2nd International Conference on
Carbon Chemistry and Materials
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CARBON CAPTURE AND UTILIZATION TOWARDS A FUTURE SUSTAINABLE EUROPE

Techno-economic and environmental assessment of CCU options

Sandra Adelung, Ralph-Uwe Dietrich Felix Habermeyer, Nathanael Heimann, Simon Maier, Francisco Moser, Moritz Raab, Yoga Rahmat, Julia Weyand,

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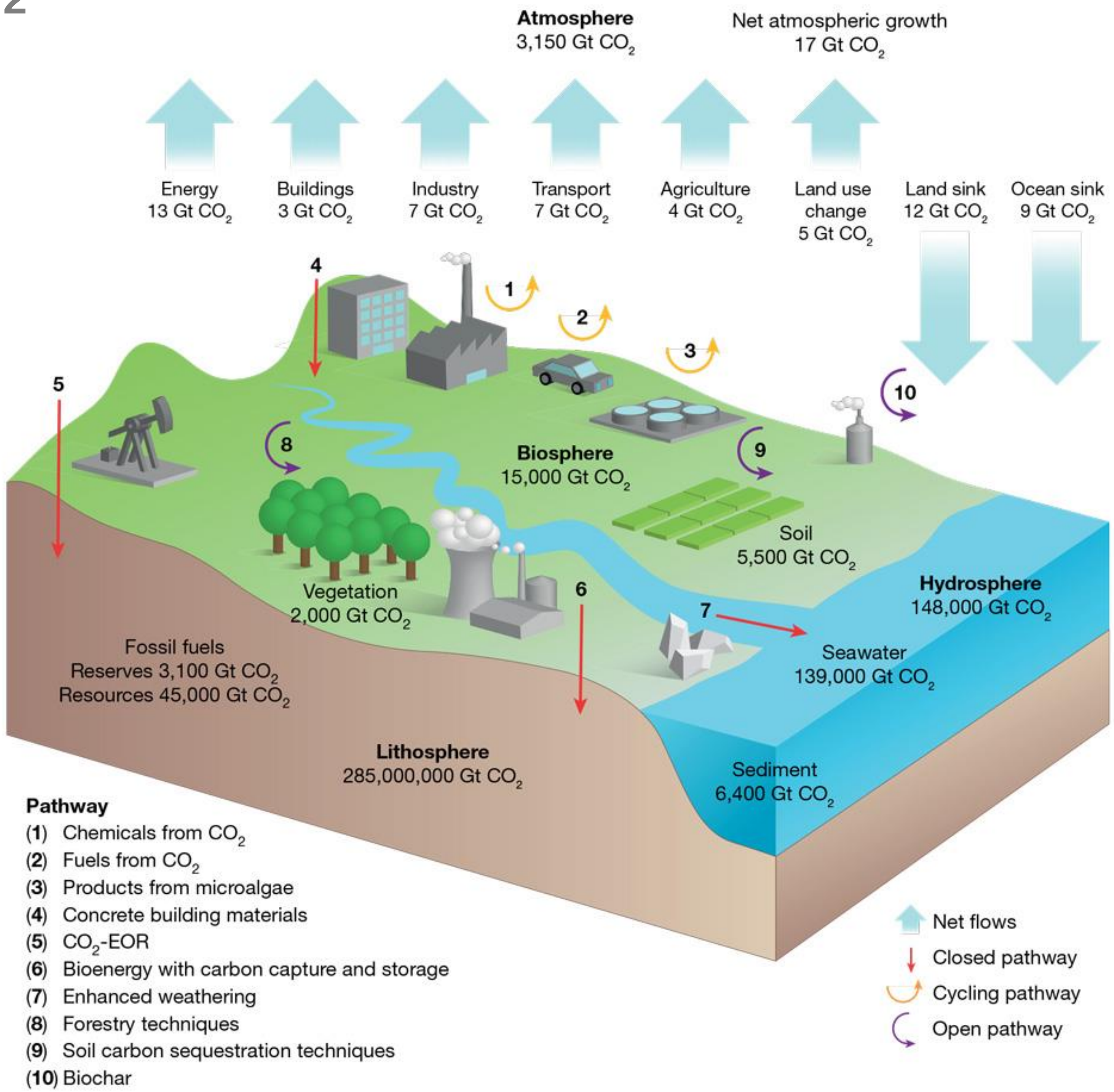
Pathways of CO_2 utilization[1]



[1] www.carbonbrief.org/guest-post-10-ways-to-use-co2-and-how-they-compare/[

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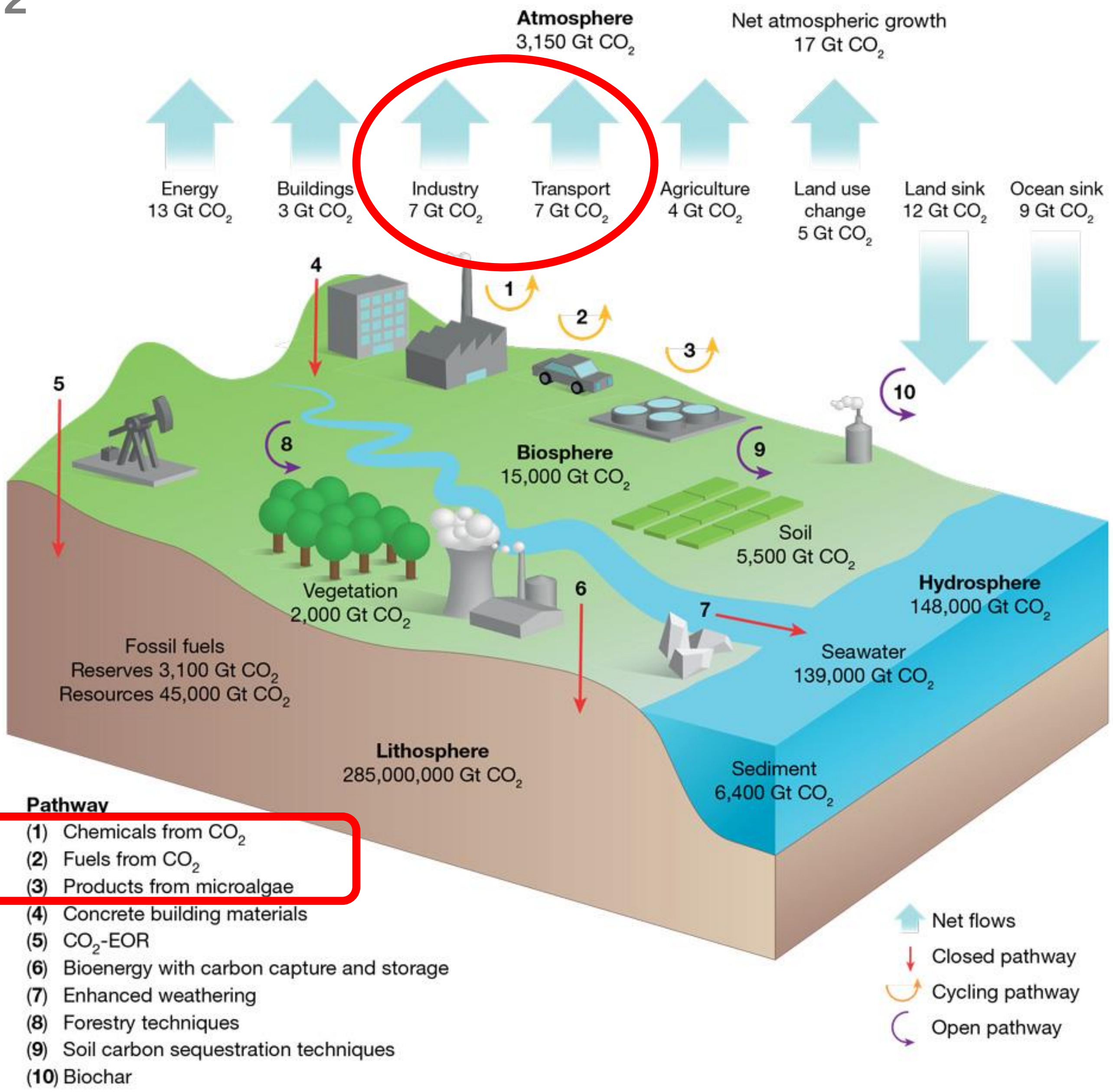

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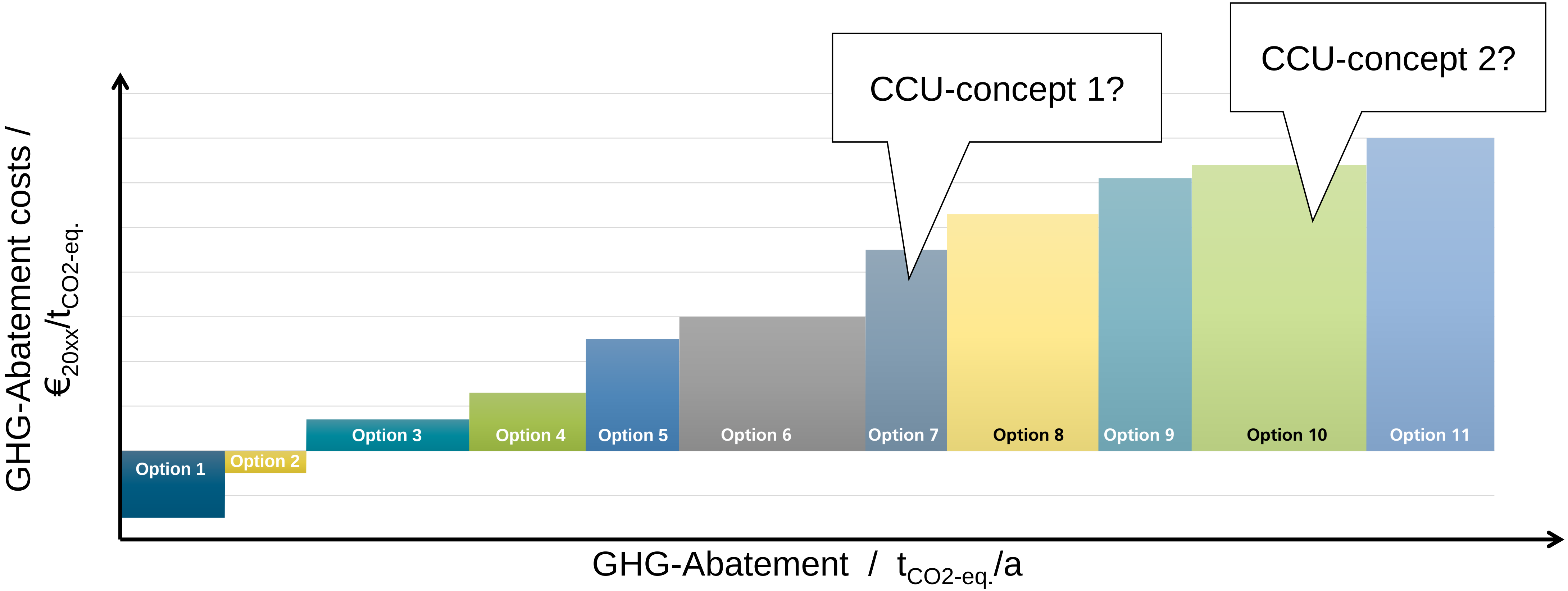
Assessment of CCU concepts

Merit-Order of GHG reduction technologies



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Assessment of CCU concepts
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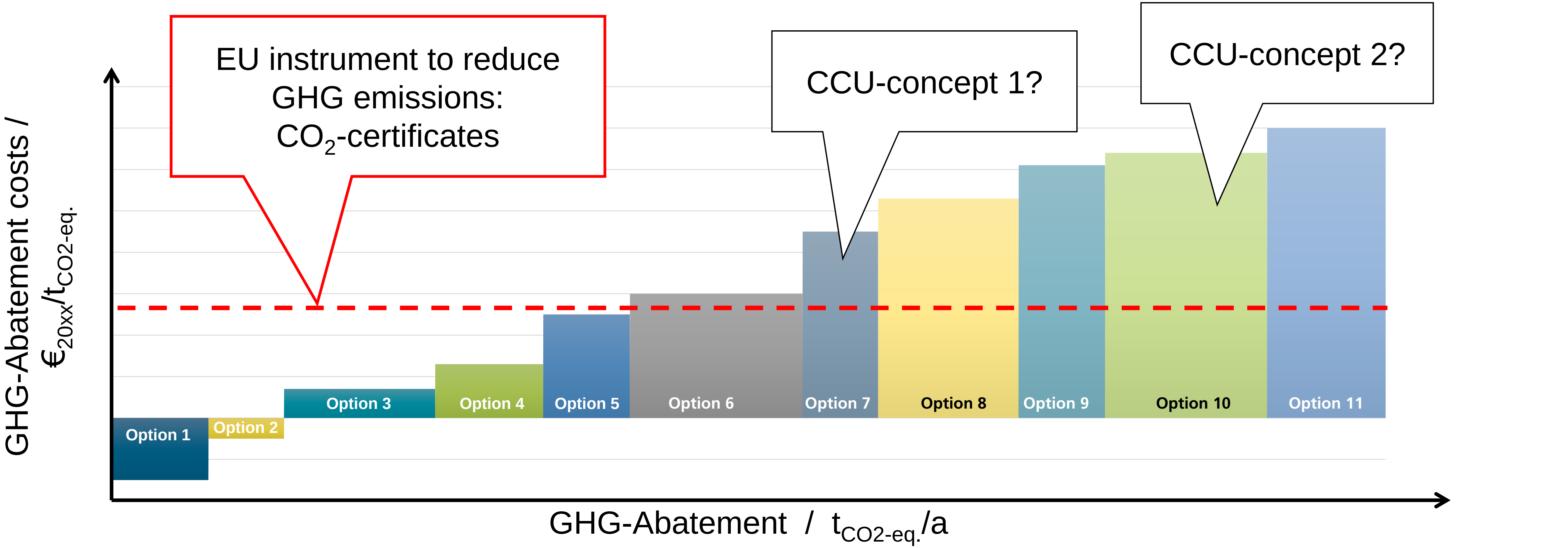

