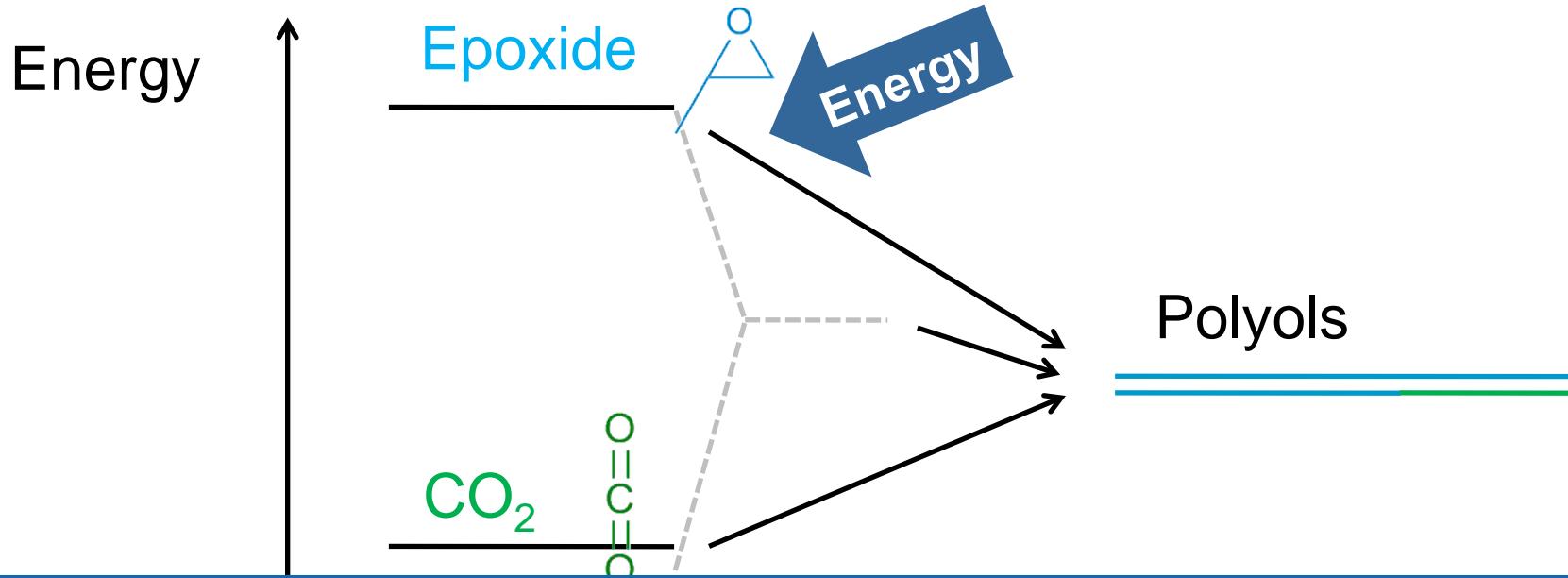
Bayer Technology Services



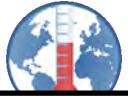
COT®
Catalytic Center

RWTH AACHEN
UNIVERSITY

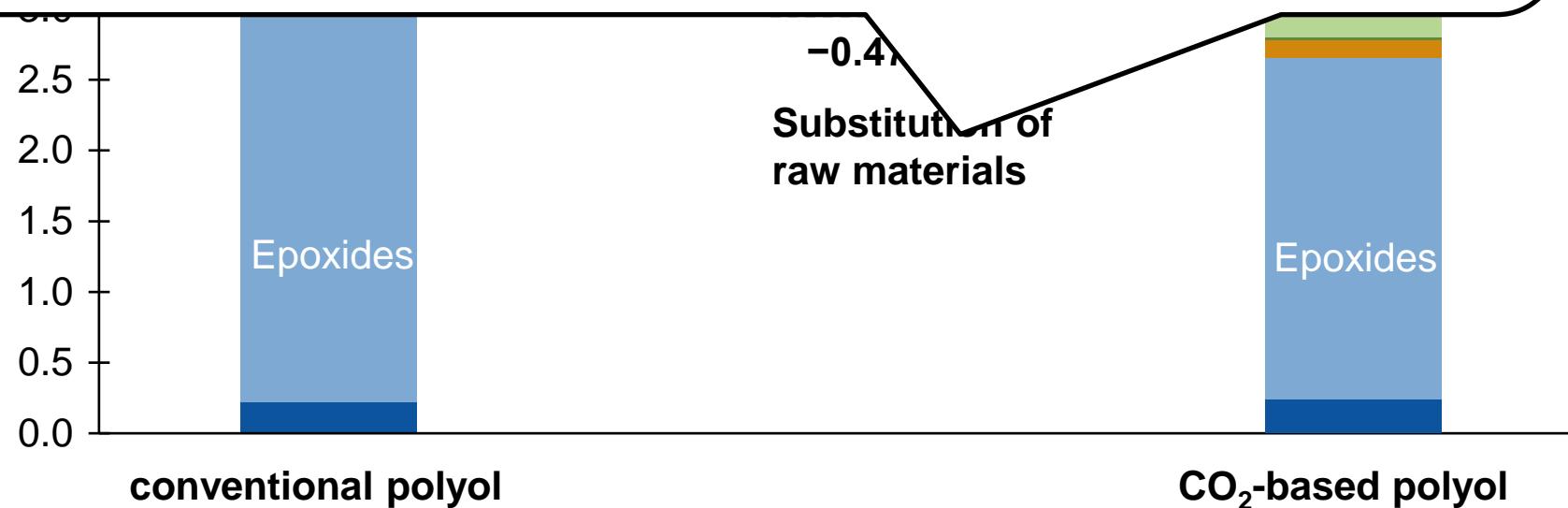
Chemical conversion of CO₂: Dream Production



