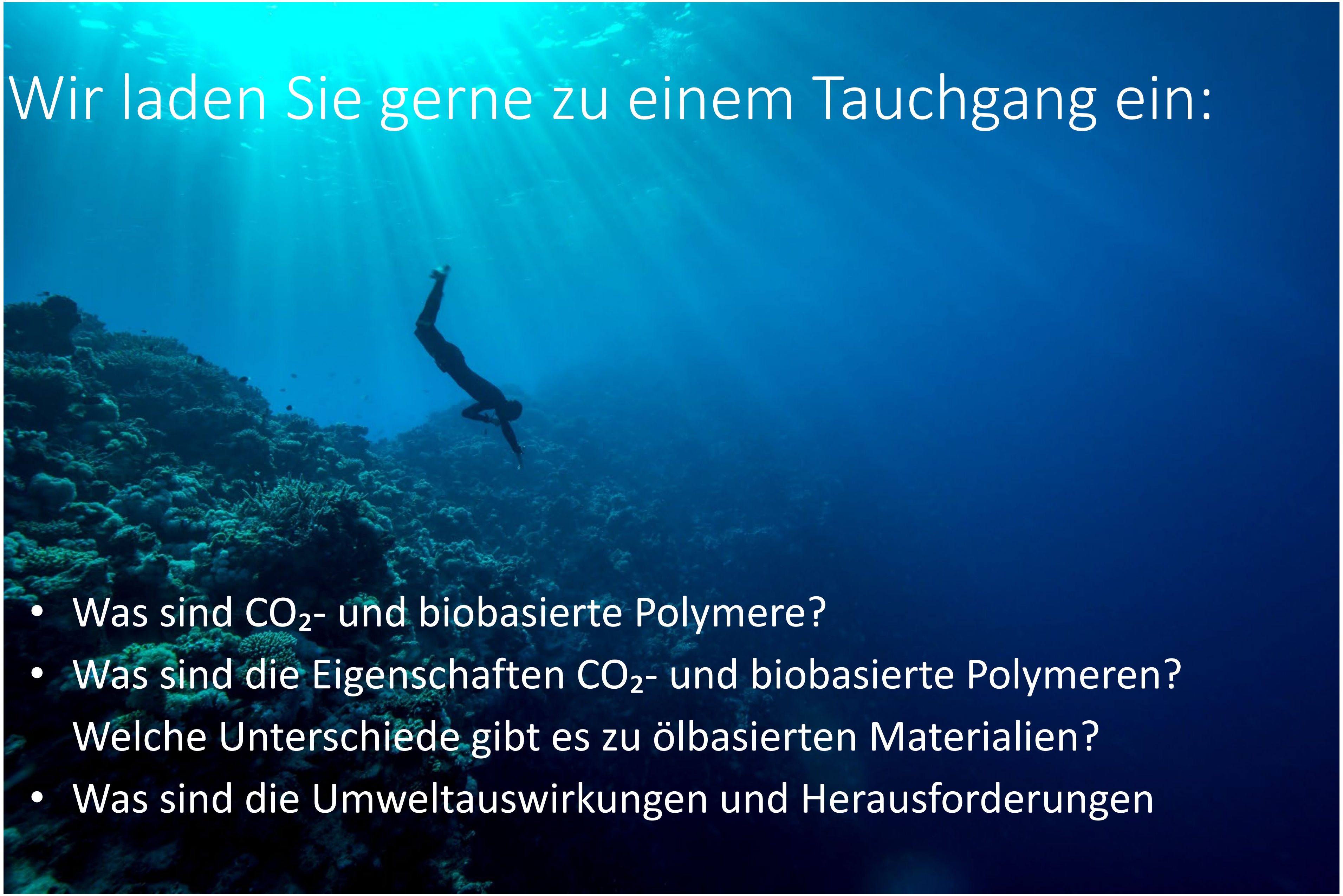
Wie nachhaltig sind CO_2- und biobasierte Polymere im Vergleich zu ölbasierten Materialien?

Deep Dive Session

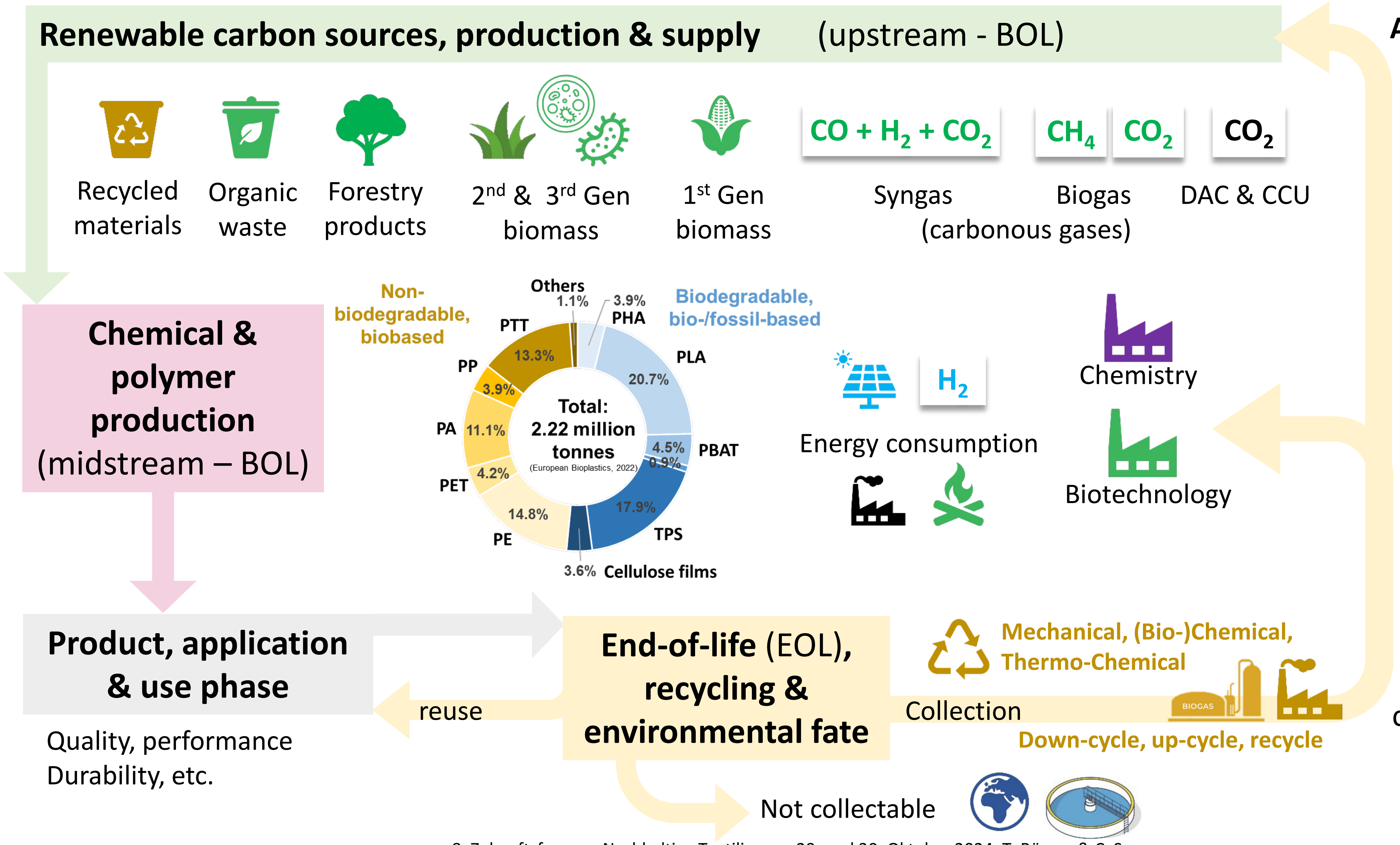
Claudia Som, Empa; **Tim Börner**, Empa / HESSO

Wir laden Sie gerne zu einem Tauchgang ein:



- Was sind CO_2- und biobasierte Polymere?
- Was sind die Eigenschaften CO_2- und biobasierte Polymeren? Welche Unterschiede gibt es zu ölbasierten Materialien?
- Was sind die Umweltauswirkungen und Herausforderungen

Übersicht über die Wertschöpfungskette: erneuerbare Polymere



Assessment criteria:

Environmental footprint, impacts (LCA) & Trade-offs

Availability & TRL

Properties, quality & performance

WMS* & recyclability

Biodegradability & biocompatibility

Regulations, policies, certification, standards

*Waste management system

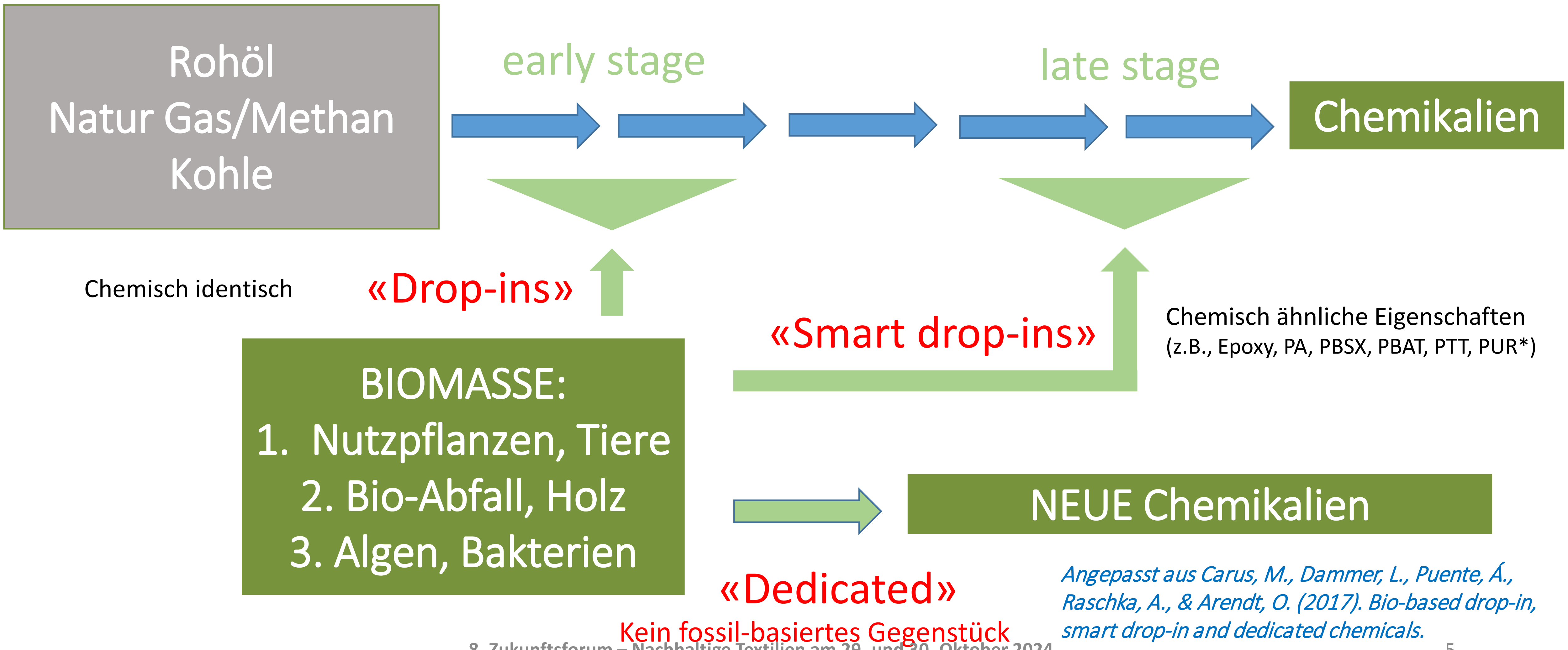
Wieso ist CO_2- und biobasierter Plastik so interessant?

