E-FUEL OPTIONS IN PRIVATE TRANSPORT, AVIATION AND SHIPPING

Techno economic and environmental assessment

Ralph-Uwe Dietrich, Sandra Adelung, Felix Habermeyer, Simon Maier, Moritz Raab, Yoga Rahmat, Francisco M. Rossel, Julia Weyand
(DLR e.V., www.DLR.de/tt)

DLR

Techno-economic & ecological assessment (TEEA) @ DLR

BEniVer
Begleitforschung Energiewende im Verkehr

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

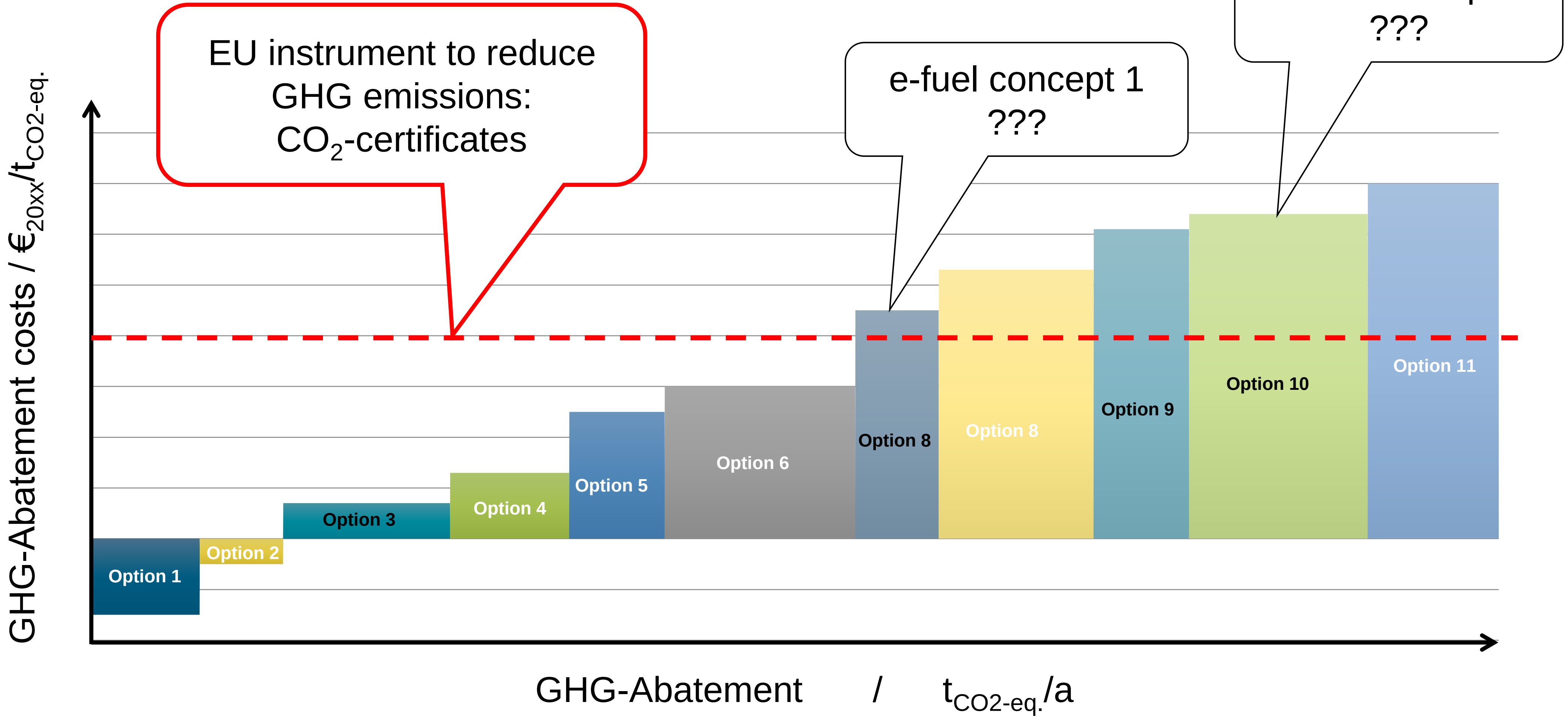
- EiV: funding 99 Mio. € | 16 projects | 100+ partner
- Renewable electricity based fuels for aviation, road transport and shipping

Cluster	Fuels in focus	Application
C3-Mobility	synth. Gasoline, DME, $OME_{3\text{-}5}$, Methanol, Butanol, Octanol	
CombiFuel	Hythan (Hydrogen + Methane)	
E2Fuels	Methanol, $OME_{3\text{-}5}$, Methan, Hythan	
FlexDME	Dimethylether (DME)	
ISystem4EFuel	synth. Diesel, $OME_{3\text{-}5}$	
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	

- 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

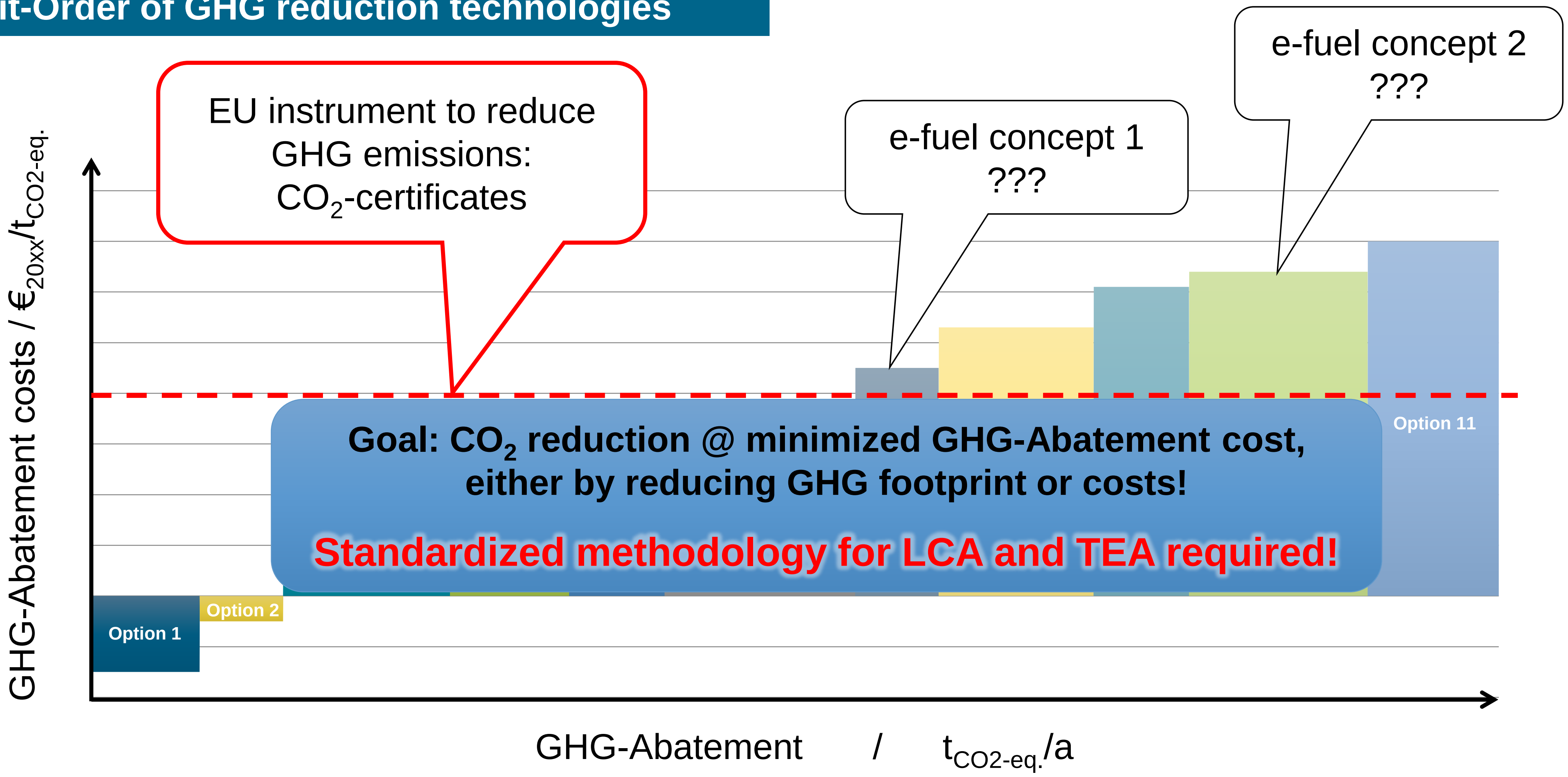
Assessment of Energy transition in the transport sector

Merit-Order of GHG reduction technologies



Assessment of Energy transition in the transport sector

Merit-Order of GHG reduction technologies

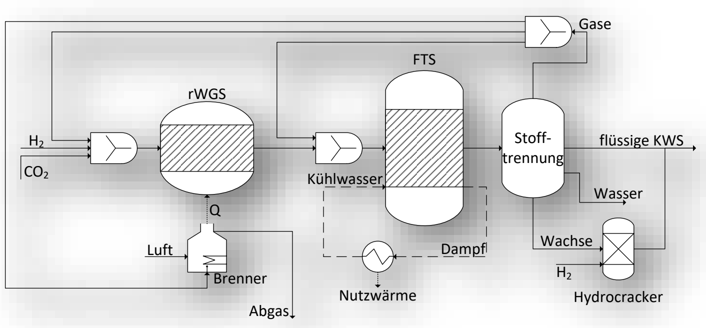


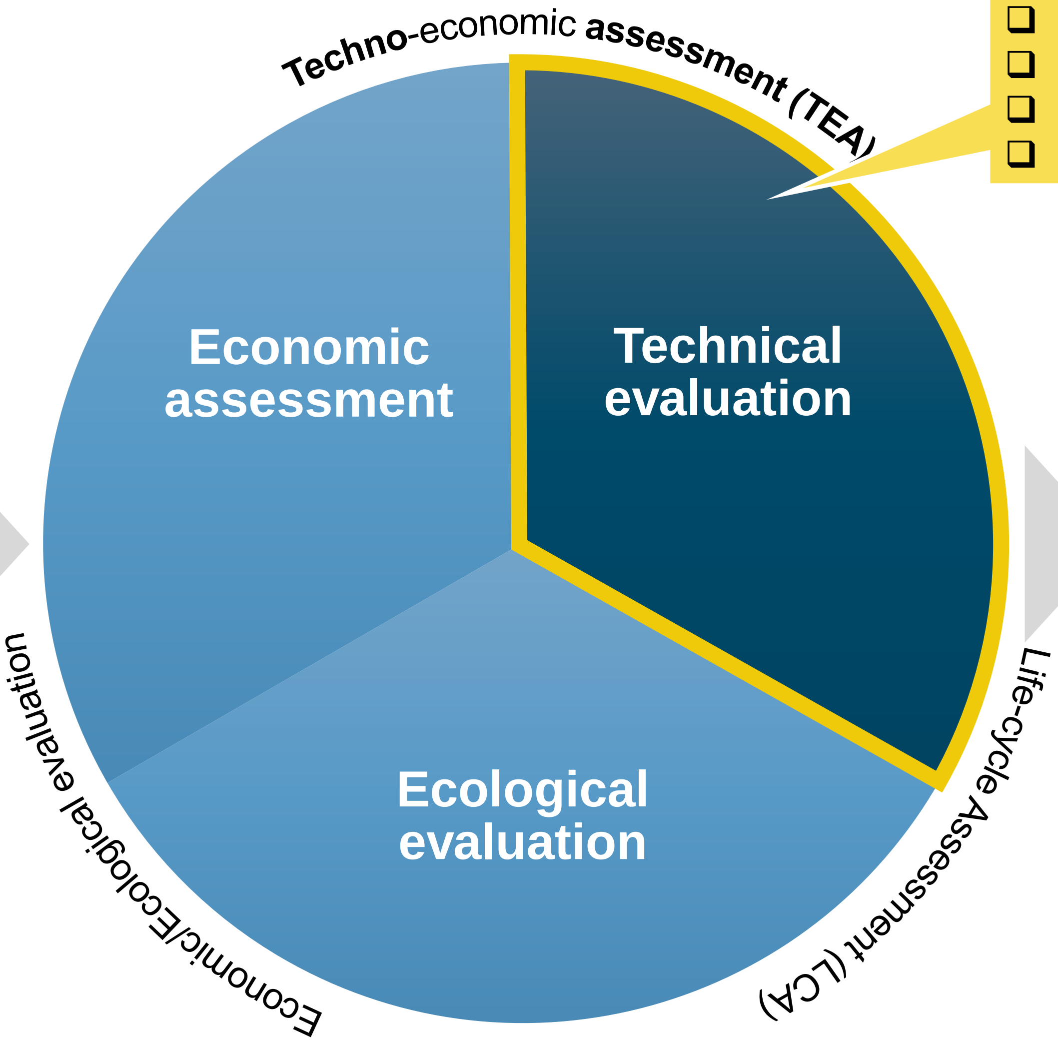
Goal: CO_2 reduction @ minimized GHG-Abatement cost, either by reducing GHG footprint or costs!

