Tuesday, 19. September 2023

Session Climate and energy - Hydrogen and fuels II

17 – 21 September 2023 · City Cube Berlin · Germany
ECCE 14 & ECAB 7
14th European Congress of Chemical Engineering
7th European Congress of Applied Biotechnology
www.ecce-ecab2023.eu

COST EFFICIENT OPTIONS FOR FUTURE ICE DRIVEN TRANSPORT

Techno- economic evaluation of synthetic natural gas (SNG) and hydrogen containing synthetic natural gas (HSNG) production for future sustainable transport in Germany

Ralph-Uwe Dietrich, Nathanael Heimann, Simon Maier, Yoga Rahmat, Francisco Moser Rossel, (DLR e.V., www.DLR.de/tt)

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Global e-fuel assessment for future sustainable German transport

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Energy transition in the transport sector (EiV)

- EiV: funding 99 Mio. € | 16 projects | 100+ partner
- Renewable electricity based fuels for aviation, road transport and shipping

Cluster	Fuels in focus	Application
C3-Mobility	synth. Gasoline, DME, OME_{3-5}, Methanol, Butanol, Octanol	
CombiFuel	Hythan (Hydrogen + Methane)	
E2Fuels	Methanol, OME_{3-5}, Methan, Hythan	
FlexDME	Dimethylether (DME)	
ISystem4EFuel	synth. Diesel, OME_{3-5}	
KEROSyN100	synth. Jet fuel	
LeanStoicH2	Hythan (Hydrogen+ Methane)	
MEEMO	Methanol	
MENA-Fuels	(Import strategies from MENA region)	
MethQuest	Methan, Methanol, Hydrogen	
NAMOSYN*	OME, Methylformiat (MeFo), Dimethylcarbonat (DMC)	
PlasmaFuel	synth. Diesel	
PowerFuel	synth. Jet fuel	
SHARC	(Smart energy management in harbors)	
SolareKraftstoffe	synth. Gasoline	
SynLink	synth. Diesel, synth. Jet fuel, Methanol	

Global e-fuel assessment for future sustainable German transport

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Energy transition in the transport sector (EiV) – Beniver: Scientific supervision

BEniVer Begleitforschung Energiewende im Verkehr

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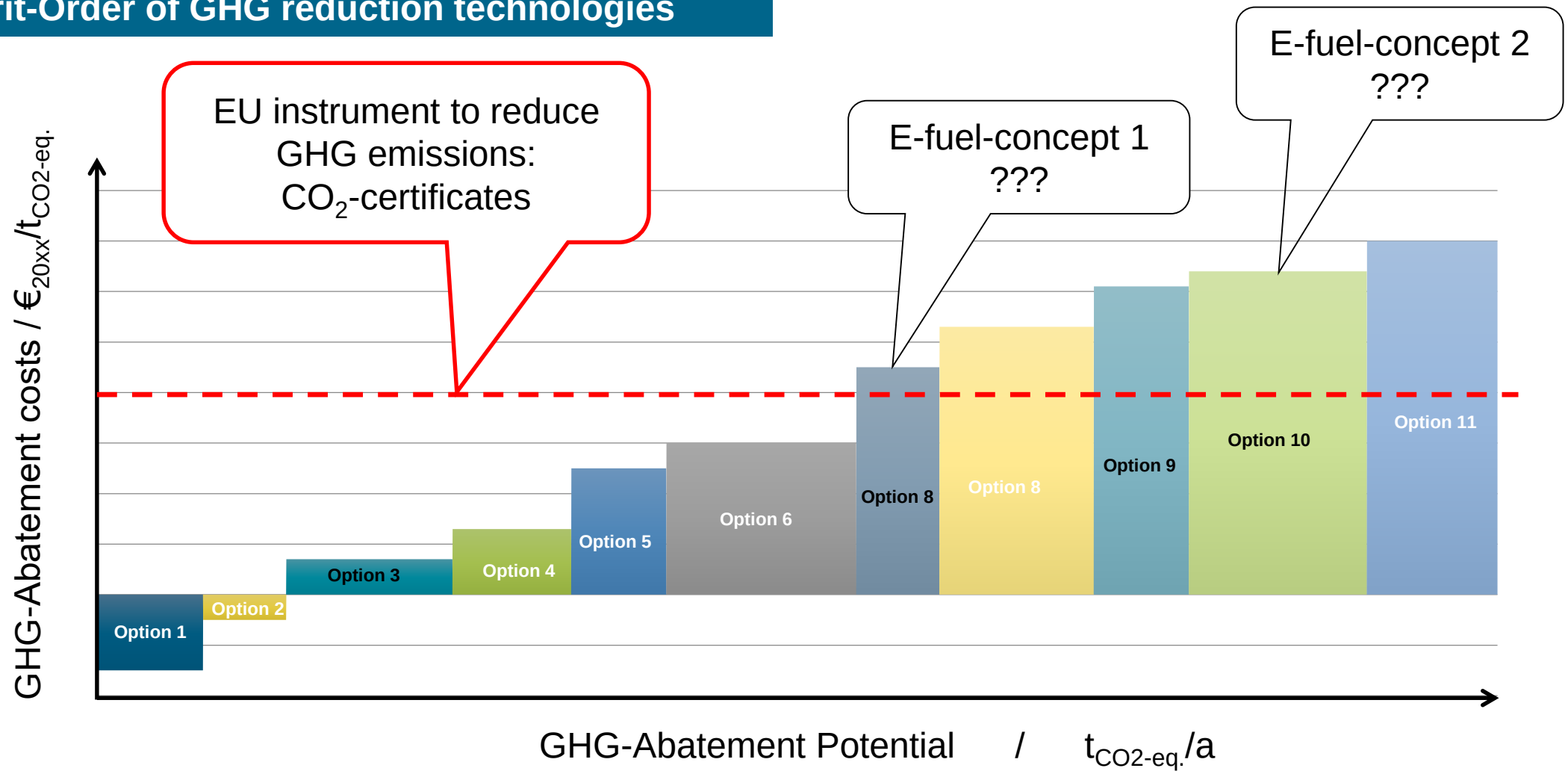
DLR, izes gGmbH Institut für ZukunftsEnergie- und Stoffstromsysteme, FfE, Helmholtz Zentrum für Umweltforschung UFZ, DBFZ, GWS Specialists in Empirical Economic Research, DECHEMA, DGMK

- BEniVer – Scientific supervision of „Energy transition in the transport sector (EiV)"
- BEniVer funding - 9 Mio. € (8 partner)
- Goal: Multicriterial assessment of different options for GHG abatement in transport

Assessment of E-fuels concepts / options / configurations / locations / …

Merit-Order of GHG reduction technologies



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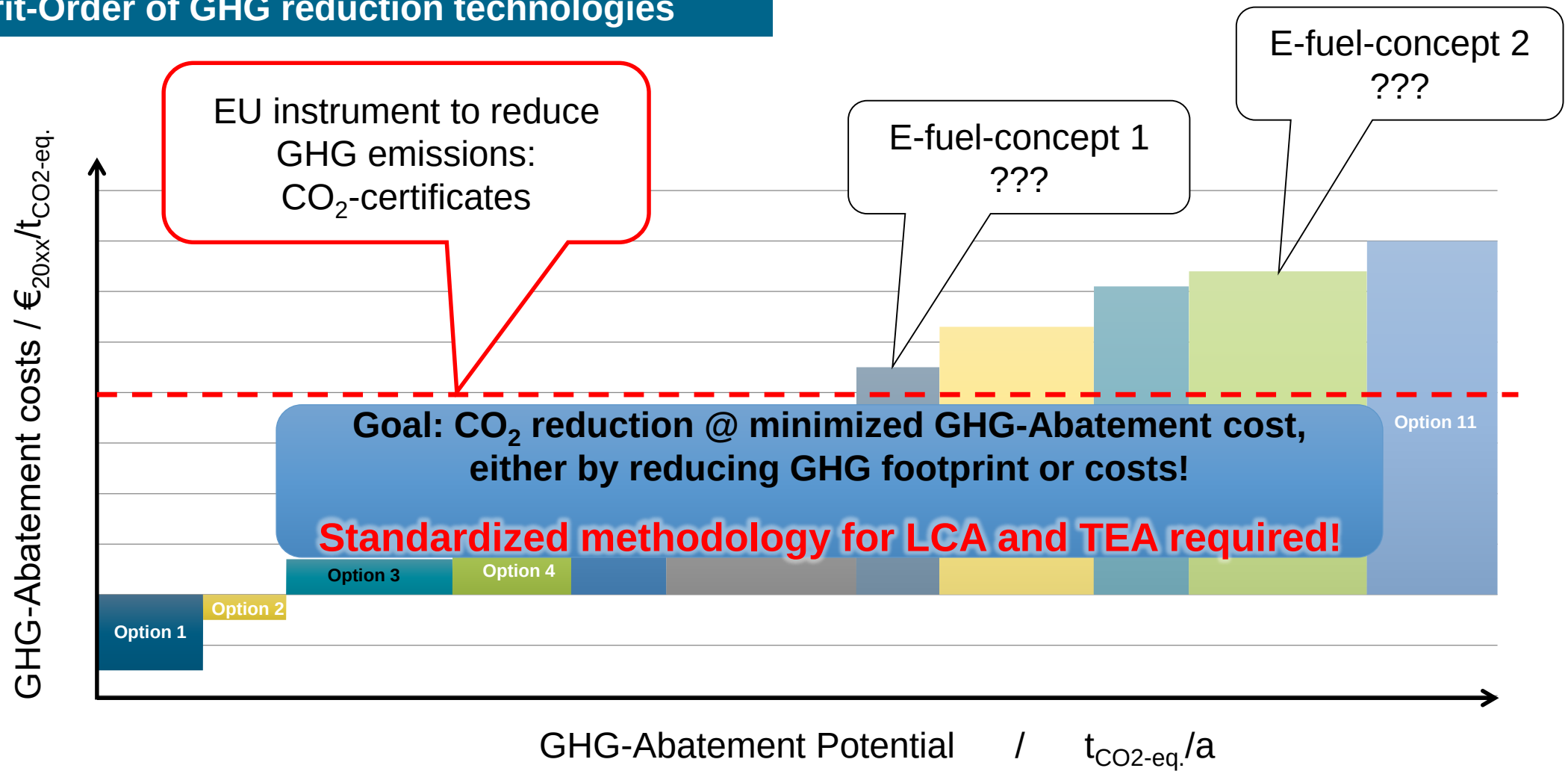
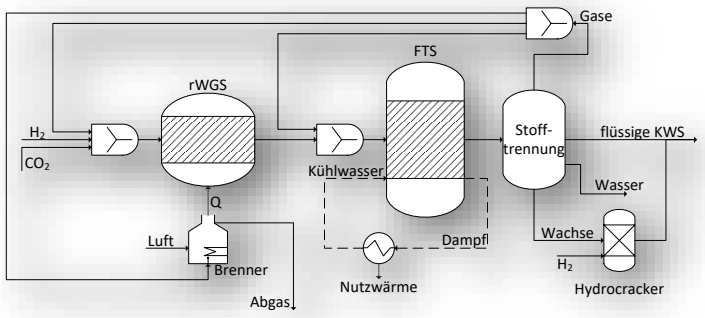
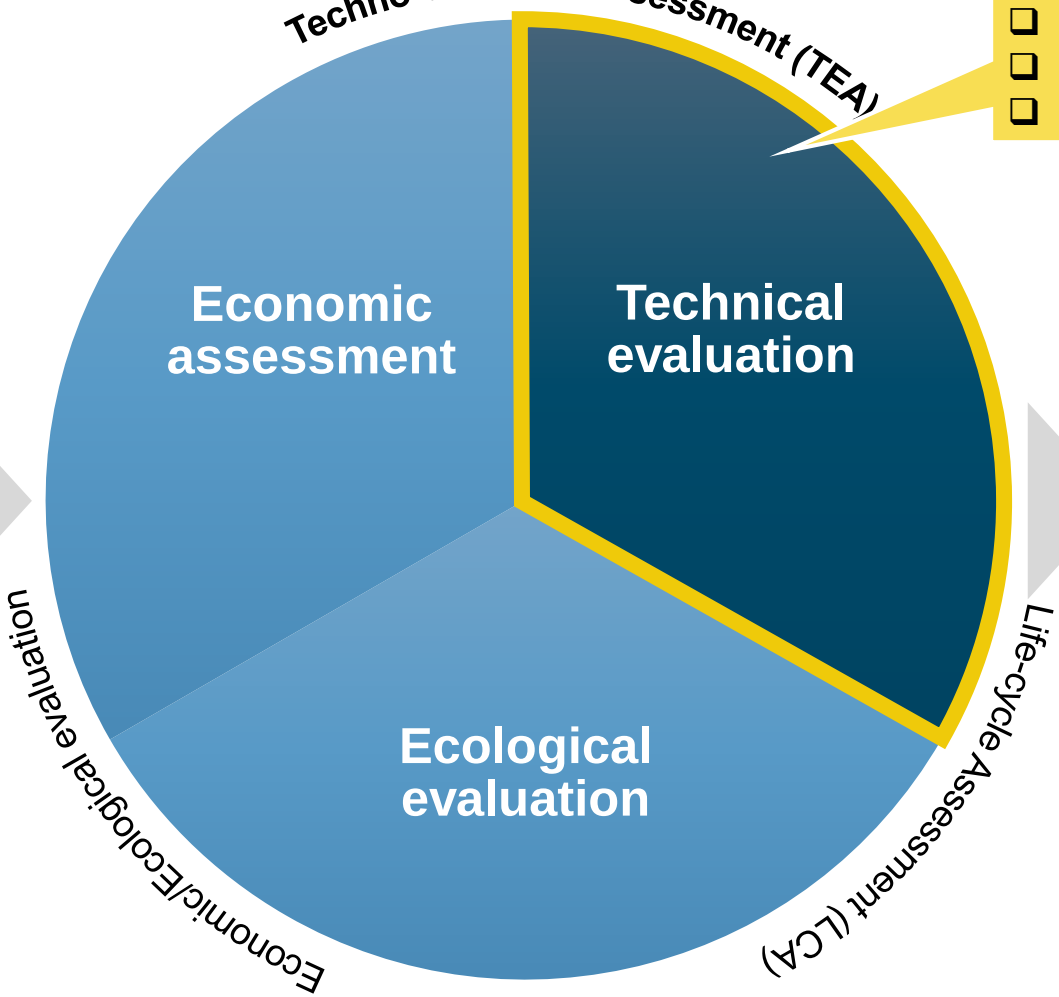
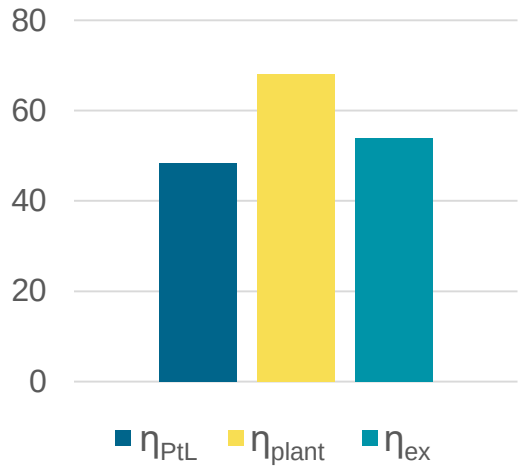