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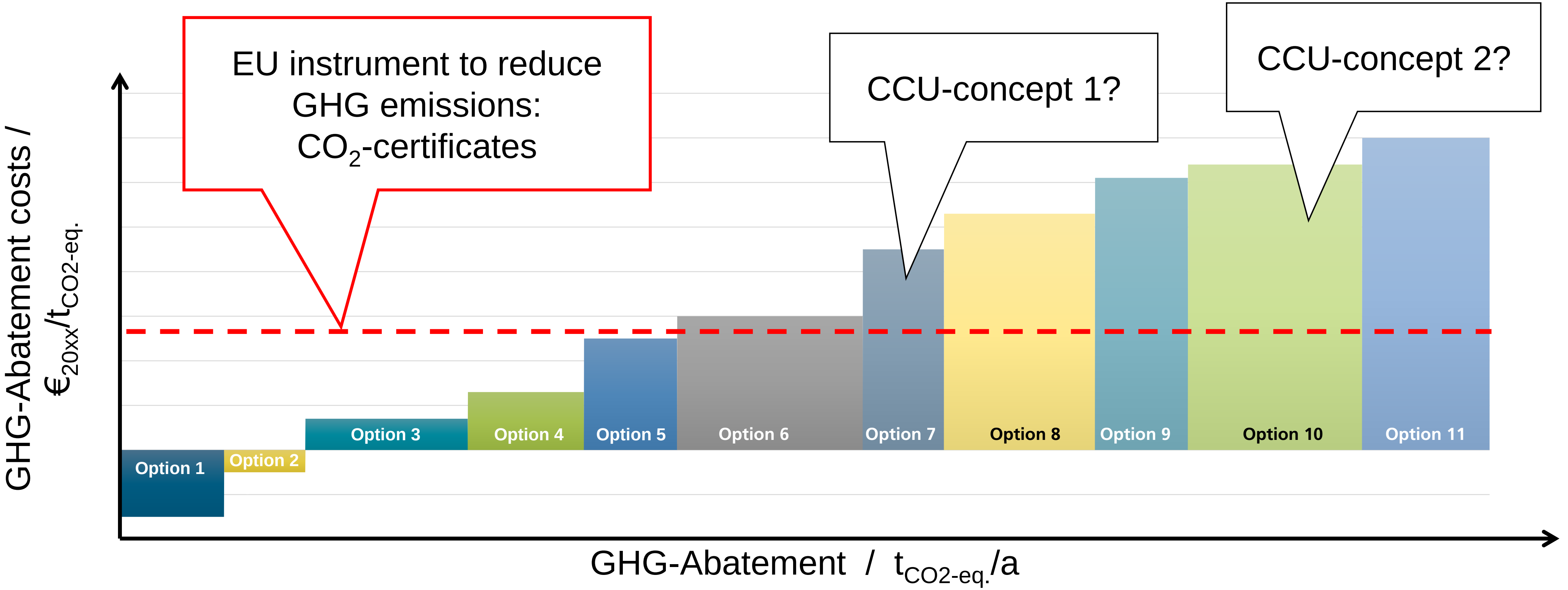

Goal: Maximal CO_2 reduction @ minimized GHG-Abatement cost, either by reducing GHG footprint or costs!

→ Standardized methodology for LCA and TEA

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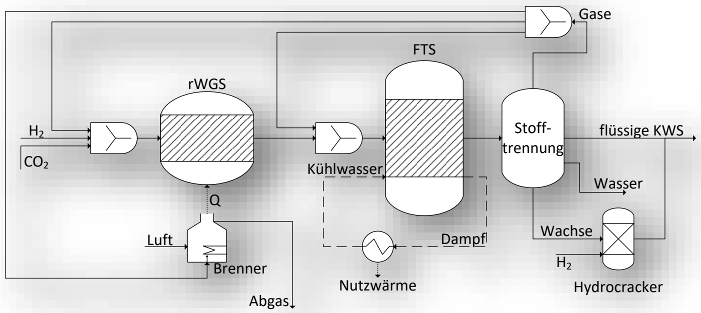
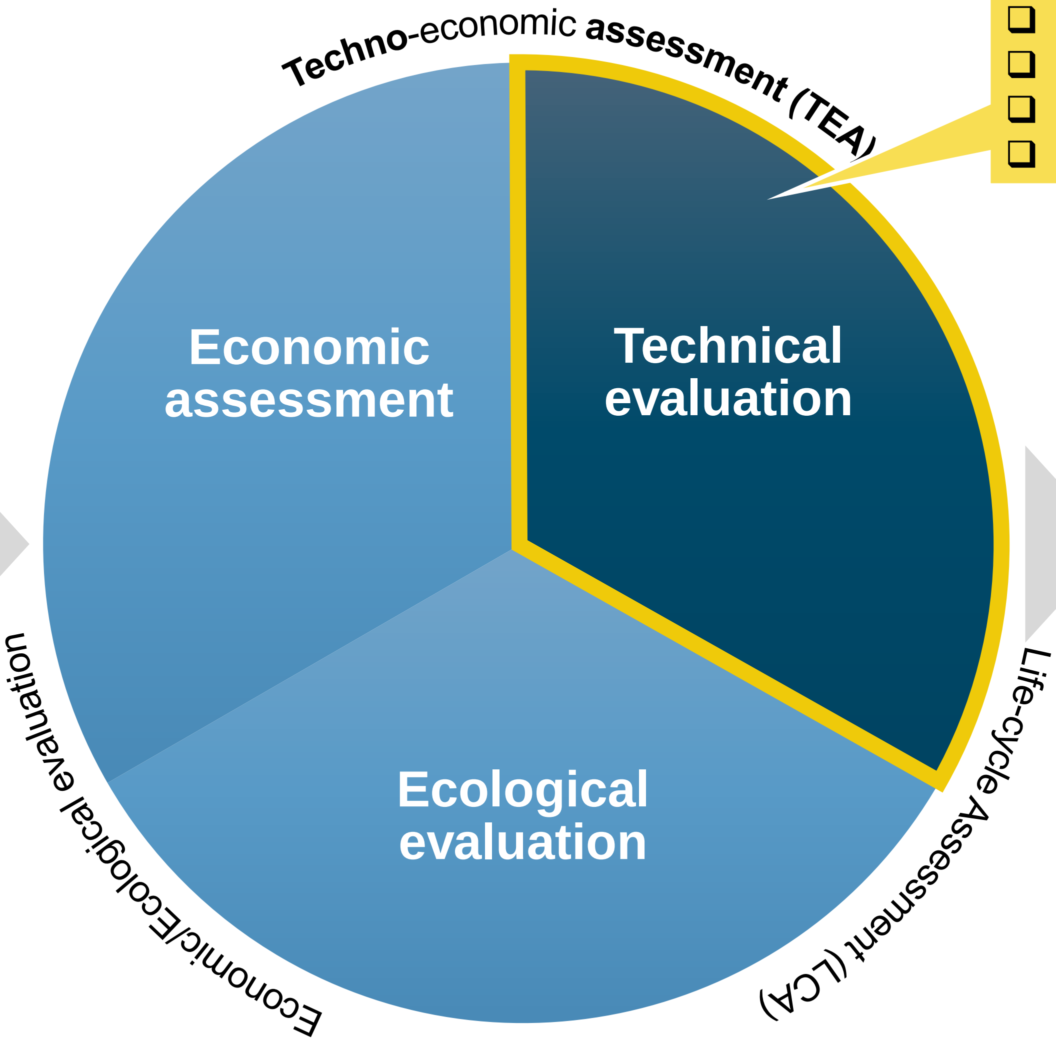
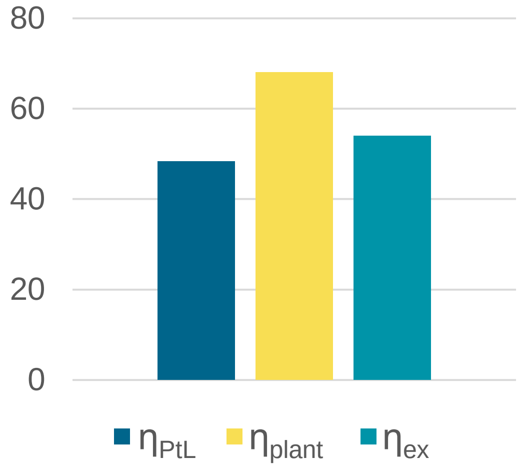
Techno-Economic and ecological assessment (TEEA)





- ❑ Efficiencies (X-to-Liquid, Overall)
- ❑ Carbon conversion
- ❑ Specific feedstock demand
- ❑ Exergy analysis



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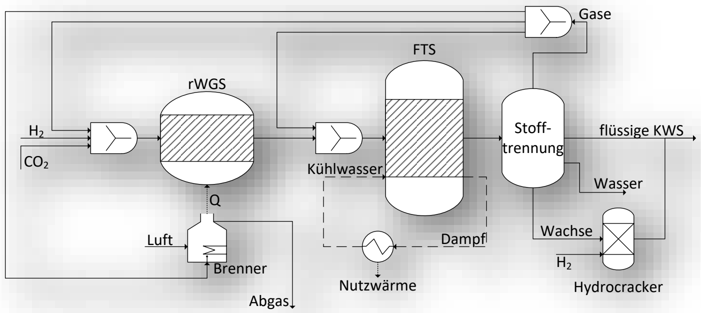

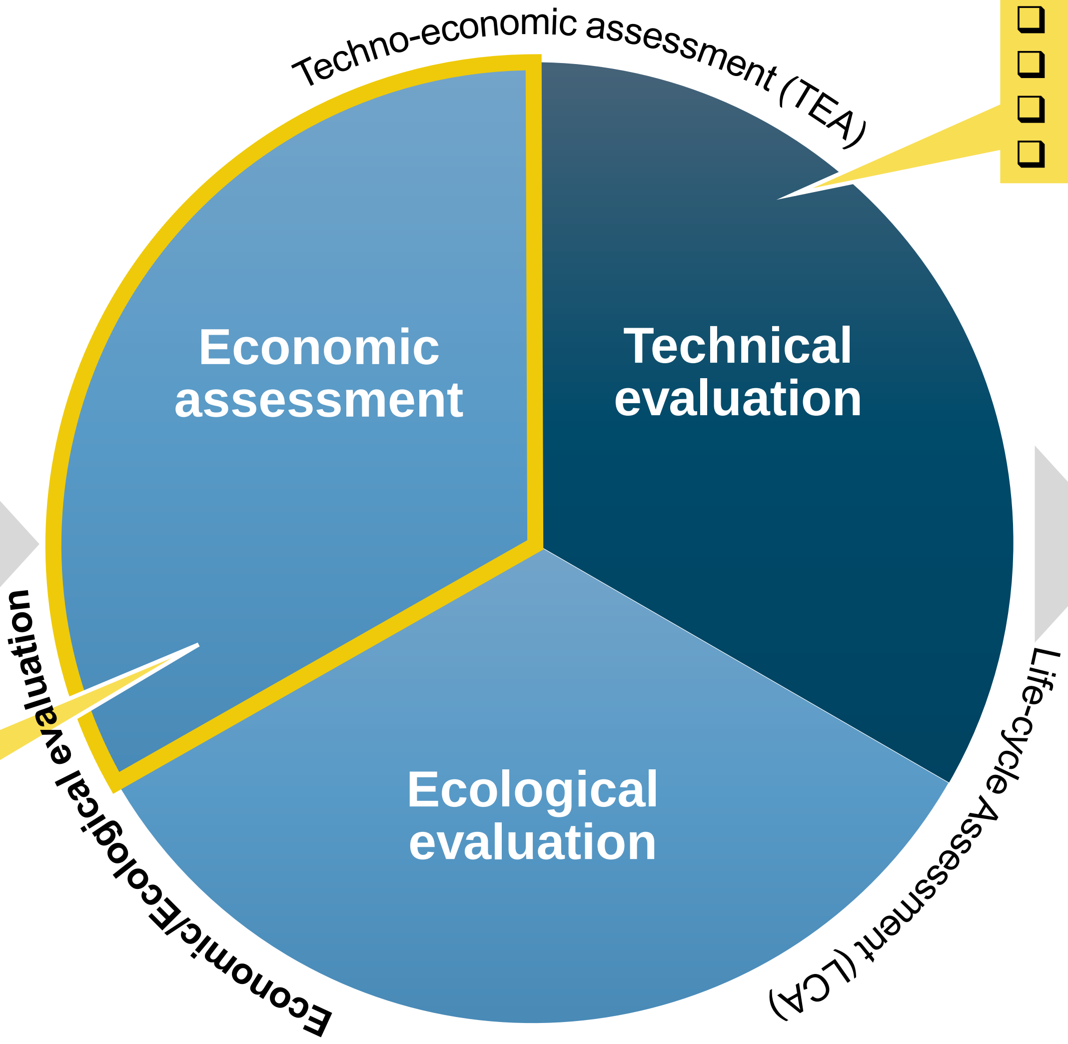

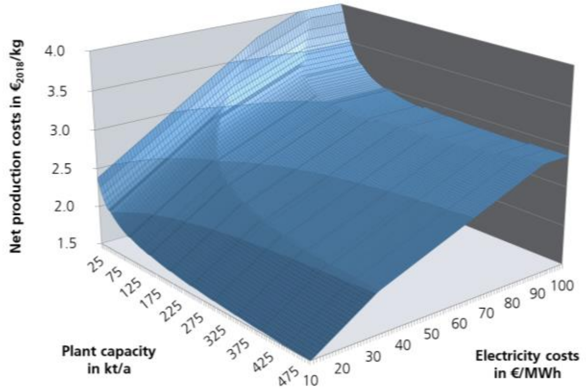

- ❑ CAPEX, OPEX, NPC
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- ❑ Identification of most economic feasible process design

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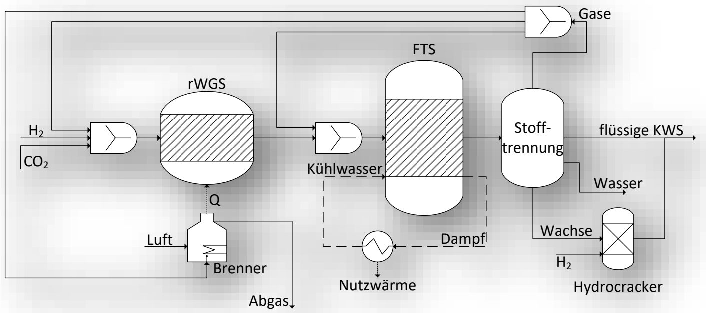