Die Motivation:

- Erneuerbarer Rohstoff
- Bio-abbaubare Plastik-Produkte
- Regionaler Rohstoff
- «Klimafreundlicher» Rohstoff, besserer Kohlenstoff-Fussabdruck
- Neuartige innovative Materialien

Erfüllen diese Polymere die Erwartungen?

Erneuerbarer Rohstoff als Ersatz für fossil-basiert - wie geht das?



Angepasst aus Carus, M., Dammer, L., Puente, Á., Raschka, A., & Arendt, O. (2017). Bio-based drop-in, smart drop-in and dedicated chemicals.

Erneuerbarer Rohstoff?

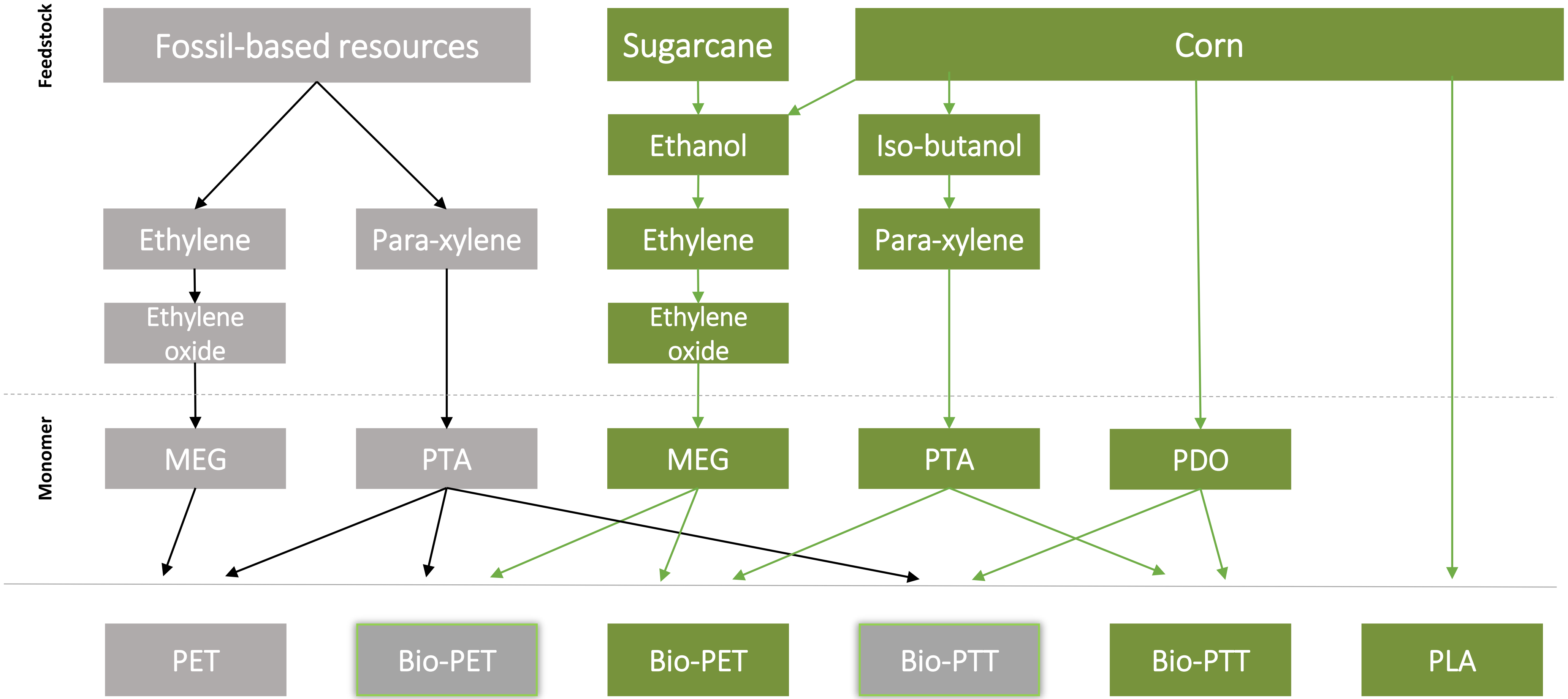
Bio-basierter Polyester

applied sciences
MDPI
Article

Bio-Based Polyester Fiber Substitutes: From GWP to a More Comprehensive Environmental Analysis

Tijana Ivanović, Roland Hischier and Claudia Som *

https://doi.org/10.3390/app11072993



Bio-abbaubar?

Bio-Polyethylen-Terephthalat (bio-PET)
Bio-Polyamid (bio-PA)
Bio-Polyethylen (bio PE)

bio-basiert

Zellophan
Chitosan
Seide
Polyhydroxialkanoate (PHAs)
Polymilchsäure (PLA)

nicht bio-abbaubar

bio-abbaubar

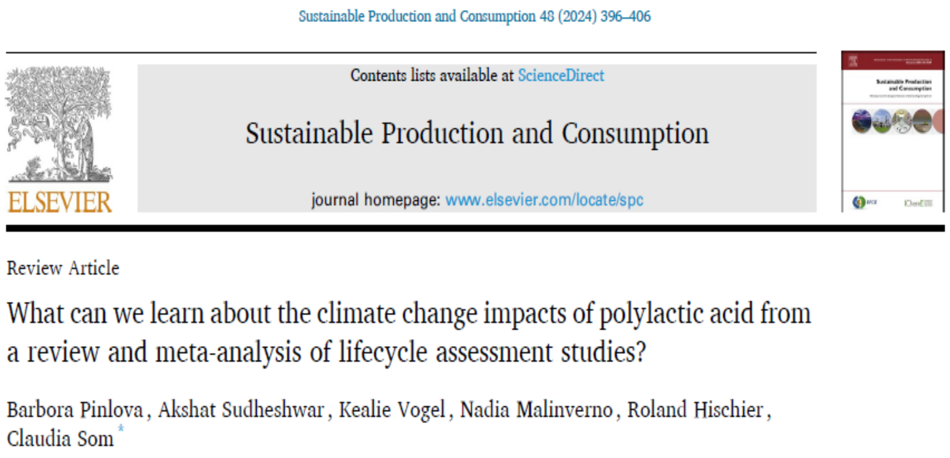
Acrylonitril-Butadien-Styrene (ABS)
Polyamide (PA)
Polyethylen (PE)
Polyethylen Terephthalat (PET)
Polypropylen (PP)
Polyvinylchlorid (PVC)

fossil-basiert

Abgeändert von Marti, R., Meyer, H. P., & Zinn, M. (2019): Factsheet Bioplastics

Polybuten Adiapat Terephtalat (PBAT)
Polybutylen Succinat (PBS)
Polycaprolakton (PCL)
Polyvinyl Alkohol (PVA)

«Klimafreundlich»? Meta-Analyse CO_2-Fussabdruck für Polymilchsäure


Sustainable Production and Consumption 48 (2024) 396–406

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journal homepage: www.elsevier.com/locate/spc

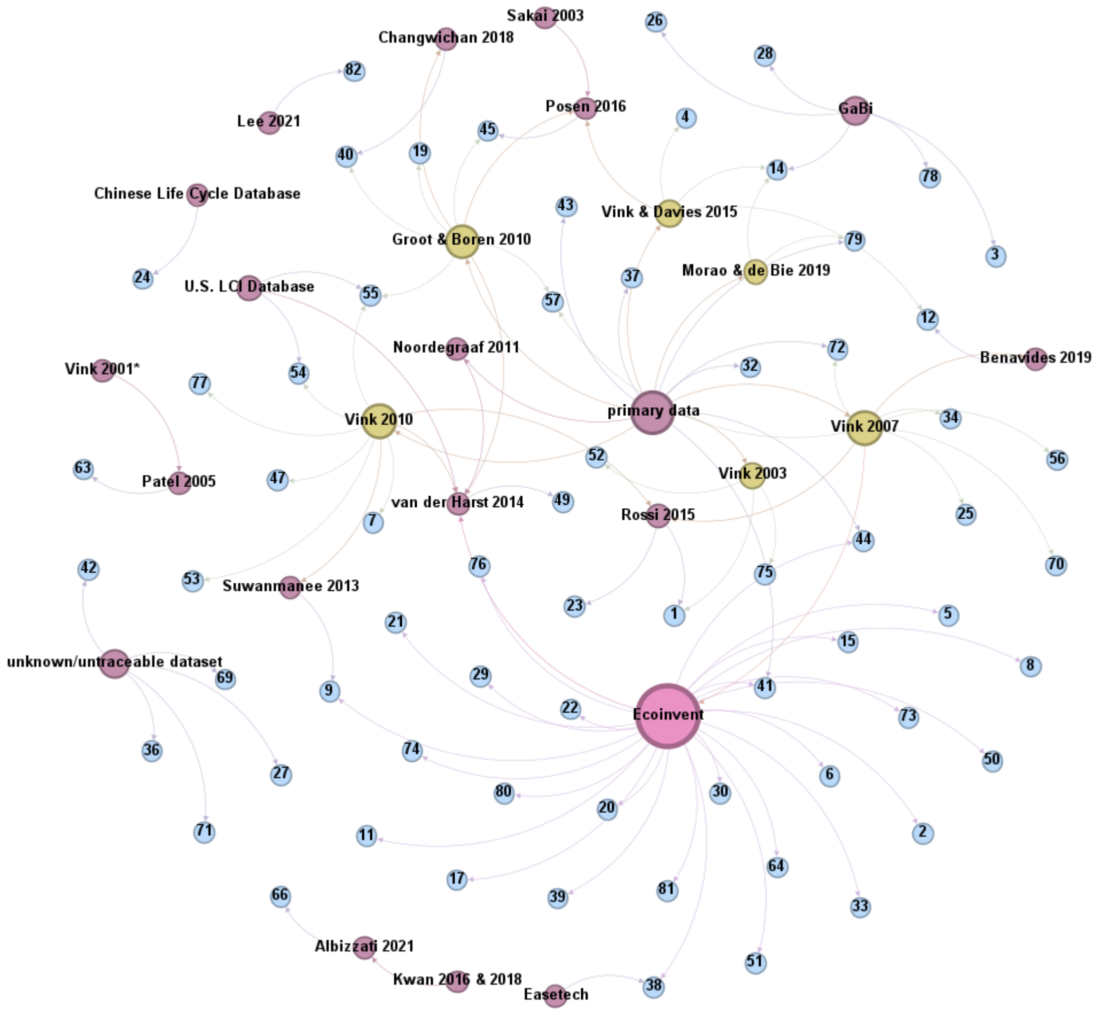
ELSEVIER

Review Article

What can we learn about the climate change impacts of polylactic acid from a review and meta-analysis of lifecycle assessment studies?