Techno-Economic and ecological assessment





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



Techno-Economic and ecological assessment

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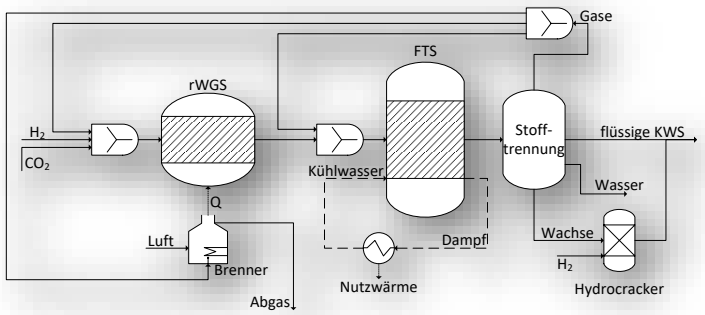
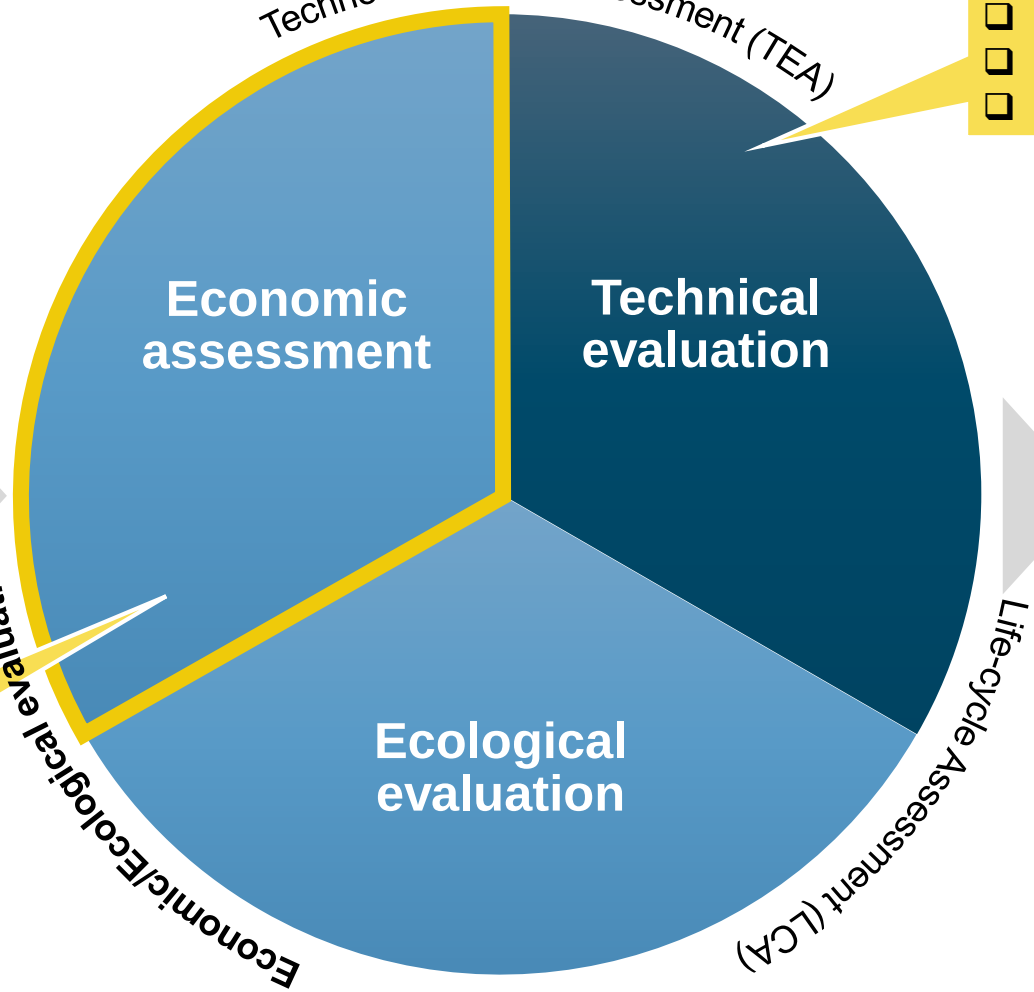
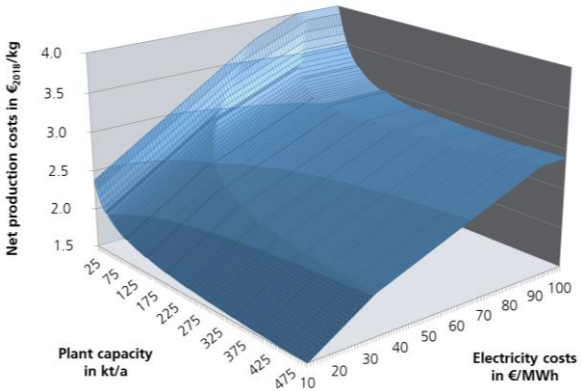
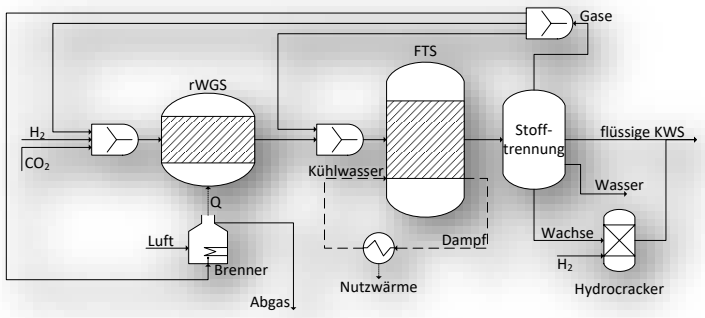


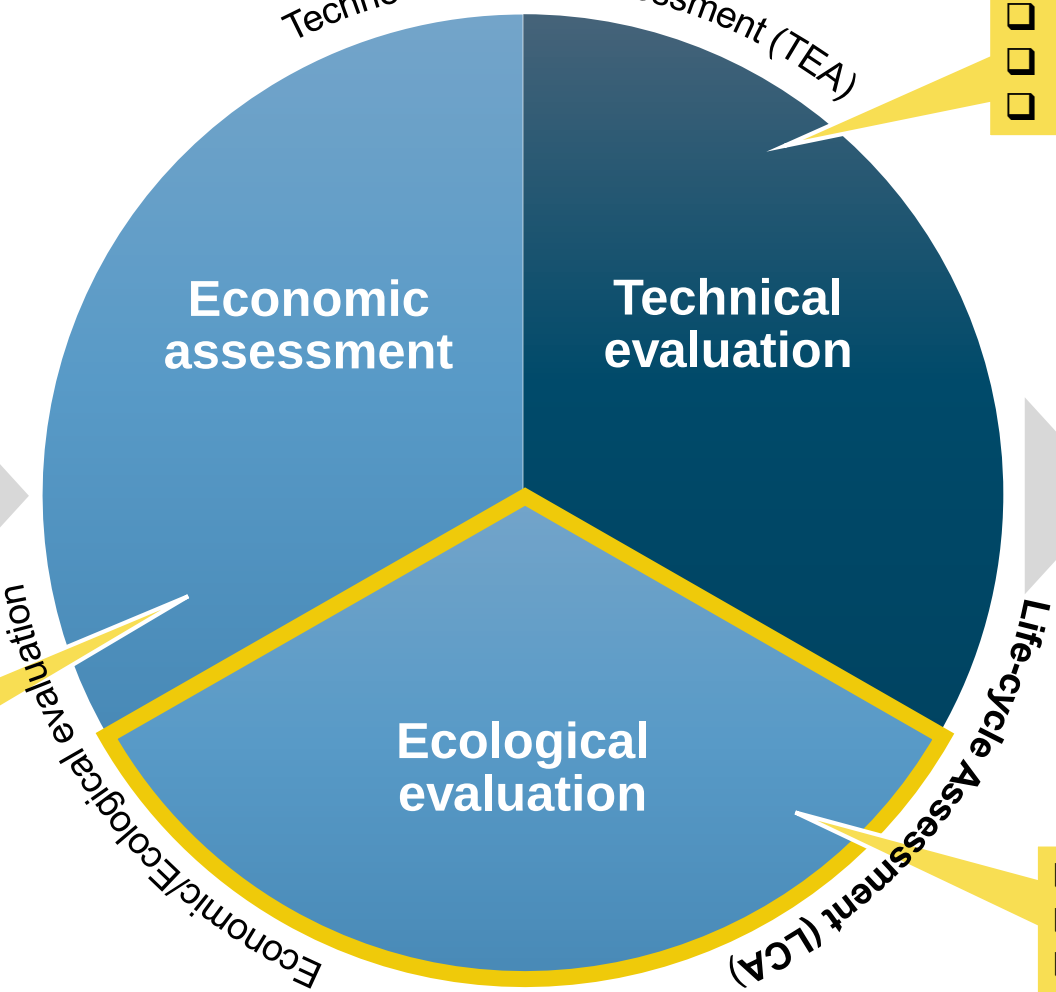




- ❑ CAPEX, OPEX, NPC
- ❑ Sensitivity analysis
- ❑ Identification of most economic feasible process design

Techno-Economic and ecological assessment





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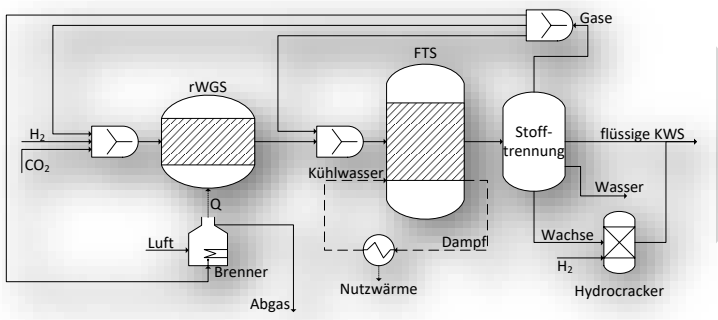
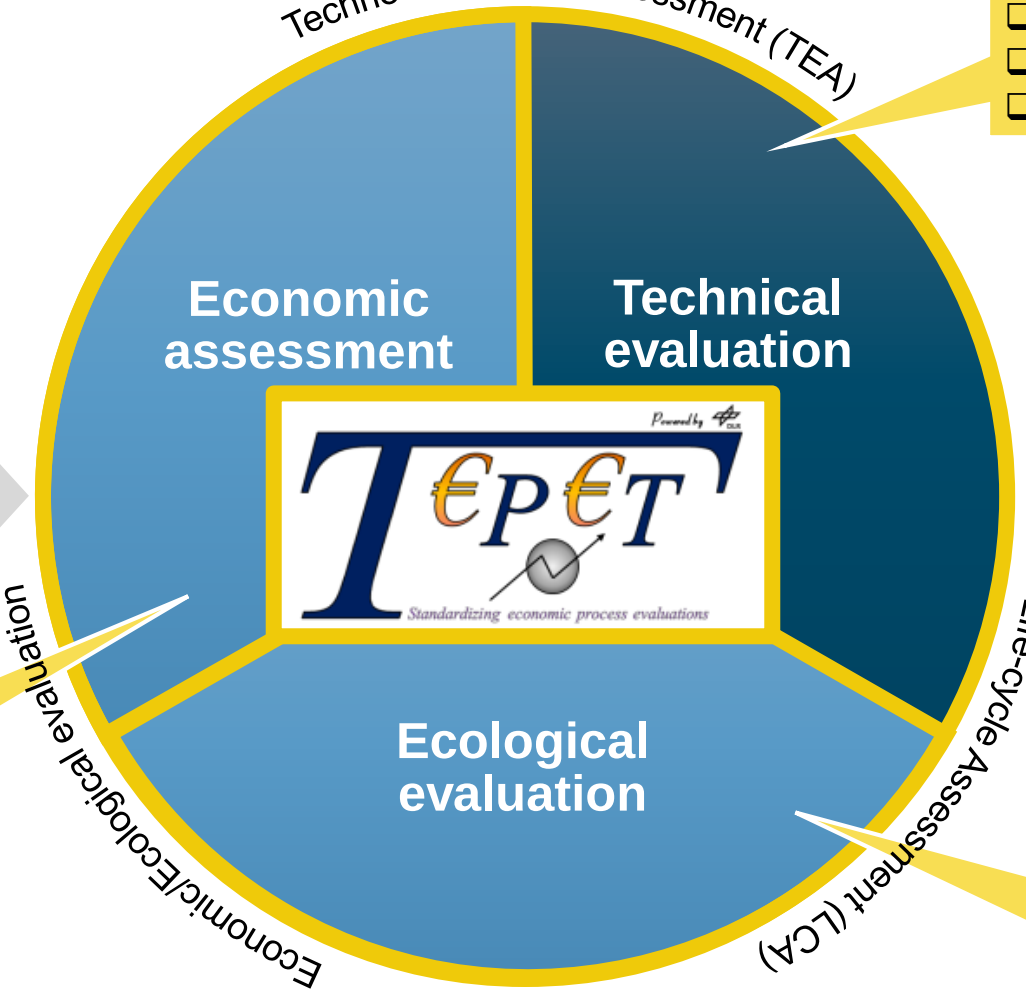
- ❑ GWP
- ❑ Other impact categories
- ❑ Identification of impact drivers