Standardized methodology for LCA and TEA required!

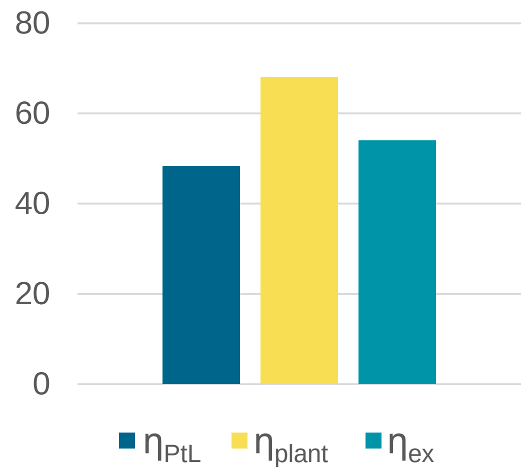
Techno-Economic and ecological assessment

TEEA methodology @ DLR





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



Techno-Economic and ecological assessment
TEEA methodology @ DLR

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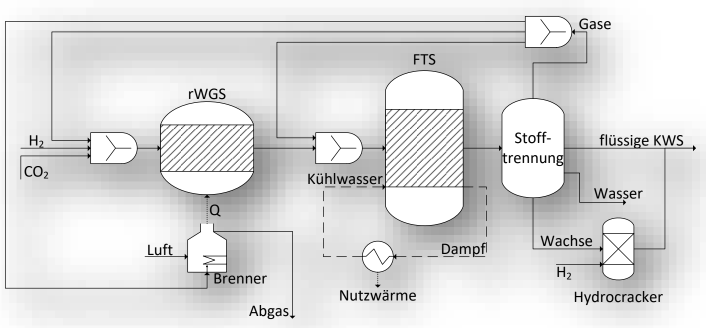
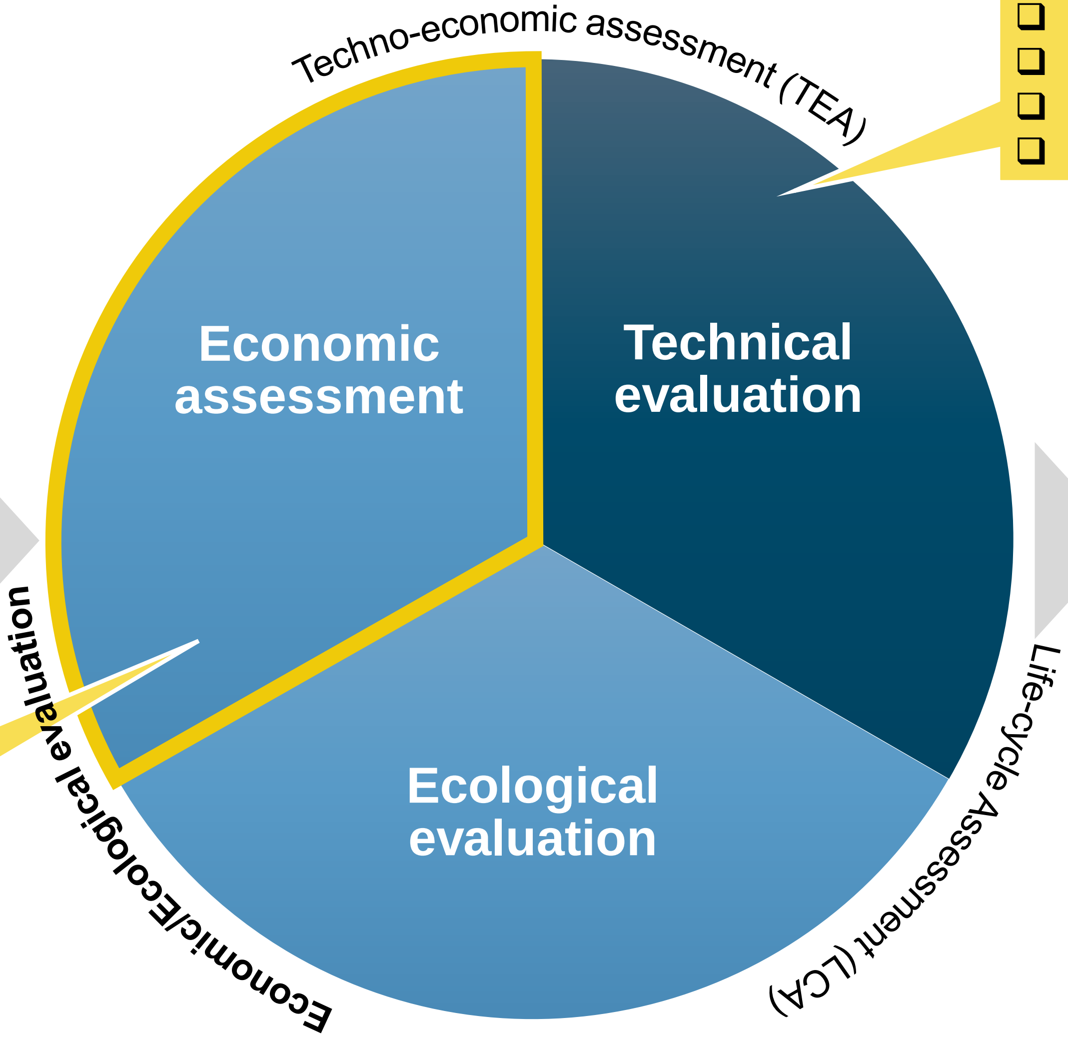
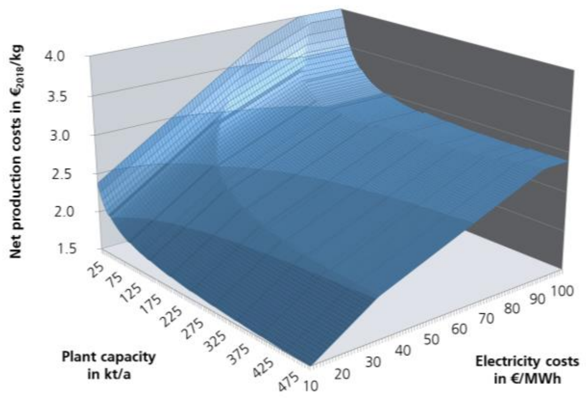
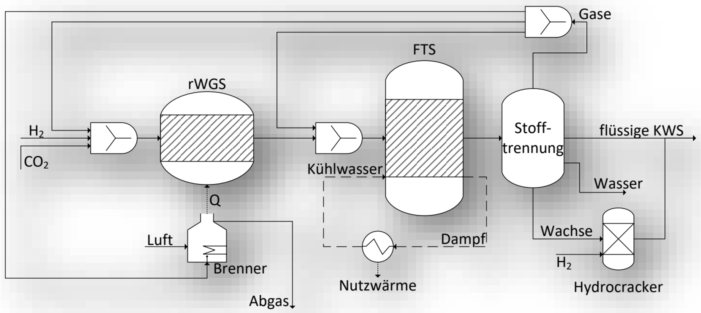


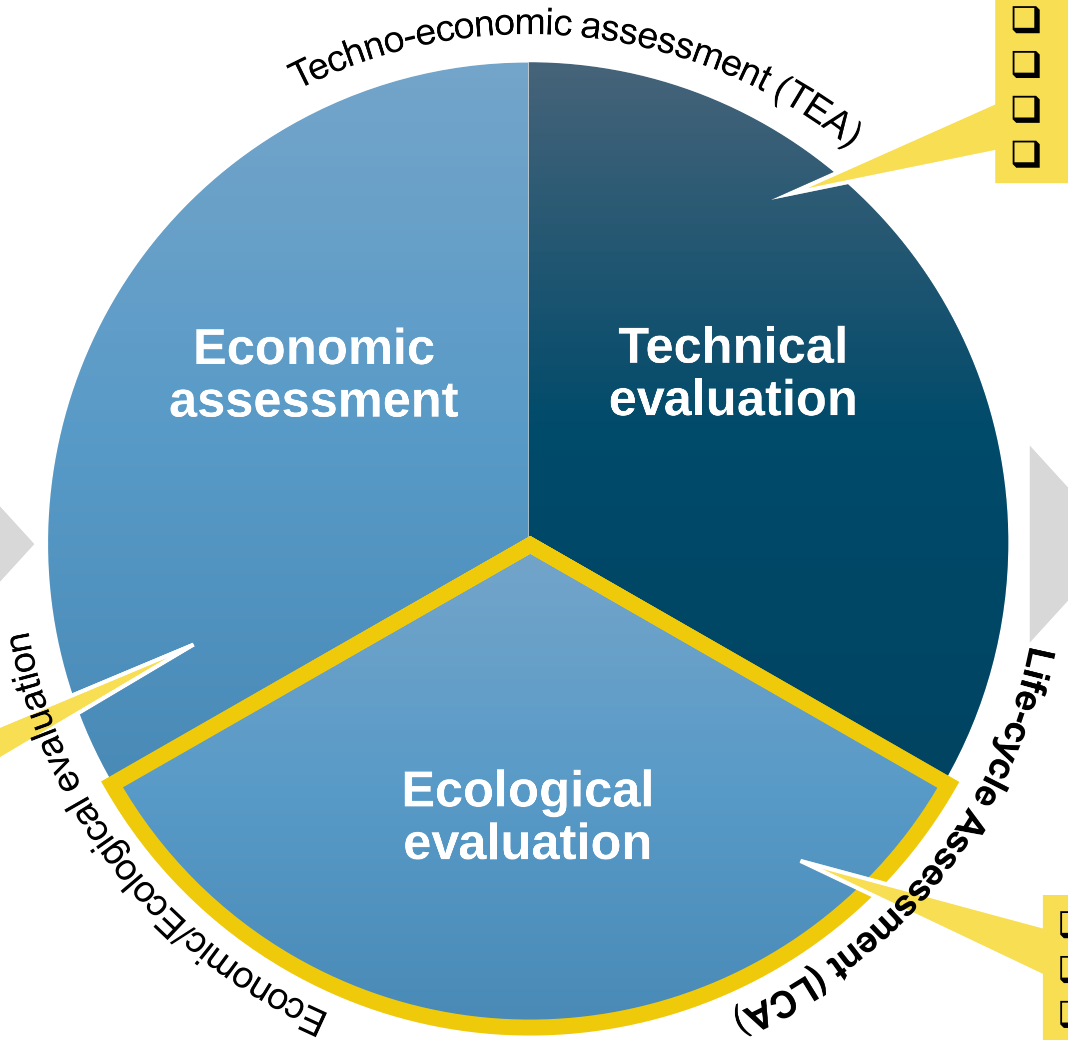




- ❑ CAPEX, OPEX, NPC
- ❑ Sensitivity analysis
- ❑ Identification of most economic feasible process design