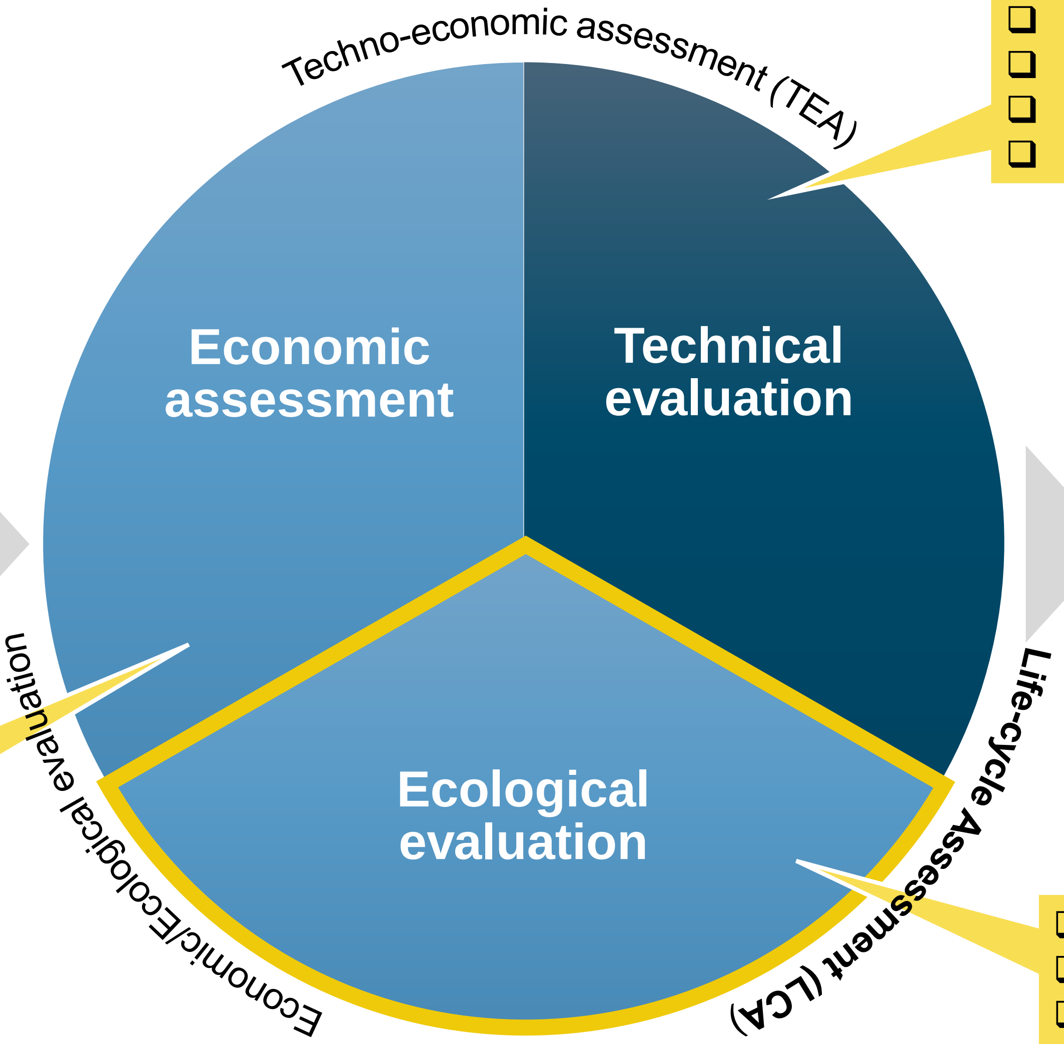

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- ❑ GWP
- ❑ Other impact categories
- ❑ Identification of impact drivers

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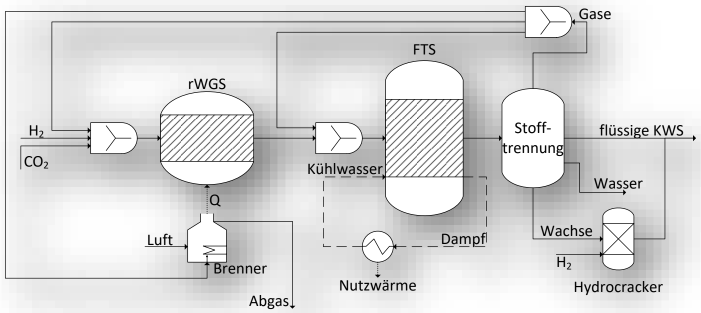

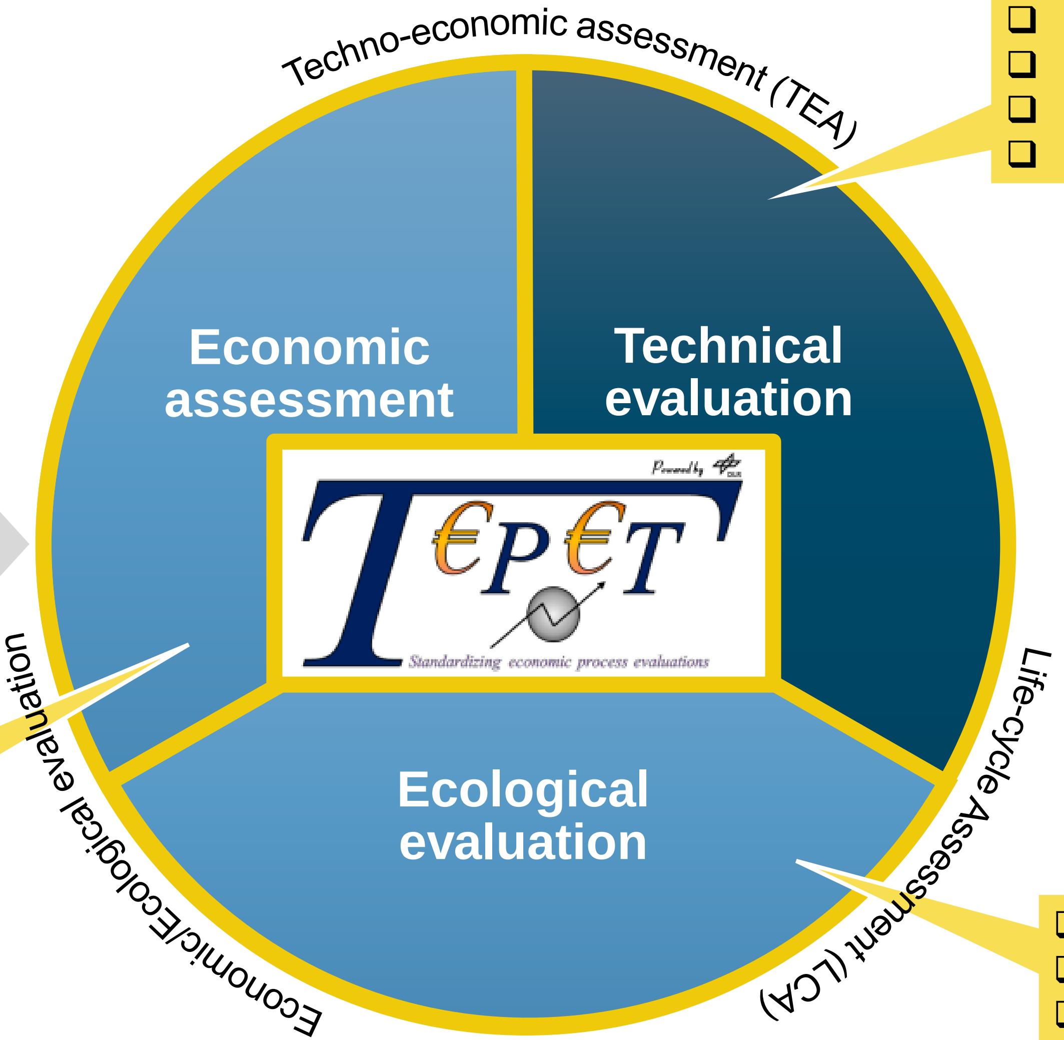

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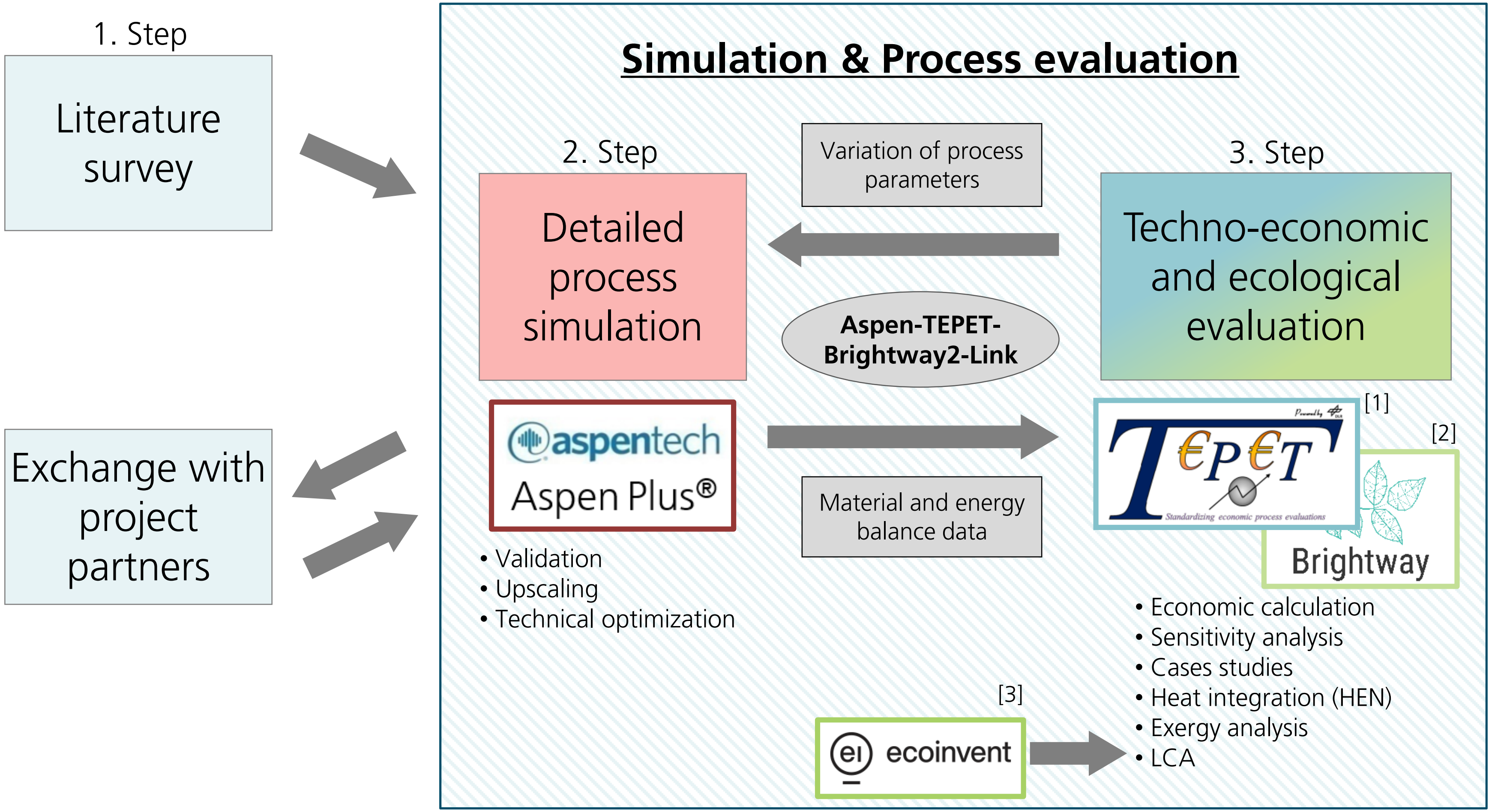
Techno-Economic and ecological assessment (TEEA) @DLR



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[2] Mutel (2017) - Brightway: An open source framework for Life Cycle Assessment, Journal of Open Source Software, 2(12): 236
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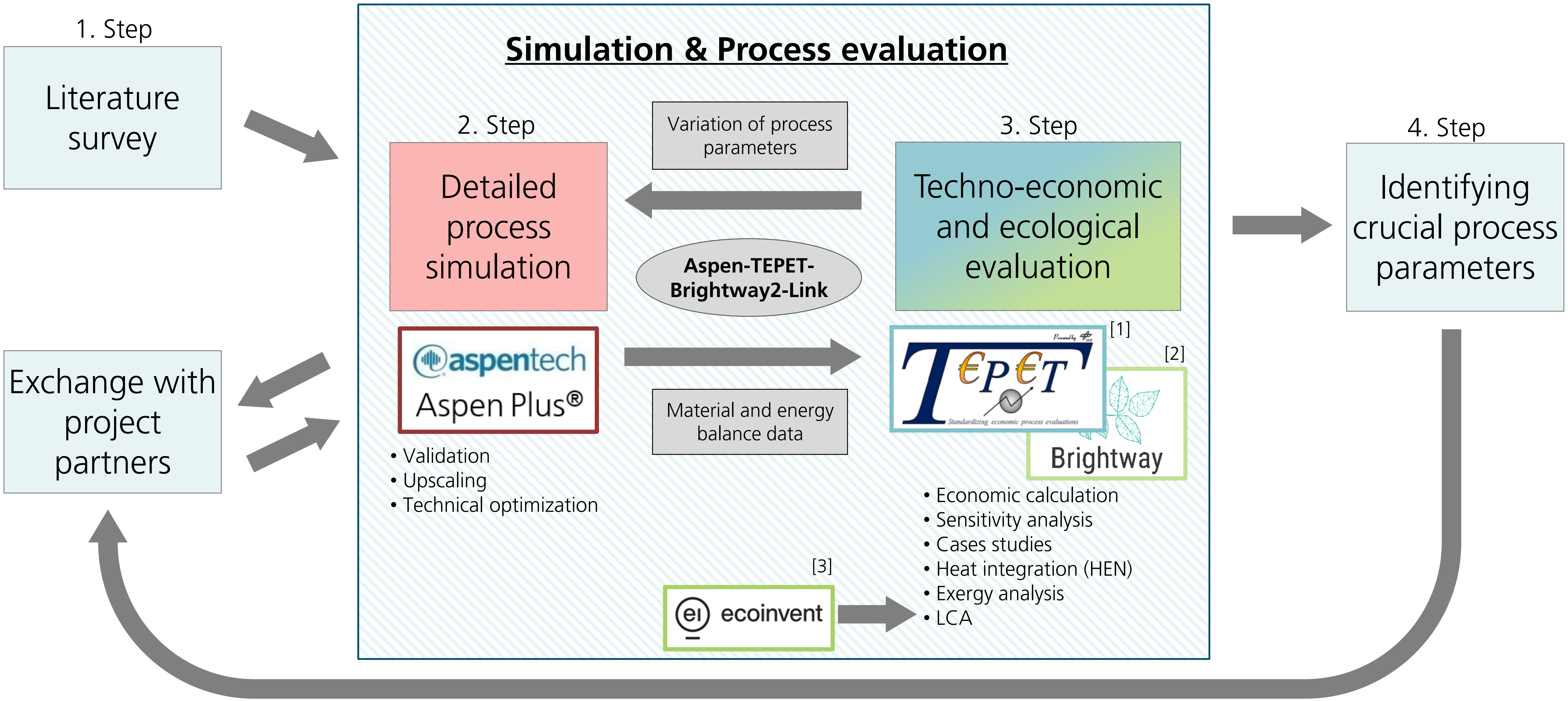
Techno-Economic and ecological assessment (TEEA) @DLR