Techno-Economic and ecological assessment





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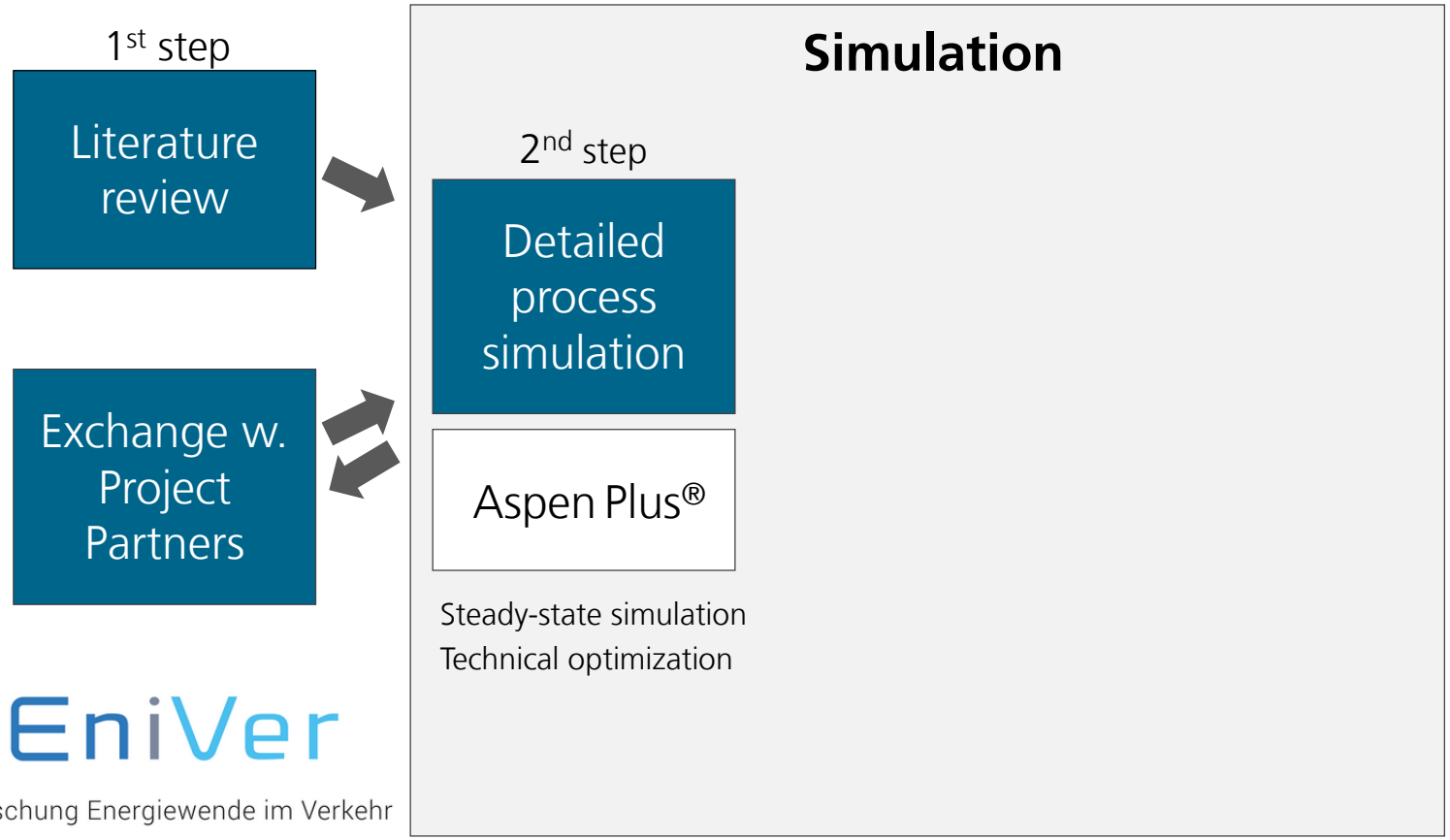
Assessment workflow

1st step

Literature review

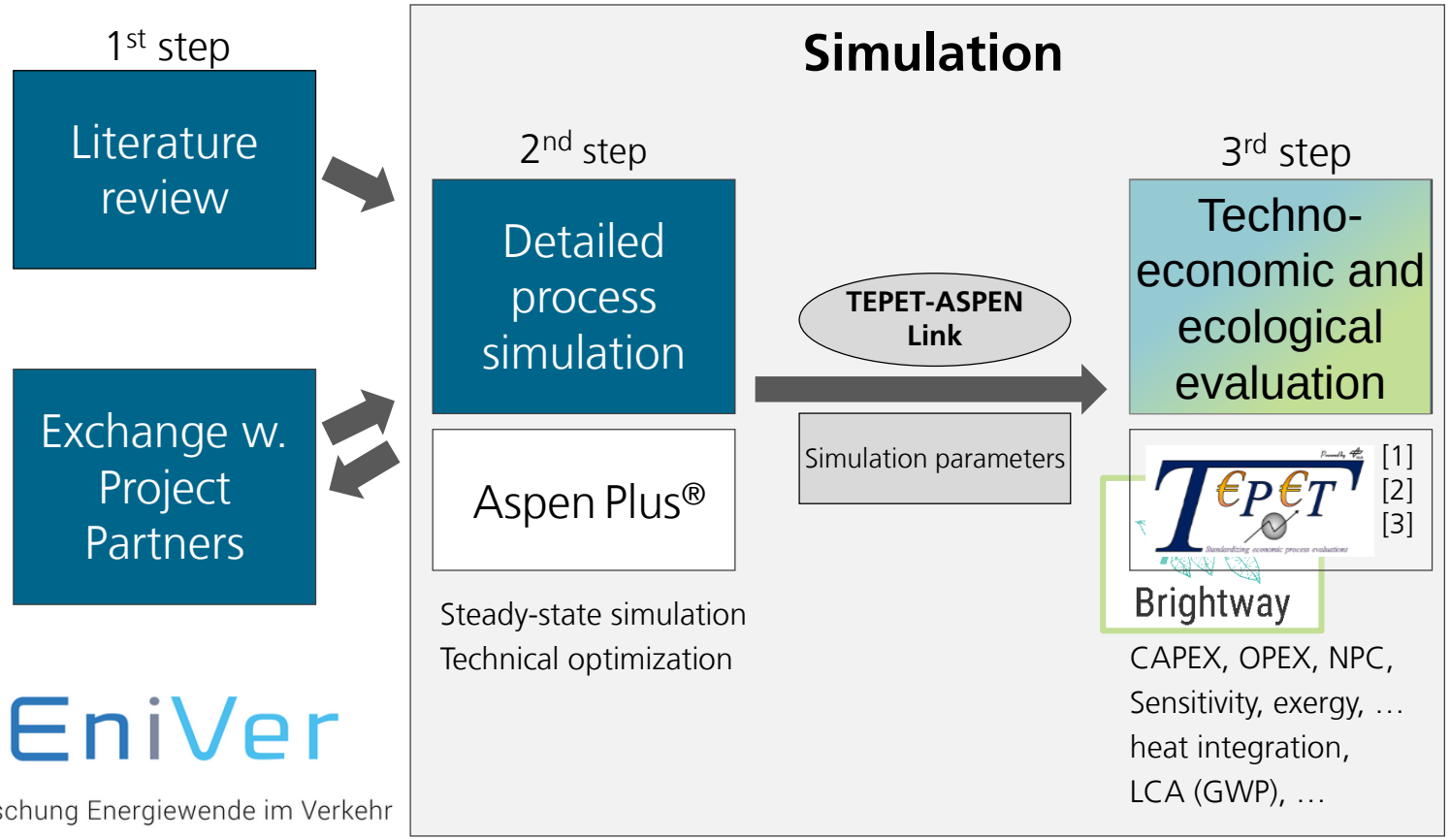
Exchange w. Project Partners

Assessment workflow



BEniVer
Begleitforschung Energiewende im Verkehr

Assessment workflow



BEniVer
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[1] Albrecht et al. (2017). A Standardized Methodology for the Techno-Economic Evaluation of Alternative Fuels
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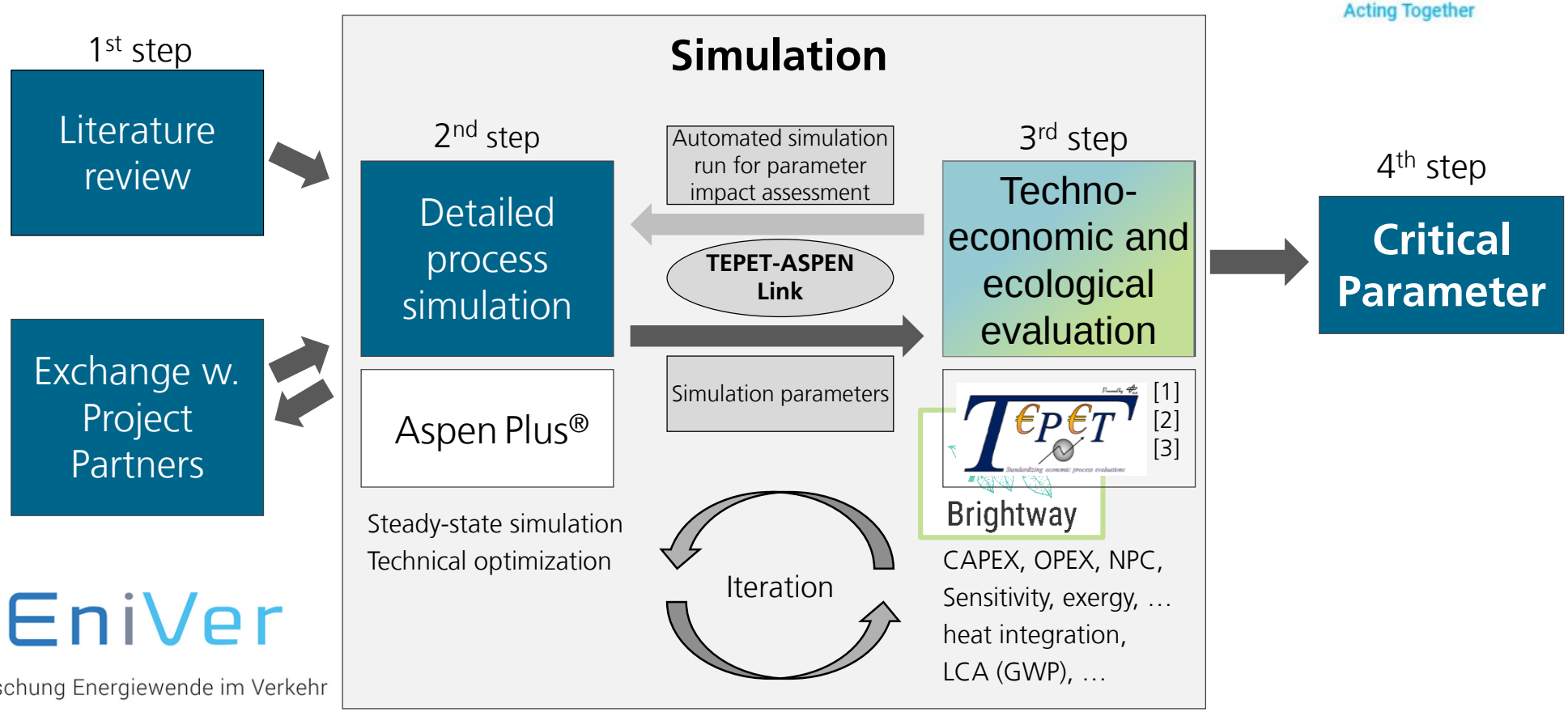

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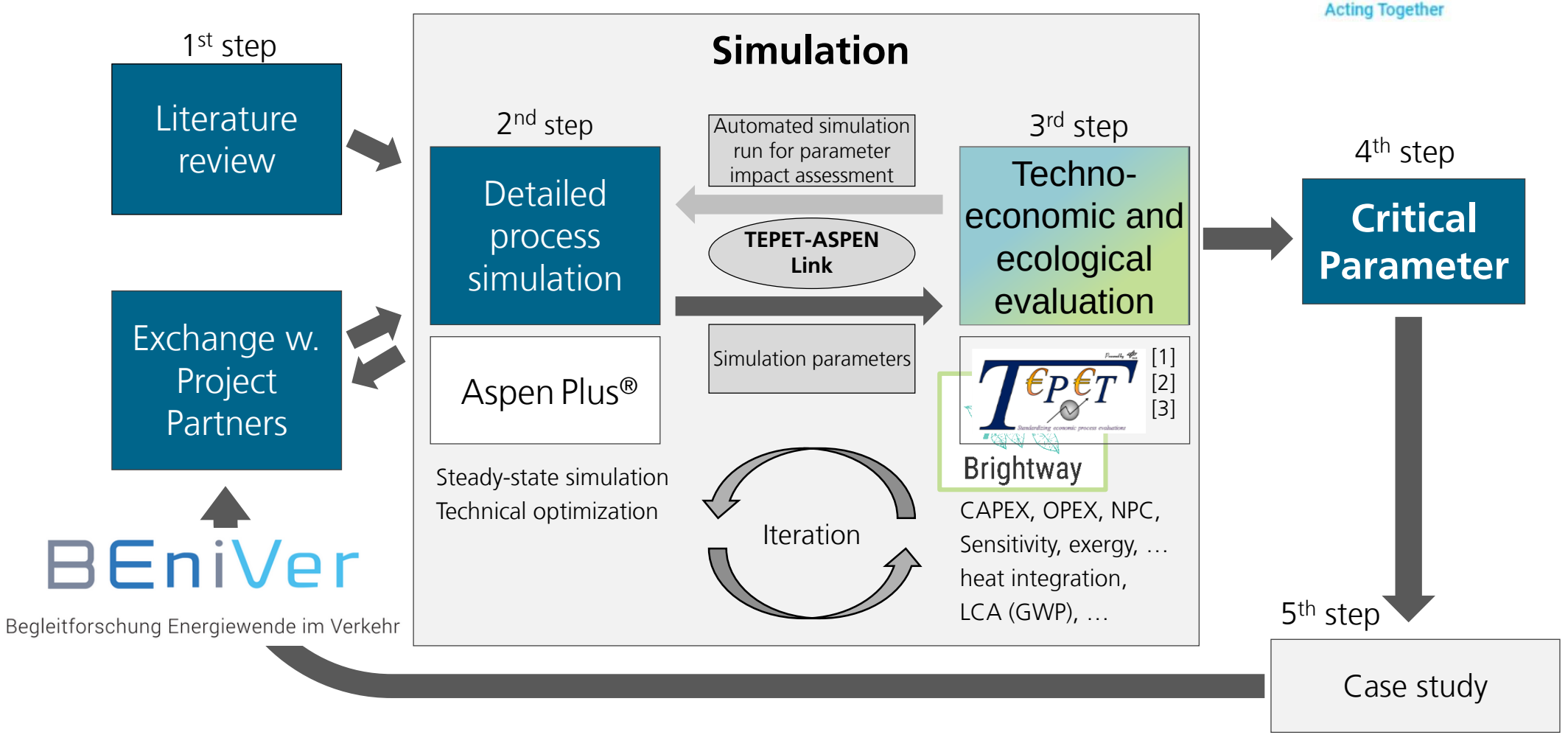

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Global e-fuel assessment – Summary

Chemical and Biochemical Engineering – Acting Together

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BEniVer Begleitforschung Energiewende im Verkehr

NAMOSYN Nachhaltige Mobilität durch synthetische Kraftstoffe

Comparing generic fuels / designer fuels

	SNG	MeOH	FT	OME_{3-5}	DMC	MeFo
Production: technical						
η_{PtF} [%]	57	53	40	42	47	52
Production: economics & environment						
NPC [€$_{2018}$/MWh$_{LHV}$]	173	204	321	360	329	298

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Other ECCE presentations about e-fuels assessment @ DLR:

Session (A6): Process Systems Analysis I
- S. Maier et al: Identifying the ideal process configuration for green methanol production

Session (A1): Climate and energy - Industry decarbonisation
- Y. Rahmat et al: Techno-economic analysis of e-methanol production

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Even if e-methane is somewhat cheaper to produce,
there will be no competitiveness with fossil fuels
(compare ≈ 5 €/MWh crude oil)
CO_2-certificates prizes need to reach some 1’000 €/t_{CO2}

Global e-fuel assessment – Summary

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GHG (and more environmental impact criteria): provided by FfE (BEniVer), LTT RWTH AACHEN UNIVERSITY (NAMOSYN)						
Application: many parameters, no systematic, no monetary assessment						
Application parameter examples	• Heavy truck conversion • Methane slip • …	• Used in China • Low vapor pressure • Further conversion in Europe? • …	• Certified sustainable jet fuel • …	• Better combustion • Blending ratio? • …	• Better combustion • Blending ratio? • …	• Better combustion • Blending ratio? • …

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Application parameter exa	• Heavy truck conversion	• Used in China • Low vapor • …	• Certified sustainable	• Better combustion	• Better combustion	• Better combustion ratio?