- 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



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

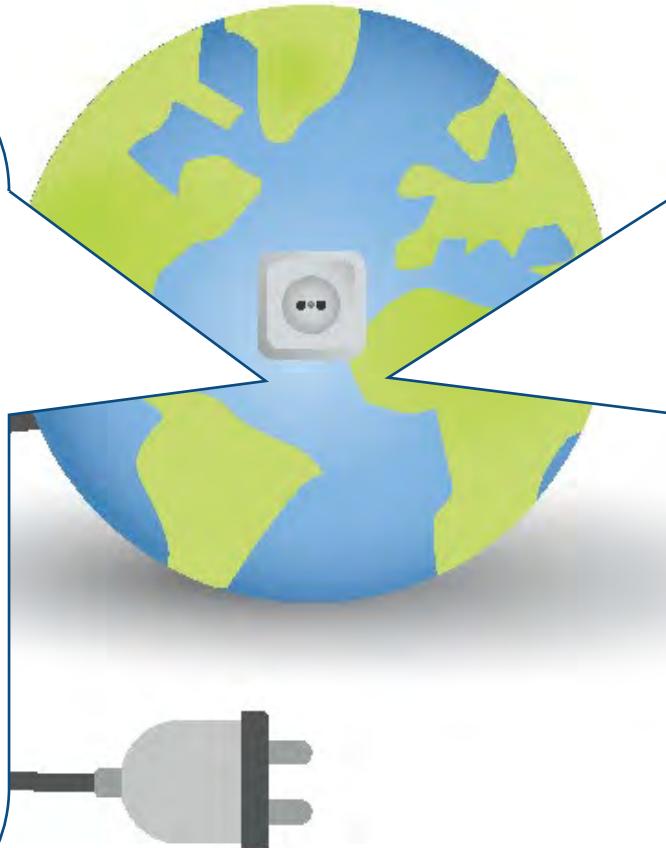
Conclusions from CO₂-based polymers

- 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

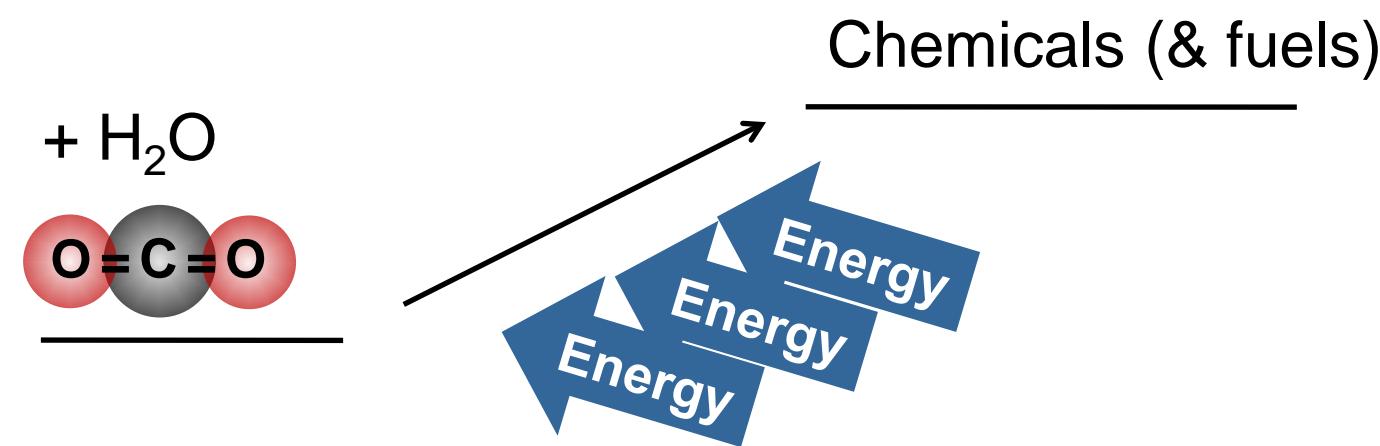
R Geyer, JR Jambeck, KL Law. Production, use, and fate of all plastics ever made. *Sci. Adv.*, 2017