Techno-Economic and ecological assessment (TEEA)





- ❑ Efficiencies (X-to-Liquid, Overall)
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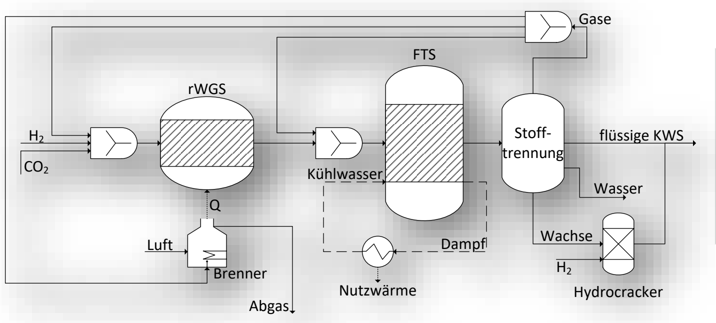
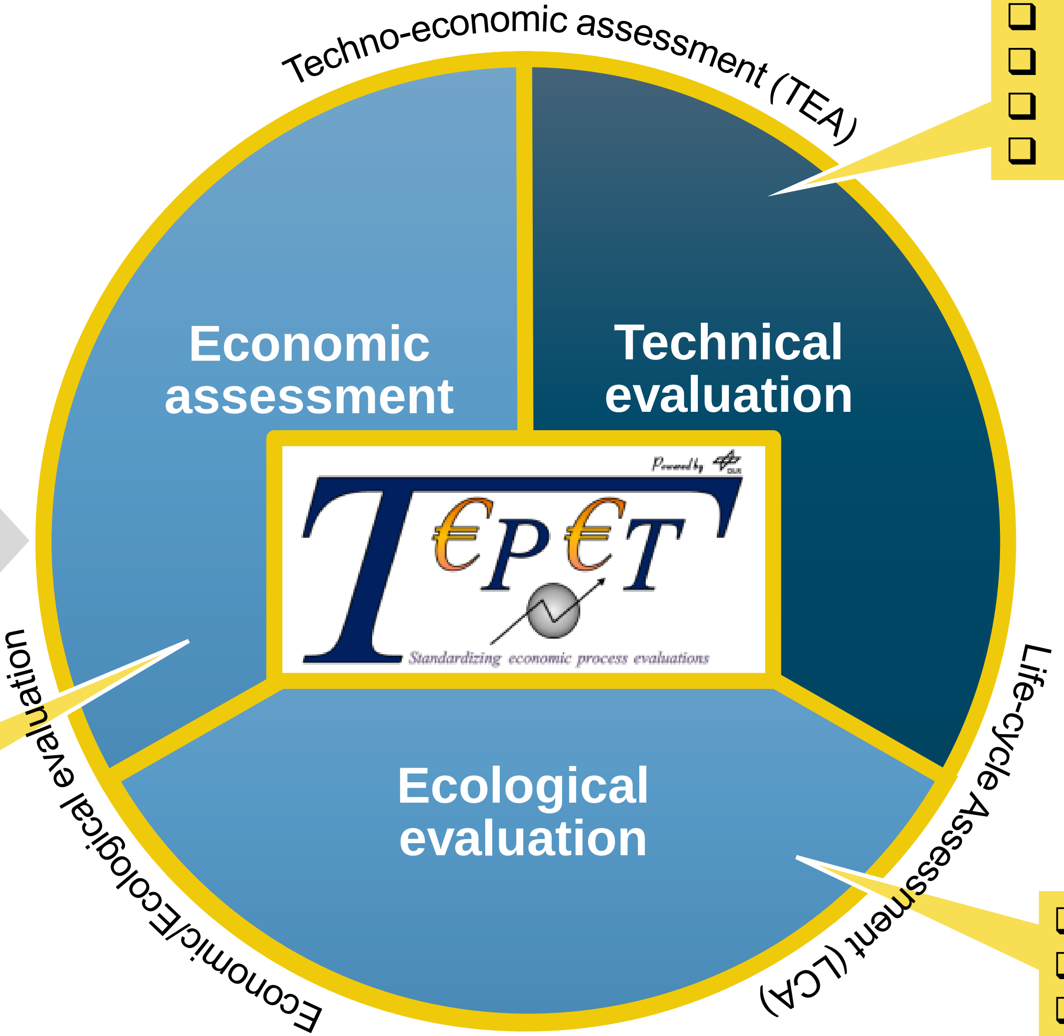
- ❑ GWP
- ❑ Other impact categories
- ❑ Identification of impact drivers

Techno-Economic and ecological assessment
TEEA methodology @ DLR





- ❑ Efficiencies (X-to-Liquid, Overall)
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- ❑ CAPEX, OPEX, NPC
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- ❑ Identification of most economic feasible process design

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

TEEA @ DLR

1. Step

Literature survey

Exchange with project partners

Simulation & Process evaluation

2. Step

Detailed process simulation

Variation of process parameters

Aspen-TEPET-Brightway2-Link

Material and energy balance data

aspentech Aspen Plus®

- Validation
- Upscaling
- Technical optimization

3. Step

Techno-economic and ecological evaluation

TEPET [1]

Brightway [2]

ecoinvent [3]

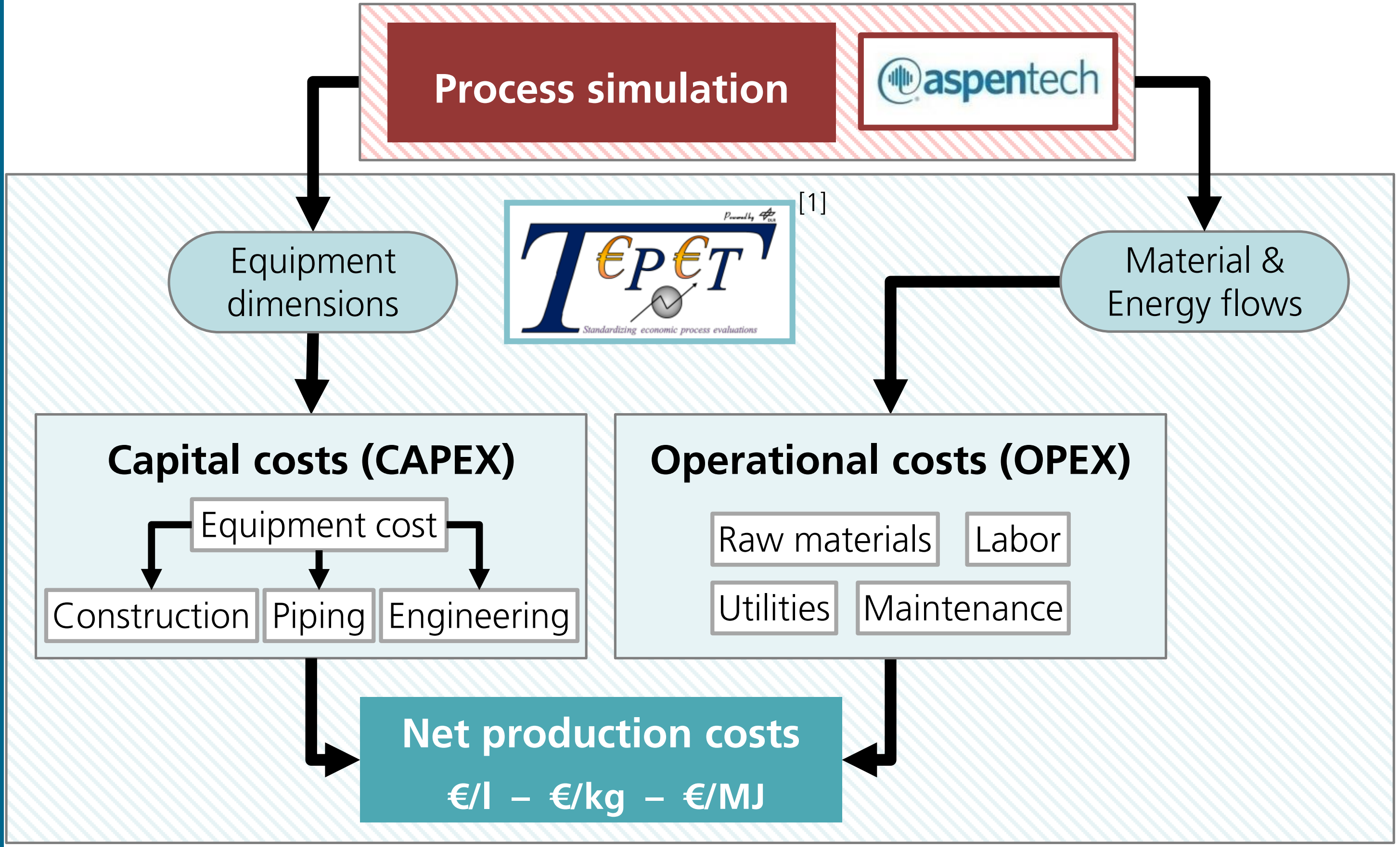
- Economic calculation
- Sensitivity analysis
- Cases studies
- Heat integration (HEN)
- Exergy analysis
- LCA

4. Step

Identifying crucial process parameters

[1] Albrecht et al. (2016) - A standardized methodology for the techno-economic evaluation of alternative fuels – A case study, Fuel, 194: 511-526
[2] Mutel (2017) - Brightway: An open source framework for Life Cycle Assessment, Journal of Open Source Software, 2(12): 236
[3] Wernet, G et al. (2016) – The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, 21(9): 1218–1230.