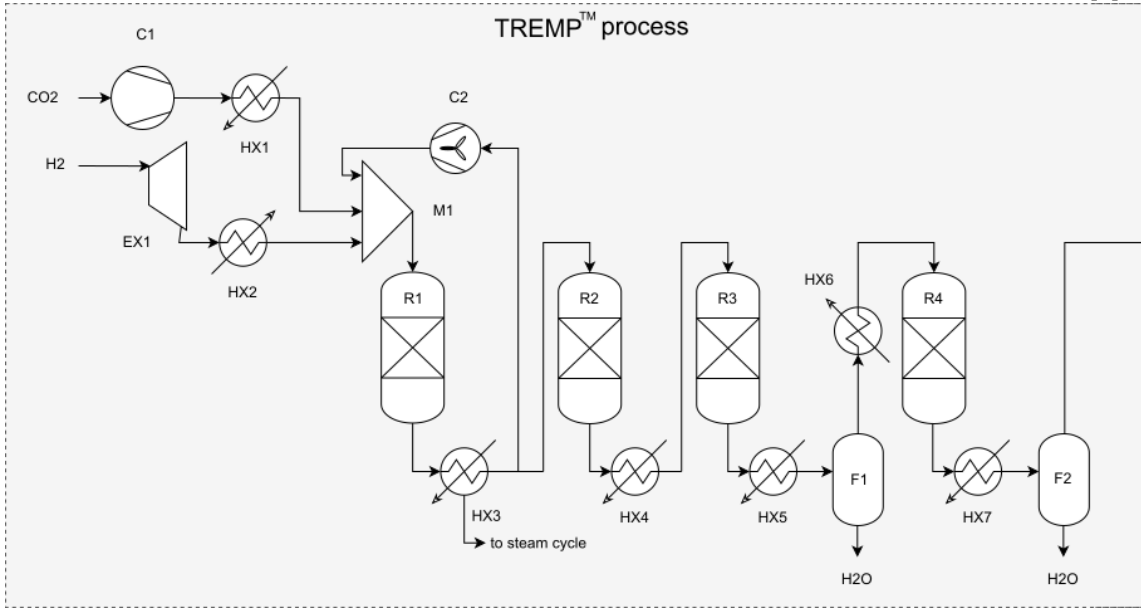
Ecological assessment necessary
Application advantages / drawbacks to be added

TECHNICAL ASSESSMENT OF SNG / HSNG

Large scale e-Methane production (SNG w. 98 vol.% CH_4)

TREMP™-process

[1]



Assumptions in the simulation:

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- No side reactions

[1] Rönsch, S., et al., 2016

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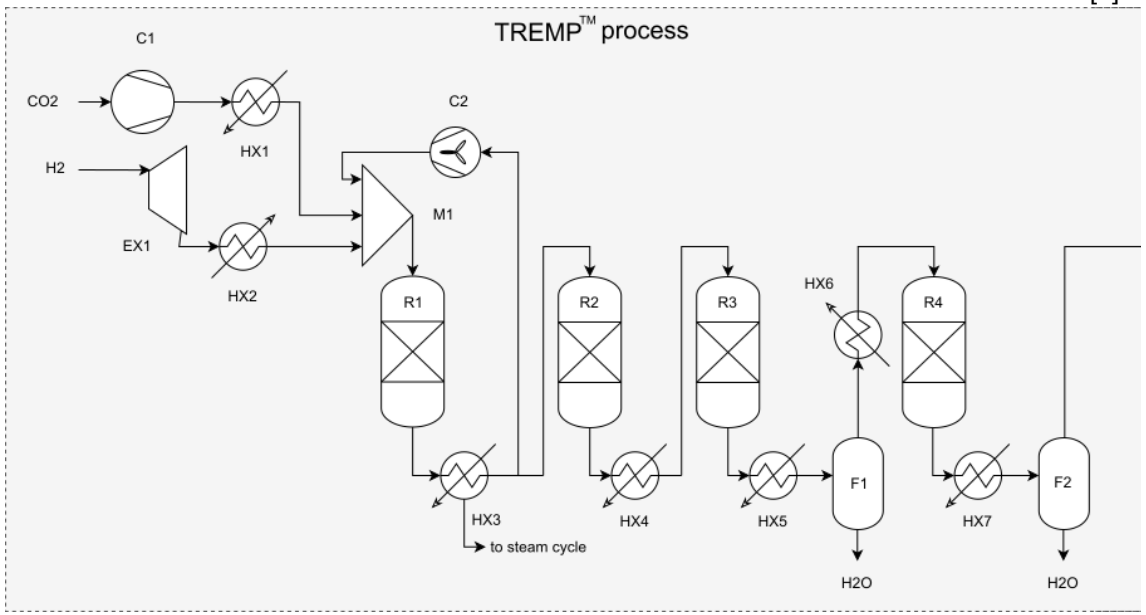

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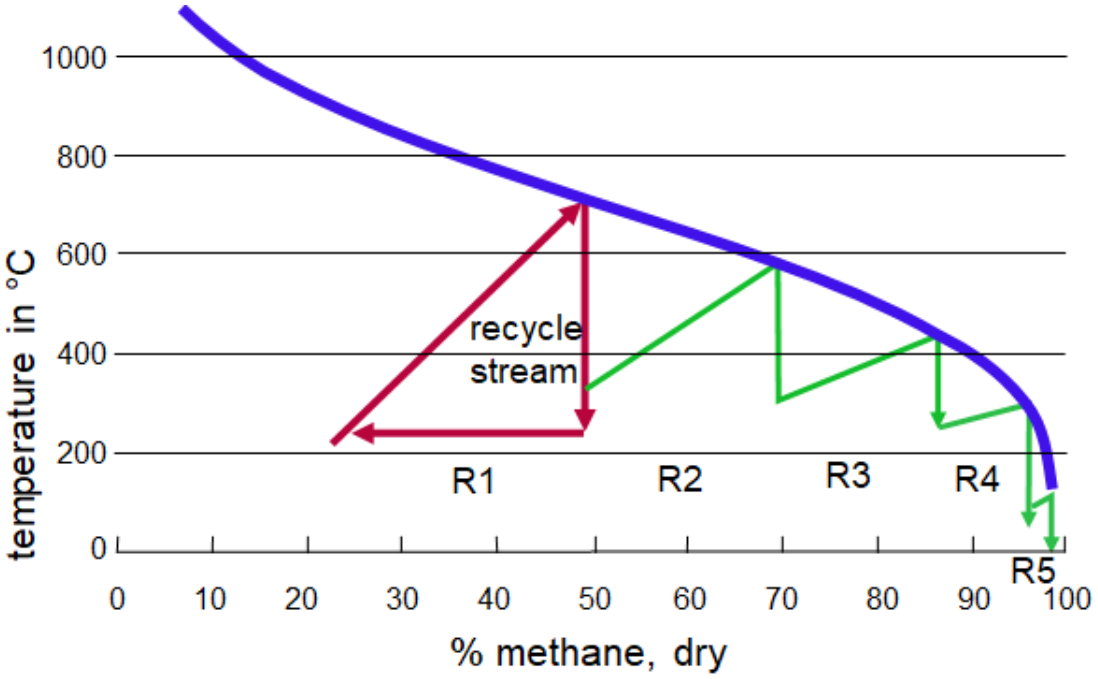
- No side reactions

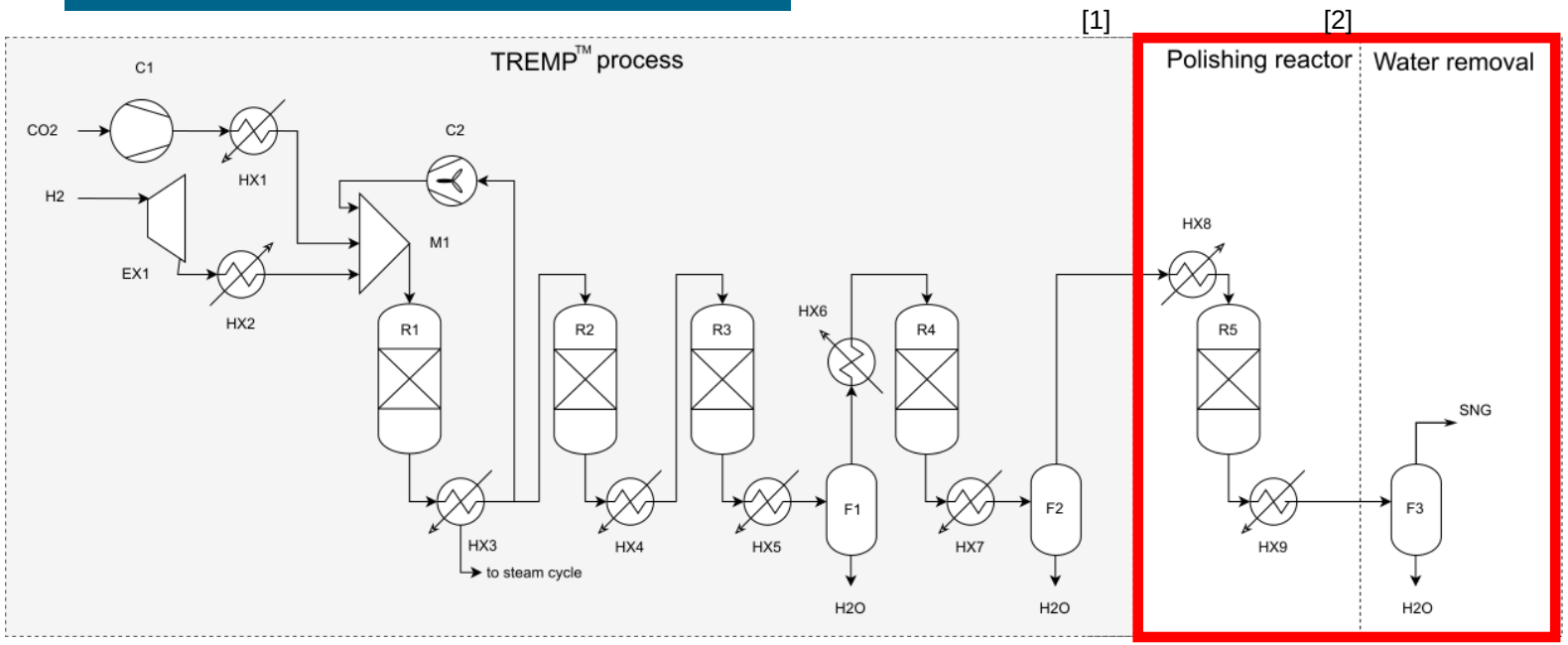
- High temperature in R1
  - Steam cycle



[1] Rönsch, S., et al., 2016

Large scale e-Methane production (SNG w. 98 vol.% CH_4)

Advanced TREMP™-process



- High temperature in R1
  - Steam cycle
- Composition adjustment
  Transport: DIN EN 16723-2:2017-10
  Gas grid: DVGW G260
  - Polishing reactor & water removal

Assumptions in the simulation:
- No impurities
- No side reactions

[1] Rönsch, S., et al., 2016
[2] Heimann, N. et al (2023), Standardized tea of sCNG and HCNG, to be submitted

Large scale e-Methane production (SNG w. 98 vol.% CH_4)

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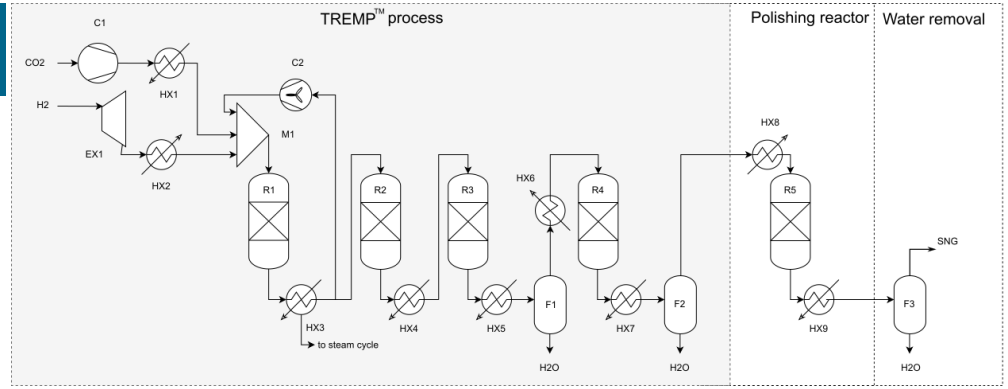
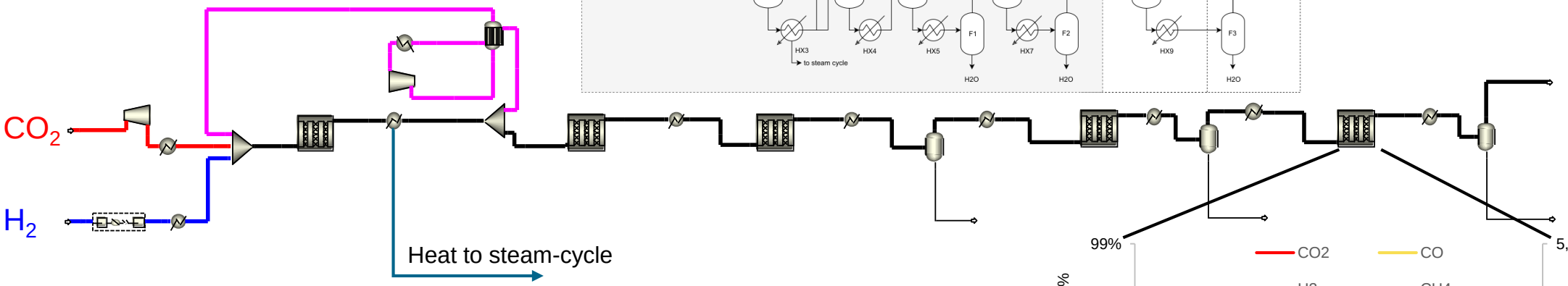
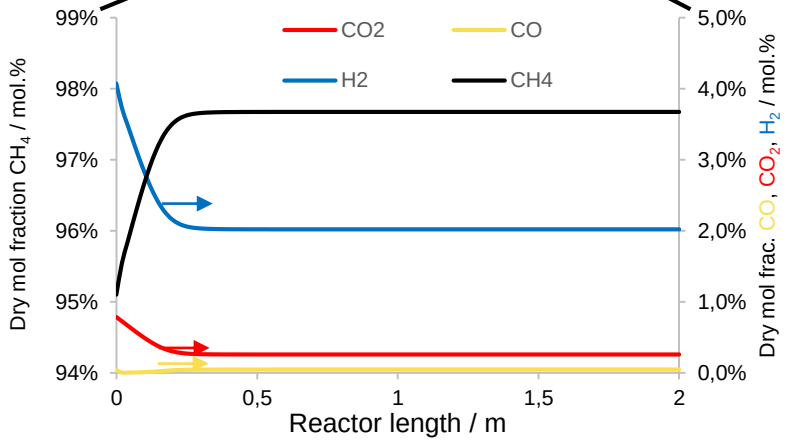
Process simulation Aspen Plus®