Barbora Pinlova, Akshat Sudheshwar, Kealie Vogel, Nadia Malinverno, Roland Hischier, Claudia Som*

https://doi.org/10.1016/j.spc.2024.05.021



Vorgehen:

1 . Auswertung aller wissenschaftlichen Studien LCA/CO_2-Fussabdruck (Global Warming Potential, GWP) von PLA

2. Gruppieren der Literatur in Bereich (Scope):

Wiege zum Tor **(cradle-to-gate)**

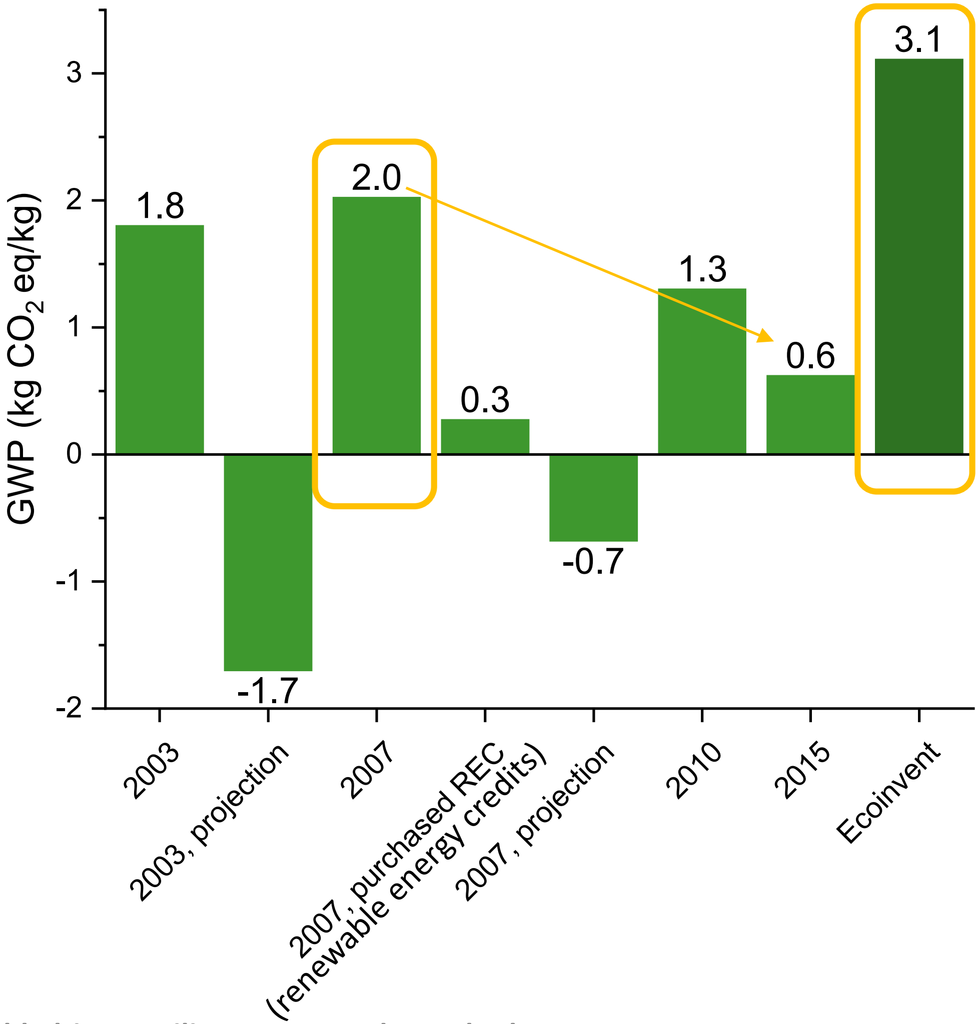
Wiege zu Bahre **(cradle-to-grave)**

Daten-Analyse:

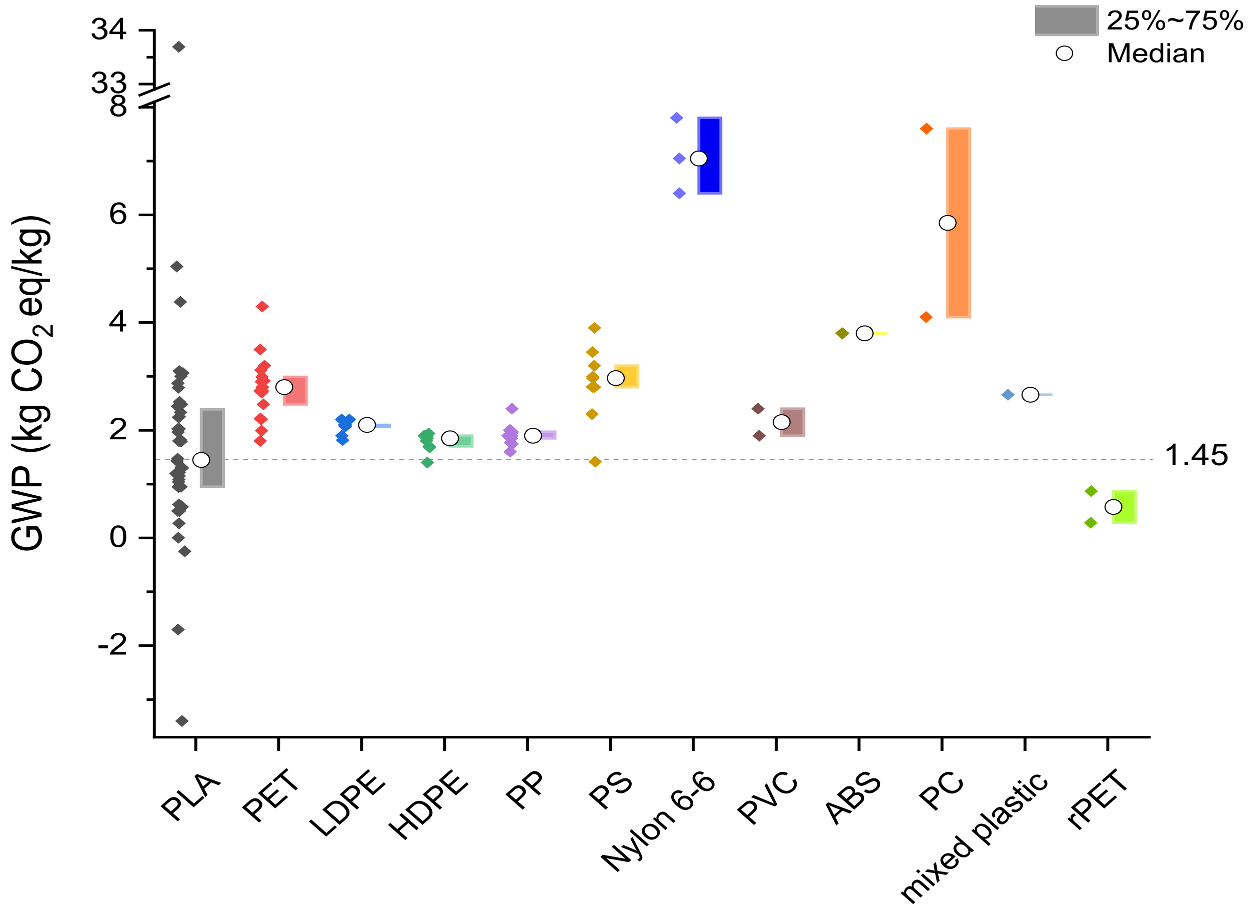
Auf welche Daten stützen sich die Studien?

LCA von einem Hersteller über die Zeit - NatureWorks

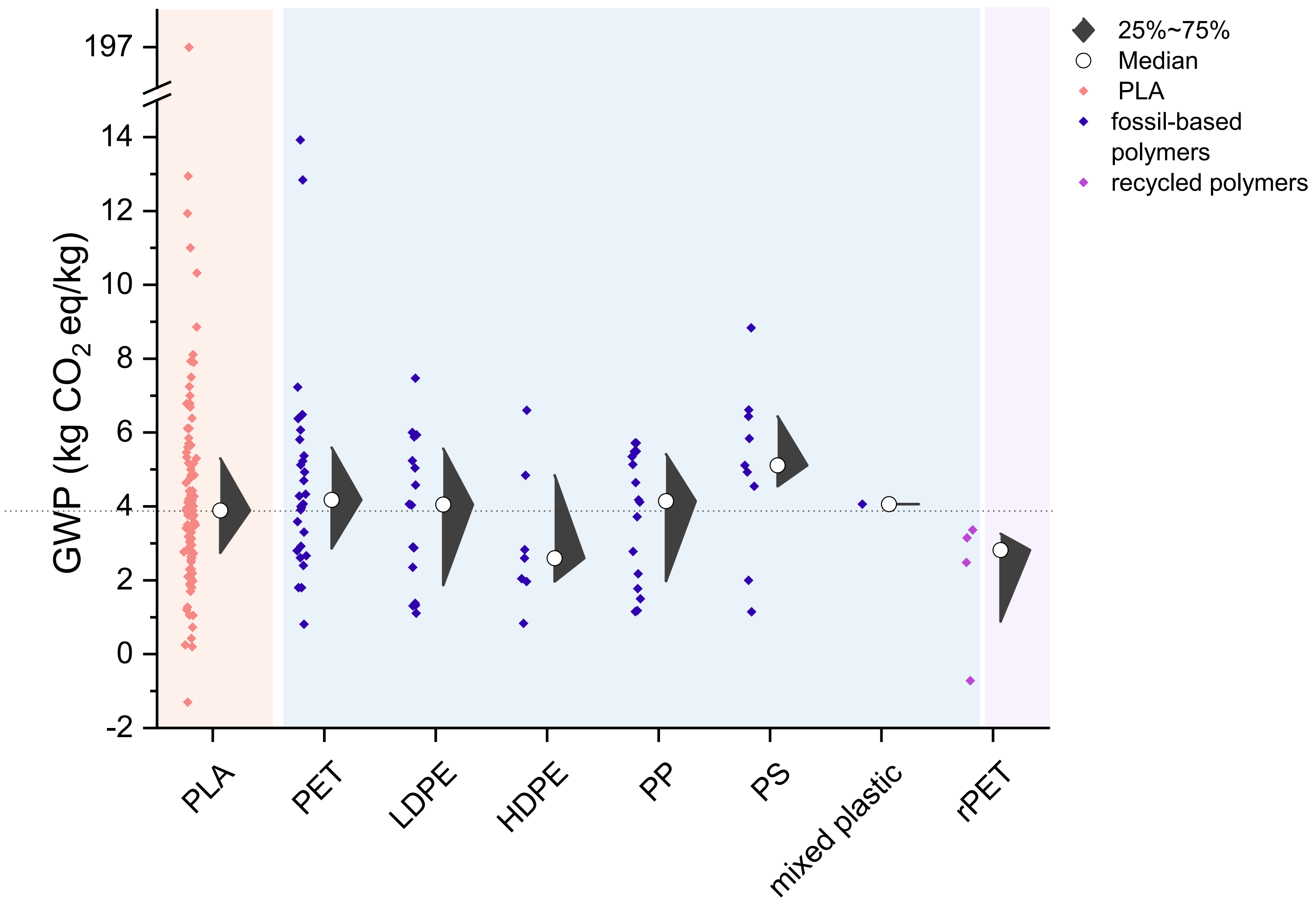
- 4 Studien
- Autor: Vink
- Cradle-to-gate