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



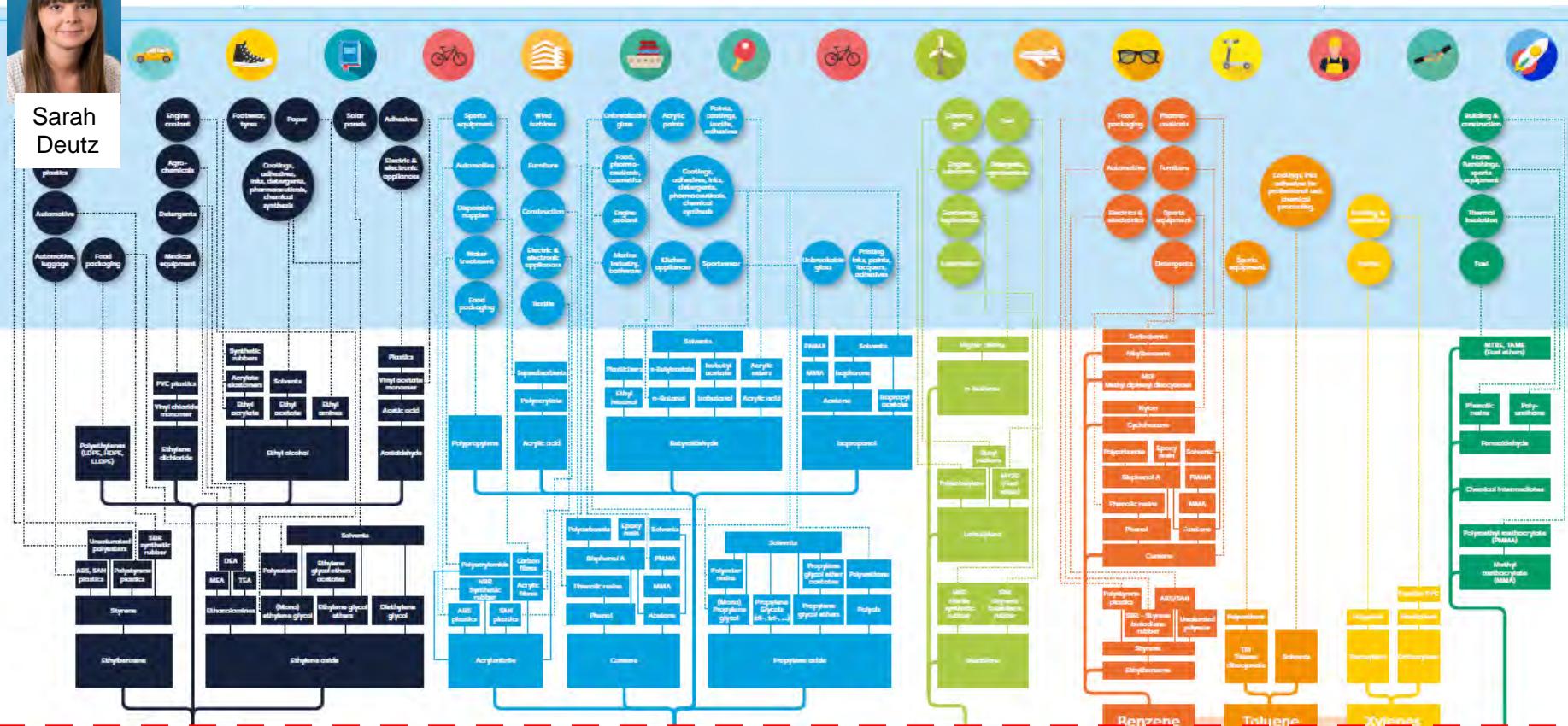
Arne
Kätelhön



Raoul
Meys

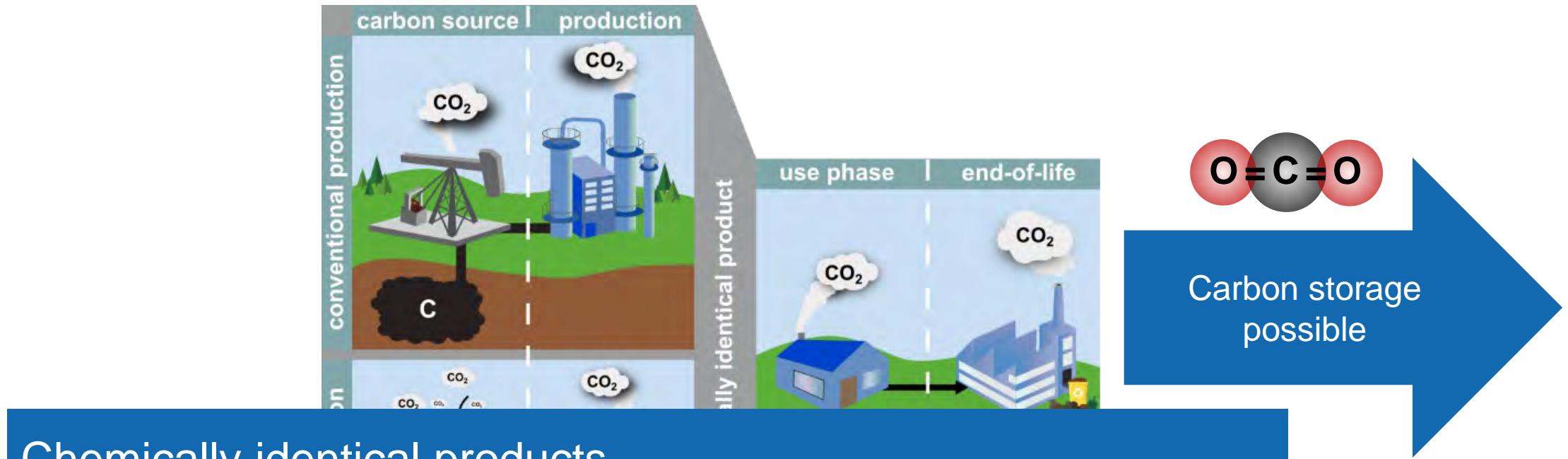


Sarah
Deutz



What is the large-scale potential of CCU in the chemical industry ?