TEEA tool TEPET @ DLR (part 1)



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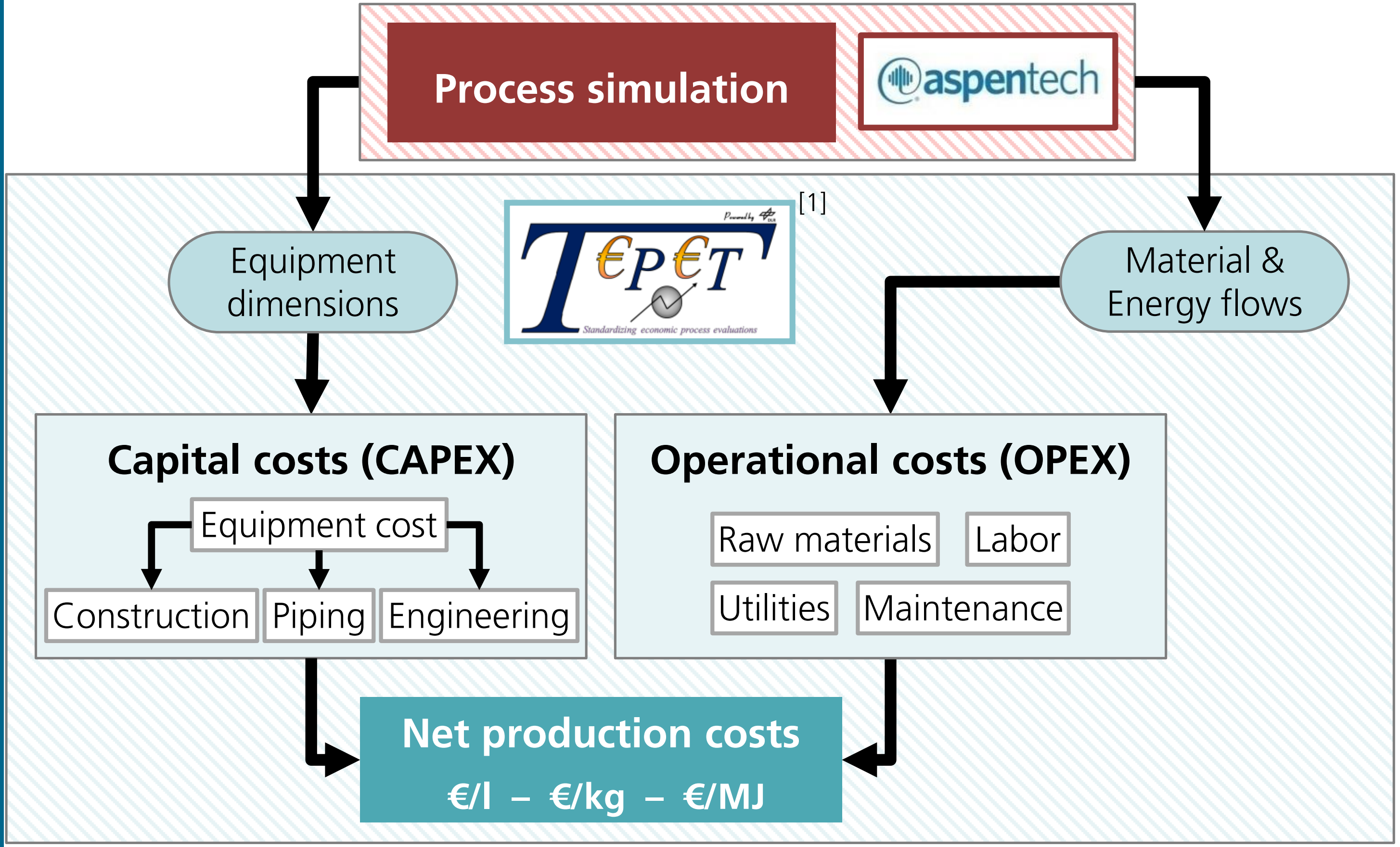
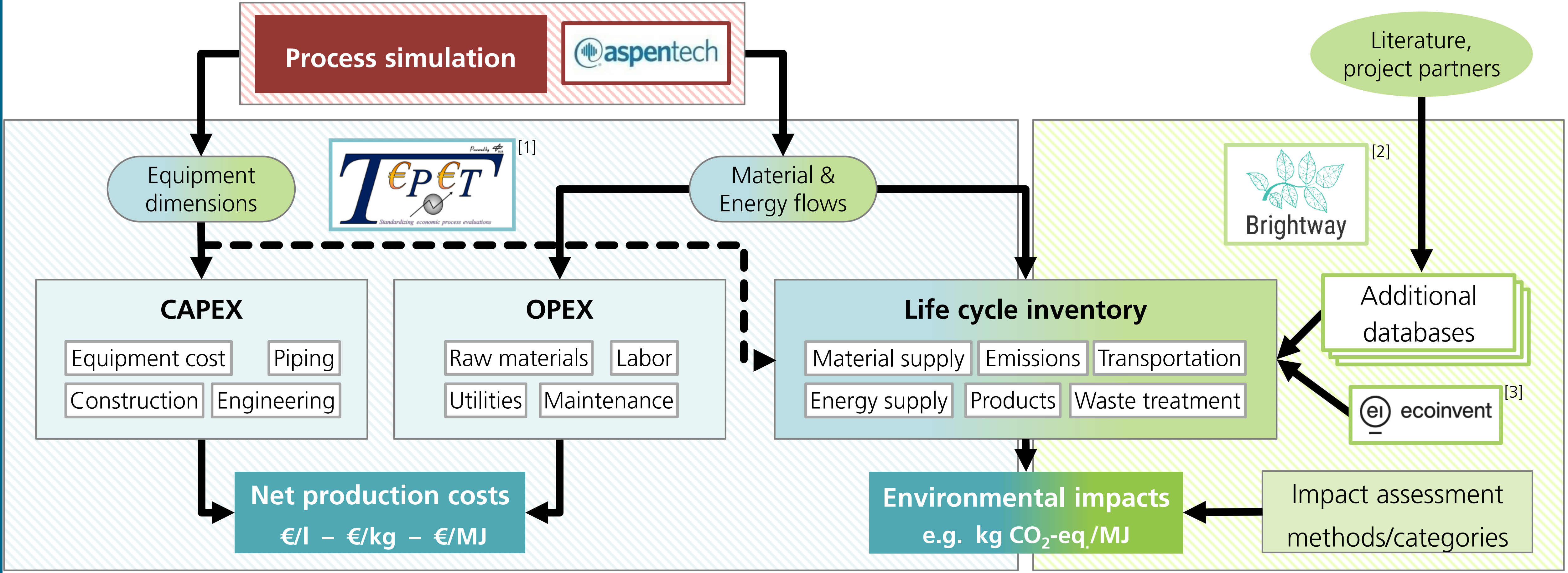


- Adapted from **best-practice chem. eng. methodology**
- Meets AACE class 3-4, Accuracy: **+/- 30 %**
- **Year specific** using annual CEPCI Index
- Automated interface for **seamless integration, heating networks, …**
- Easy sensitivity studies for **each** parameter
- Learning curves, economy of scale,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

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

TEEA tool TEPET @ DLR (part 2)



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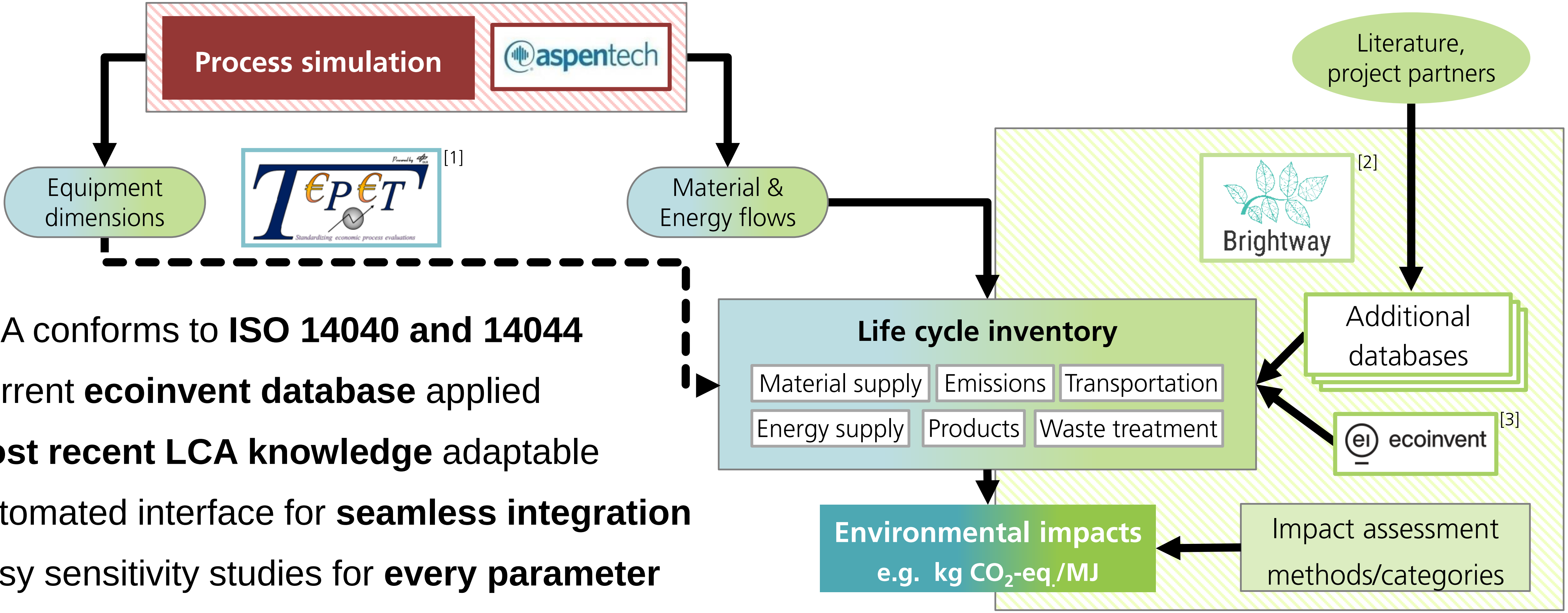

- LCA conforms to **ISO 14040 and 14044**
- Current **ecoinvent database** applied
- **Most recent LCA knowledge** adaptable
- Automated interface for **seamless integration**
- Easy sensitivity studies for **every parameter**

[1] Albrecht et al. (2016) - A standardized methodology for the techno-economic evaluation of alternative fuels – A case study, Fuel, 194: 511-526
[2] Mutel (2017) - Brightway: An open source framework for Life Cycle Assessment, Journal of Open Source Software, 2(12): 236
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TEEA @ DLR

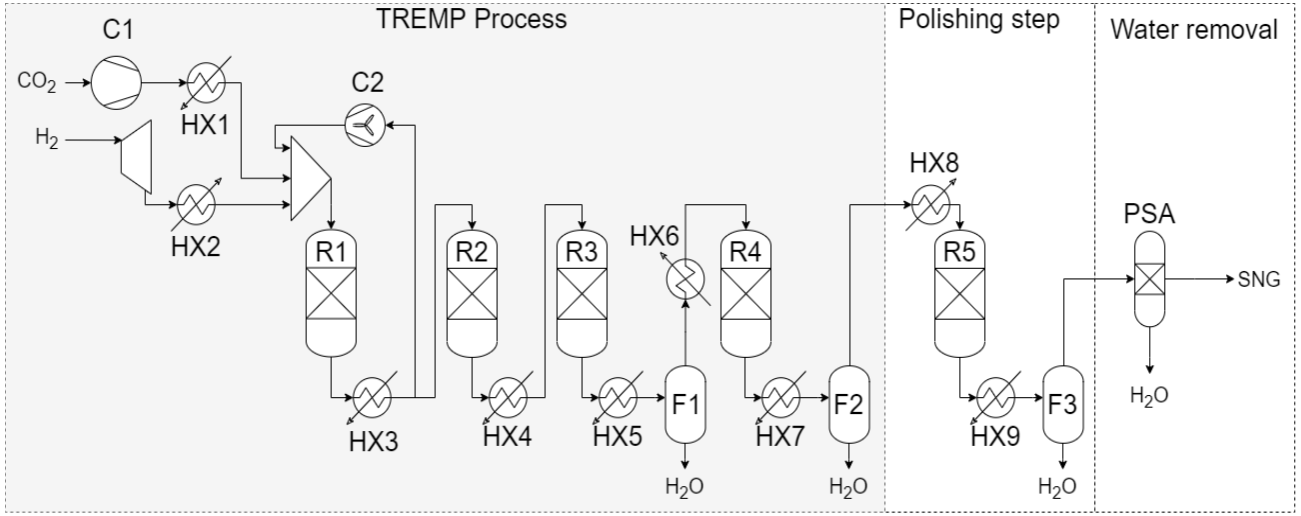
ASSESSMENT OF „GENERIC“ FUELS

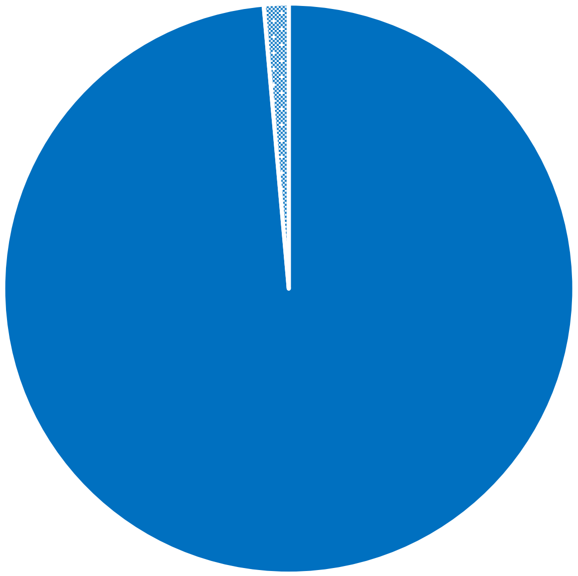
Techno-Economic and ecological assessment