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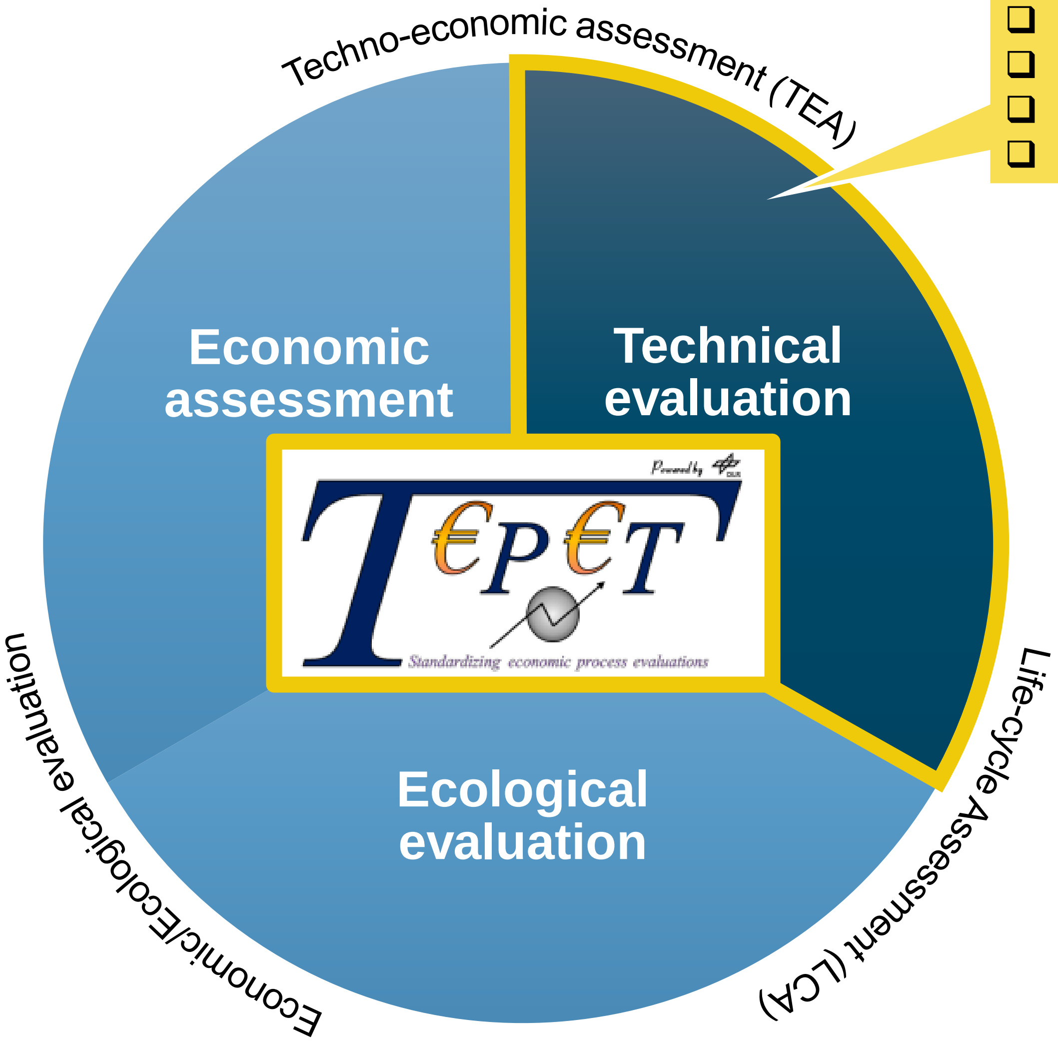

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Example: Evaluation of biofuels production
COMSYN BtL process concept

DFB Pilot plant / VTT

Mobile synthesis unit / INERATEC

5 m³/h SLIP-STREAM TO SYNTHESIS

Straw → DFB gasifier → Filter → Reformer → Ultracleaning steps → Fischer-Tropsch synthesis →

Bark

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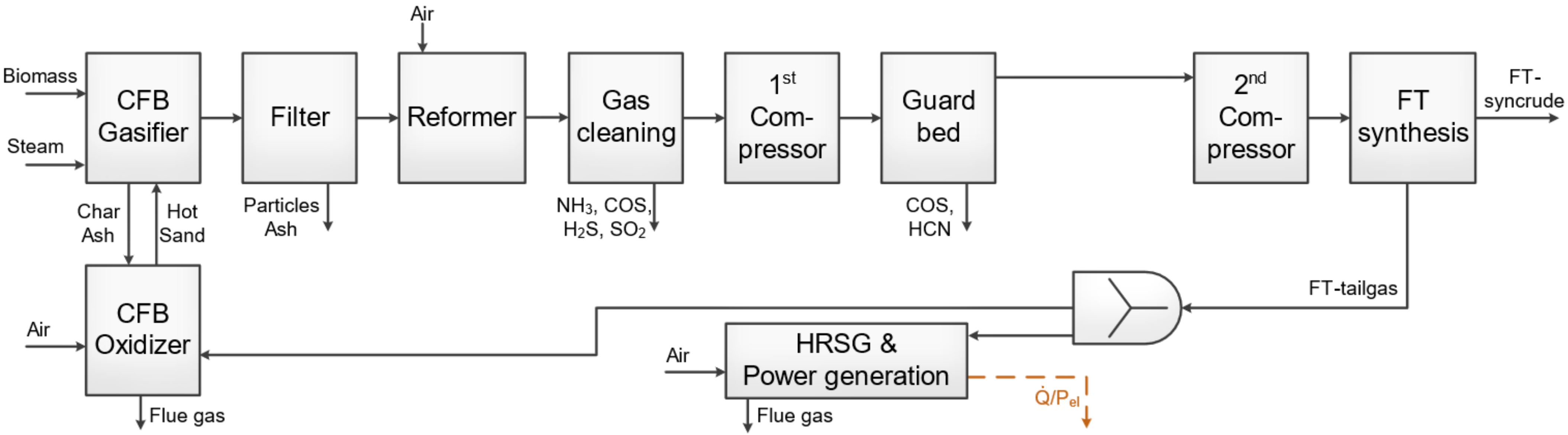
Example: Evaluation of biofuels production
COMSYN BtL process options [1]



Case 1

- Base case
- Autothermal reforming with air

[1] Maier et al., Techno-economically-driven identification of ideal plant configurations for a new biomass-to-liquid process – A case study for Central-Europe, 2021.

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Example: Evaluation of biofuels production

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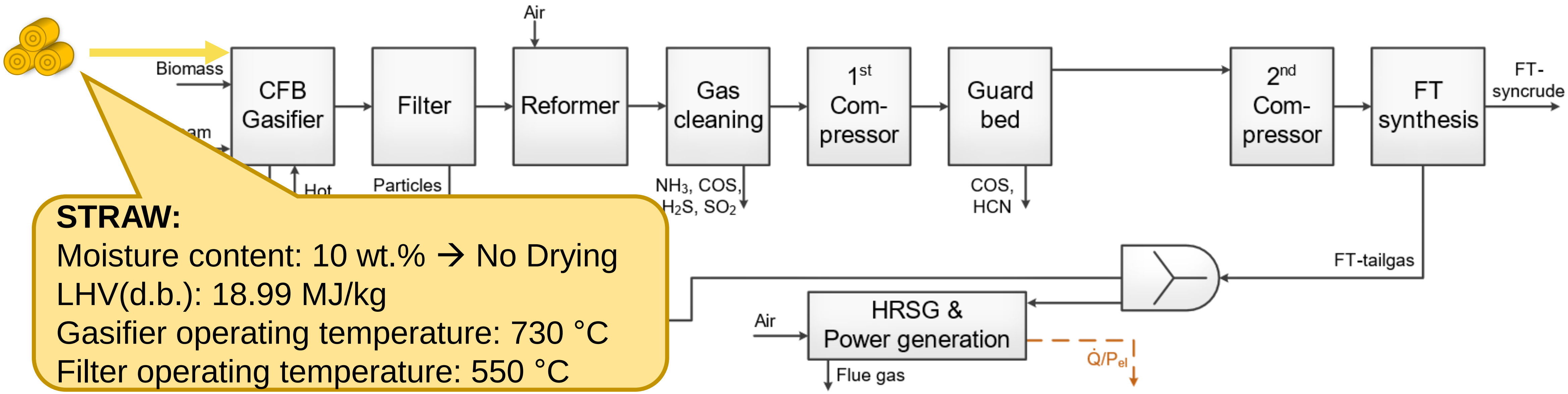

STRAW:
Moisture content: 10 wt.% → No Drying
LHV(d.b.): 18.99 MJ/kg
Gasifier operating temperature: 730 °C
Filter operating temperature: 550 °C

Case 1

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- Autothermal reforming with air

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Example: Evaluation of biofuels production

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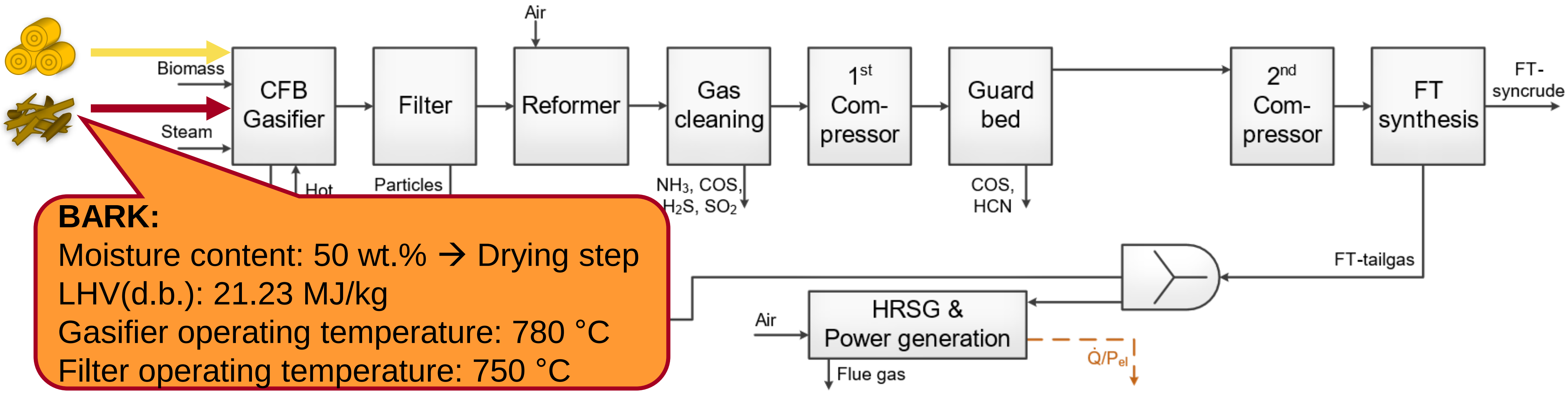

BARK:
Moisture content: 50 wt.% → Drying step
LHV(d.b.): 21.23 MJ/kg
Gasifier operating temperature: 780 °C
Filter operating temperature: 750 °C

Case 1

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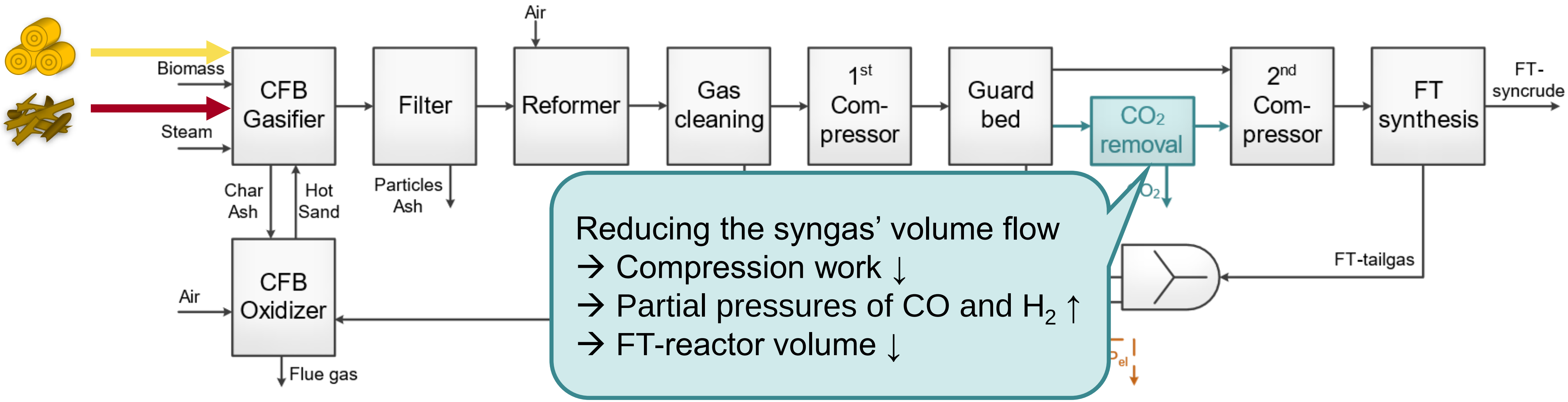

Case 1	Case 2
• Base case • Autothermal reforming with air	• Autothermal reforming with air • **CO_2 removal** after guard bed ➢ Operating at 5 bar ➢ 80 % CO_2 is removed

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Example: Evaluation of biofuels production

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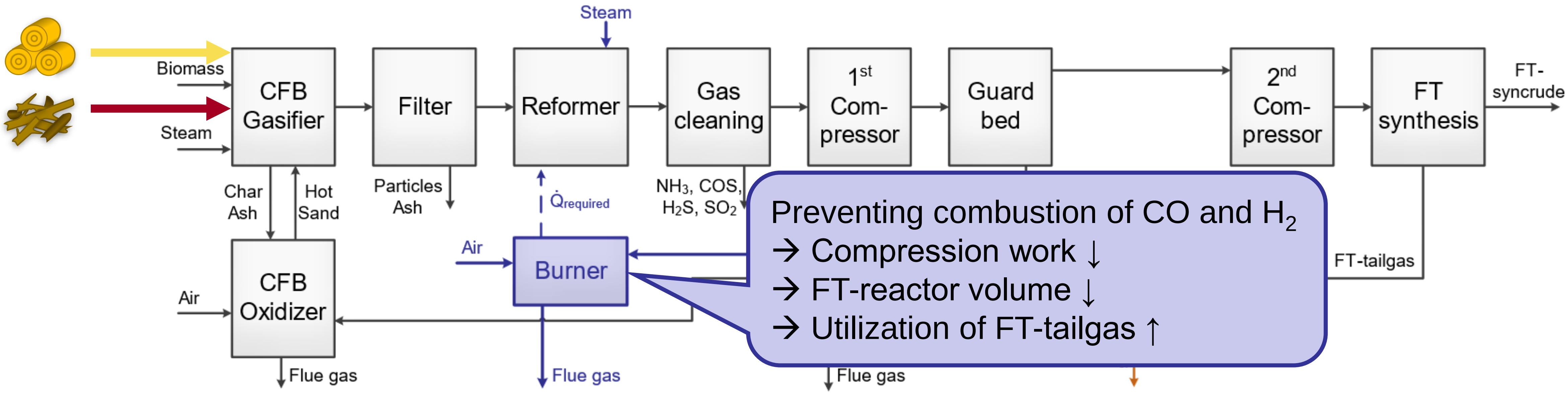

Case 1	Case 2	Case 3
• Base case • Autothermal reforming with air	• Autothermal reforming with air • **CO_2 removal** after guard bed ➢ Operating at 5 bar ➢ 80 % CO_2 is removed	• **Allothermal** steam reforming ➢ Required heat is provided by an additional burner ➢ Steam is led into the reformer

[1] Maier et al., Techno-economically-driven identification of ideal plant configurations for a new biomass-to-liquid process – A case study for Central-Europe, 2021.