⇒ 20 basic chemicals = 75% of CO₂ emissions of chemical industry



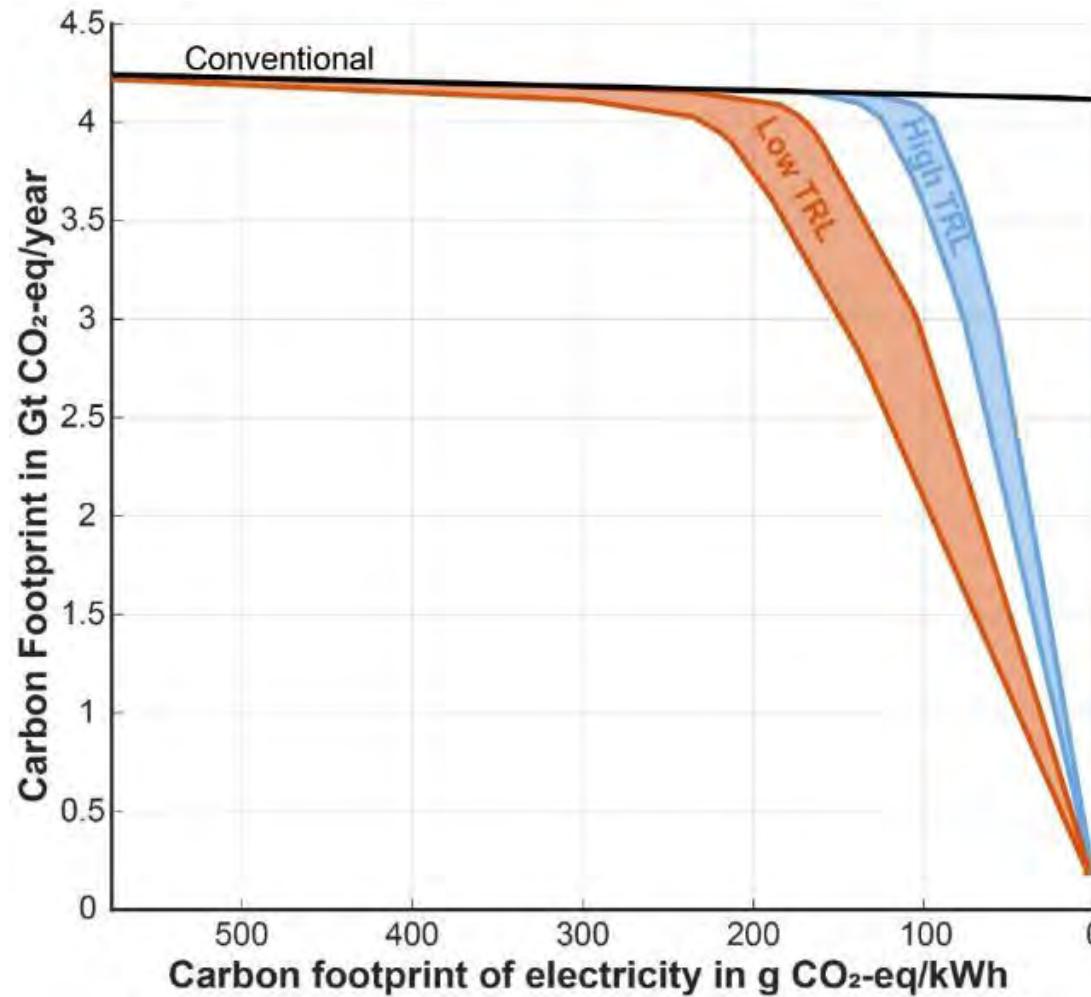
Chemically identical products

⇒ 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

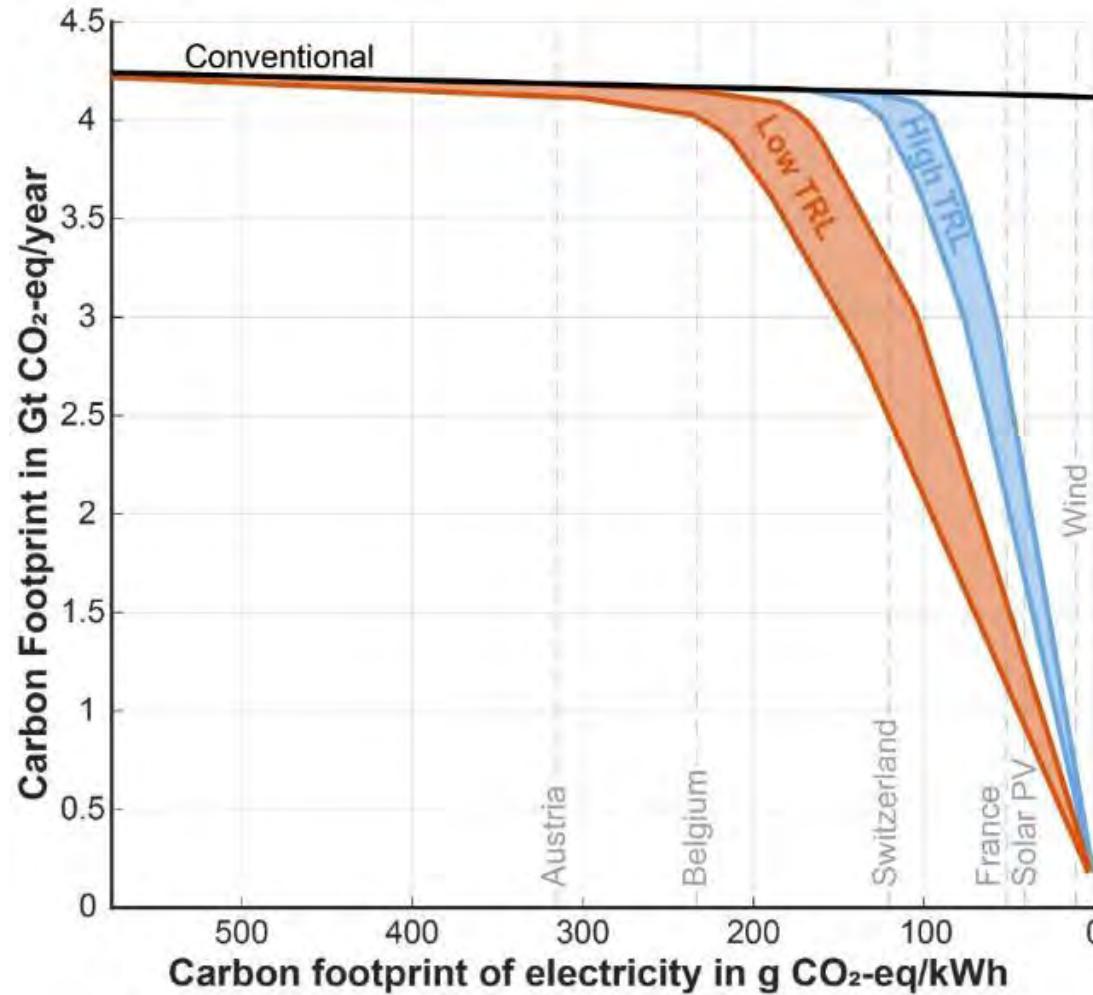