DLR

Methane (97.7% CH_4, 2% H_2)

Energy demand : 300.0 MW_e – 15.9 MW_e*
Methane prod. : 169.1 MW_{LHV}



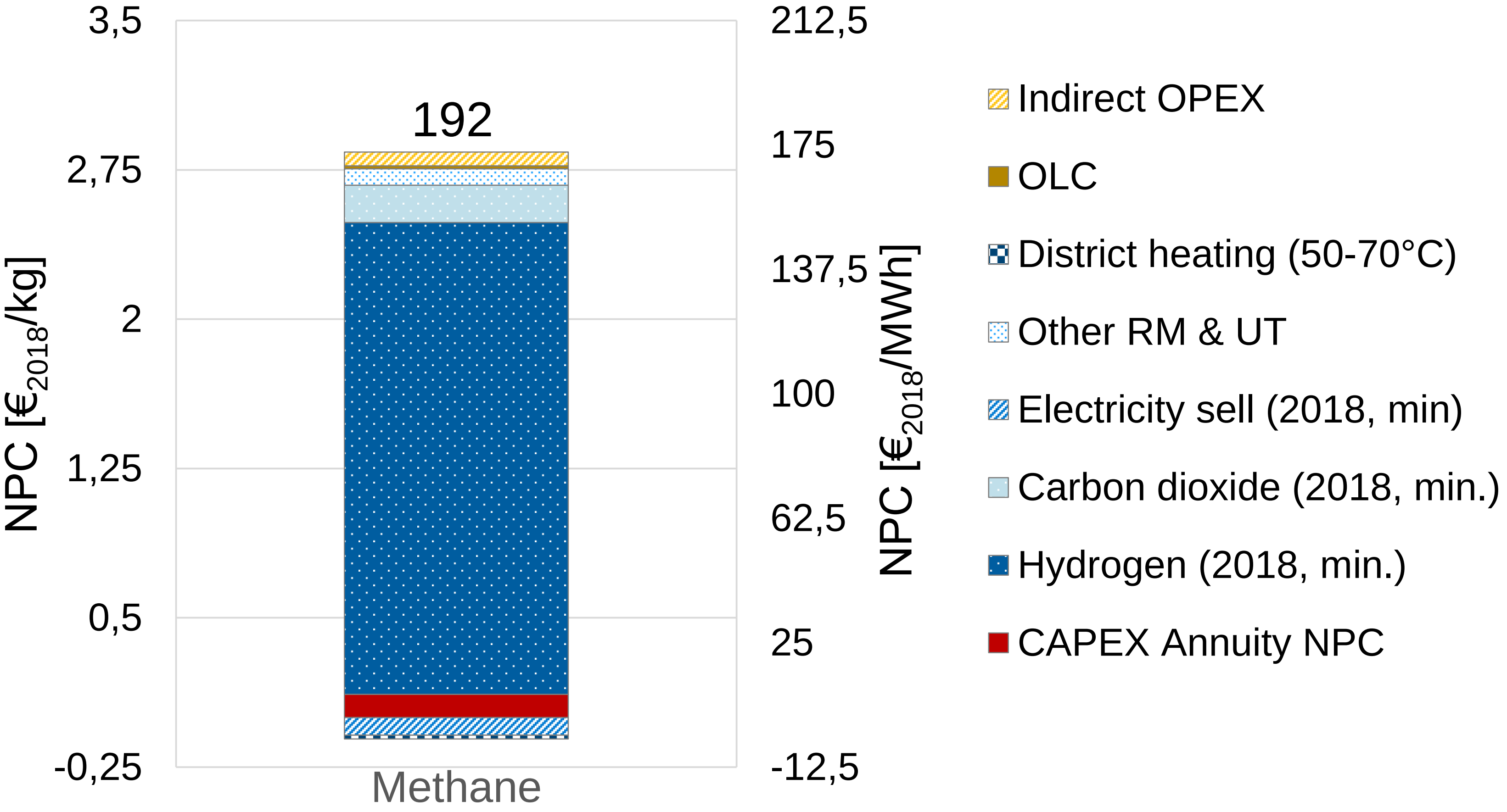


$$\eta_{PtG} = \frac{169.1\mathrm{MW}_{LHV}}{300.0\ MW_e - 15.9\ MW_e} = \mathbf{59.5}\ \%$$

* Steam cycle integrated into the TREMP Process

Techno-Economic and ecological assessment

Methane (97.7% CH_4, 2% H_2)



BEniVer

Begleitforschung Energiewende im Verkehr

Assumptions		V3.2*
Basis year		2018
Full-load hours		8’000
CO_2	€/t	69
H_2	€/t	4’742
Electricity	€/MWh	55.7

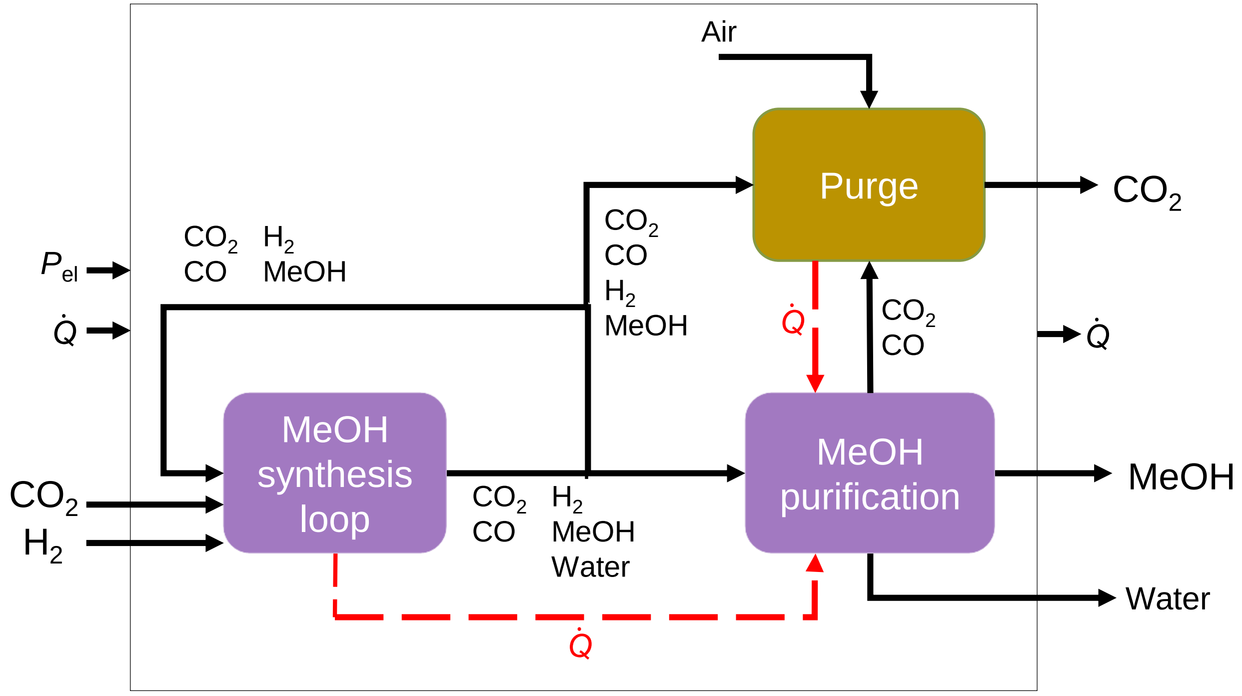
*BEniVer general assumptions:
- 300 MW_e power input
- generic costs - minimum 2018

- H_2 is the cost driver
- NPC_{NG} fossil:
  ➔ 305 [$€_{2022}$/MWh][1]
  ➔ 36 [$€_{2020}$/MWh][2]

[1] www.bundesnetzagentur.de/.../220826_gaslage.pdf, → Future September/22 NL, 26.08.22
[2] https://ycharts.com/indicators/europe_natural_gas_price, 06.2022

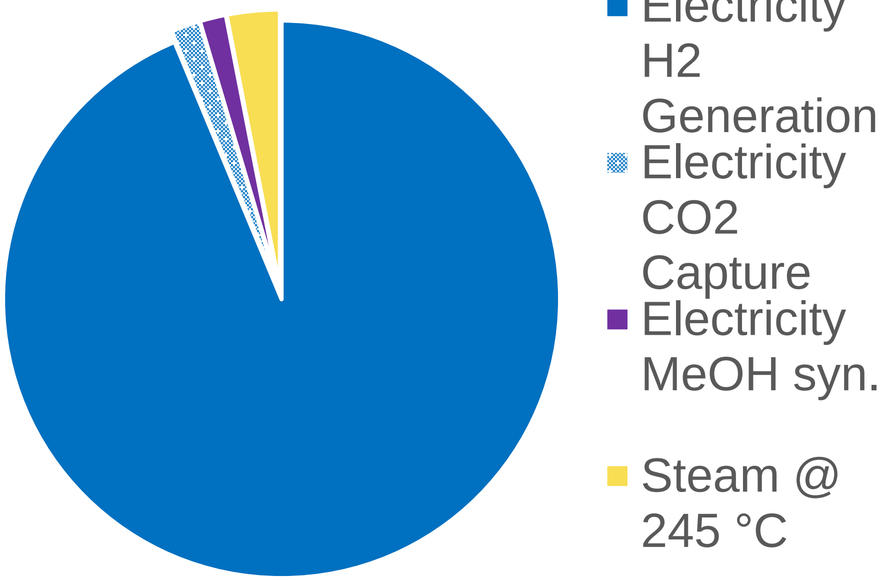
Techno-Economic and ecological assessment

Methanol (99,85 wt.% MeOH)