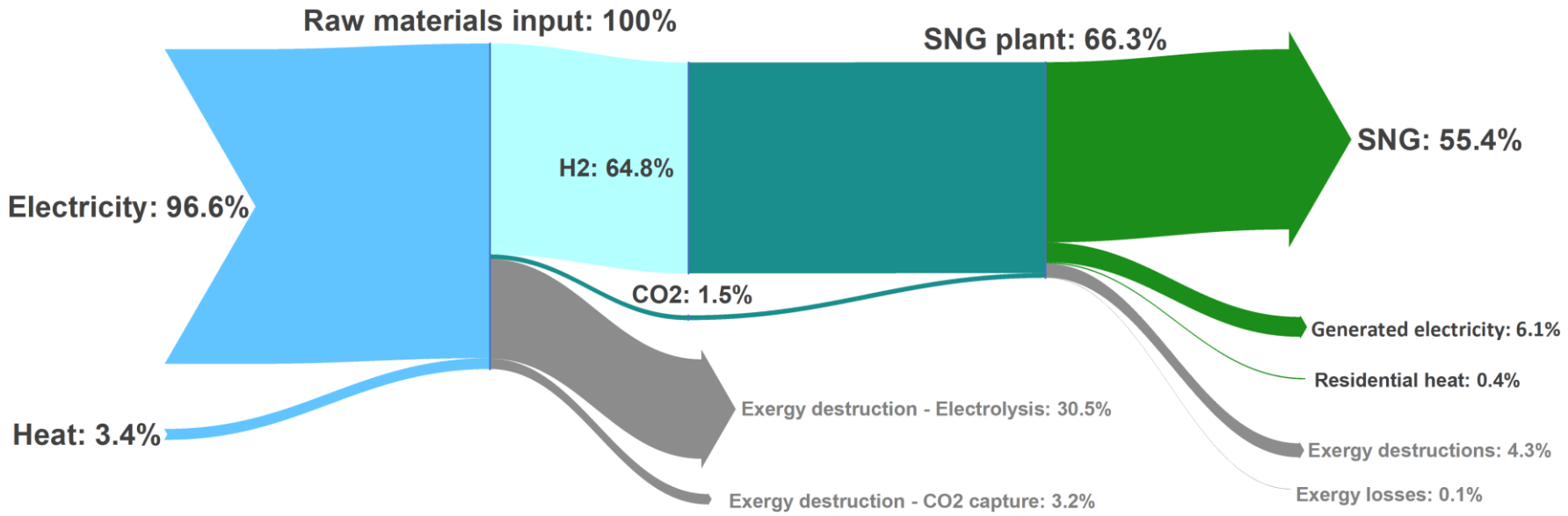
Design spec.:

- $CH_4 \geq 97.7$ Vol.%
- $H_2 \leq 2$ Vol.%
- $CO_2 \leq 0.3$ Vol.%



Large scale e-Methane production (SNG w. 98 vol.% CH_4)

SNG production exergy flow [1]



- Exergy reuse: steam-cycle and residential heat
- Highly exergy efficiency optimized

[1] Heimann, N. et al (2023), Standardized tea of SNG and HSNG, to be submitted

Hythane (HCNG) in transport?

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Combifuel project of Graforce GmbH, Berlin [1]

- Plasma-derived HCNG production from wastewater treatment plant
  - up to 60 % H_2 achievable
  - First driver experiences
- Synthetic production of Hythane?

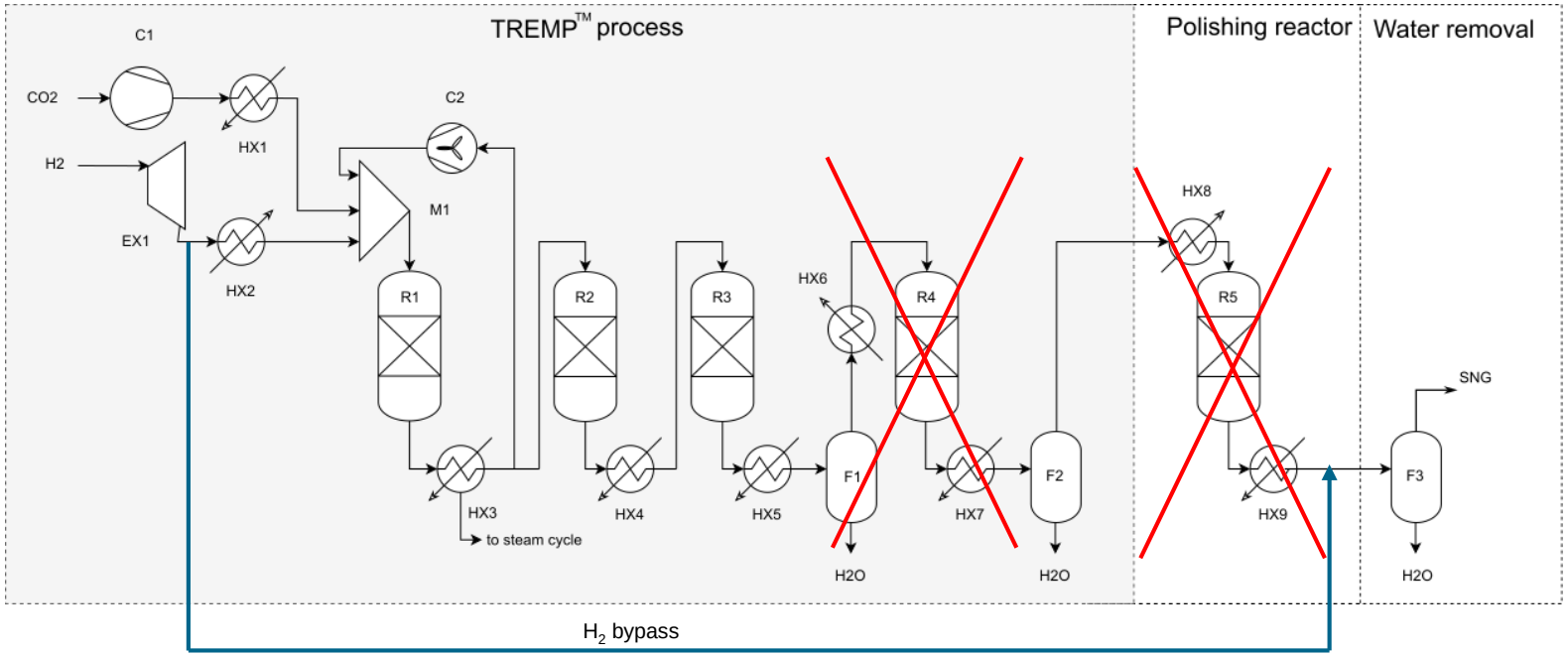
➔ Hythane versus SNG?

[1] Schlussbericht CombiFuel, FKZ 03EIV091A, Graforce GmbH, Synreform GmbH, 2022

Large scale e-Hythane production (HSNG w. 30 vol.% H_2)

Adopted TREMP™ process [2]

[1]



Assumptions in the simulation:

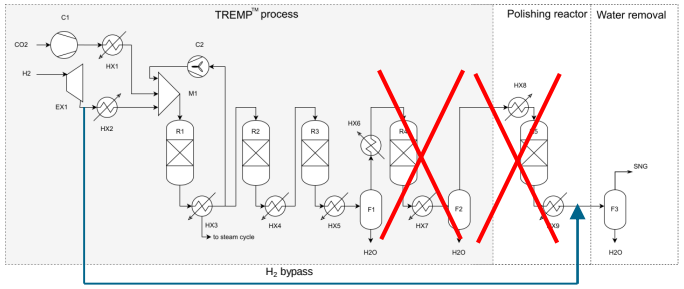
- No impurities
- No side reactions

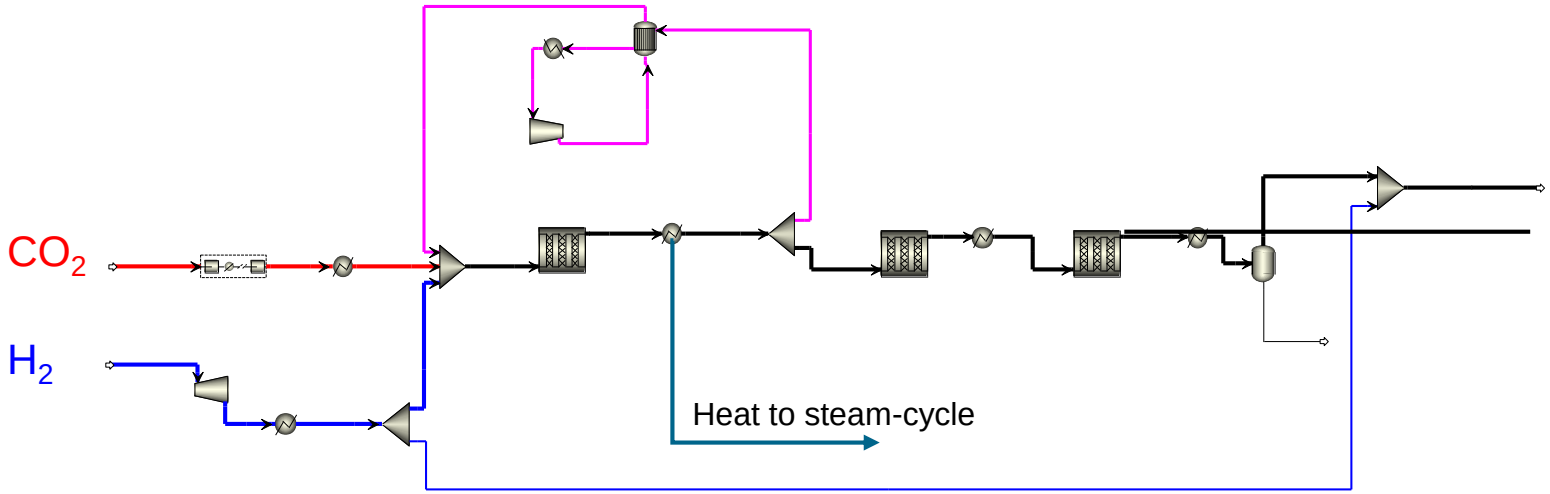
- High temperature in R1
  - Steam cycle
- Composition adjustment
  30 vol.% H_2 content → HSNG-30 [2]
  - Number of reactors reduced
  - Partial H_2 bypass
  - Smaller reactors for same output
  - less H_2O production

[1] Rönsch, S., et al., 2016
[2] Heimann, et al 2023, to be submitted
[3] Schlussbericht CombiFuel, FKZ 03EIV091A, Graforce GmbH, Synreform GmbH, 2022

Large scale e-Hythane production (HSNG-30)

Process simulation Aspen Plus®





Large scale e-Hythane production (HSNG-30)

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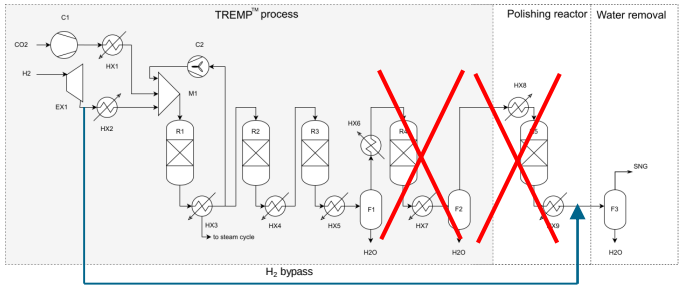
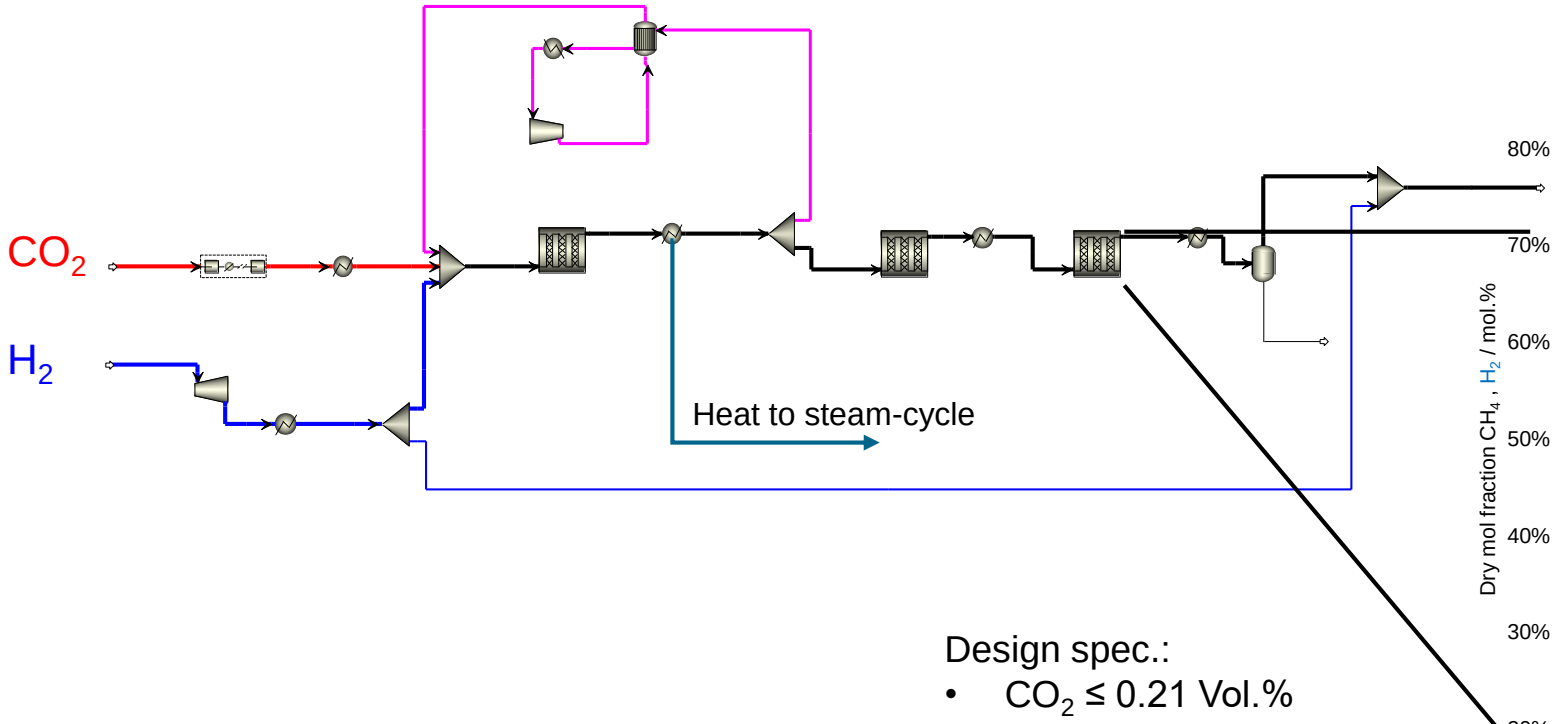
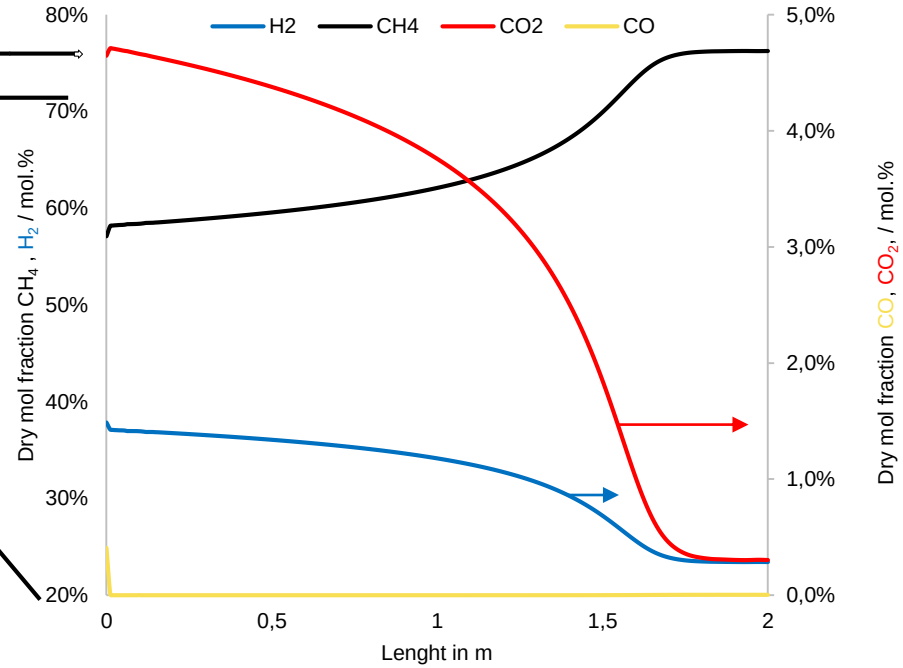
Process simulation Aspen Plus®