CO₂-Mitigation Potential of CCU in the Chemical Industry



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

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

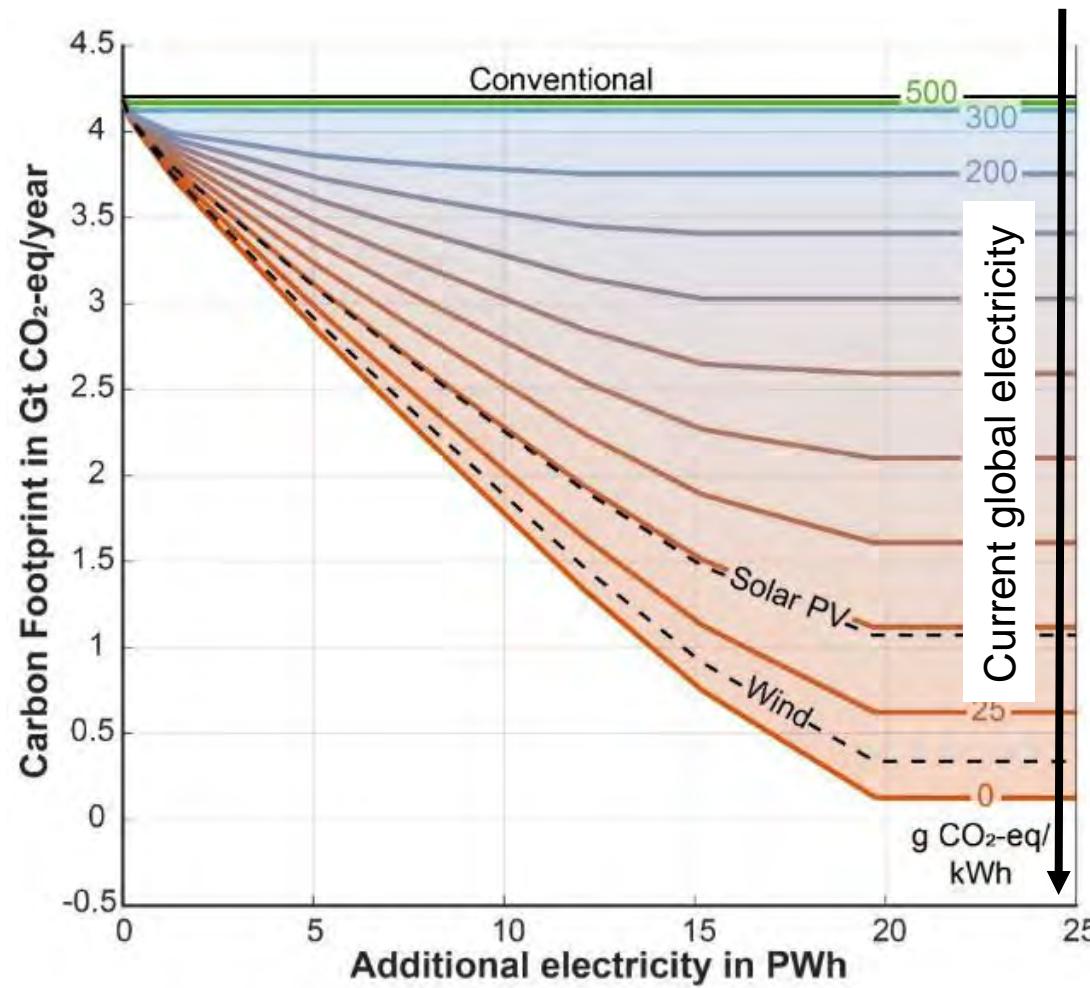
CO₂-Mitigation Potential of CCU in the Chemical Industry