LCA «Cradle to Gate»: PLA vs fossil-basierte Polymere



LCA «Cradle to Grave»: PLA vs fossil-basierte Polymere



«Klimafreundlich»? Meta-Analyse CO_2-Fussabdruck für Lignin und Zellulose

RSC Sustainability

ROYAL SOCIETY OF CHEMISTRY

PAPER

View Article Online
View Journal

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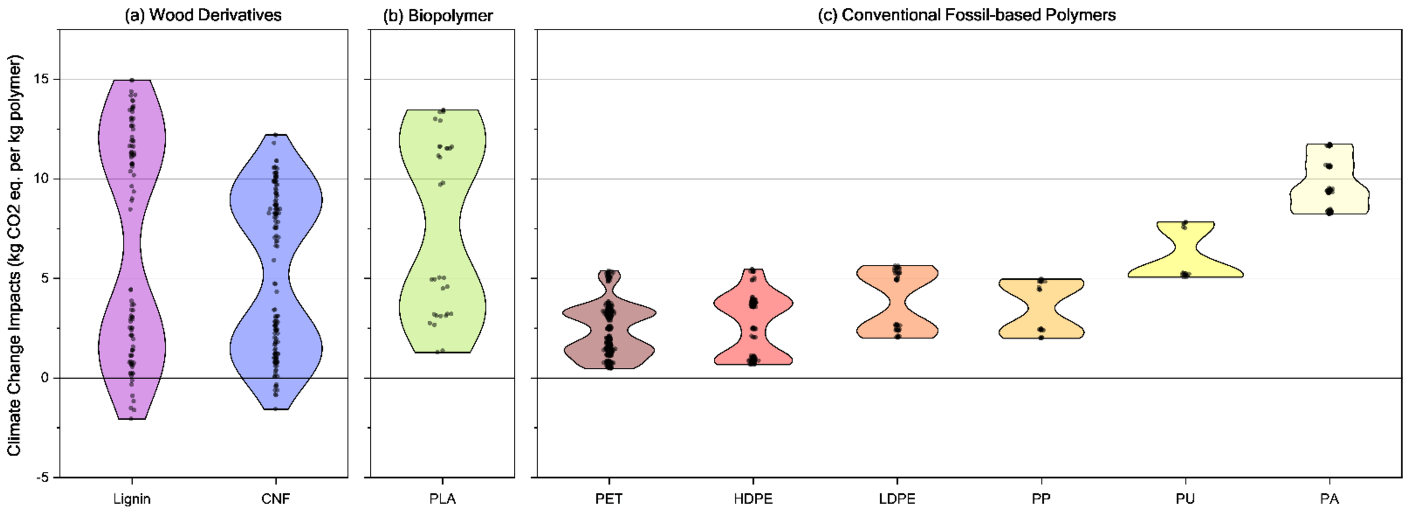
Cite this: DOI: 10.1039/d4su00010b

Unraveling the climate neutrality of wood derivatives and biopolymers†

Akshat Sudheshwar,[a] Kealie Vogel,[ab] Gustav Nyström,[b] Nadia Malinverno,[a] Monica Arnaudo,[a] Carlos Enrique Gómez Camacho,[a] Didier Beloin-Saint-Pierre,[a] Roland Hischier[a] and Claudia Som*[a]

DOI: 10.1039/d4su00010b



Vorgehen:

1 . LCA/CO_2-Fussabdruck (Global Warming Potential, GWP) von Lignin und Cellulose

2. Gruppieren der Literatur in Bereich (Scope):

Wiege zum Tor **(cradle-to-gate)**

Wiege zu Bahre **(cradle-to-grave)**

Biobased vs. fossil-based Nylon (cradle-to-gate)

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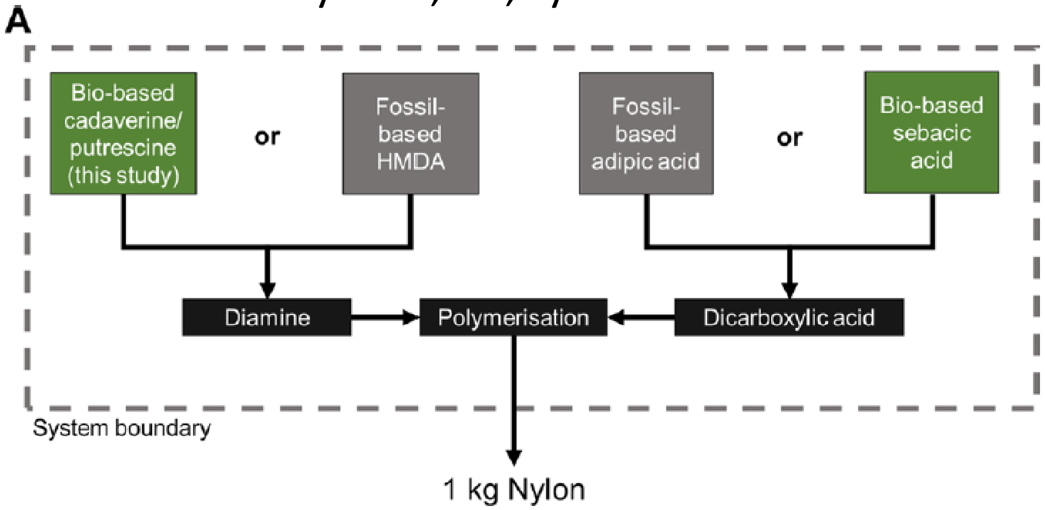
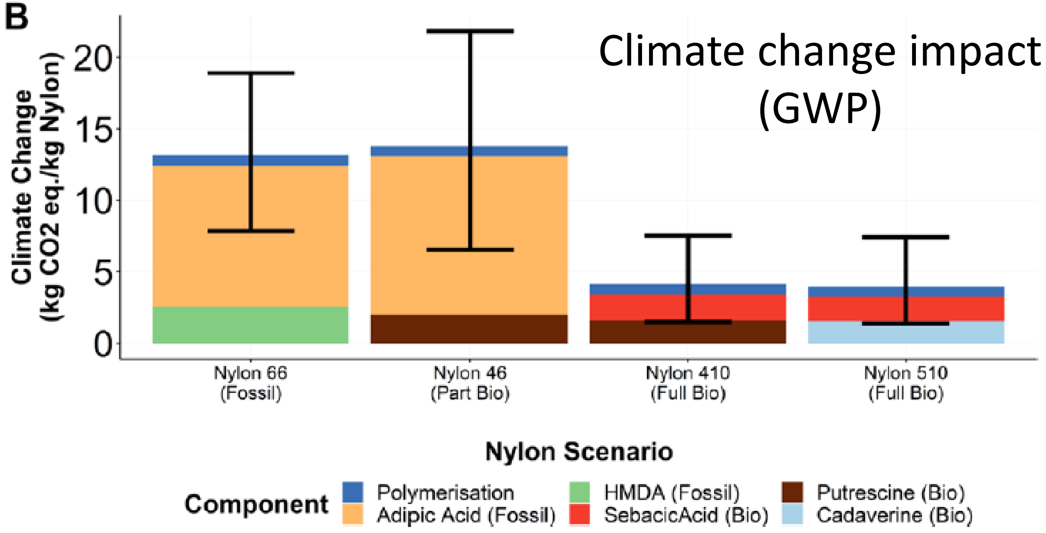
Materials Science and Technology

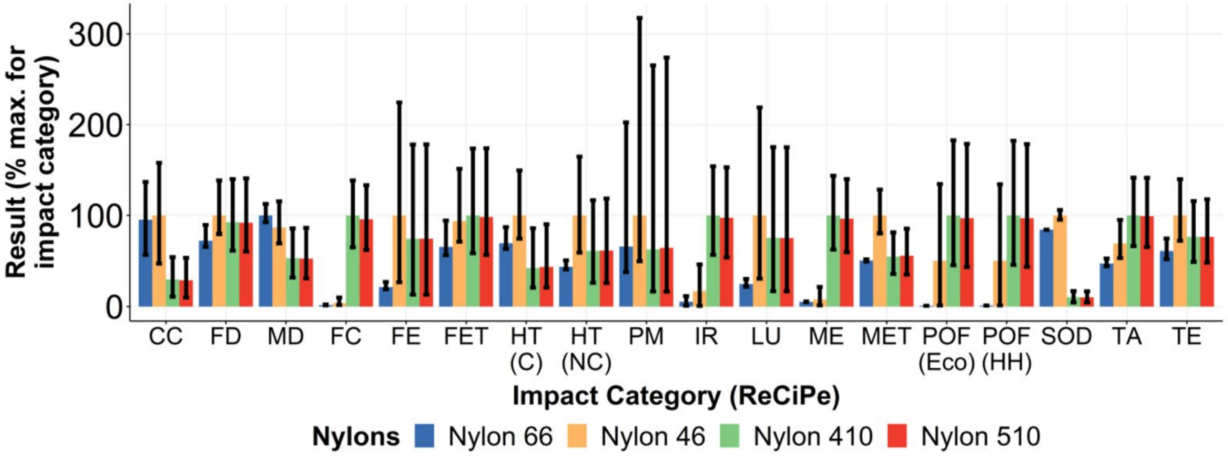
Product system, FU, system boundaries



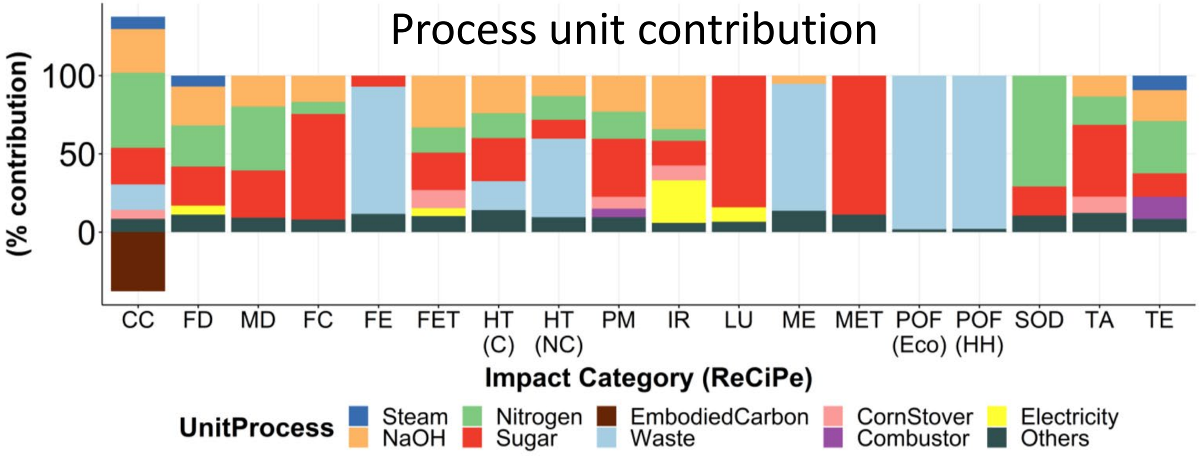
Climate change impact (GWP)



Environmental categories: trade-offs



Process unit contribution

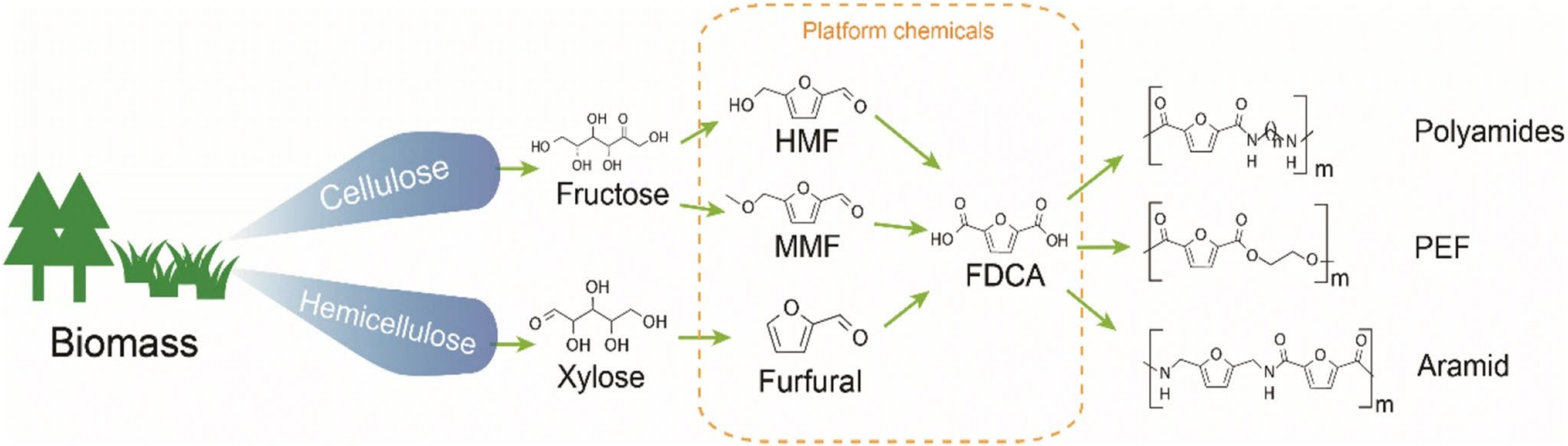


CC – Climate change, incl. biogenic credit
FD – Freshwater depletion
MD – Metal depletion
FC – Freshwater consumption
FE – Freshwater ecotoxicity
FET – Freshwater eutrophication
HT (C) – Human toxicity (cancer)
HT (NC) – Human toxicity (non-cancer)
PM – Particulate matter
IR – Ionising radiation
LU – Land use
ME – Marine ecotoxicity
MET – Marine eutrophication
POF (Eco) – Photochemical ozone formation (ecosystems)
POF (HH) - Photochemical ozone formation (human health)
SOD – Stratospheric ozone depletion
TA – Terrestrial acidification
TE – Terrestrial ecotoxicity

Source: Matthews et al. (2019). Collaborating constructively for sustainable biotechnology. *Scientific Reports*, *9*(1), 19033.