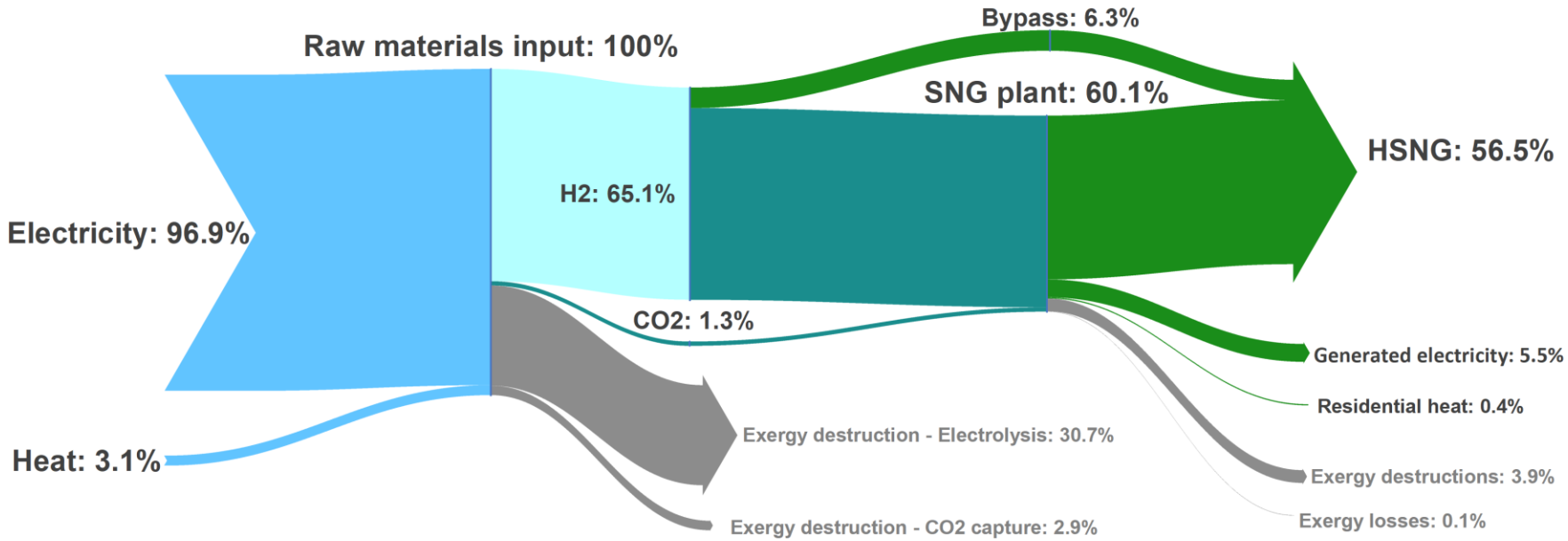
Design spec.:

- $CO_2 \leq 0.21$ Vol.%



Large scale e-Hythane production (HSNG-30)

HSNG production exergy flow [1]



- 1.1 % more power to fuel than SNG
- 5.5 % reused in steam-cycle (compared to 6.1 %)

[1] Heimann, N. et al (2023), to be submitted

ECONOMICAL ASSESSMENT OF SNG / HSNG-30

Comparison of e-fuels

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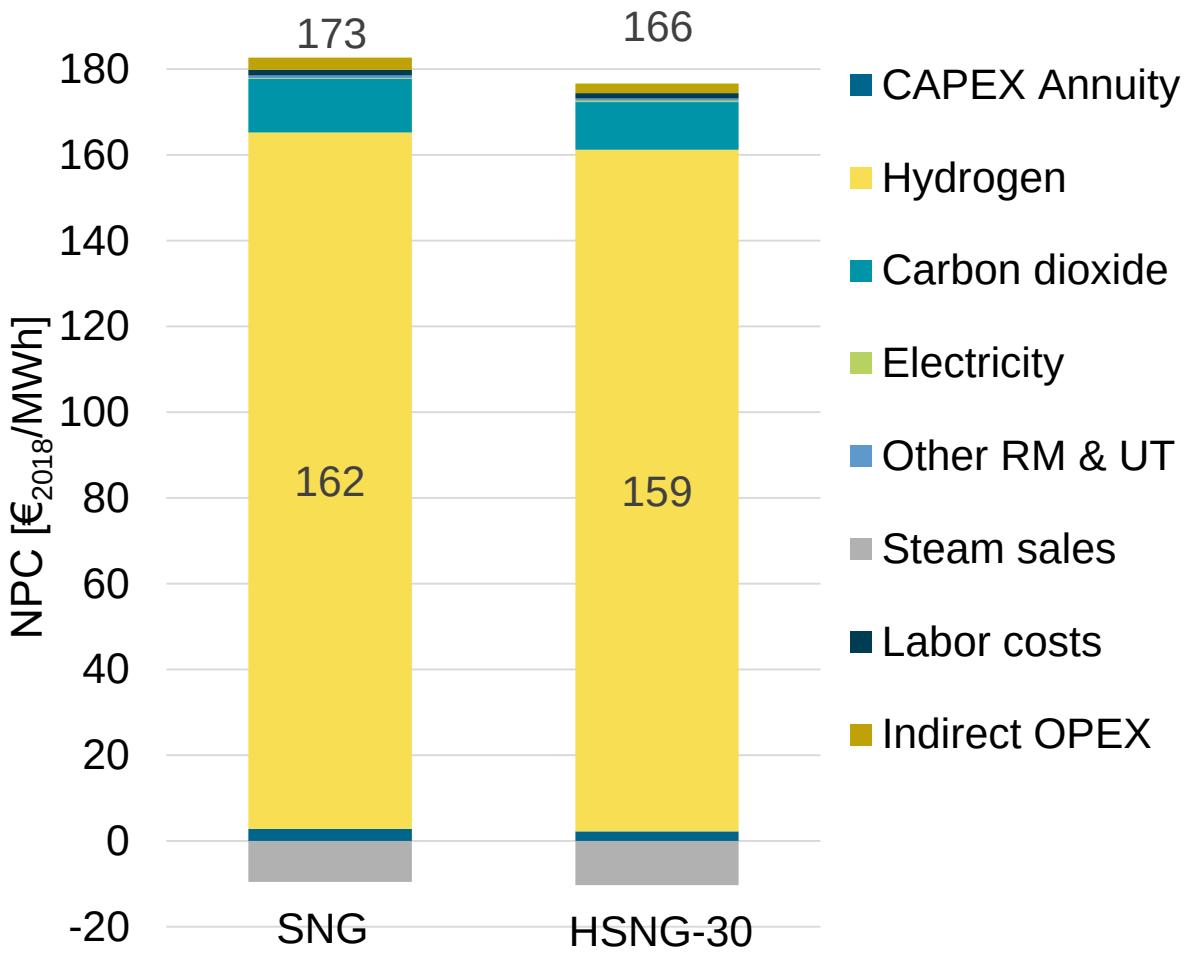
BEniVer Begleitforschung Energiewende im Verkehr

NPC breakdown (electrolyzer excluded)

Basic conditions	[1]
Base Year	2018
Location	Germany
Currency	$€_{2018}$
Electricity input (plant + electrolysis)	300 MW_{el}
Full-load Hours	8,000 h/a
Electricity	56 $€_{2018}$/MWh
H_2 cost	4,742 $€_{2018}$/t
H_2 feed conditions	50 bar; 50 °C
CO_2 cost	69 $€_{2018}$/t
CO_2 feed conditions	3 bar; 25 °C
Interest Rate	5 %
Labor cost	41 $€_{2018}$
Plant lifetime	20 a



[1] Heimann et. al. 2023, to be submitted

Comparison of e-fuels

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NPC breakdown (electrolyzer excluded)

Basic conditions	[1]
Base Year	2018
Location	Germany
Currency	$€_{2018}$
Electricity input (plant + electrolysis)	300 MW_{el}
Full-load Hours	8,000 h/a
Electricity	56 $€_{2018}$/MWh
H_2 cost	4,742 $€_{2018}$/t
H_2 feed conditions	50 bar; 50 °C
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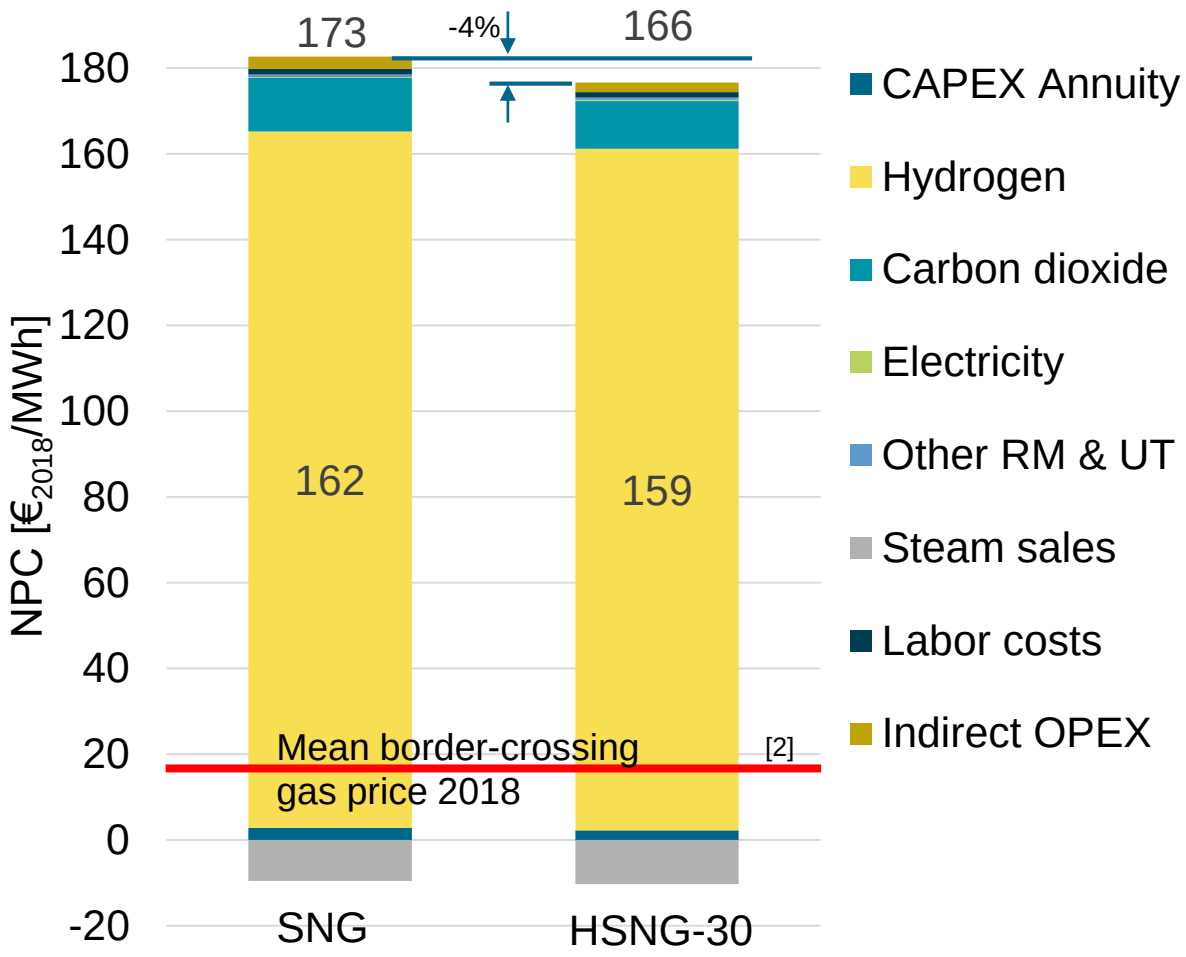