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

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

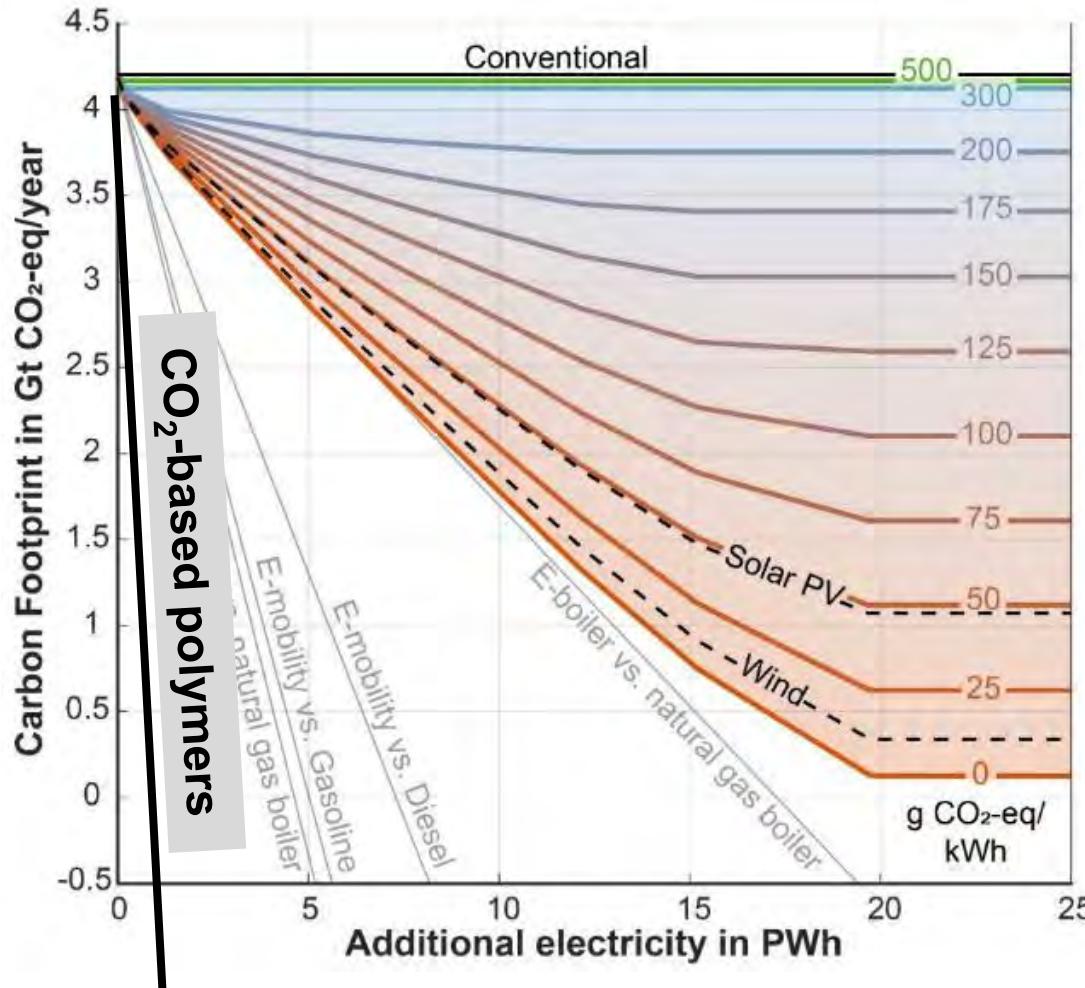
Electricity need for CCU in the Chemical Industry