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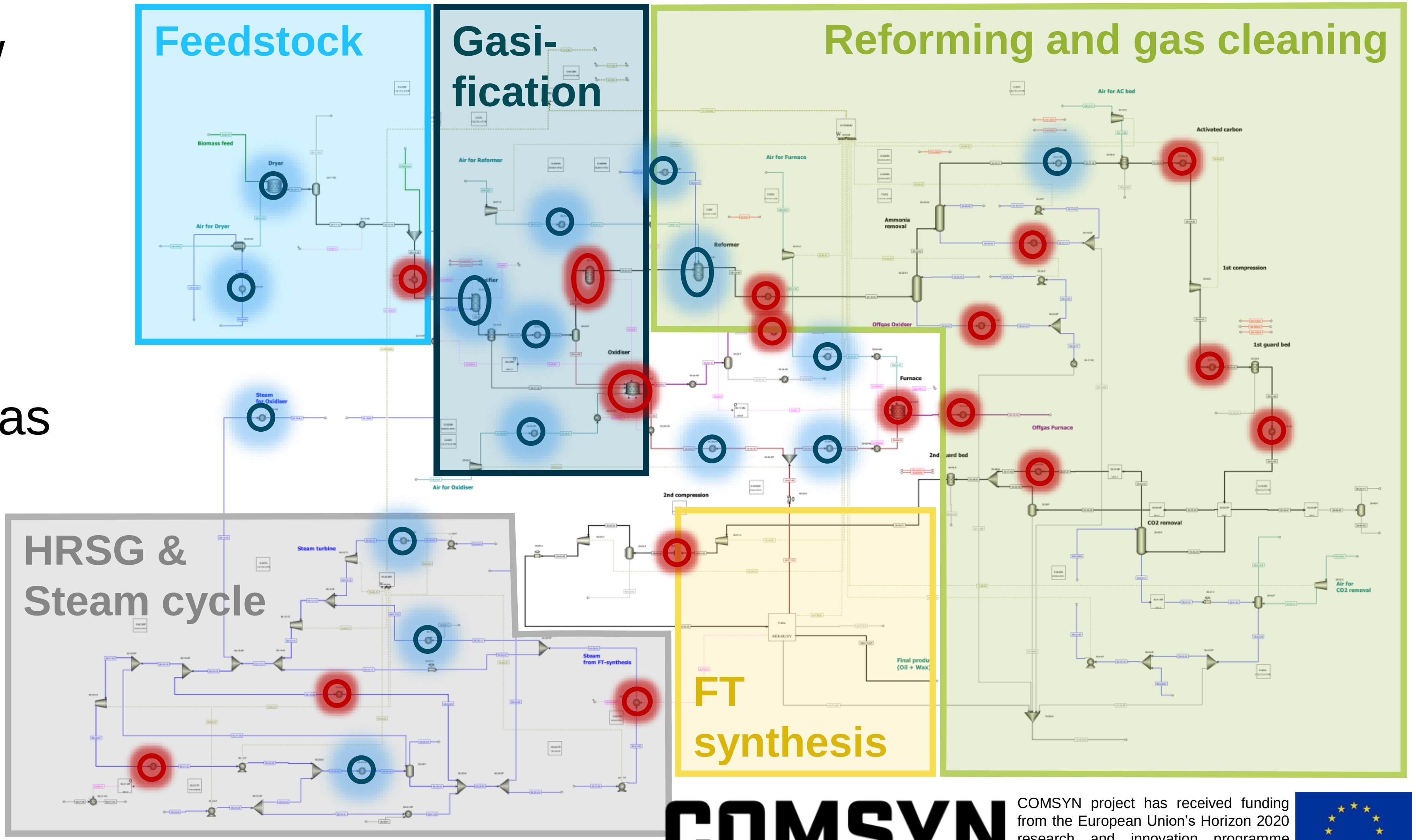
Example: Evaluation of biofuels production
COMSYN BtL process simulation

- Validated process flow diagram
  - Reaction kinetic
  - Unit performance
  - Pressure drop
  - Optimal heat integration
- Additional process ideas
  - Steam cycle integration



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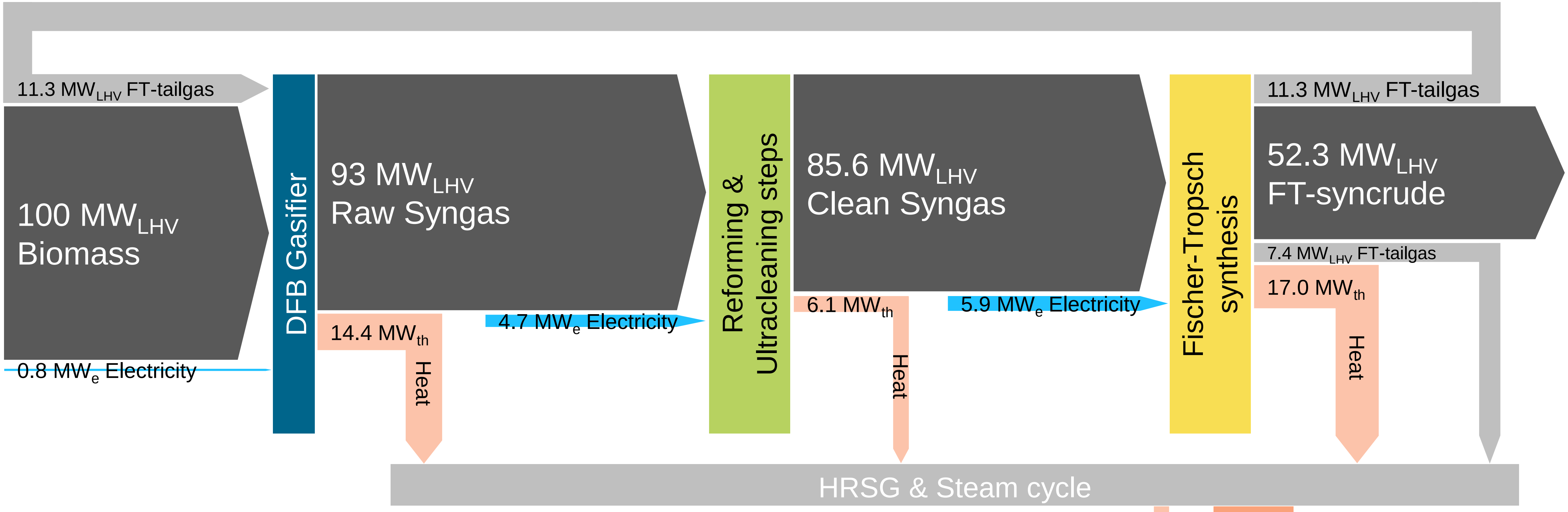
Example results: Evaluation of biofuels production

COMSYN BtL process energy flows



Biomass input	MW_{LHV}	100
Electricity demand	MW_e	11.4
Steam + Distr. heating	MW_{th}	37.5

BtL efficiency	**46.1 %**
Energetic efficiency	**81.7 %**

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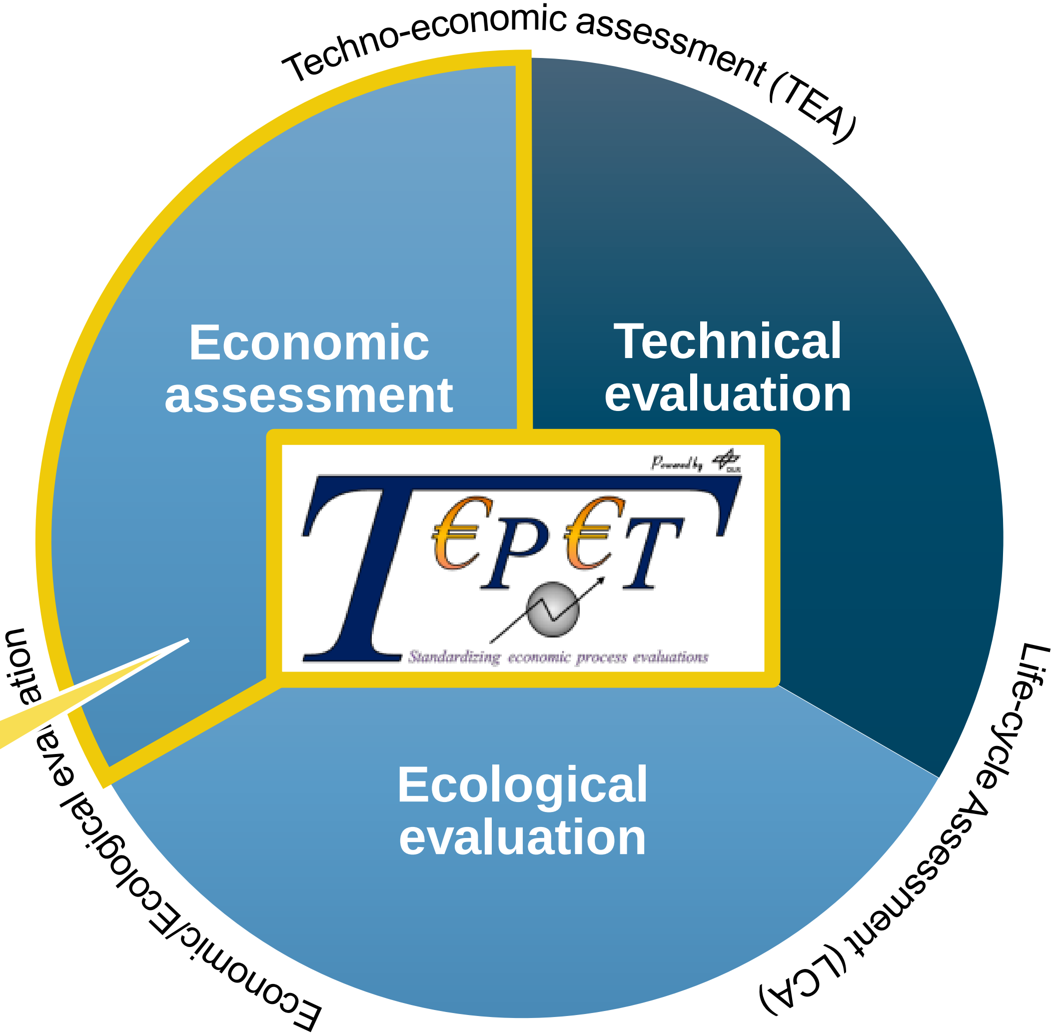
Techno-Economic and ecological assessment (TEEA)



- CAPEX, OPEX, NPC
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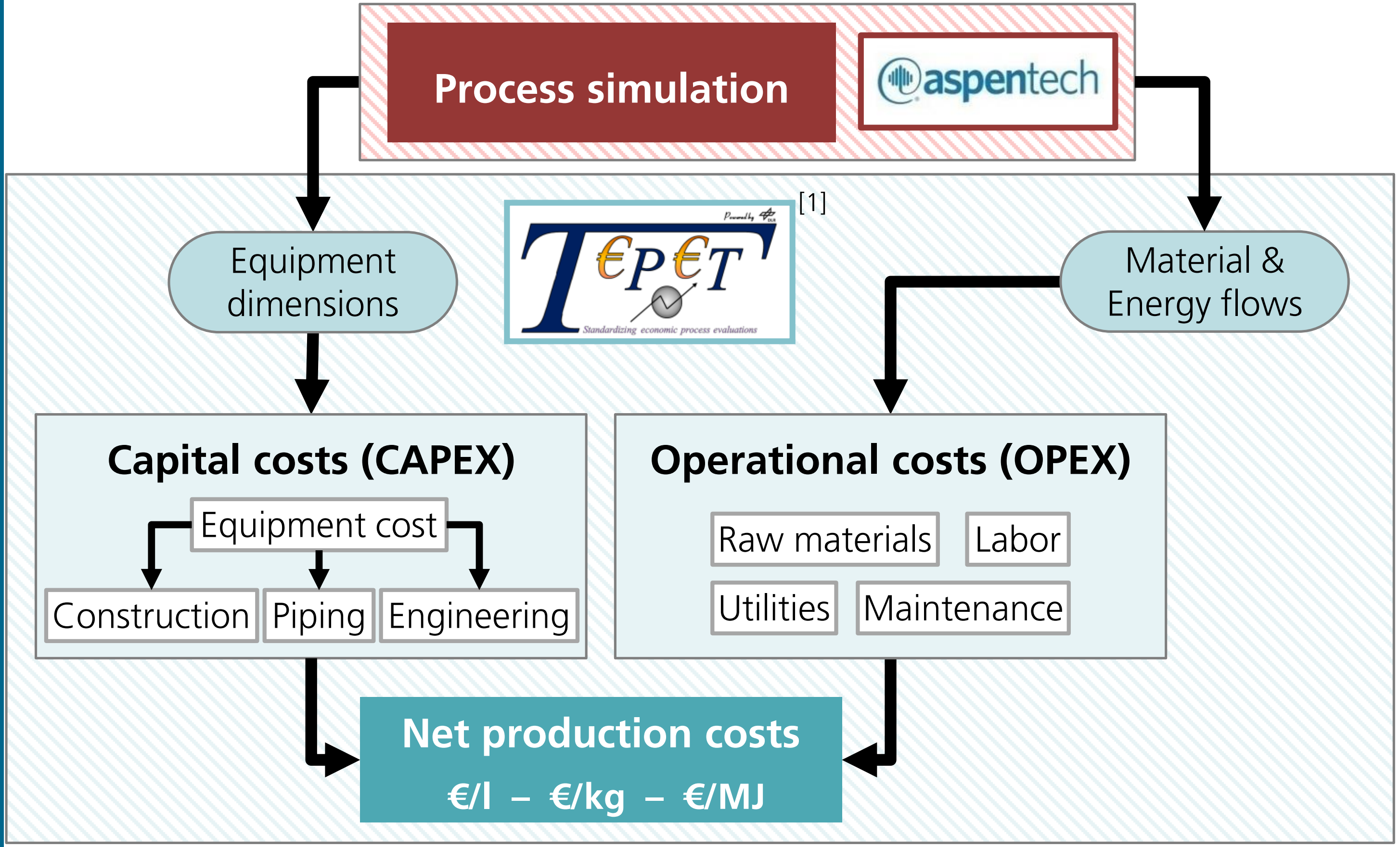
TEEA tool TEPET @ DLR (part 1)