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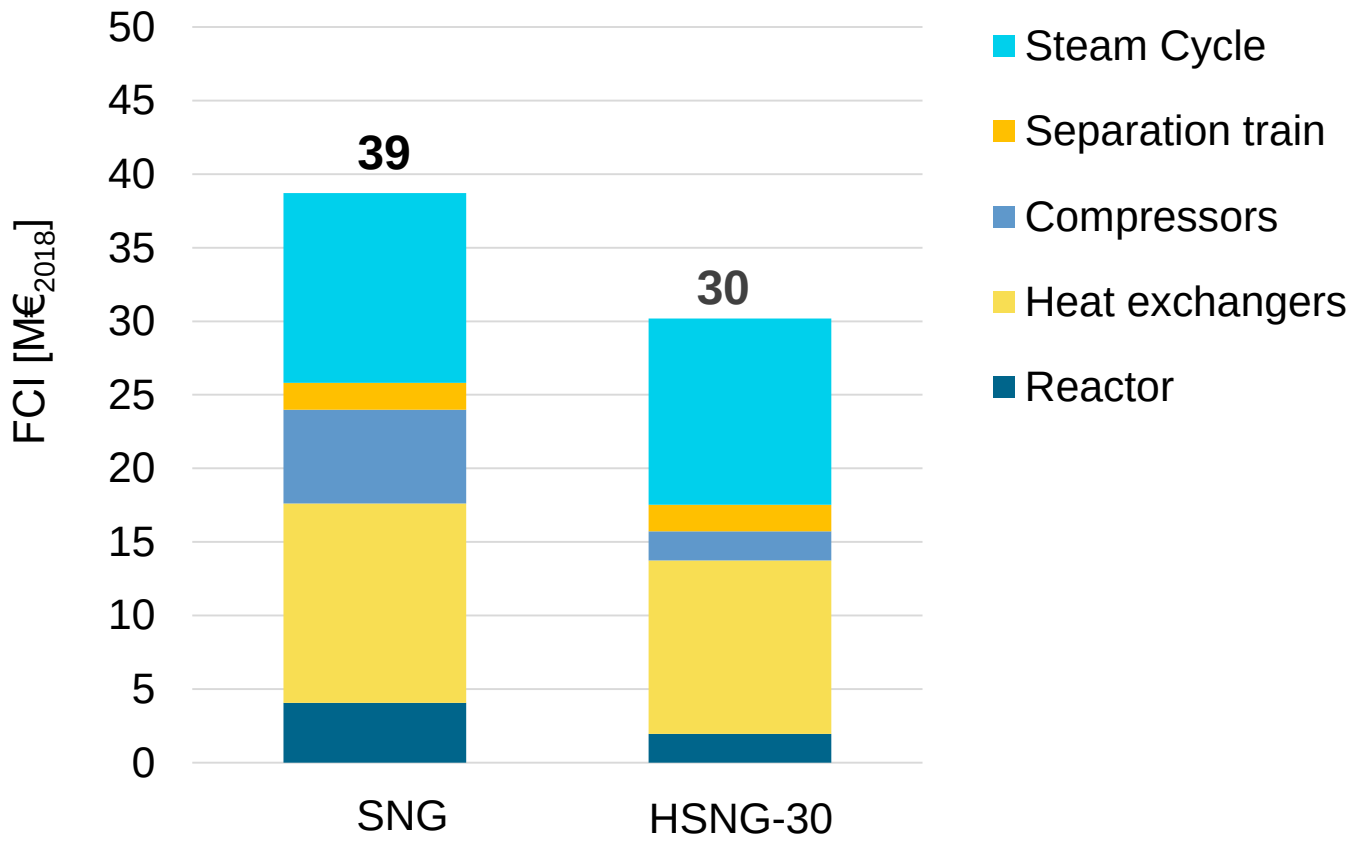
[2] BAFA - Erdgasstatistik

Comparison of e-fuels

FCI breakdown



Comparison of e-fuels

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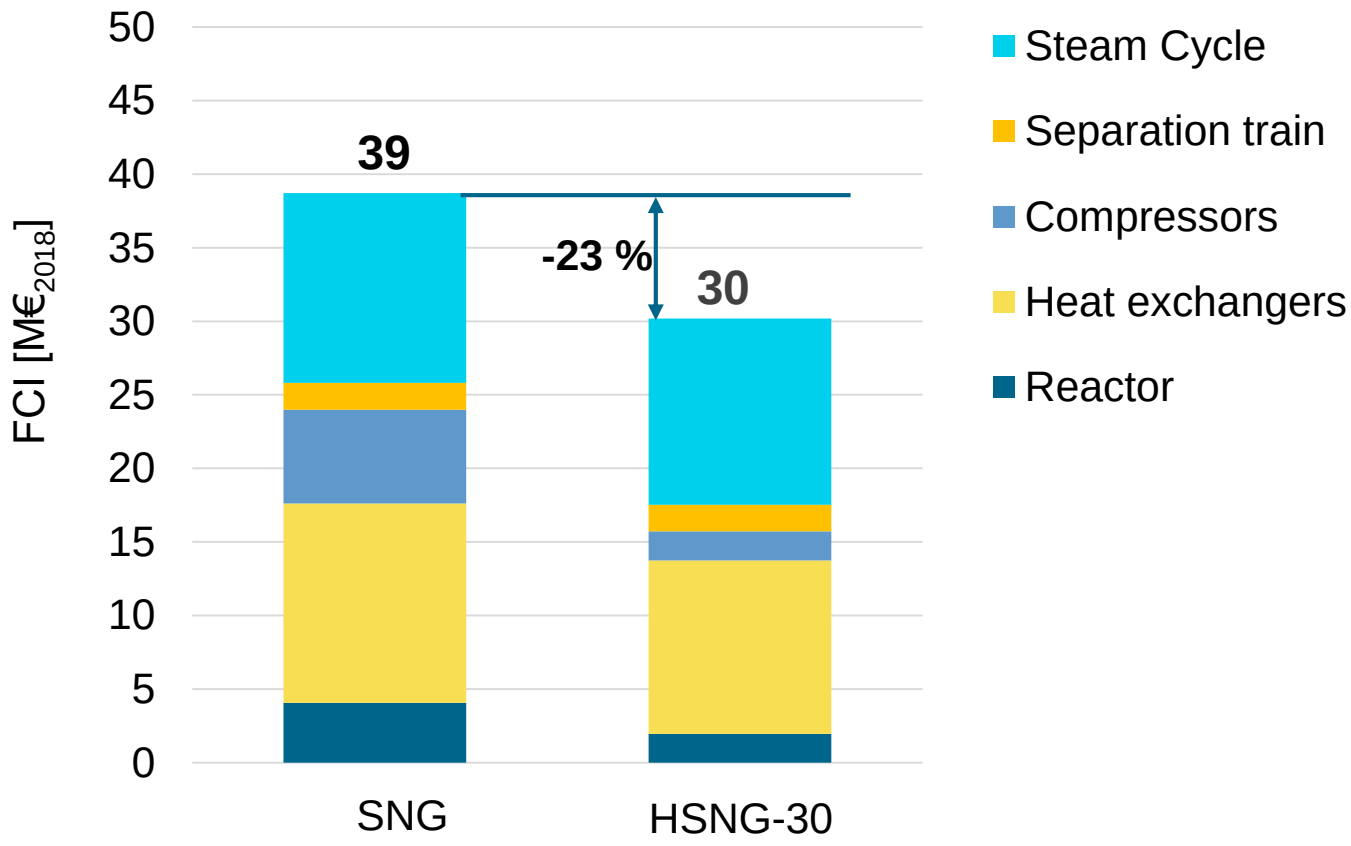
FCI breakdown



FCI reduction for Hythan30 compared to SNG
➔ 23 %

Significant reduction in compressors and reactors

steam cycle, heat-exchangers remain significant FCI

Comparison of e-fuels

Sensitivity of NPC: electricity price

BEniVer
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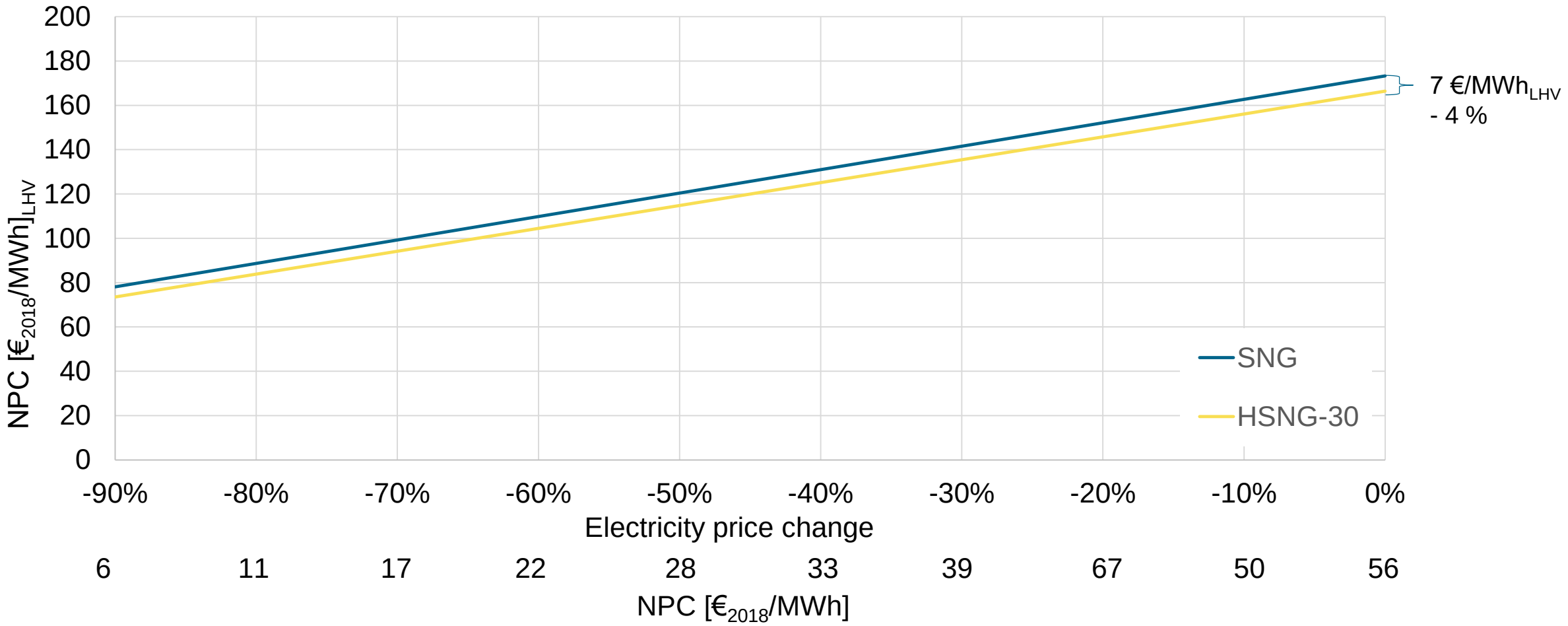

Comparison of e-fuels

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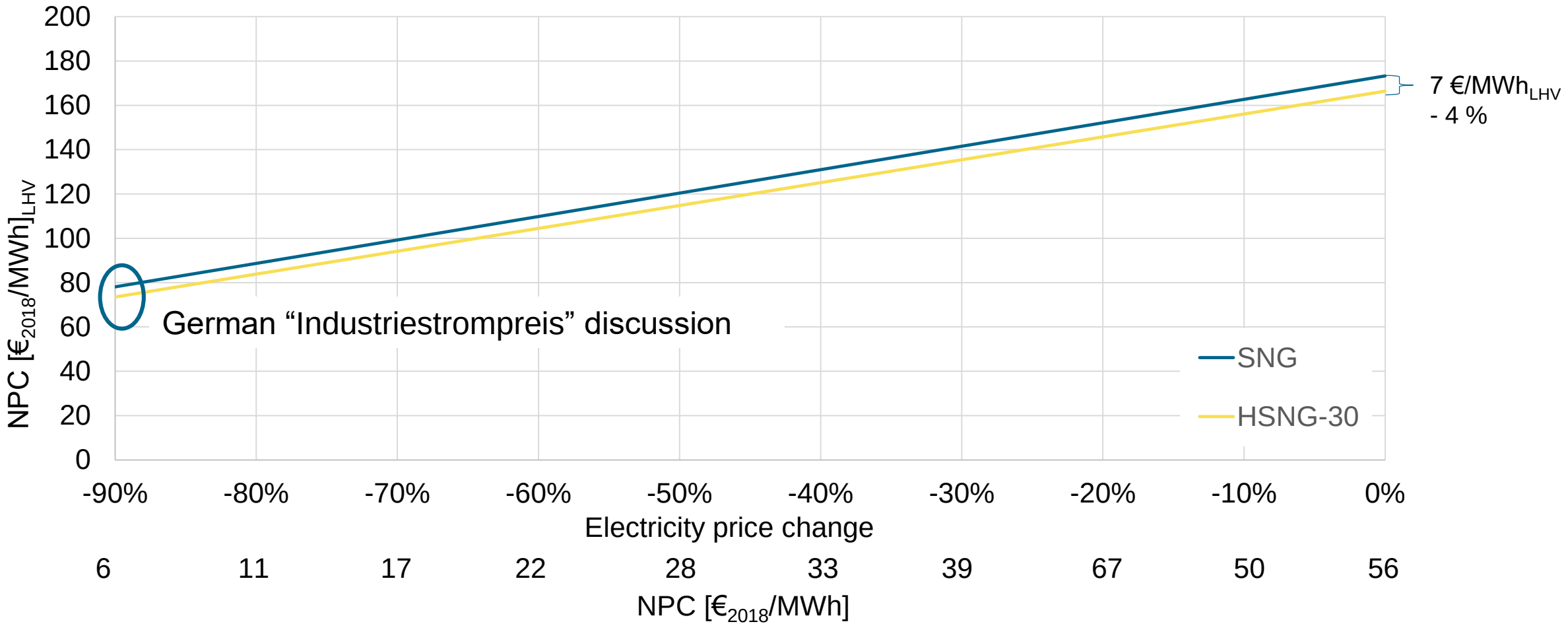
Sensitivity of NPC: electricity price