- GHG savings require **a lot of** low-carbon electricity

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

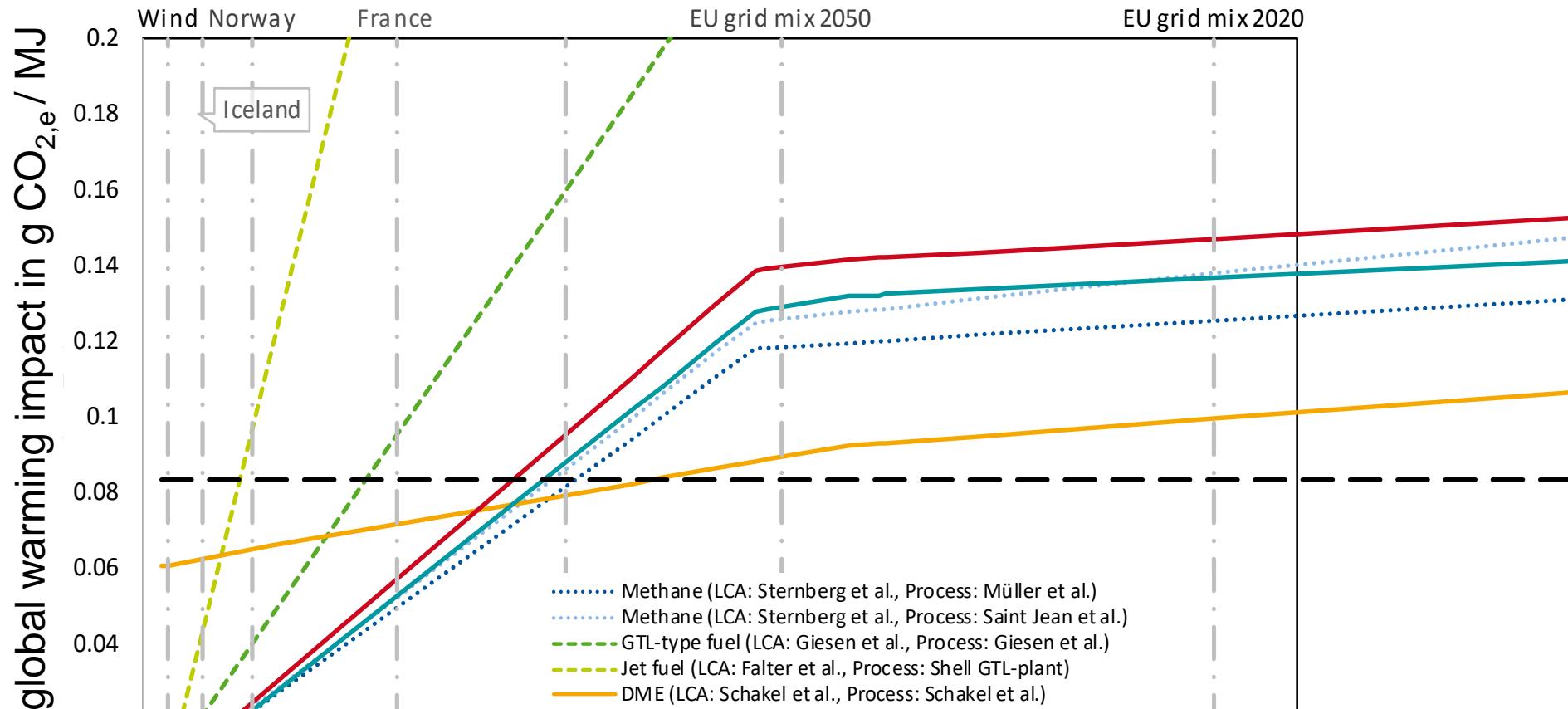
Power-to-Chemicals vs Power-to-X



- 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

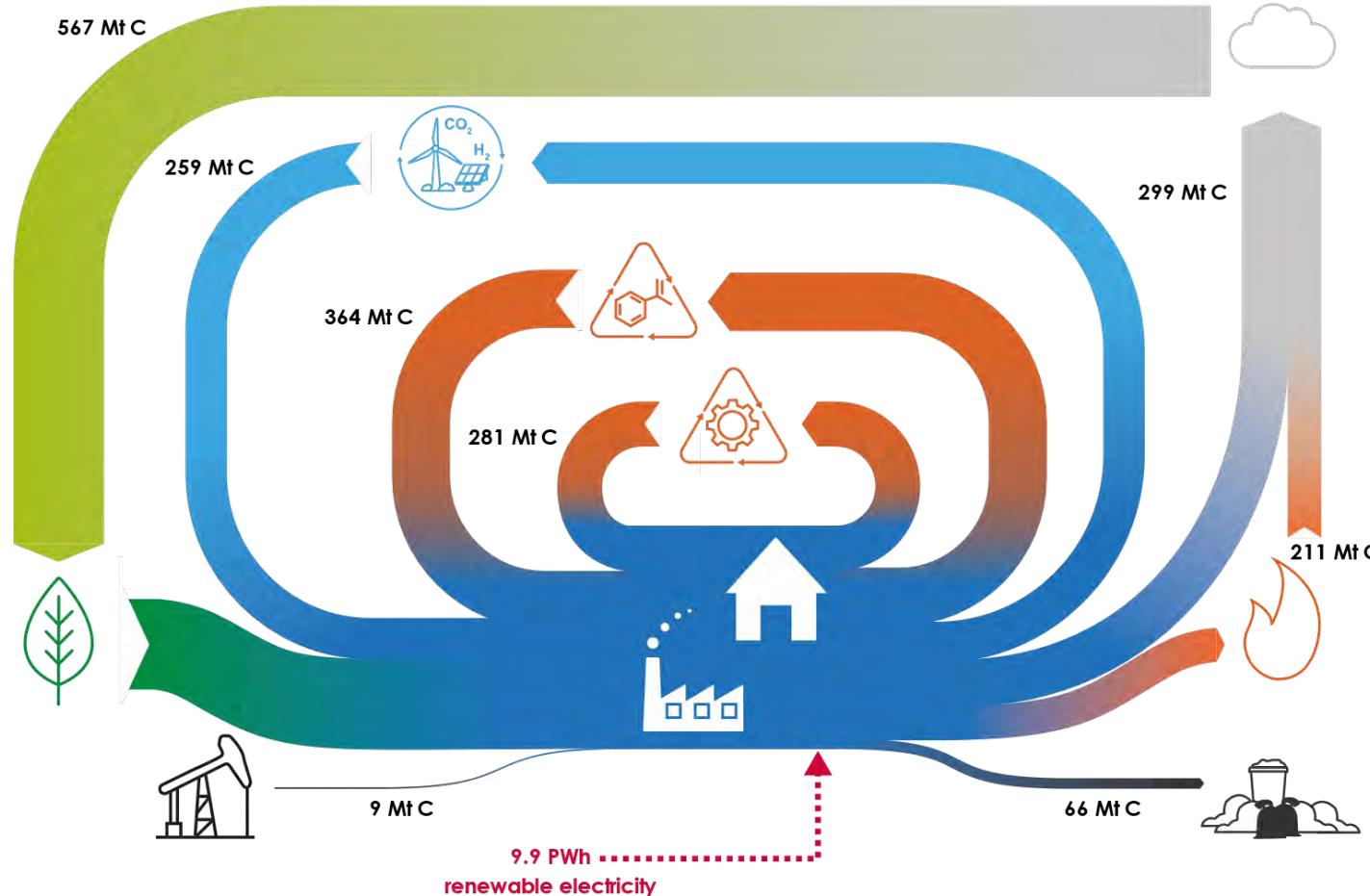
Kätelhön, Meys, Deutz, Suh, Bardow, *PNAS*, 2019
Sternberg, Bardow, *Energy Environ. Sci.*, 2015, 8, 389