Energy demand : 298.7 MW_e + 9.5 MW_{th}*

MeOH prod. : 158.5 MW_{LHV}



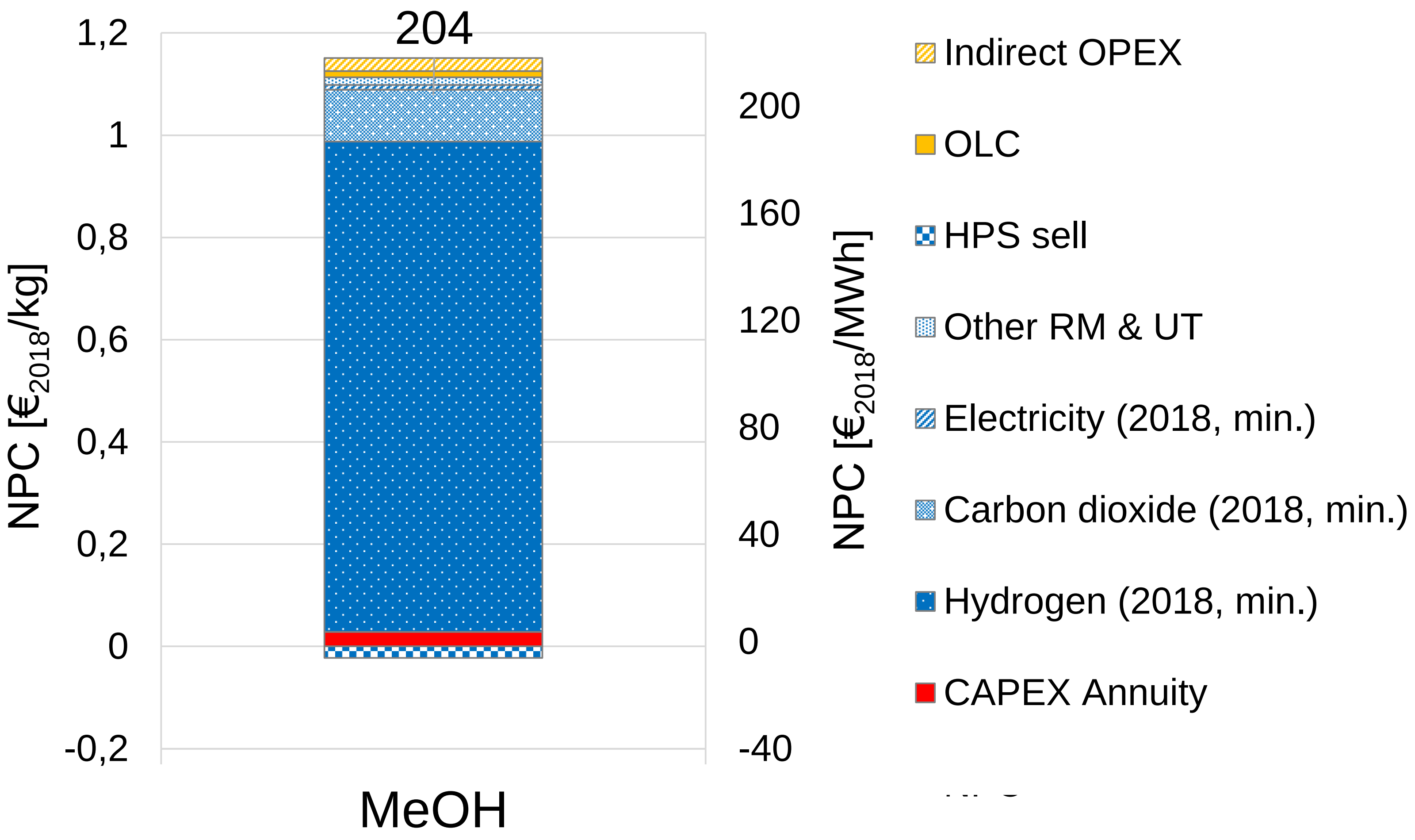
$$\eta_{PtL} = \frac{158.5\ MW_{LHV}}{298.7\ MW_e} = \mathbf{53.1}\ \% \qquad \eta_{XtL} = \frac{158.5 MW_{LHV}}{298.7\ MW_e + 9.5\ MW_{th}} = \mathbf{51.4}\ \%$$

* External steam supplement assumed

Techno-Economic and ecological assessment

DLR

Methanol (99,85 wt.% MeOH)



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*BEniVer general assumptions:
- 300 MW_e power input
- generic costs - minimum 2018

- H_2 is the cost driver
- NPC_{MeOH} fossil[1]:
  ➔ ca. 120 [$€_{2022}$/MWh]
  ➔ ca. 60 [$€_{2020}$/MWh]

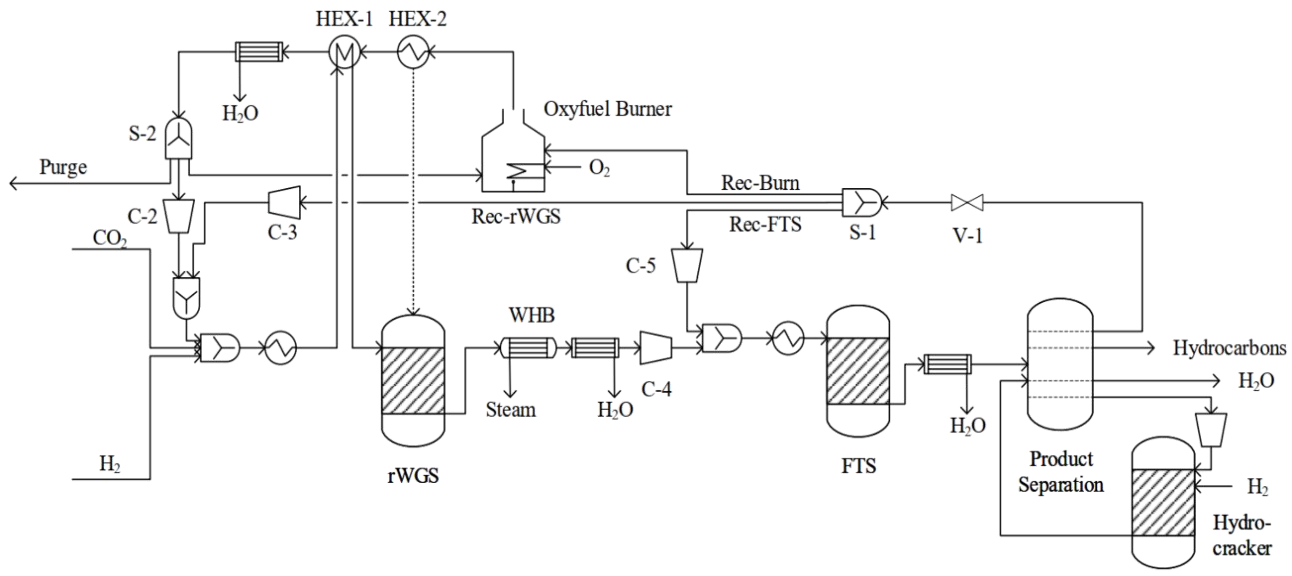
[1] www.methanol.org/methanol-price-supply-demand

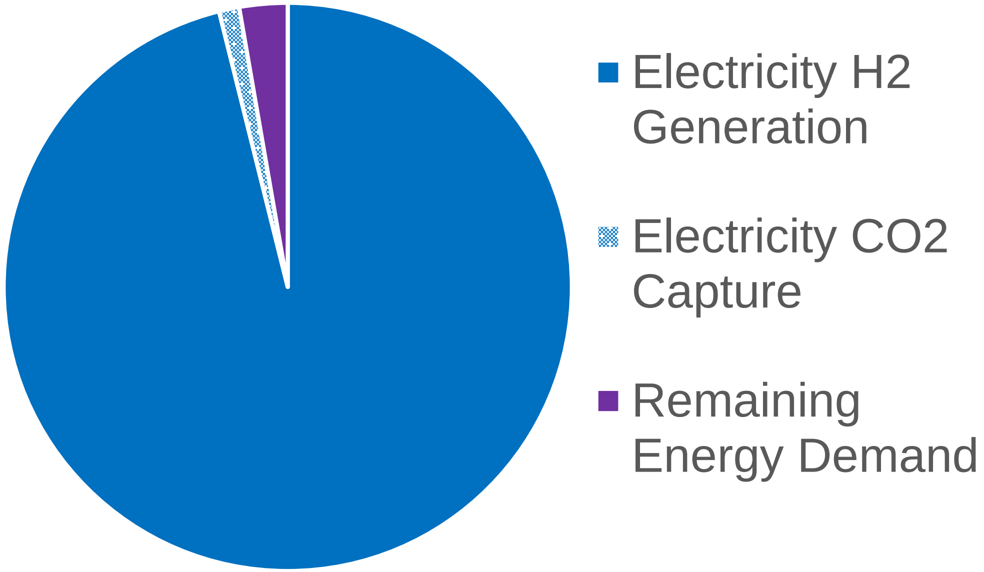
Techno-Economic and ecological assessment

FT-Diesel / Kerosene (C_{5+})[1]