Comparison of e-fuels

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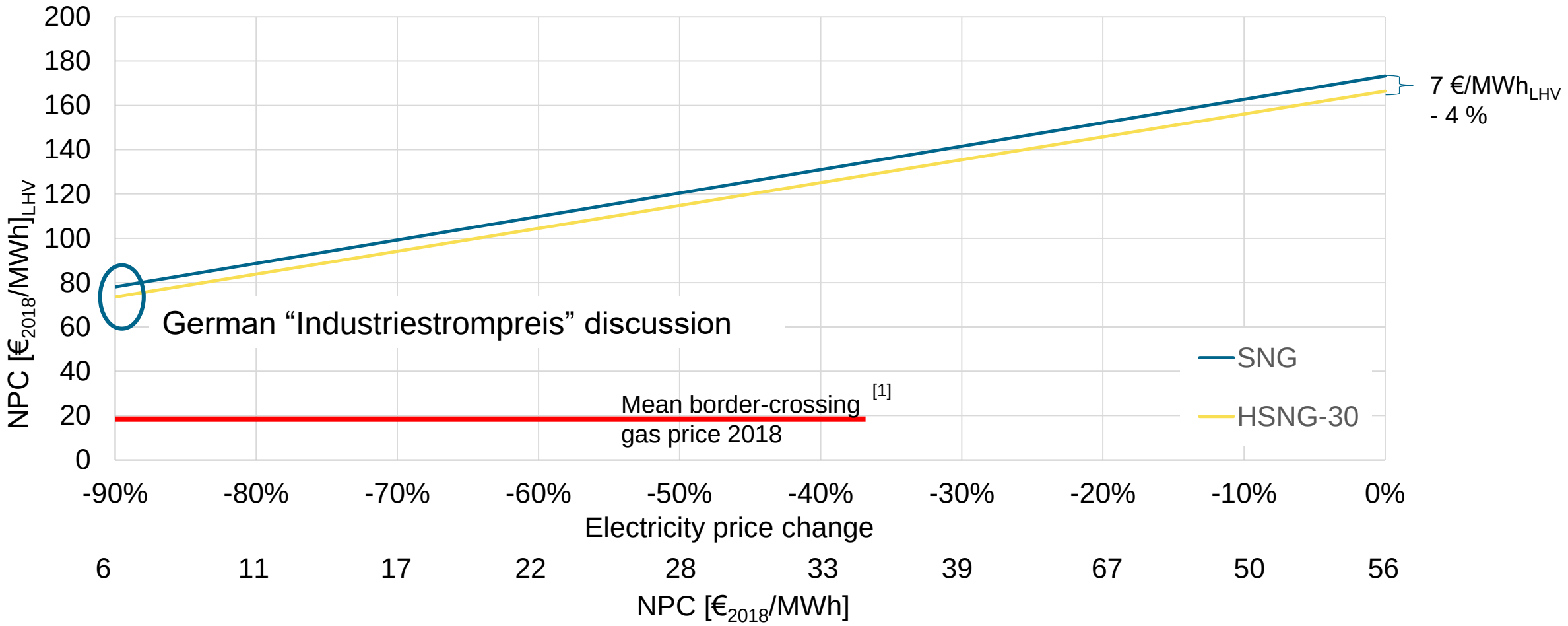

[1] BAFA - Erdgasstatistik

APPLICATION EXPERIENCE

Practical experience using HCNG in transport [1]

Combifuel project of Graforce GmbH, Berlin

- Application on test fleet
  - Modification of gasoline passenger car (tank system of VW Caddy 2.0 EcoFuel, 2009)
  - Unmodified CNG passenger car (VW Caddy 1.4 TGI, 2020)

[1] Schlussbericht CombiFuel, FKZ 03EIV091A, Graforce GmbH, Synreform GmbH, 2022

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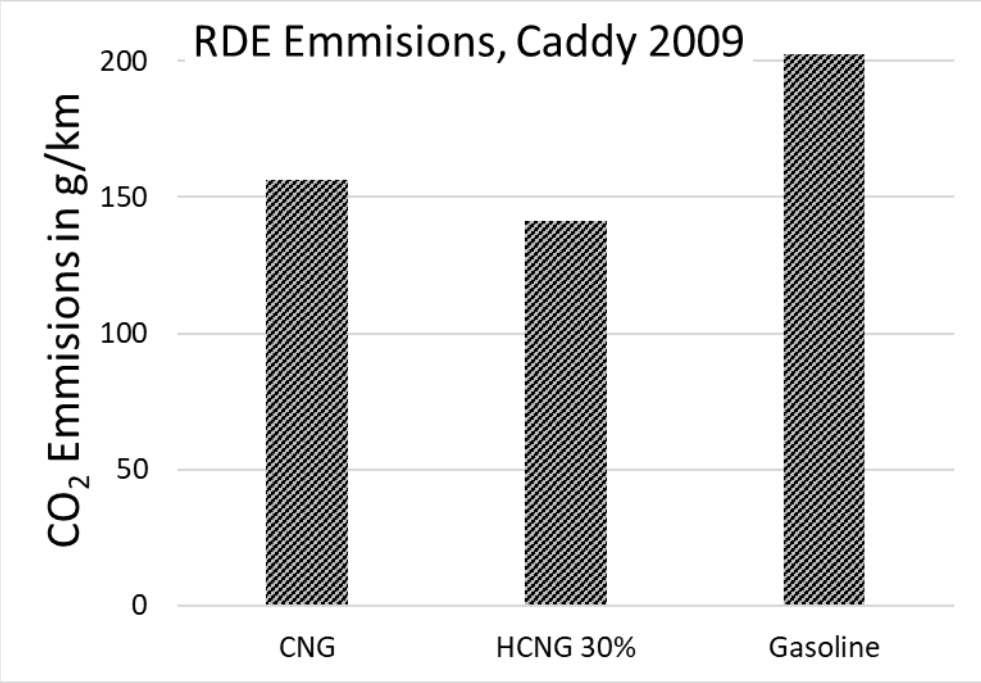
  - Modification of gasoline passenger car (tank system of VW Caddy 2.0 EcoFuel, 2009)
  - Unmodified CNG passenger car (VW Caddy 1.4 TGI, 2020)
- Emission measurement program
  - Motor power testing station (HTW Berlin)
  - Portable Emission Measurement System (real life emissions, TU Berlin)
  - OEM tests (VW Innovation Group, Wolfsburg)

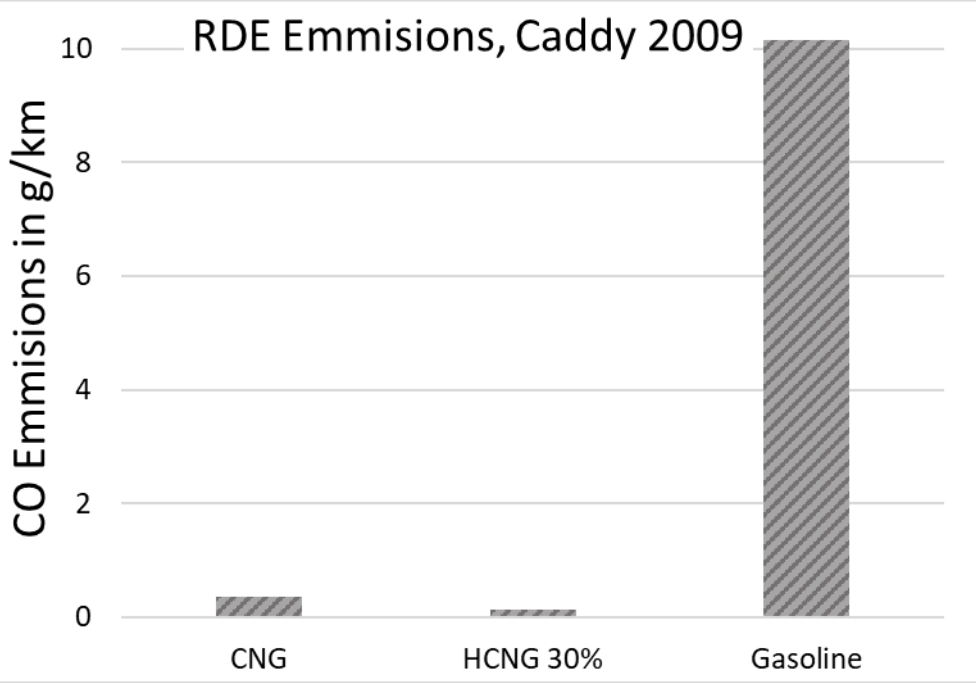
[1] Schlussbericht CombiFuel, FKZ 03EIV091A, Graforce GmbH, Synreform GmbH, 2022

Practical experience using HCNG in transport [1]

Combifuel project of Graforce GmbH, Berlin

- Power decrease 3.3 % HCNG-30 versus CNG @ 3 % less fuel consumption
- Emission reduction for CO_2, CO, HC, increase for NOx





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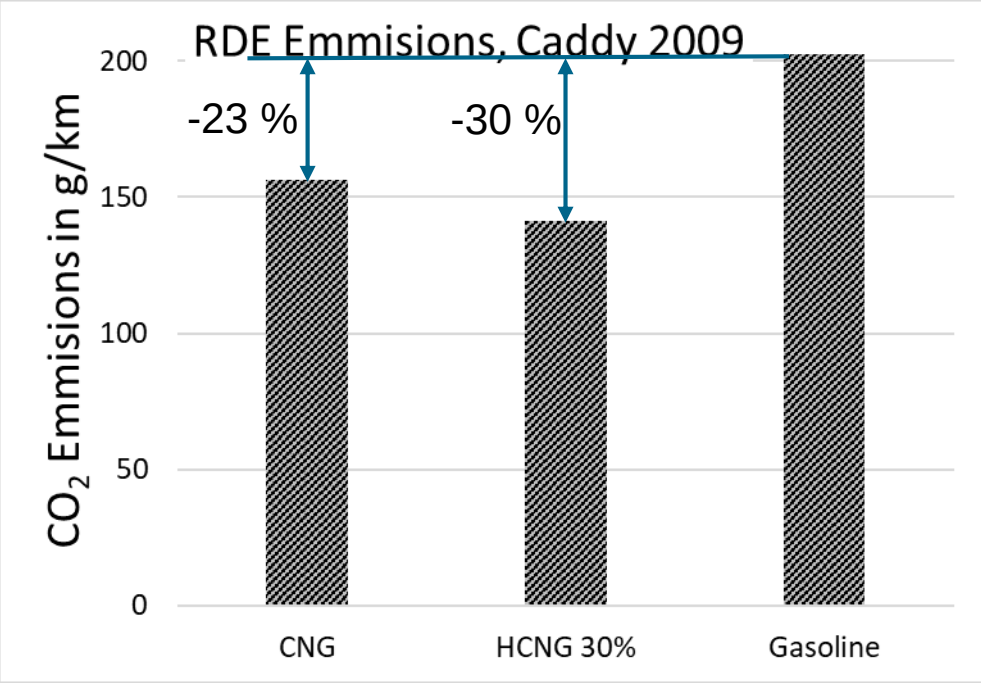

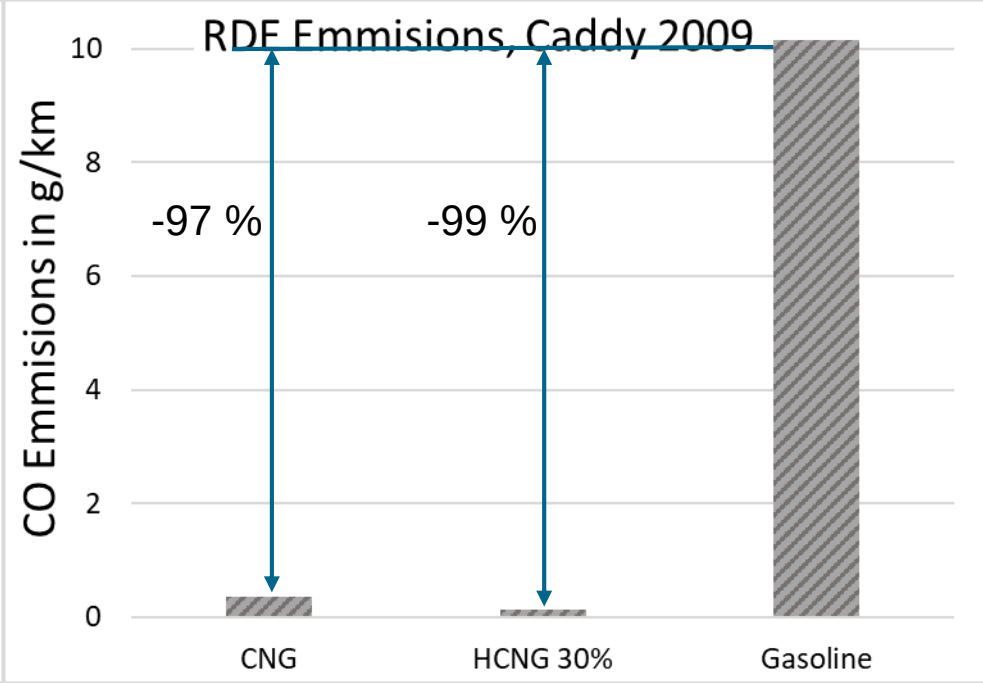

[1] Schlussbericht CombiFuel, FKZ 03EIV091A, Graforce GmbH, Synreform GmbH, 2022

SUMMARY, CONCLUSION

Global e-fuel assessment – Hythane included

Comparing generic fuels / designer fuels

	SNG	HSNG-30	MeOH	FT	OME_{3-5}	DMC	MeFo
η_{PtF} [%]	57	58	53	40	42	47	52
NPC [€$_{2018}$/MWh$_{LHV}$]	173	166	204	321	360	329	298
Application parameter examples	• Heavy truck • Drivetrain retrofit • …	• Combifuel • Heavy truck • Drivetrain retrofit • …	• Us… China • Low vap… •	• Certified …stainable	• Better combusti on	• Better combustion • Blending	• Better combustion • Blending

HSNG-30 can be produced with highest efficiency
cheapest e-fuel of EiV
Ecological assessment still pending
Application assessment just started

Opportunities and challenges for electro-fuels in future aviation

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Summary

- Sustainable transport ➔ cheap, sustainable, scalable fuels required
- Cheapest carbon containing e-fuels are methane and hythane
- HSNG-30 (compared to SNG)
  - Efficiency: +1 %
  - NPC: -3.9 %
  - FCI: - 23 %
  - less emissions in production and drive tests

➔Outlook: Identical HSNG spec. for both heat and transport applications

Transparent, standardized DLR assessment methodology available

Tuesday, 19. September 2023

Session Climate and energy - Hydrogen and fuels II

17 – 21 September 2023 · City Cube Berlin · Germany

ECCE 14 & ECAB 7

14th European Congress of Chemical Engineering

7th European Congress of Applied Biotechnology

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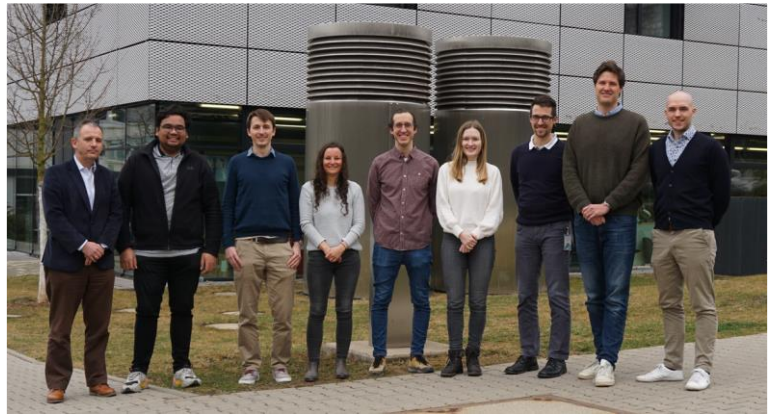
THANKS TO THE TEAM.
THANK YOU FOR YOUR ATTENTION.
QUESTIONS?

Techno- economic evaluation of the synthetic production of compressed natural gas (SNG) and hydrogen compressed natural gas (HSNG) for the future sustainable transport in Germany



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