Biobased chemicals for PEF and Polyamides (cradle-to-gate)

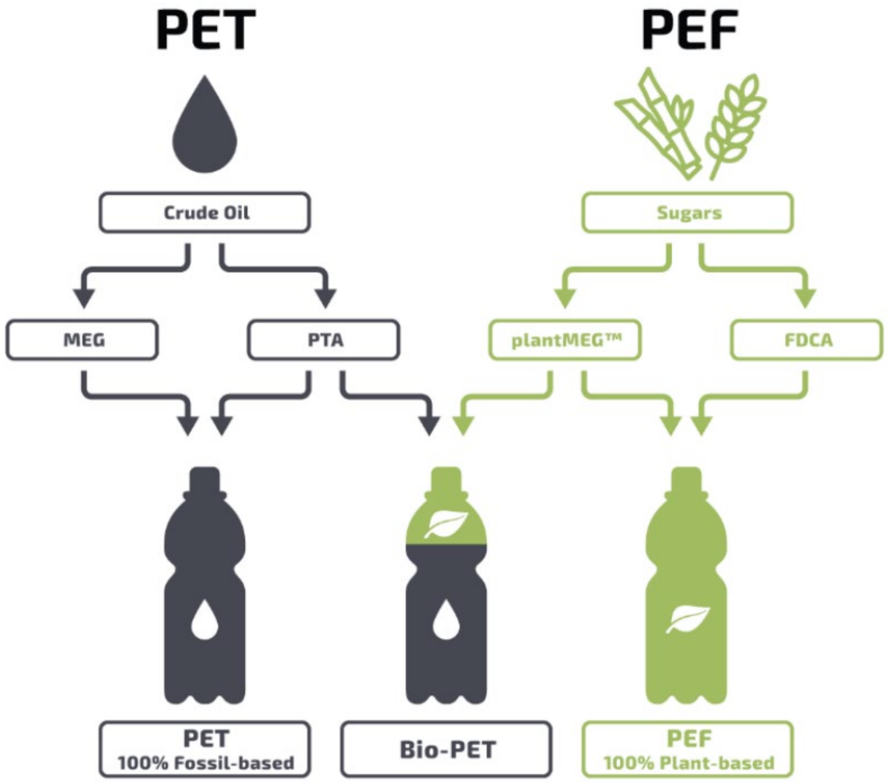
FDCA - 2,5-Furandicarboxylic acid
PEF - polyethylene furanoate

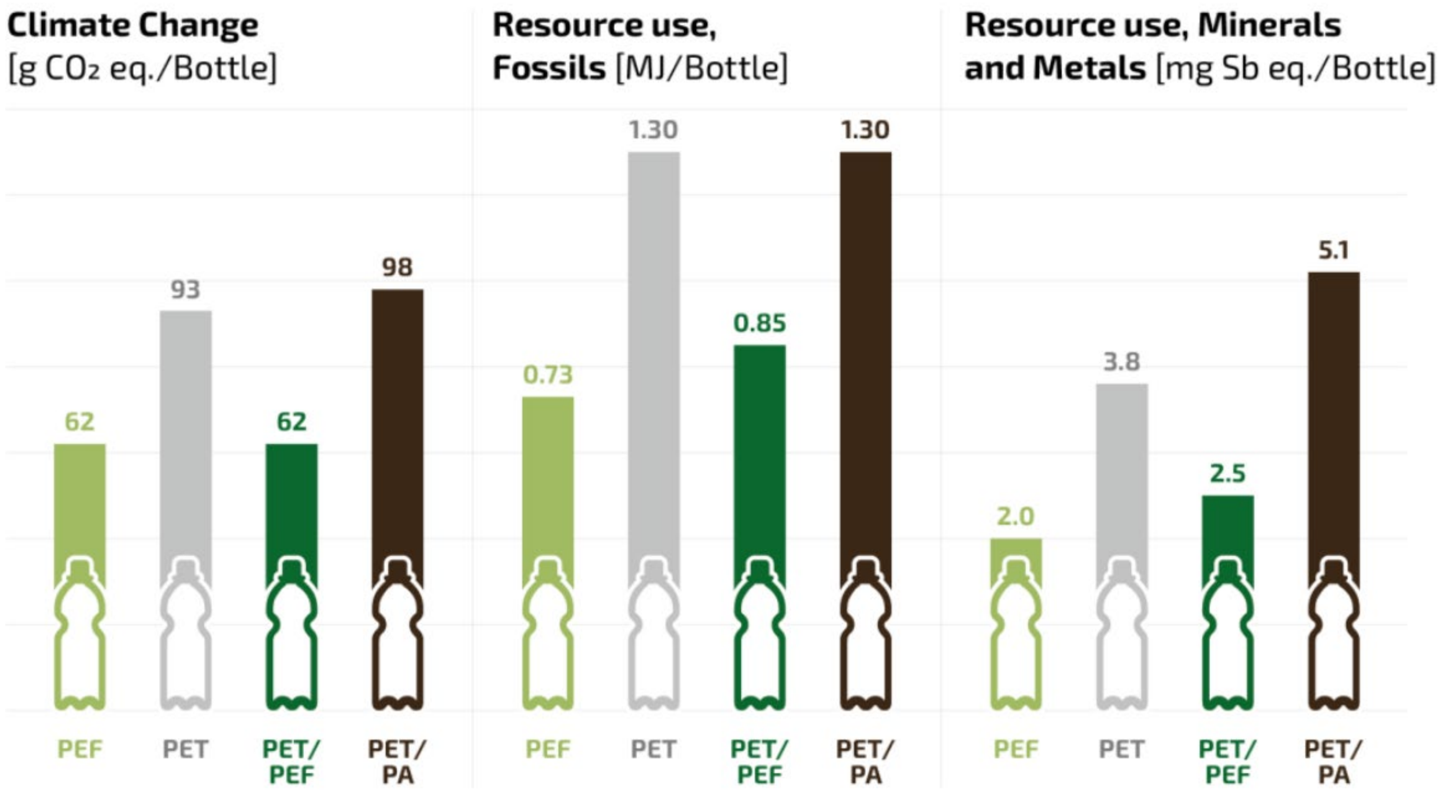


Source: Yuan, H., Liu, H., Du, J., Liu, K., Wang, T., & Liu, L. (2020). *Applied microbiology and biotechnology*, *104*(2), 527-543.

PET versus biobased PEF (cradle-to-gate)

FDCA - 2,5-Furandicarboxylic acid
PEF - polyethylene furanoate





Source: https://avantium.com/wp-content/uploads/2022/02/20220221-PEF-bottles-%E2%80%93-a-sustainable-packaging-material-ISO-certified-LCA.pdf

Schlussfolgerungen aus den Meta-Analysen zu PLA, Lignin und Zellulose

- Grosse Variation in den Resultaten
- Jeder Datenpunkt ist einzigartig berechnet
- Erneuerbare Energien scheinen wichtig für einen tieferen CO_2- Fussabdruck
- Vergleicht man PLA mit fossil-basierten Polymeren sieht man keine relevante Reduktion des CO_2-Fussabdruckes
- «Carbon Crediting» nicht missbrauchen
- Jedoch: Die Daten für PLA sind veraltet und fossil-basierte Polymere haben seit kurzem einen 30% höheren CO_2-Fussabdruck (neue Berechnungsmethoden)
- «End of Life» (EoL) Management ist wichtig (extended producer responsibility, recycling)
- «Carbon-tunnel vision» bestraft die Bioabbaubarkeit und Mikro/Makro-plastik Auswirkungen werden (noch) nicht erfasst.

Carbon Capture & Utilization (CCU) Technologies for CO2-based chemicals & polymers

Tim Börner*, Carlos Gomez, Akshat Sudheshwar, Claudia Som

Carbon capture, storage & utilization pathways

Overview

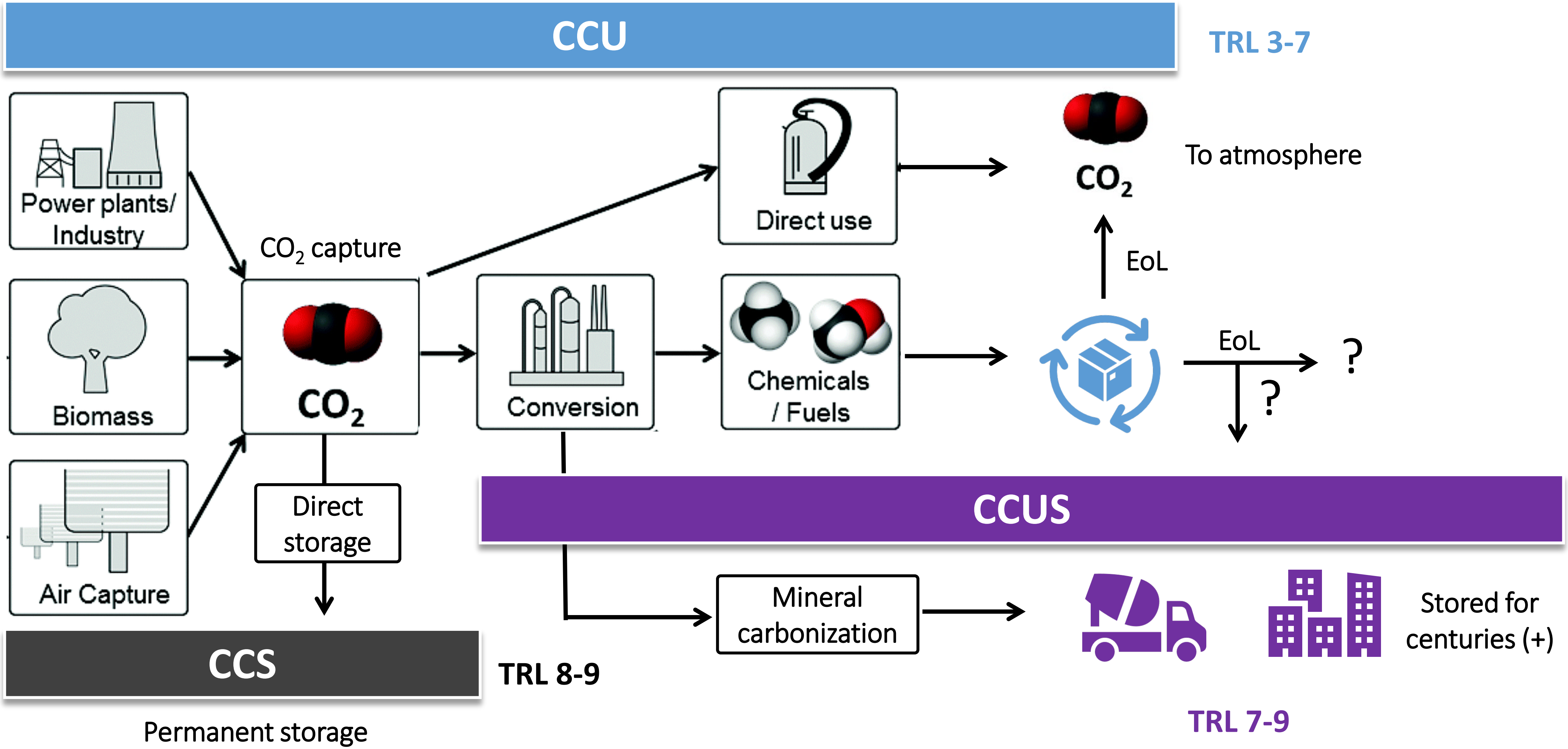
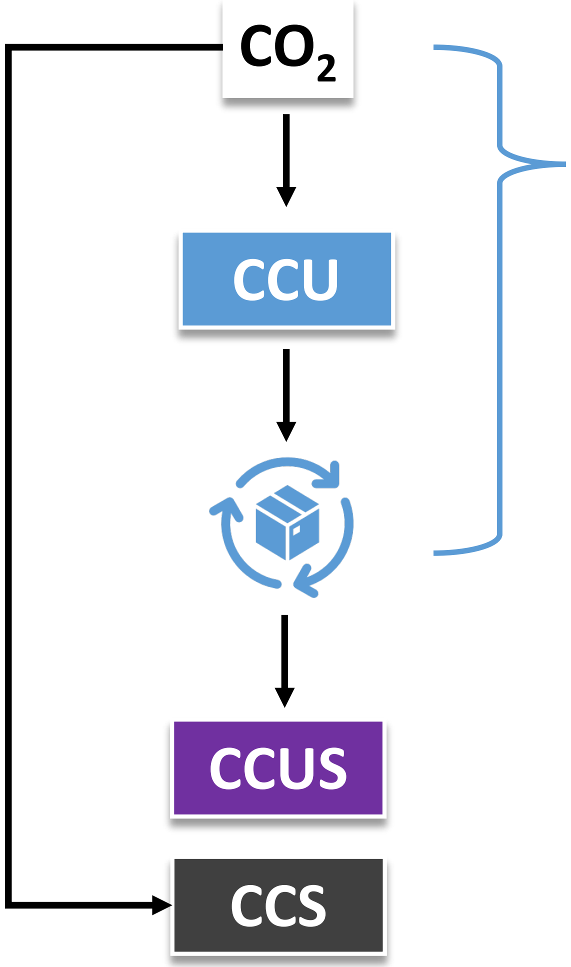