Energy demand : 302 MW_e + 13.1 MW_e*
C_{5+} production : 121.6 MW_{LHV}

* External power for CO_2 capture, compression work



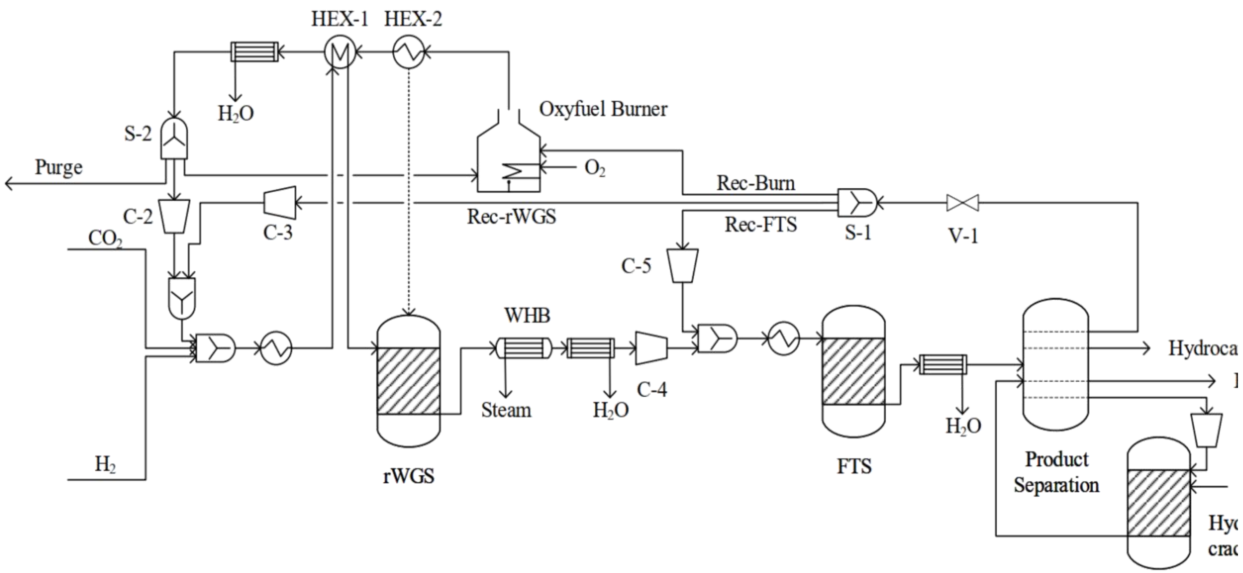


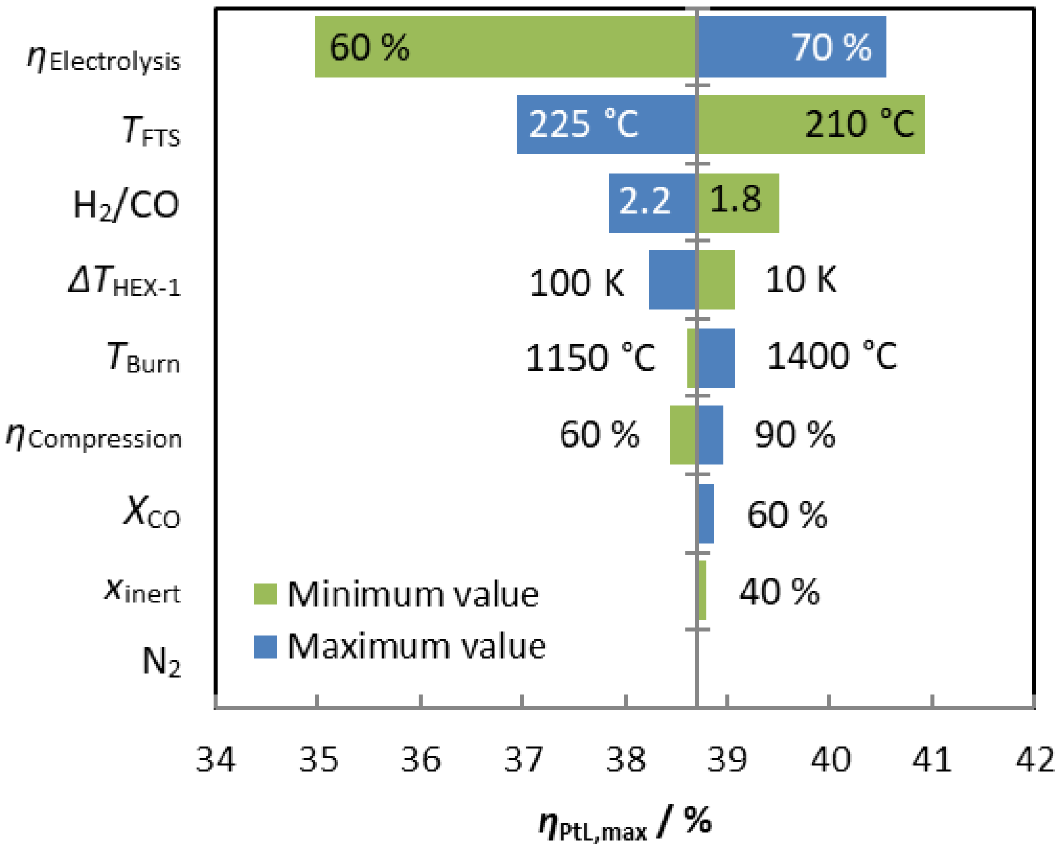
$$\eta_{XtL} = \frac{121.6\ \mathrm{MW}_{LHV}}{302\ \mathrm{MW_e} + 13.1\ \mathrm{MW_e}} = \mathbf{38.7}\ \%$$

[1] Adelung, S., Maier, S., & Dietrich, R. U. (2021). Impact of the reverse water-gas shift operating conditions on the Power-to-Liquid process efficiency. Sustainable Energy Technologies and Assessments, 43, 100897.

Techno-Economic and ecological assessment

FT-Diesel / Kerosene (C_{5+})[1]





$$\eta_{XtL} = \frac{121.6\ \mathrm{MW}_{LHV}}{302\ \mathrm{MW_e} + 13.1\ \mathrm{MW_e}} = \mathbf{38.7}\ \% \text{ ☛ } max.: 40.8\ \%,$$ adding a Clausius−Rankine cycle

[1] Adelung, S., Maier, S., & Dietrich, R. U. (2021). Impact of the reverse water-gas shift operating conditions on the Power-to-Liquid process efficiency. Sustainable Energy Technologies and Assessments, 43, 100897.

Techno-Economic and ecological assessment

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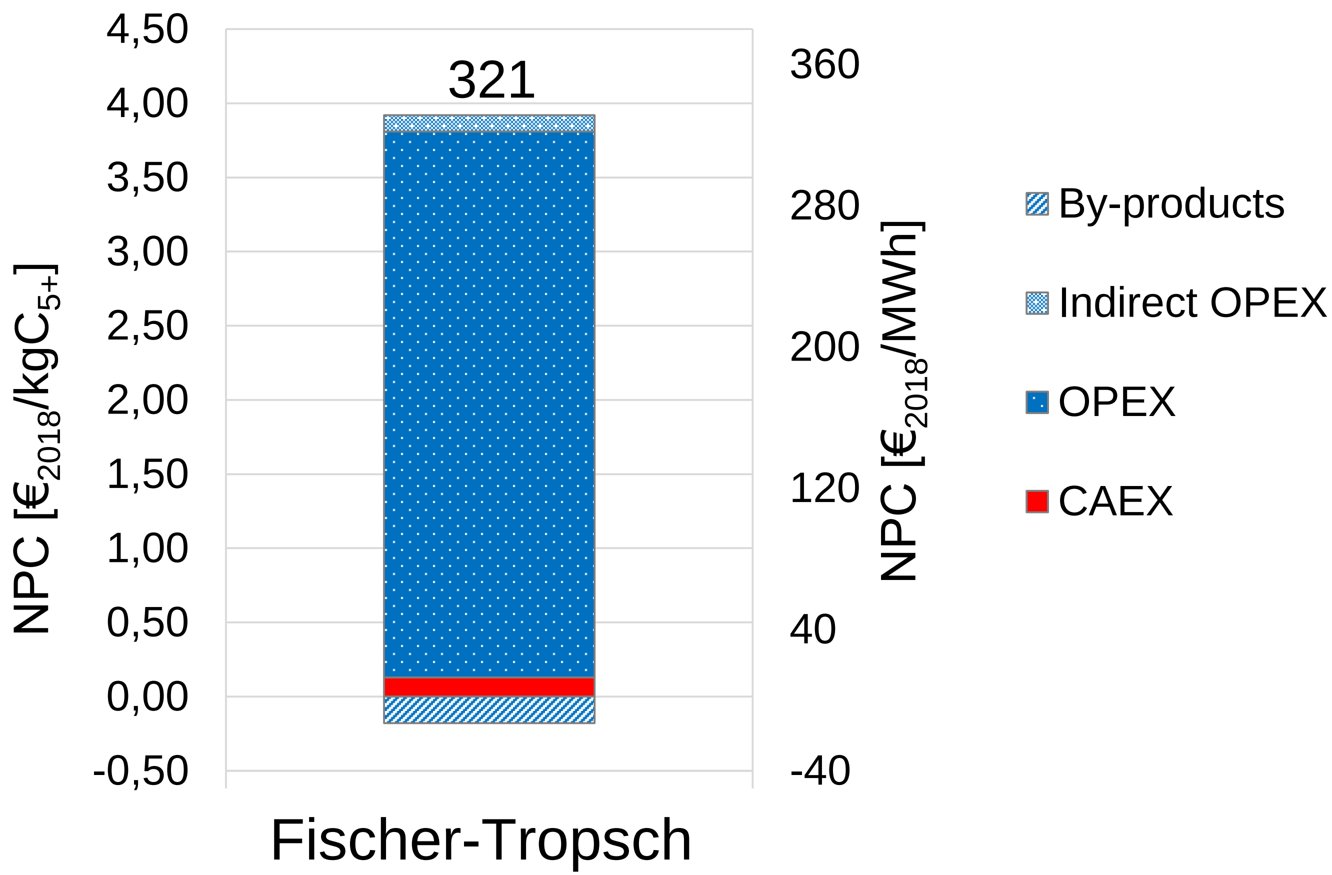

BEniVer

Begleitforschung Energiewende im Verkehr

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H_2	€/t	4'742
Electricity	€/MWh	55.7

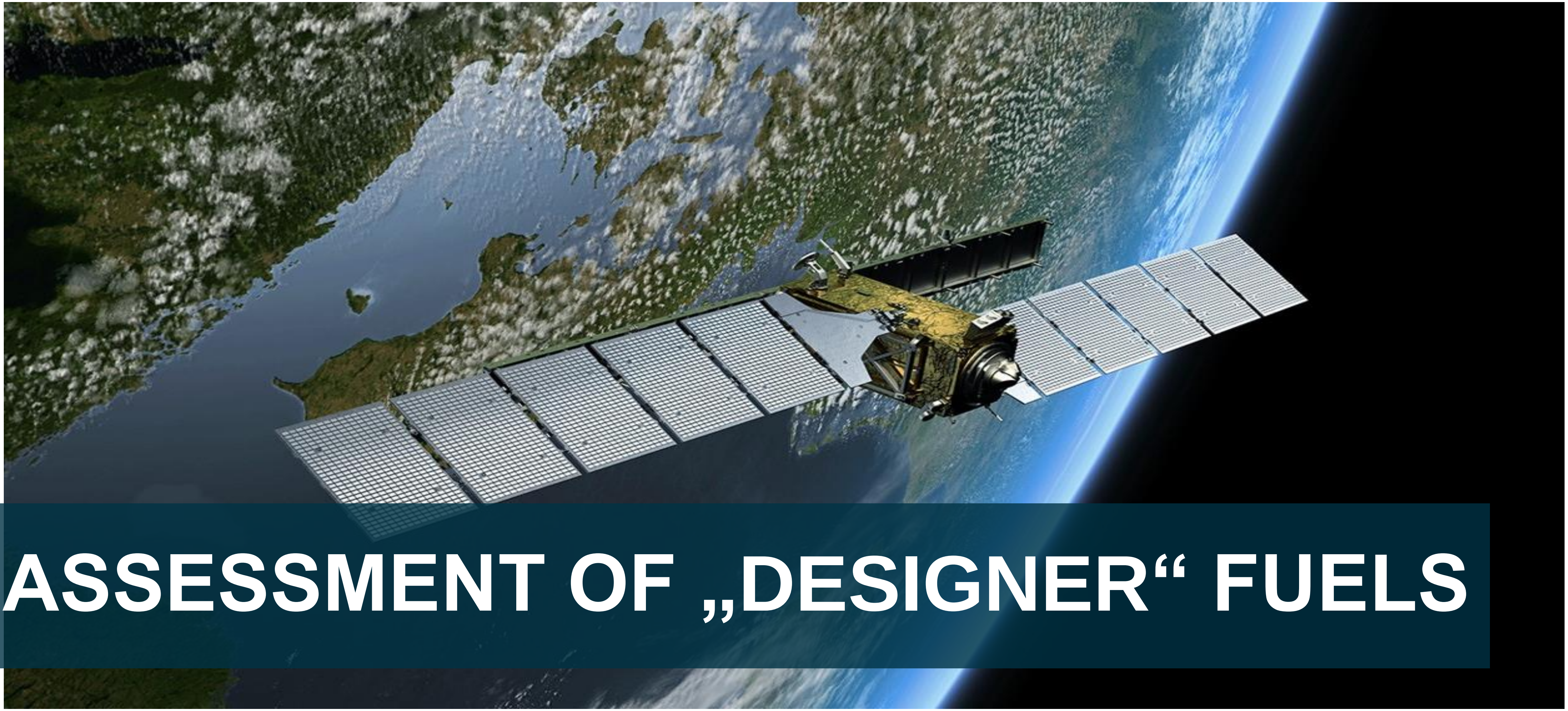
*BEniVer general assumptions:
- 300 MW_e power input
- generic costs - minimum 2018

- H_2 is the cost driver
- NPC: 3.74 $€_{2018}/kg_{C5+}$ ➔ 3 time of fossil kerosene price [1]

[1] https://www.indexmundi.com/commodities/?commodity=jet-fuel&months=12&currency=eur Future September/22 NL, 03.08.2022