- Adapted from **best-practice chem. eng. methodology**
- Meets AACE class 3-4, Accuracy: **+/- 30 %**
- **Year specific** using annual CEPCI Index
- Automated interface for **seamless integration, heating networks, …**
- Easy sensitivity studies for **each** parameter
- Learning curves, economy of scale, …

[1] Albrecht et al. (2016) - A standardized methodology for the techno-economic evaluation of alternative fuels – A case study, Fuel, 194: 511-526

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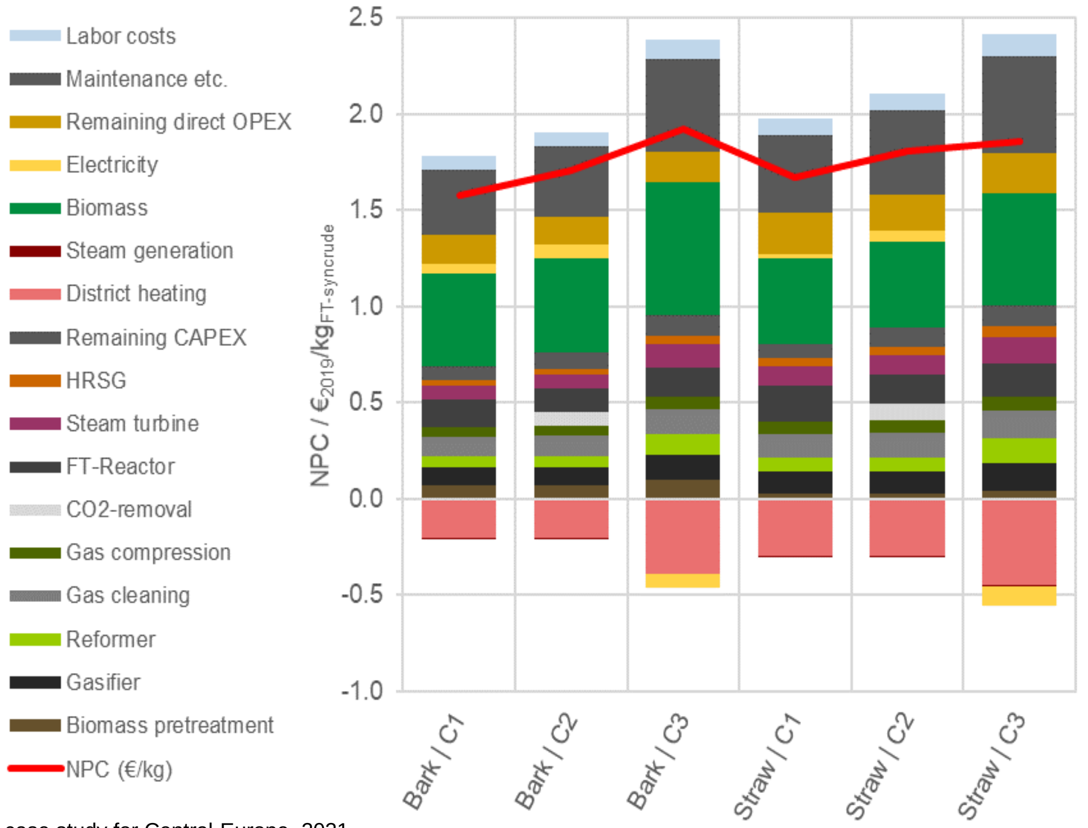
Example results: Economic evaluation of BtL production[1]

COMSYN boundary conditions and assumptions

General assumptions			
Base year	-	2019	
Max. plant size ($C_{plant,max}$)	MW_{th}	200	
Interest rate (IR)	%	10	
Full load hours (flh)	h/a	8260	
Plant lifetime (PL)	a	20	
Site-specific costs		**DE**	**Ref.**
Electricity costs/revenue (c_{EL})	€/MWh	92.8	[2]
Natural gas price (r_{Gas})	€/GJ	6.2	[3]
Biomass costs (bark) ($c_{Bio,b}$)	€/GJ	5.8	[4]
Biomass costs (straw) ($c_{Bio,s}$)	€/GJ	4.5	[4]
Biomass transport costs (c_{TrBio})	€/km/t	0.45	[4]
District heating revenue (r_{DH})	€/MWh	31.7	[6]
Process steam revenue (r_{PS})	€/MWh	33.7	[6]
Labor costs (c_L)	€/h	30.9	[5]



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[3] OECD. *Crude oil import prices (indicator)*. 2021 08 January 2021.
[4] Pablo Ruiz, A.S., Wouter Nijs,, et al., *The JRC-EU-TIMES model. Bioenergy potentials for EU and neighbouring countries*. 2015. p. 176.
[5] Commission, E., *Labour cost, wages and salaries, direct remuneration (excluding apprentices) by NACE Rev. 2 activity) - LCS surveys 2008, 2012 and 2016*. 2021.
[6] Ulrich, G.D. and P.T. Vasudevan, *How To Estimate Utility Costs.* Engineering Practice, 2006.

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Example results: Economic evaluation of BtL production[1]

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Max. plant size ($C_{plant,max}$)	MW_{th}	200						
Interest rate (IR)	%	10						
Full load hours (flh)	h/a	8260						
Plant lifetime (PL)	a	20						
Site-specific costs		**DE**	**Ref.**	**AT**	**CZ**	**HU**	**PL**	**SK**
Electricity costs/revenue (c_{EL})	€/MWh	92.8	[2]	78.4	70.5	79.6	76.3	98.9
Natural gas price (r_{Gas})	€/GJ	6.2	[3]	6.9	6.9	6.4	6.3	7.0
Biomass costs (bark) ($c_{Bio,b}$)	€/GJ	5.8	[4]	5.6	5.4	2.6	3.3	2.8
Biomass costs (straw) ($c_{Bio,s}$)	€/GJ	4.5	[4]	6.9	4.5	3.7	2.9	4.9
Biomass transport costs (c_{TrBio})	€/km/t	0.45	[4]	0.45	0.29	0.24	0.27	0.27
District heating revenue (r_{DH})	€/MWh	31.7	[6]	37.0	33.8	27.2	27.7	29.4
Process steam revenue (r_{PS})	€/MWh	33.7	[6]	39.3	35.9	28.9	29.5	31.3
Labor costs (c_L)	€/h	30.9	[5]	27.2	7.5	6.4	6.8	7.8

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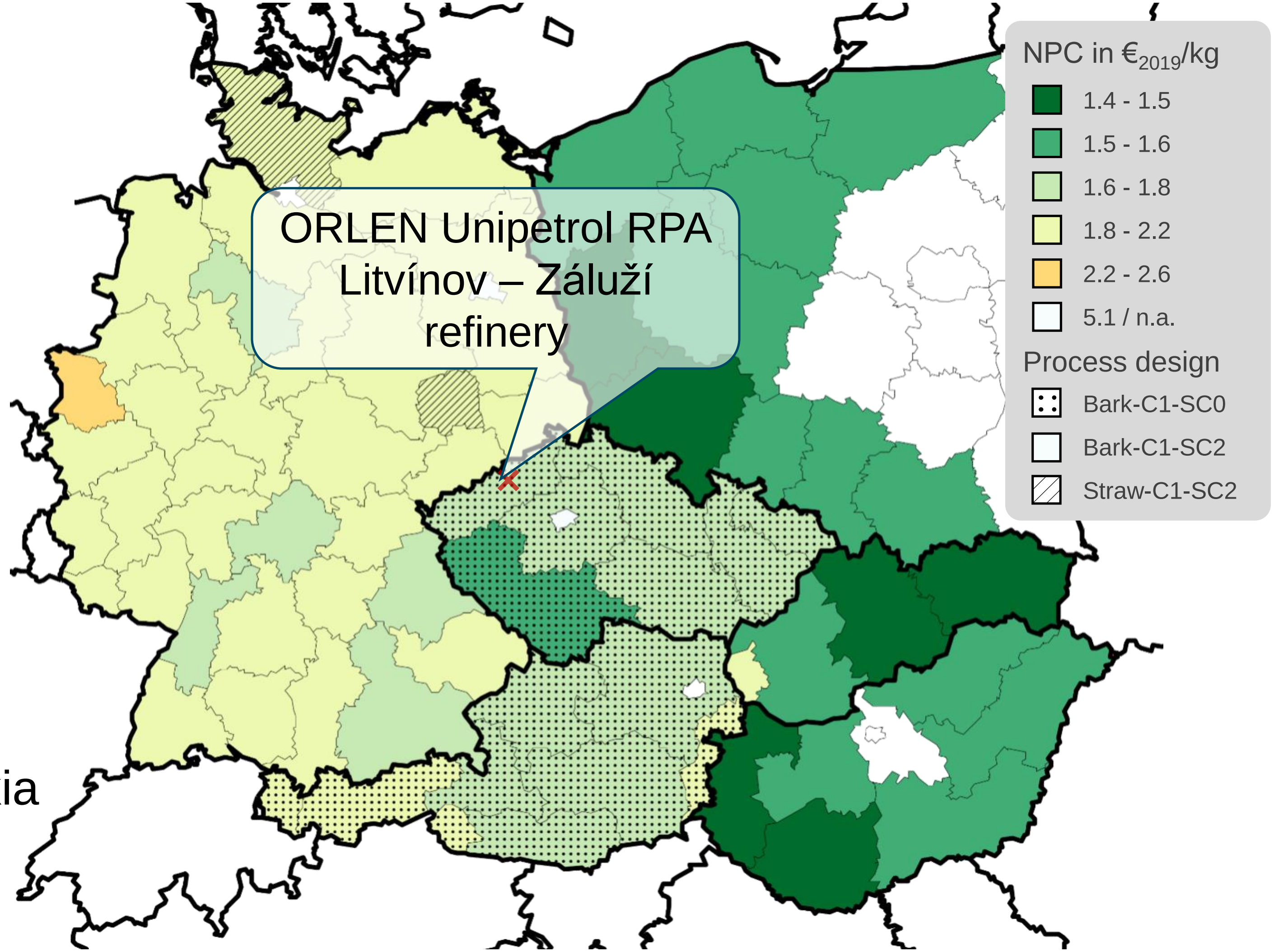
Example results: Economic evaluation of BtL production
Central European map of COMSYN roll out

- Identification of regional sweet spots shown on a map for Central-Europe.
- Net production costs and the favorable process design for each region.
- Automated selection of the optimal feedstock, process design, plant size and heat / electricity utilization.
- Refinery Point of View preferences
- Net production costs < 1.12 $€_{2019}/l_{biofuel}$ regions in Hungary, Poland, and Slovakia



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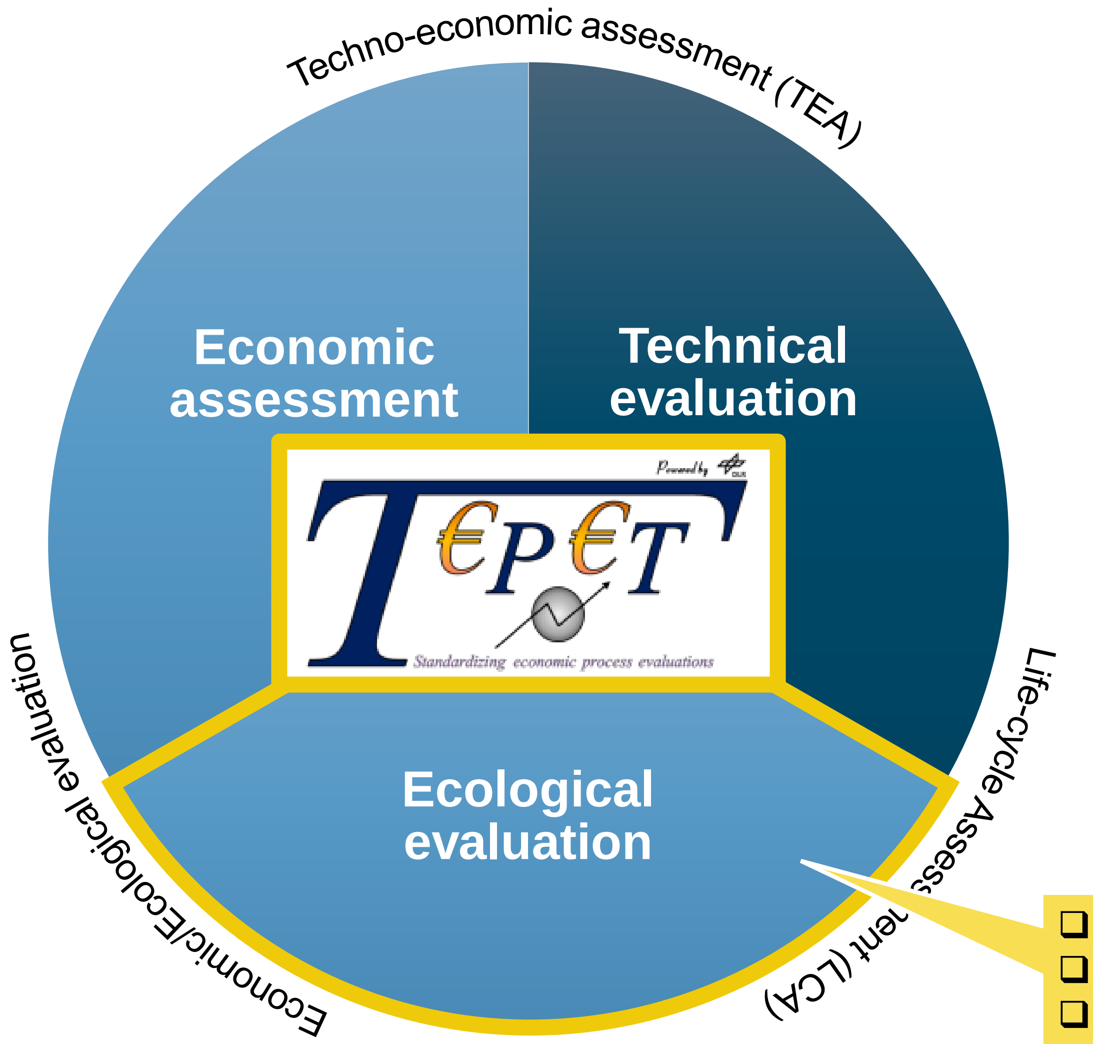