Image modified from Bui et al. (2018). *Energy & Environmental Science*, *11*(5), 1062-1176.

Can “CCU products” be certified as CO2-storage?

Current regulatory framework



CCS Directive 2009/31/EC, revised guidance document, July 2024

Commission delegated regulation CCU DA 2024/2620 (July):

- … GHGs (CO2) permanently chemically bound in a product
- … bound in product at least for a period of several centuries or longer
- … EOL routes leading to CO2 release e.g., incineration, are excluded
- … provide a similar climate benefit as geological storage
- CCU routes/products via mineral carbonization are considered to permanently chemically bind CO2: construction products (cement, lime, hydraulic binders, bricks, tiles, etc.)
- Review/update product list to adapt according to technology innovation and development

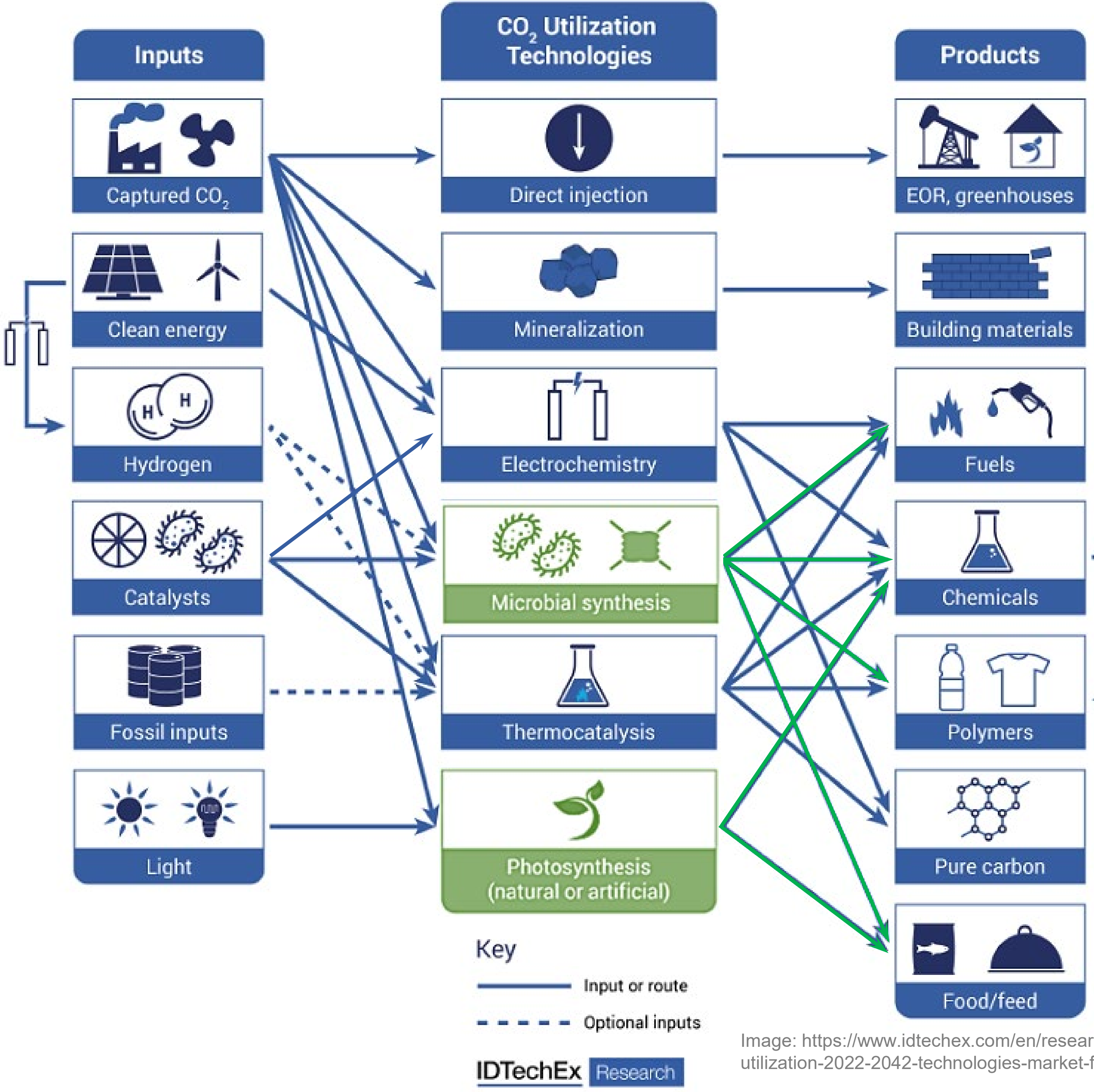


Image: https://www.idtechex.com/en/research-report/carbon-dioxide-utilization-2022-2042-technologies-market-forecasts-and-players/866

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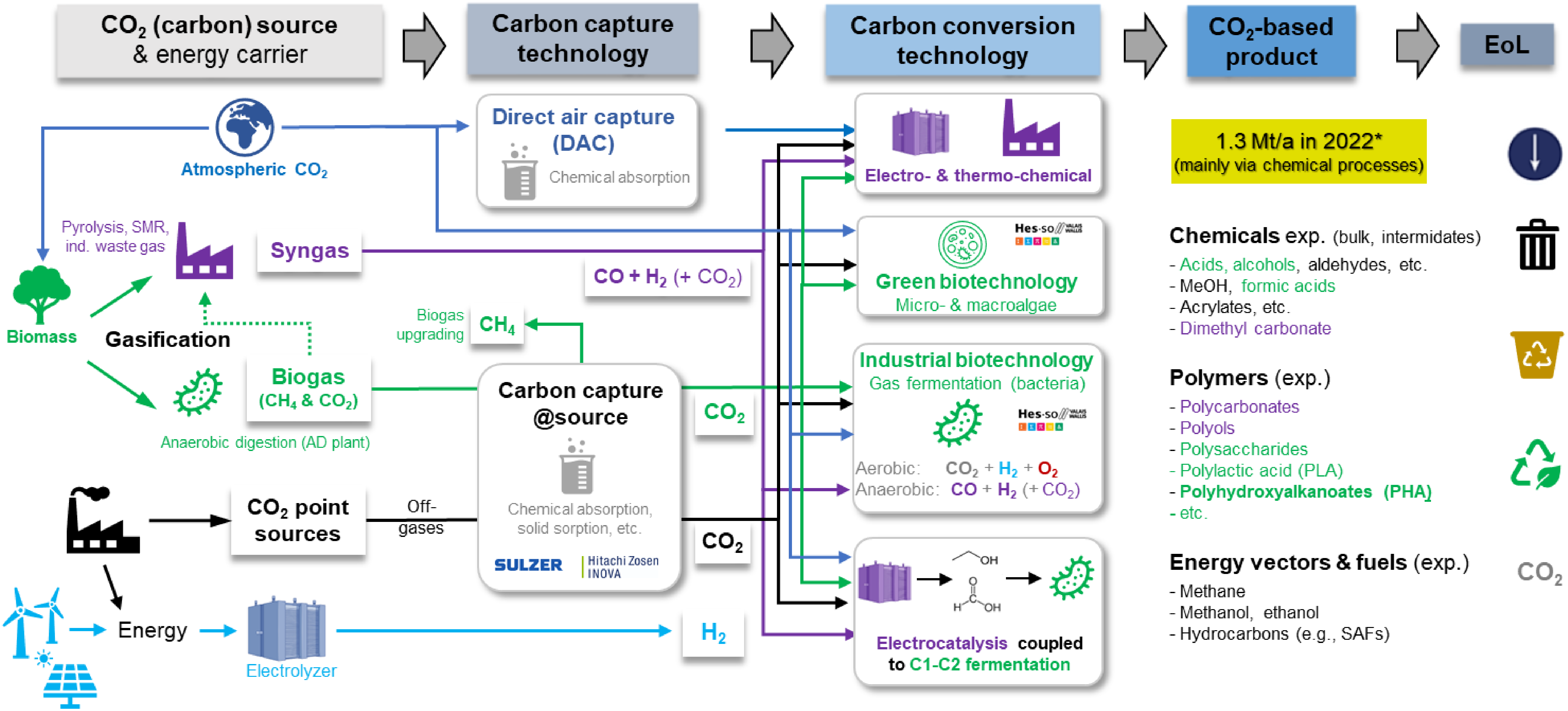
Carbon capture & utilization (CCU) pathways

Defossilization of the chemical, polymer and energy sector with the help of **Chemistry** and **Biotechnology**