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)

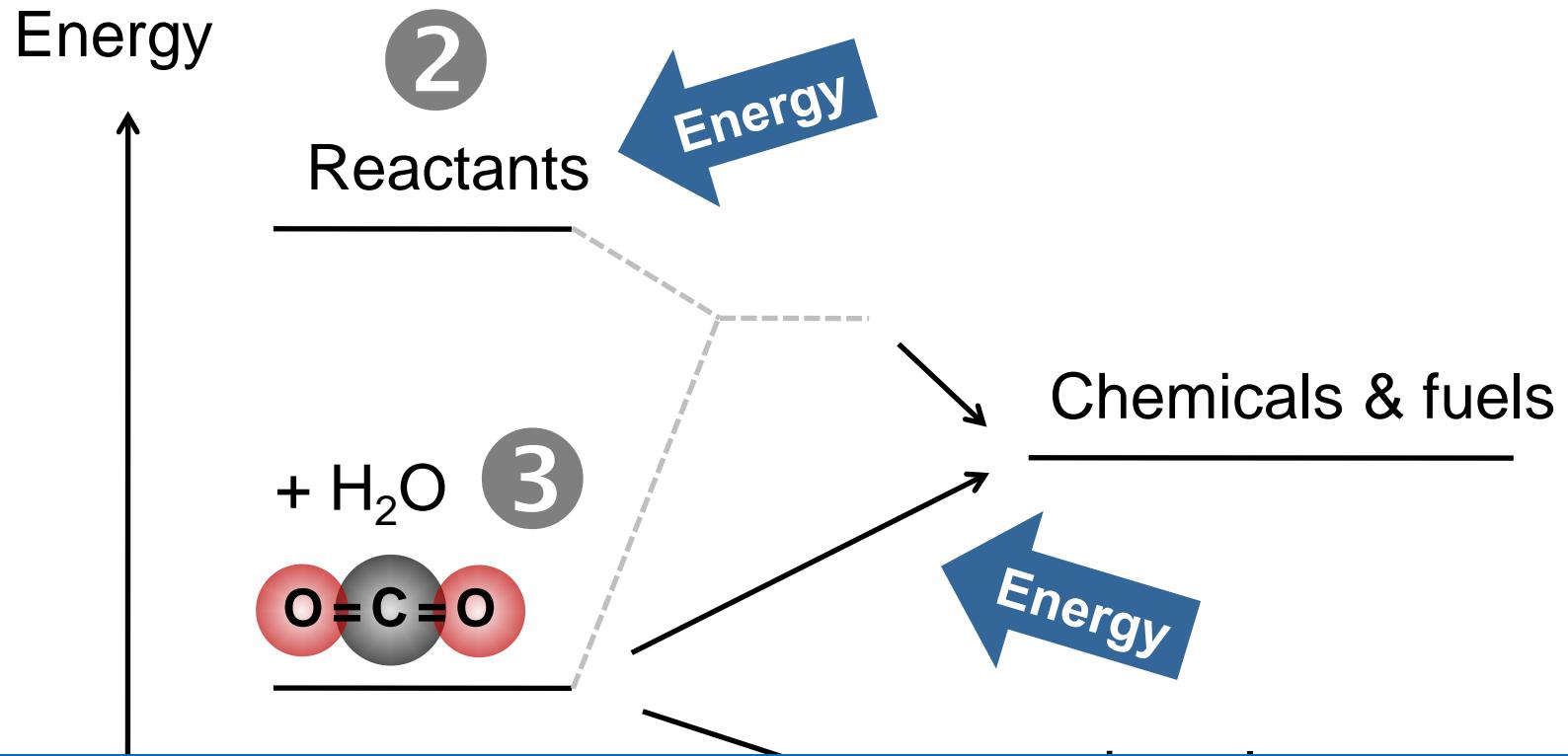
CO₂ use as part of a circular carbon economy



Meys et al., Science, 2021

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

Thermodynamics of CO₂ conversion



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



A sustainable world needs:

1. clean electricity
 2. a lot of clean electricitiy
 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

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