- ❑ GWP
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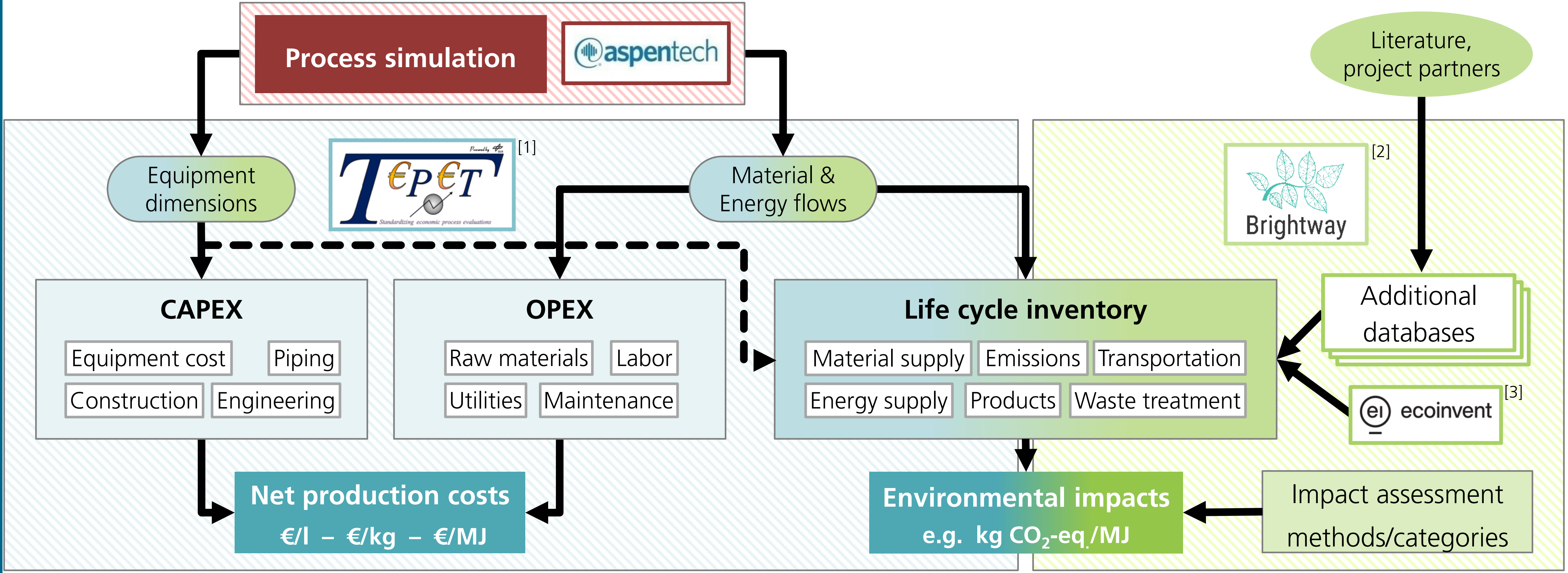
TEEA tool TEPET @ DLR (part 2)



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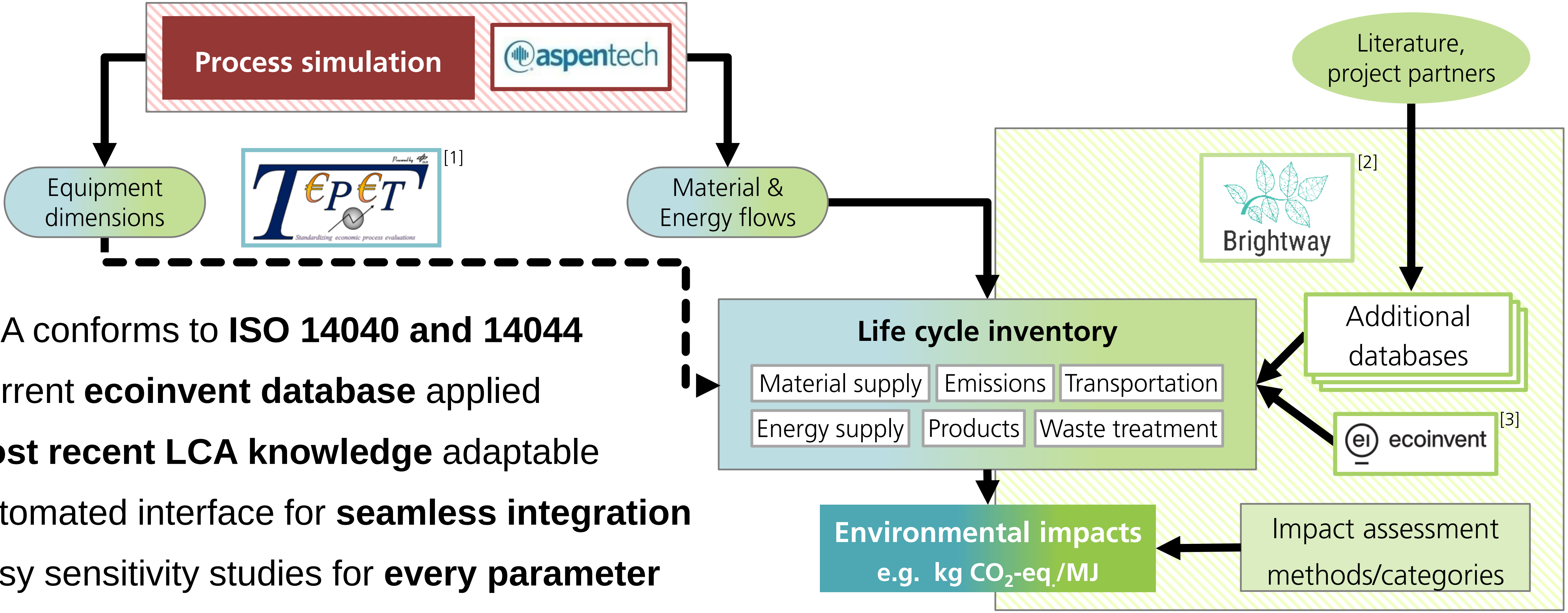

- LCA conforms to **ISO 14040 and 14044**
- Current **ecoinvent database** applied
- **Most recent LCA knowledge** adaptable
- Automated interface for **seamless integration**
- Easy sensitivity studies for **every parameter**

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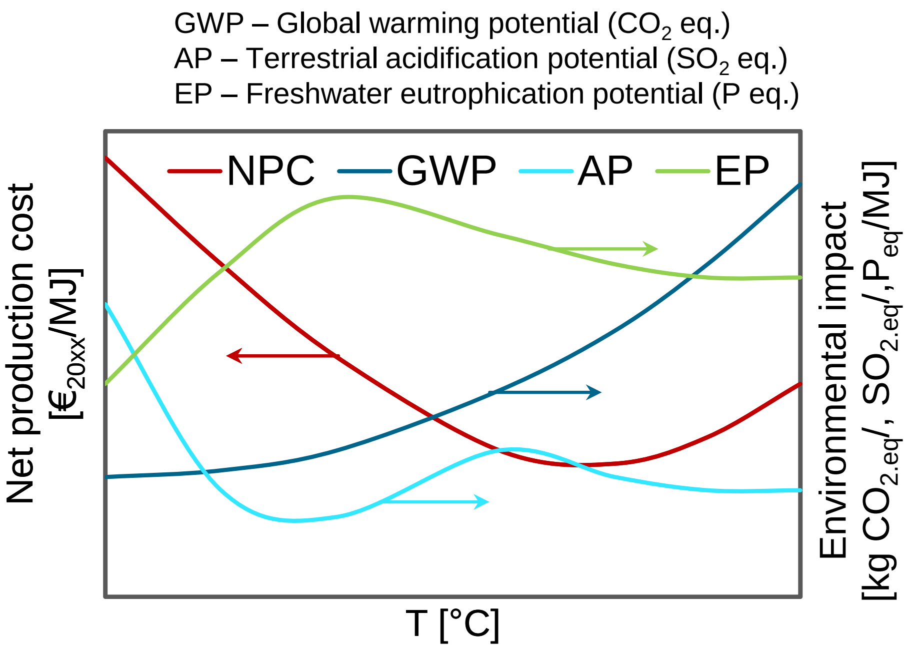
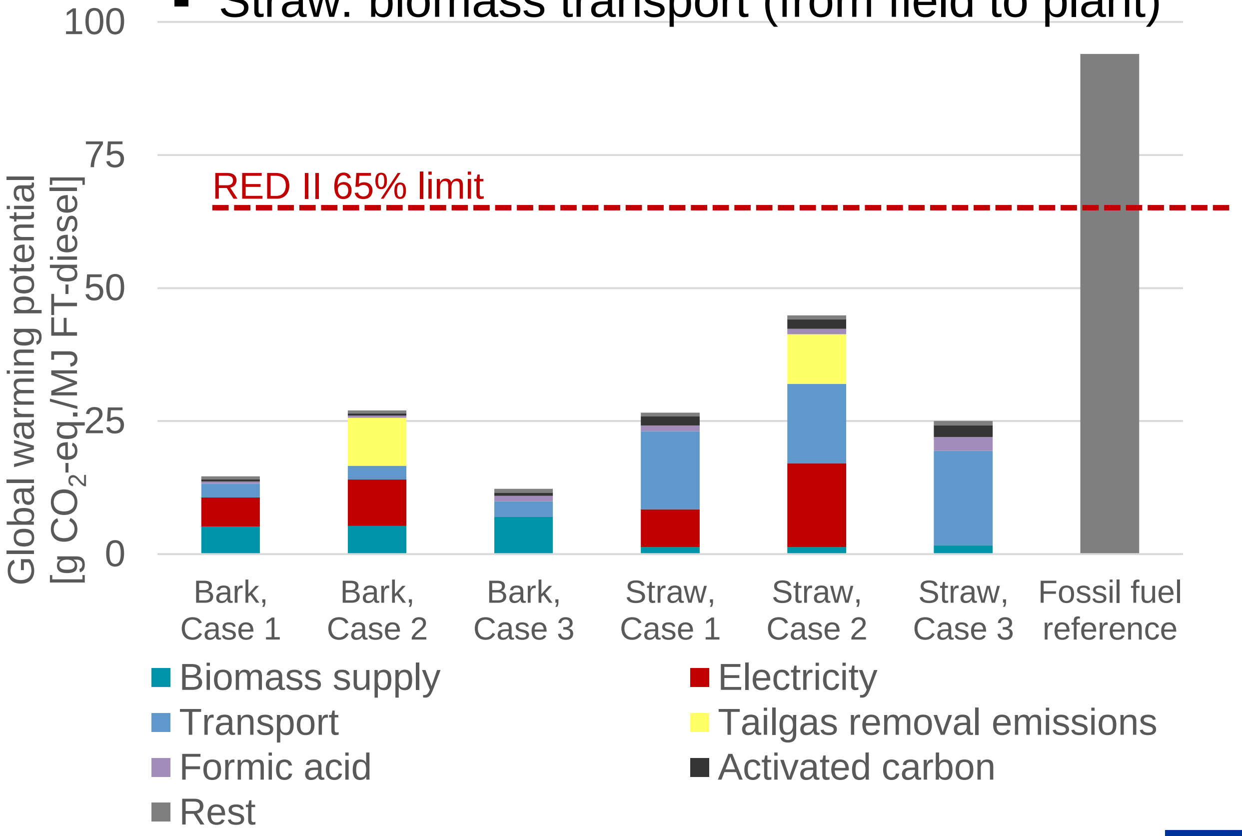
Example results: Ecological evaluation of biofuels prod.
LCA impacts and COMSYN example assessment

- Various impact categories determine LCA



Schematic net production cost (NPC) and environmental impact dependency of a particular process parameter (e.g. gasifier, reformer temperature, etc.)

- Major impact driver
  - Bark: biomass supply (harvesting)
  - Straw: biomass transport (from field to plant)



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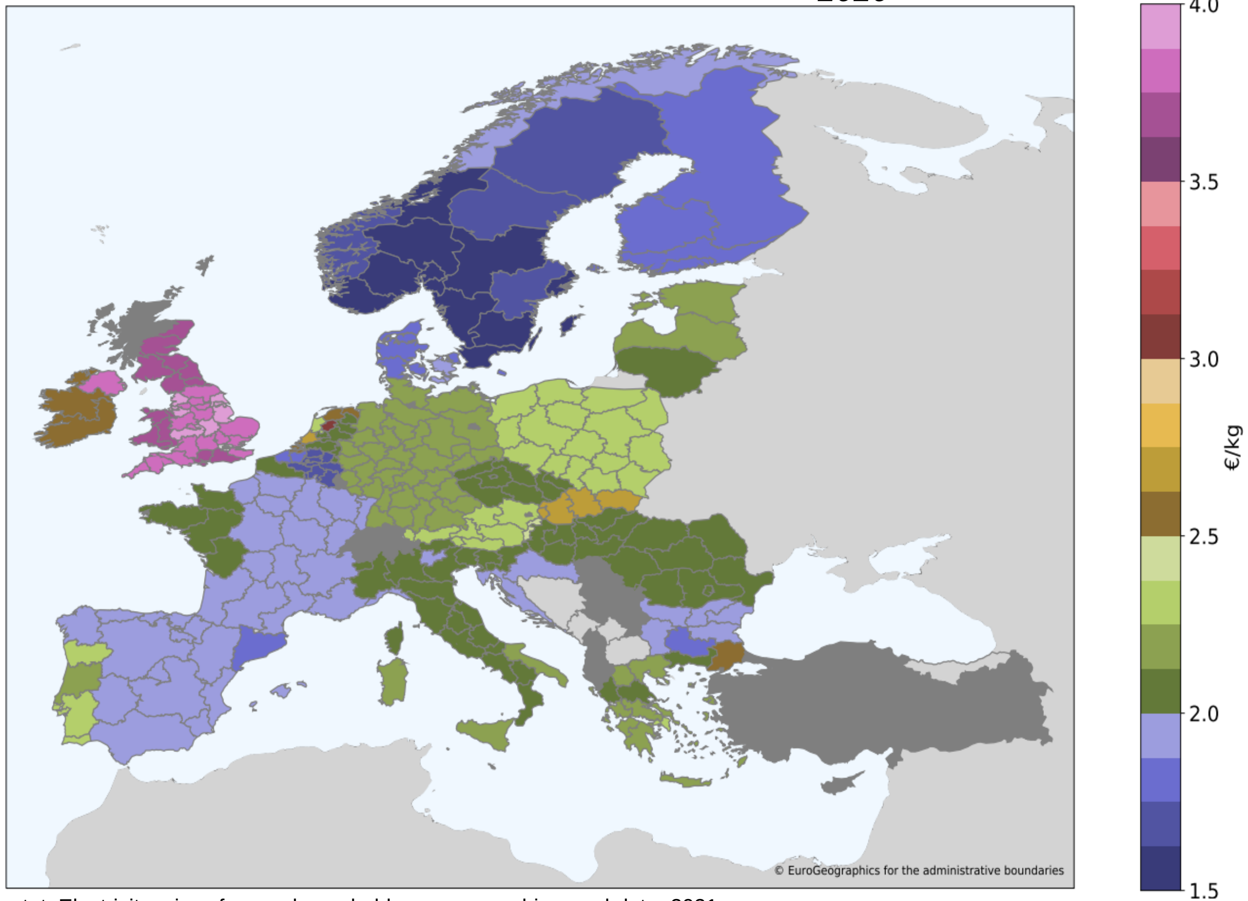
CARBON CAPTURE AND UTILIZATION TOWARDS A FUTURE SUSTAINABLE EUROPE

ASSESSMENT RESULTS EXAMPLES

TEEA results supporting Energy transition options
Sustainable Aviation Fuels for Europe

PBtL kerosene roll out costs

Net Production Costs of PBtL SAF / €$_{2020}$/kg:



Large scale deployment of sustainable aviation fuels production feasible

Lowest NPC in Northern EU using

- National electricity prices [1]
- Local biomass price [2]
- Transport distance as a function of biomass density
- Nation-specific transport and labor costs

[1] Eurostat, Electricity prices for non-household consumers - bi-annual data. 2021.
[2] Ruiz, P., Nijs, W., Tarvydas, D., Sgobbi, A., Zucker, A., Pilli, R., ... & Thrän, D. (2019). ENSPRESO-an open, EU-28 wide, transparent and coherent database of wind, solar and biomass energy potentials. *Energy Strategy Reviews*, *26*, 100379.