Carbon capture & utilization (CCU) pathways

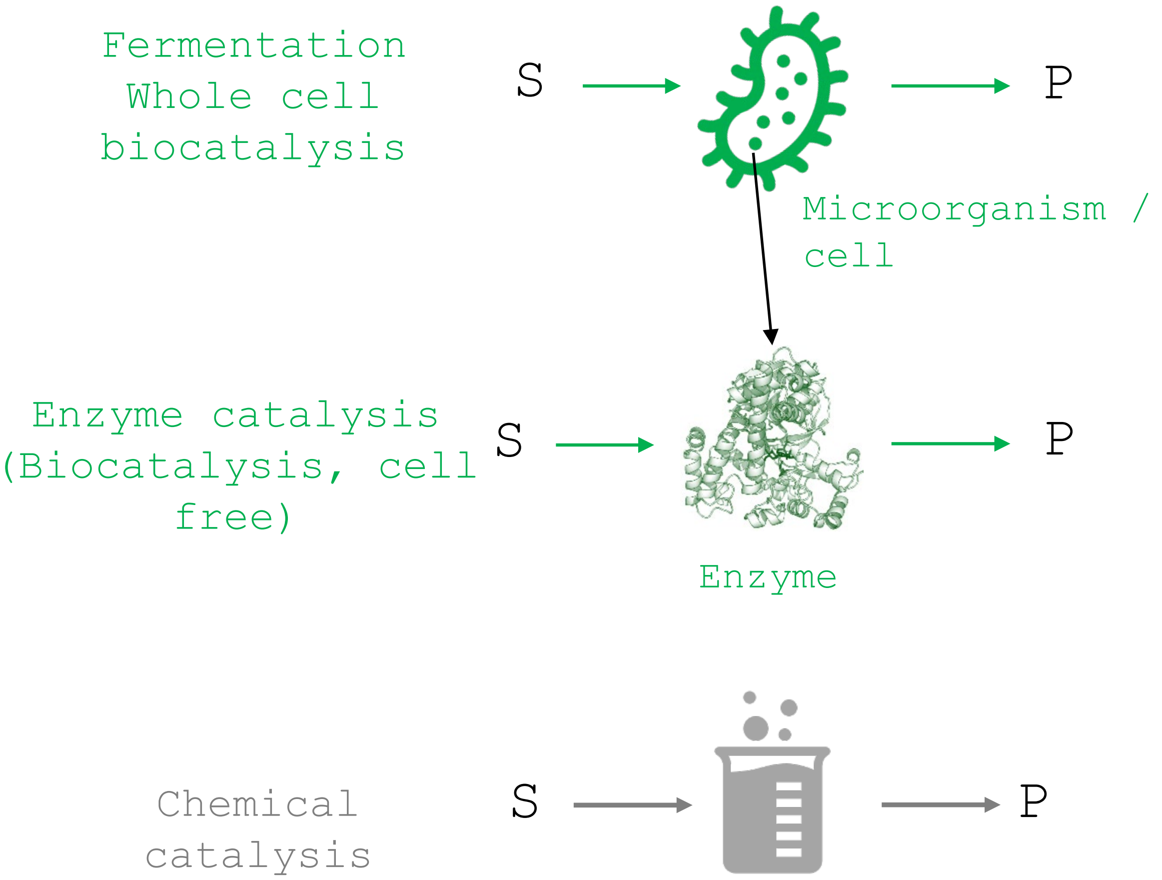
Where biotechnology can support defossilization of the chemical, polymer & energy sector



*Nova Institute, Report: Carbon Dioxide (CO_2) as Feedstock for Chemicals, Advanced Fuels, Polymers, Proteins and Minerals. April 2023

Advantages of Biotechnologies

Biocatalysts versus chemical catalysis (and electro-catalysis)



- Highly selective / specific for S and P
- Effective at low temperatures (20-40 °C, 45-95°C)
- Can catalyze complex reactions / molecules
- Renewable biocatalyst
- Handle mixed substrates / waste / impurities
- Does not need solvents, but can be used for S or P
- Microbial and enzymatic engineering (optimization, e.g., metabolic pathway, stability, novel S or P)

- Inhibition at high S and P concentration, high temp.
- Typically lower productivity (lower space time yields)
- Sensitive to organic solvents (alleviated by E. engineered)

Gas fermentation

Biotechnological conversion of CO2 into chemicals and (bio)polymers

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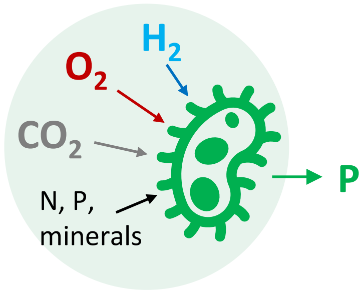
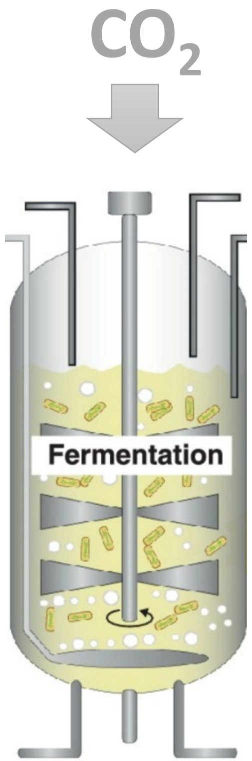
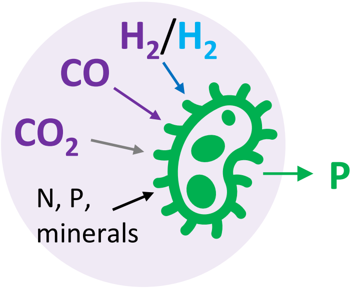
Two gas fermentation technologies

Knallgas fermentation (aerobic)

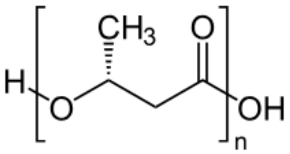
Syngas fermentation (anaerobic)

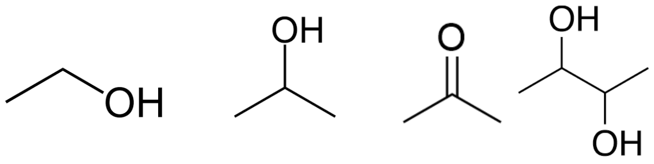


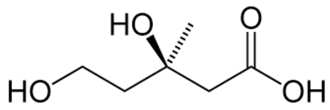


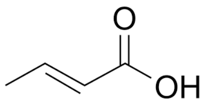


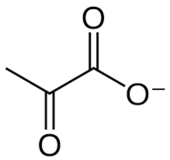
Platform chemicals and polymers as products
(examples)