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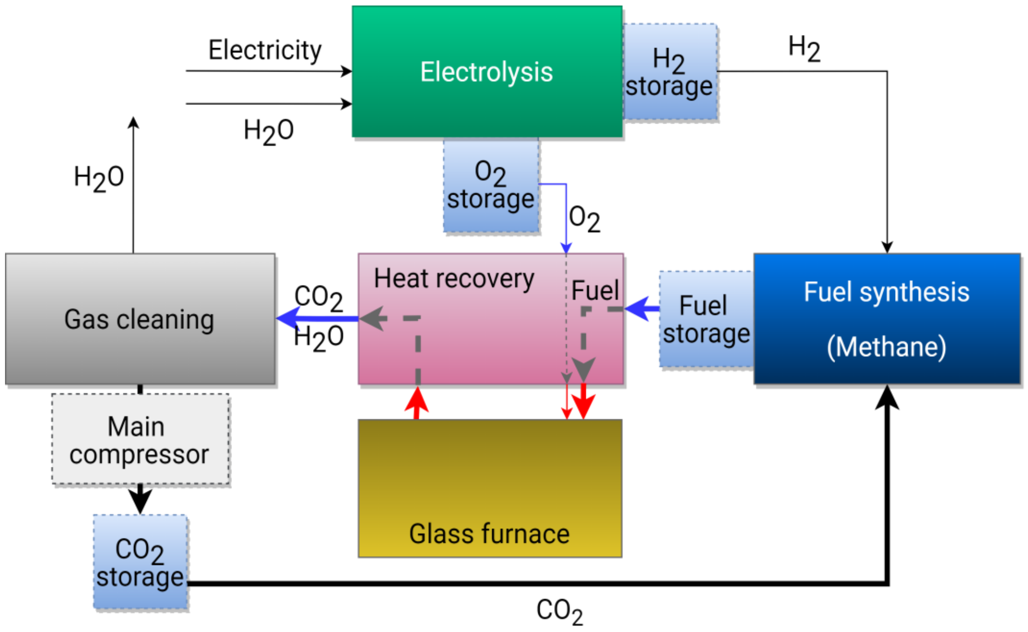
TEEA results supporting Energy transition options
Decarbonization of glass furnace

DLR

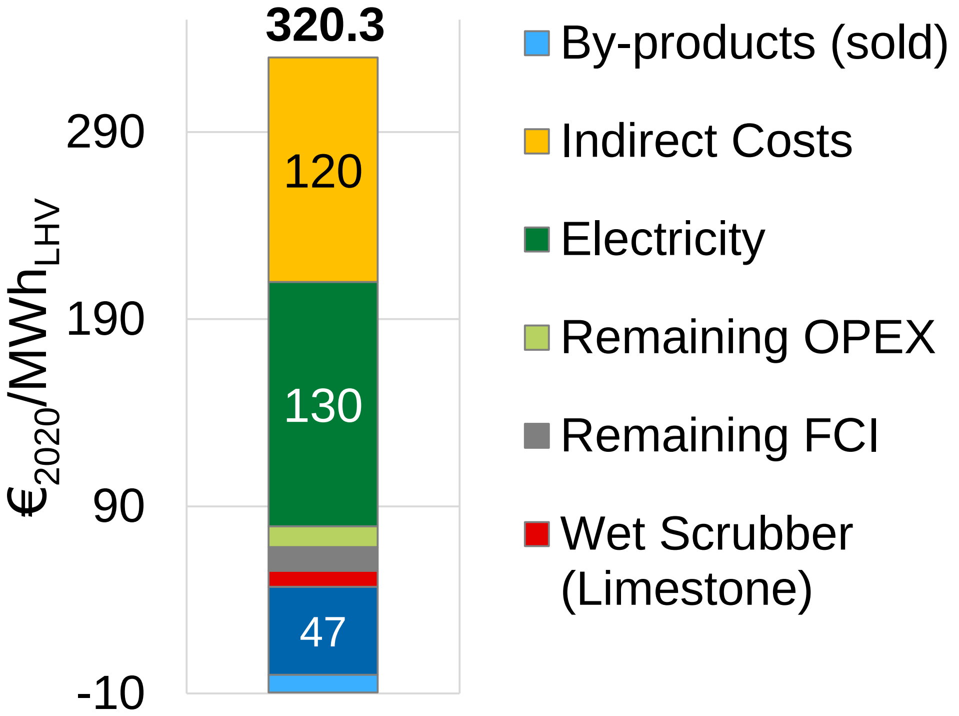
HVG-DGG Service und Forschung für die Glasherstellung

Glas-CO_2 (Methane)



Ref.: F. Drünert (HVG), F. Moser (DLR) - Closed CO2 cycle in the container glass production

Breakdown of NPC



- CCU of an **oxyfuel** glass furnace (container glass)

CH_4 ➔ CO_2 ➔ CH_4

- Surplus of CO_2 from carbonates also converted

NPC: 320 $[€_{2020}/MWh]$ ↔ 0.40 $[€_{2020}/kg_{Glass}]$

Fossil: 8.9 $[€_{2020}/MWh]$[1] ☛ 305 $[€_{2022}/MWh]$[2]

[1] Tradingeconomics (2022) https://tradingeconomics.com/commodity/eu-natural-gas
[2] www.bundesnetzagentur.de/.../220826_gaslage.pdf, 26.08.22

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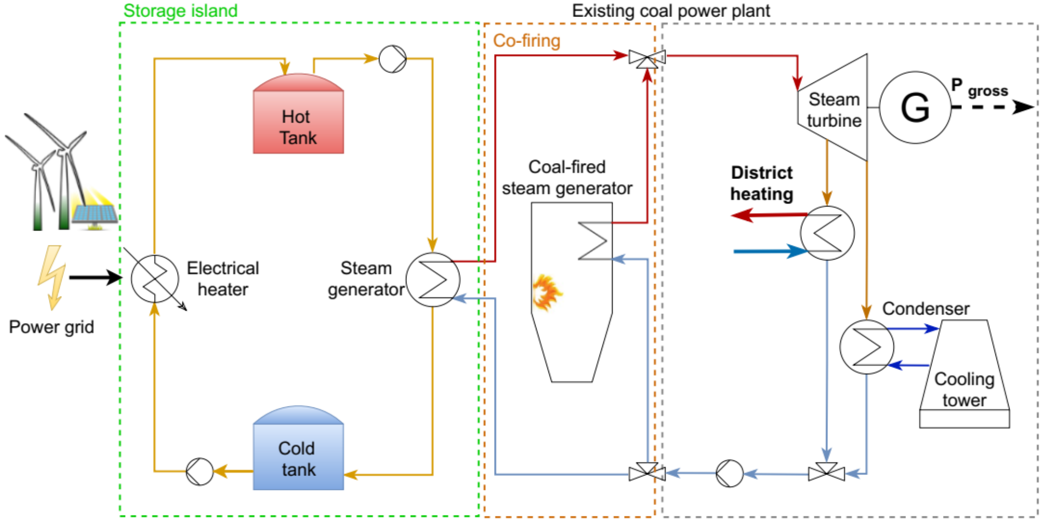
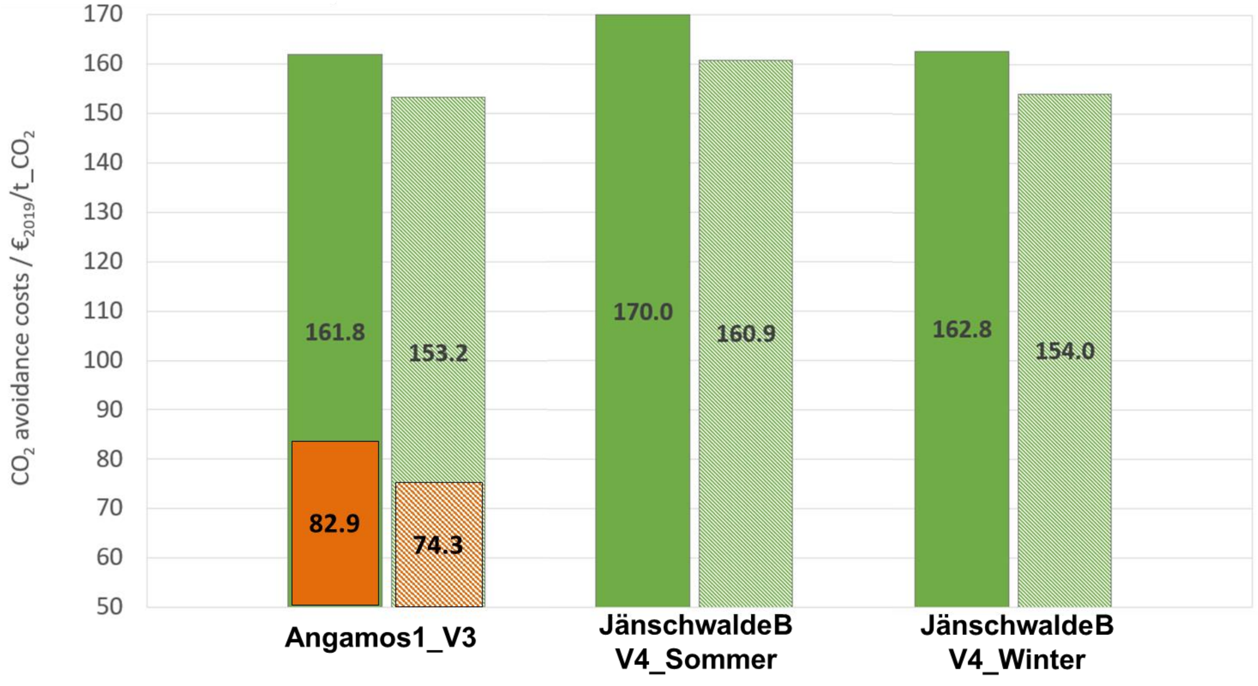
TEEA results supporting Energy transition options
2nd life coal power plants

Revamp costs / benefits

Heat-storage power plant (HSPP), option for global power supply transition





Power Plant fully depreciated; LCOE PV 51 €/MWh
Power Plant fully depreciated; LCOE PV 20 €/MWh
Power Plant with financing; LCOE PV 51 €/MWh
Power Plant with financing; LCOE PV 20 €/MWh

- Turn RE into demand driven base load
- Round-trip efficiency ~40%
- District heating can also be provided
- **CO_2 avoidance costs** for 2000+ coal power plant sites
  - Examples: Angamos, Chile & Jänschwalde, Germany
  - Angamos has **better PV potential** than Jänschwalde

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TEEA results supporting CCU options

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Summary

- Large-scale CCU can become an integral part of global energy transition
- Transparent, standardized techno-economic and environmental assessment of renewable energy applications is key for societal acceptance
  - Renewables often not competitive to fossil energy ➔ subsidies, regulation?

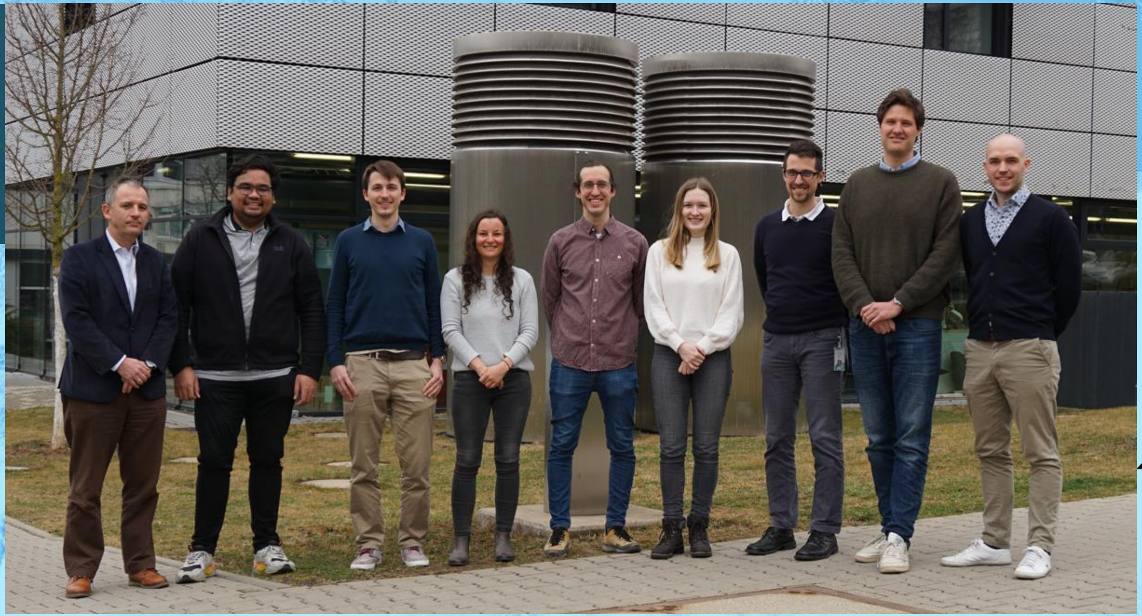
- Valid process simulation is the basic requirement for valid assessment
- Early assessment of new processes and concepts seems feasible / necessary
- Most process equipment have viable rough cost data, new equipment needs adaptation

- DLR methodology is widely accepted for different questions regarding energy transition

2nd International Conference on
Carbon Chemistry and Materials
October 10-14, 2022 | Roma RM, Italy | Hybrid

CARBON CAPTURE AND UTILIZATION TOWARDS A FUTURE SUSTAINABLE EUROPE

Thanks to the team.
Thank you for your attention.
Questions?



Sandra Adelung, Ralph-Uwe Dietrich,
Felix Habermeyer, Nathanael Heimann,
Simon Maier, Francisco Moser,
Moritz Raab, Yoga Rahmat,
Julia Weyand

DLR