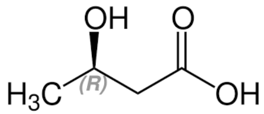

Polymers, e.g. PHB


Alcohols, ketones, aldehydes


Mevalonic acid


Crotonic acid

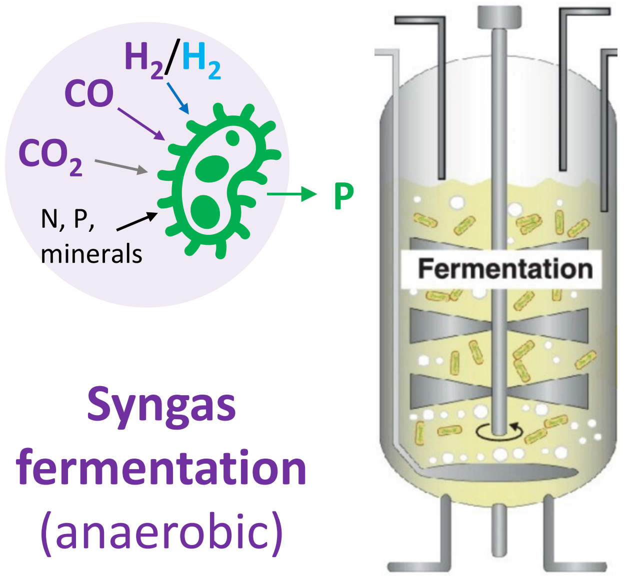

Pyruvate


3-hydroxybutyrate

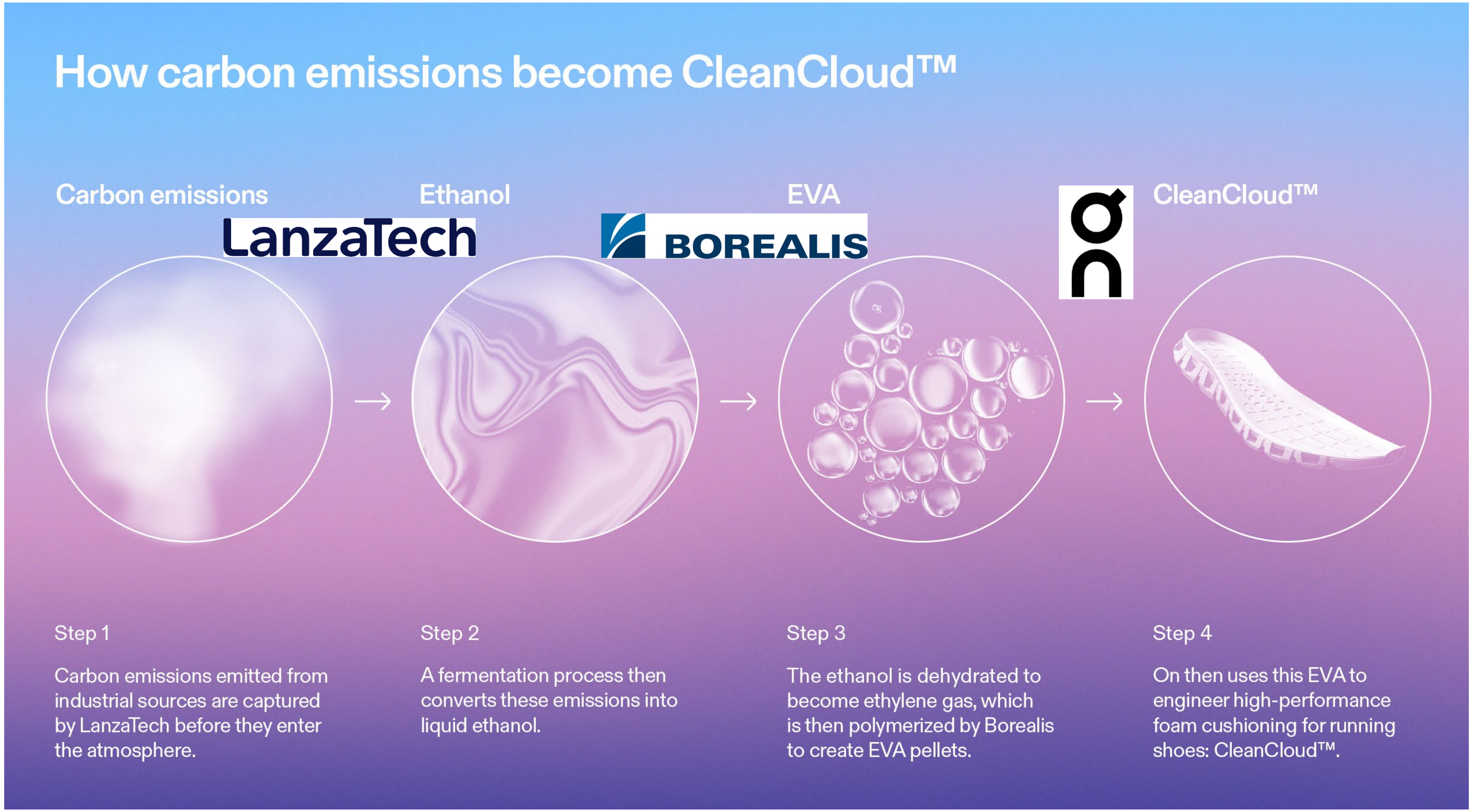
Ethylenevinyl acetate (EVA) from CO2

Biotechnology as CCU enabler coupled to chemical synthesis

LanzaTech

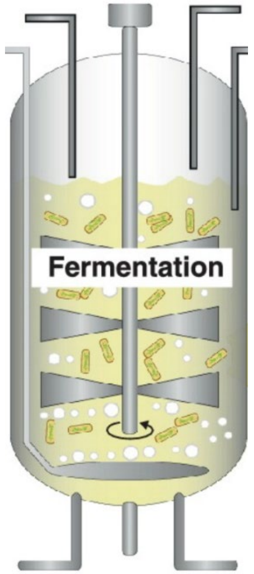


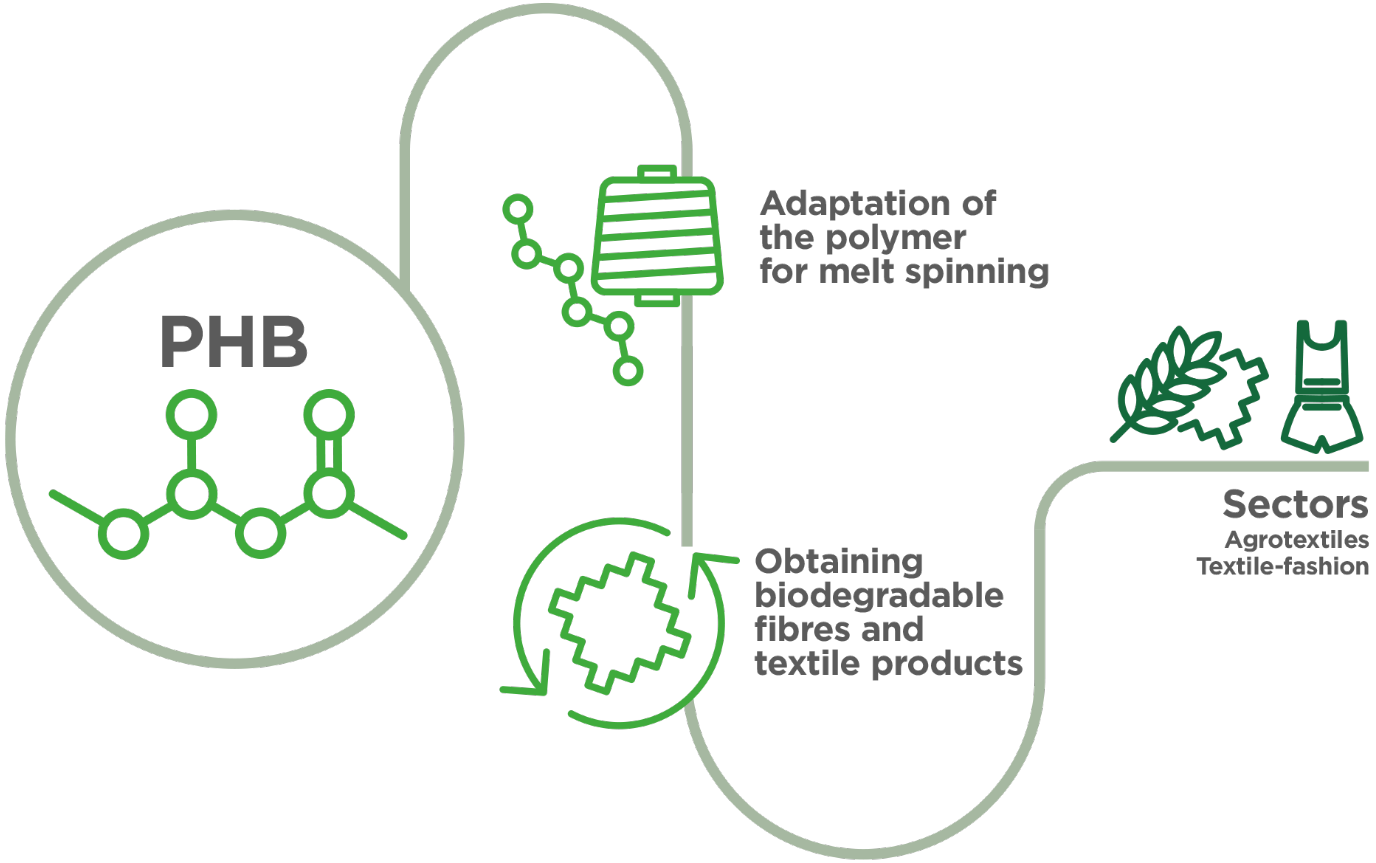
CO2-based ethanol
>100’000 tons/a



Biopolyester (PHB) from CO2 for textiles

Polyhydroxybutyrate (PHB) via Bio-CCU

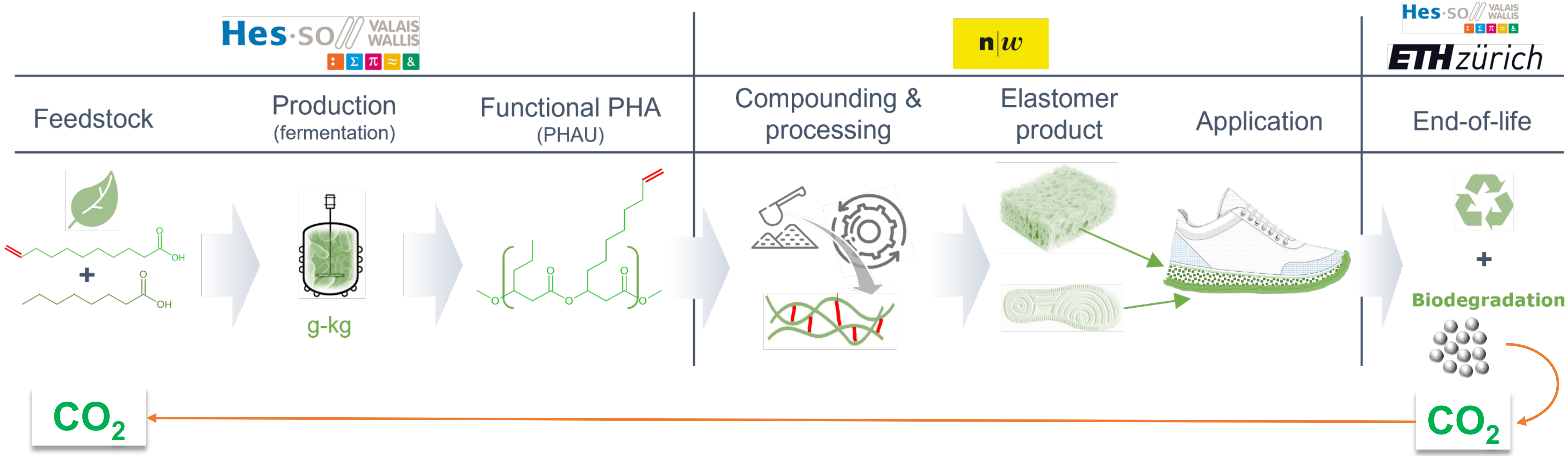




https://www.aitex.es/portfolio/phbtex-textile-production-from-biopolymers/?lang=en

Innovation project: BIO-PHAME

Functionalized PHA as life-cycle engineered elastomers



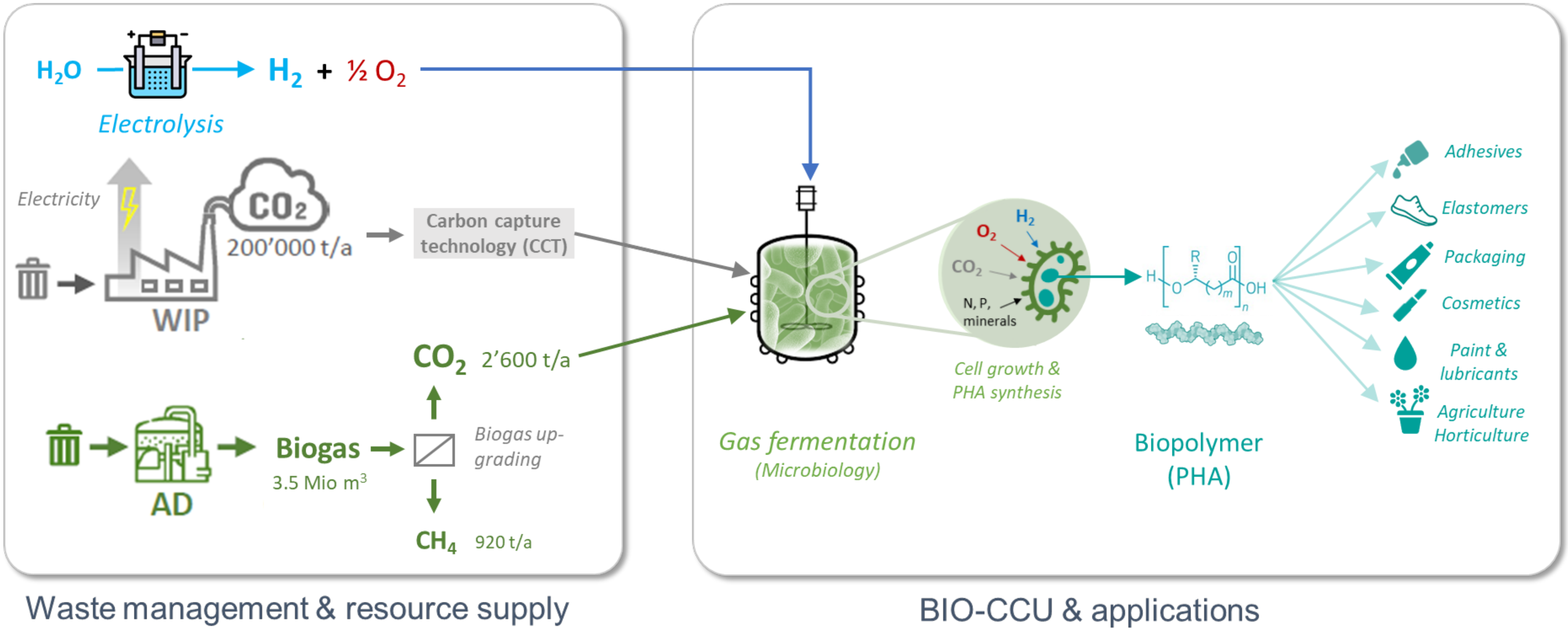
Using CO_2 as feedstock (CCU)

→ Carbon cycling

→ Temporary storage of CO_2 in the recycled product

Electro-microbial process for CO_2 –based biopolyester

Production of polyhydroxyalkanoates (PHAs)



Summary BIO-CCU

- Bio-CCU brings added-value:
  - CDR - carbon dioxide removal (CDR) technology for point sources and DAC
  - Production of (complex) platform chemicals and (bio)polymers
  - Hybrid systems of electro-chemical and biology for best performance
- Microorganisms: renewable, more robust than chemical catalysts (i.e., gas impurities)
- Further technology and infrastructure development needed across the value-chain
- All routs have carbon reduction potential (CDR) but also trade-offs
- Apply sustainability assessment (LCA) to identify best pathways

Unsere Schlussfolgerungen

- Biomasse keine unendliche Ressource
- Jeder Sektor sieht nur sich, keine Biomasse Strategie
- Recycling ist gut, aber Logistik, Energieverbrauch & Materialverlust
- Es reicht nicht auf bio-basierte Materialien umzusteigen oder zu rezyklieren
- Es muss ein breites Portfolio von Technologien entwickelt werden, um CO_2 zu verwerten - «Carbon Capture and Use (CCU)»
- Geschäftsmodelle und Konsum müssen neu gedacht werden: Weg von Verkauf von Masse hin zu Qualität/Langlebigkeit und zu neuen Dienstleistungen.

Diskussion

- Auf was achten Sie beim Einkauf?
- Wenden Sie diese Materialien schon an? Erfahrungen?
- Wie schätzen Sie die Rolle der CO_2- und biobasierten Polymere in Zukunft ein?