TEEA @ DLR

The European Carbon Dioxide Utilisation Summit
Dusseldorf
5th-6th October 2022
Addressing legislative issues and technical developments in the CO_2 Utilisation industry



ASSESSMENT OF „DESIGNER“ FUELS

Techno-Economic and ecological assessment

NAMOSYN
Nachhaltige Mobilität durch synthetische Kraftstoffe

DLR

Fraunhofer ISE | DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

Oxygenate from MeOH

H_2

CO_2

MeOH synthesis

aspentech | TEPET

Process simulation in Aspen Plus

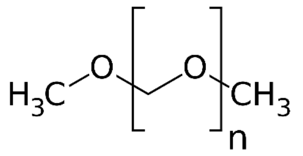
Technical analysis

Net production costs in TEPET

Economic analysis

$OME_{3\text{-}5}$ synthesis

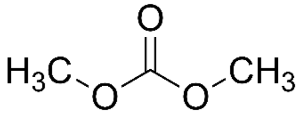
aspentech | TEPET



DMC synthesis

aspentech | TEPET

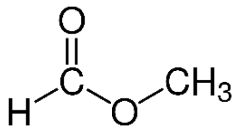
Cooperation with TU Delft



MeFo synthesis

aspentech | TEPET

BASF patent[1]

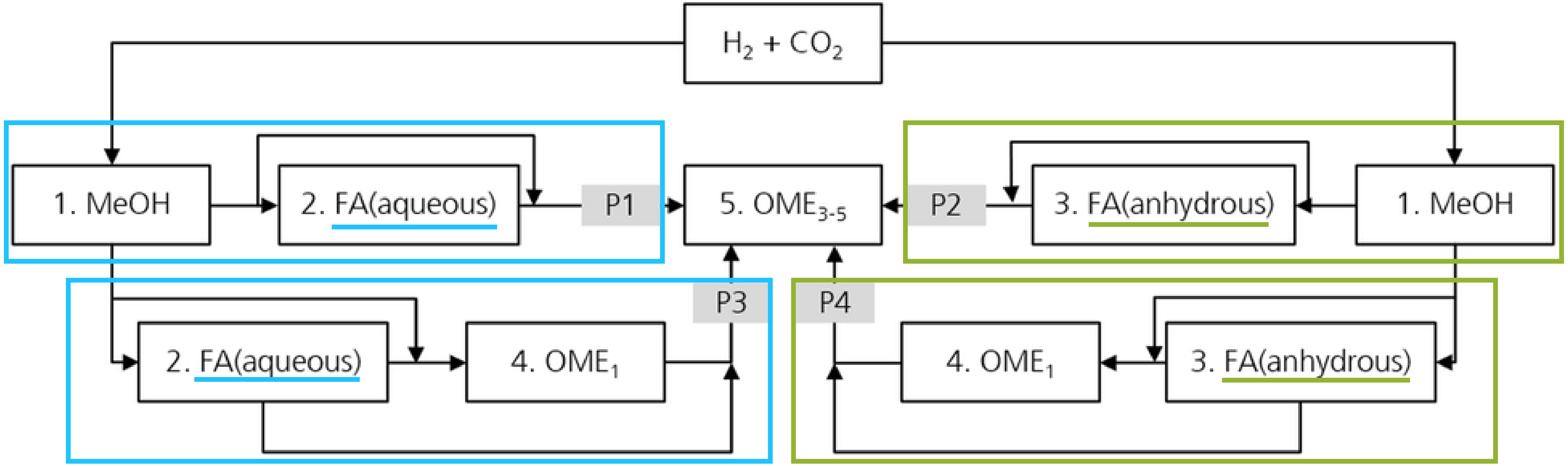


[1] BASF SE – Patent Nr. EP2922815B1

Techno-Economic and ecological assessment

Nachhaltige Mobilität durch synthetische Kraftstoffe

OME$_{3-5}$ from MeOH



Graph: Mantei et al. (2022): Techno-economic assessment and carbon footprint of processes for the large-scale production of oxymethylene dimethyl ethers from carbon dioxide and hydrogen in Sustainable Energy and Fuels (DOI: 10.1039/D1SE01270C)

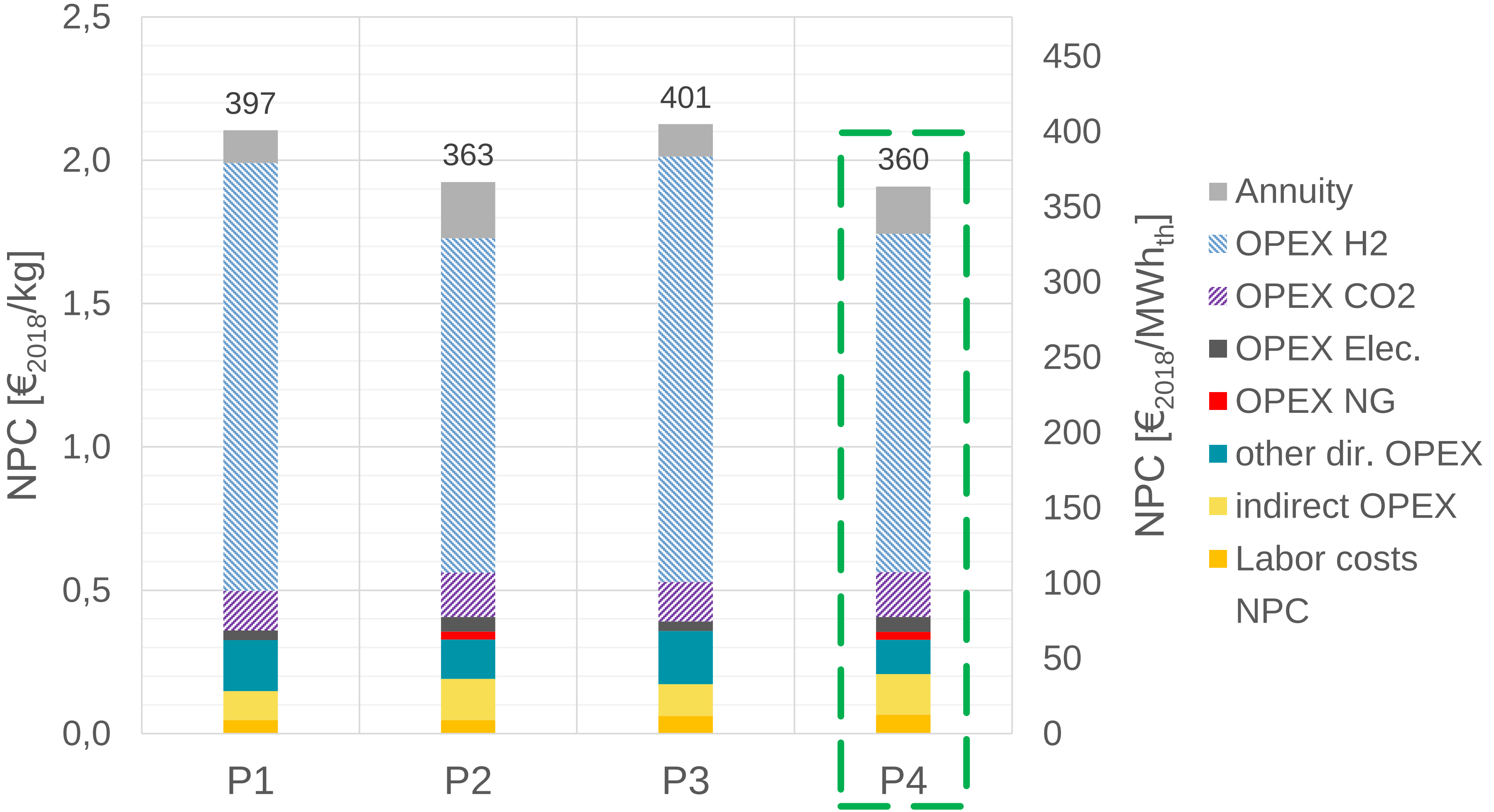
Techno-Economic and ecological assessment

NAMOSYN – Nachhaltige Mobilität durch synthetische Kraftstoffe

DLR

BEniVer – Begleitforschung Energiewende im Verkehr

$OME_{3\text{-}5}$ from MeOH



Assumptions		V3.2*
Basis year		2018
Full-load hours		8’000
CO_2	€/t	69
H_2	€/t	4’742
Electricity	€/MWh	55.7

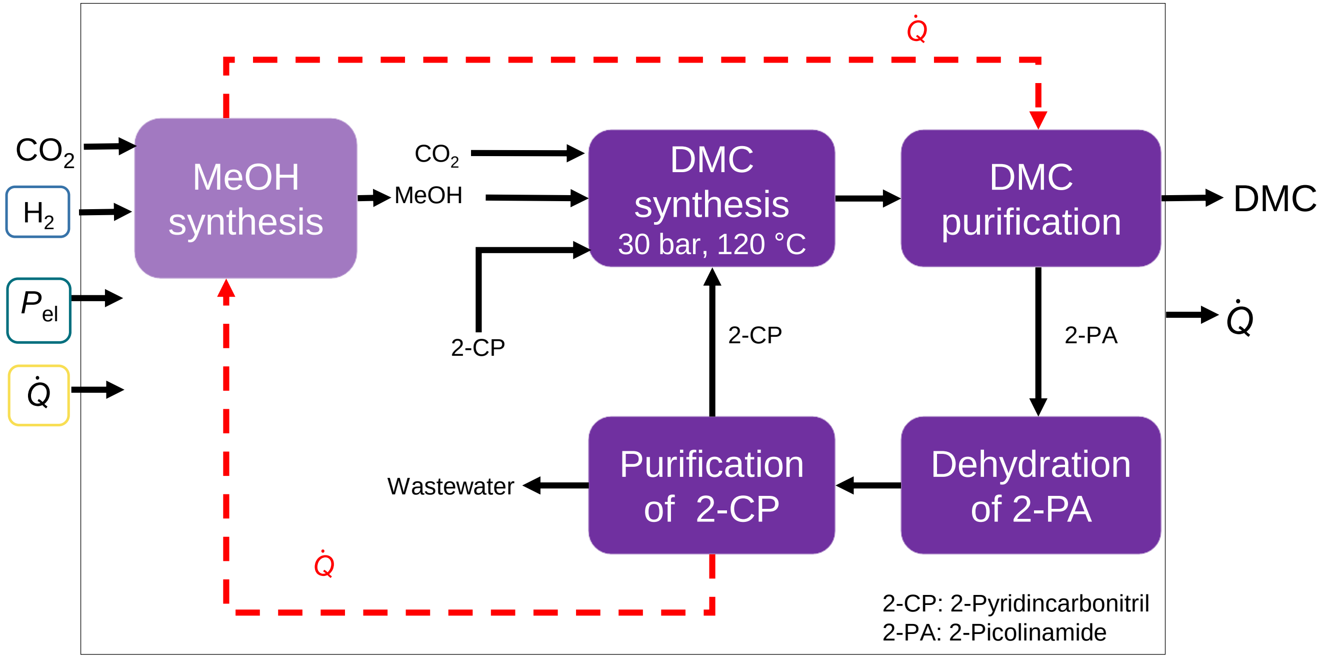
*BEniVer general assumptions:
- 300 MW_e power input
- generic costs - minimum 2018

- P1 and P3 (aqueous) have similar NPC
- P2 and P4 (anhydrous) have similar NPC
- P4 is the slightly better $OME_{3\text{-}5}$ production option

Techno-Economic and ecological assessment

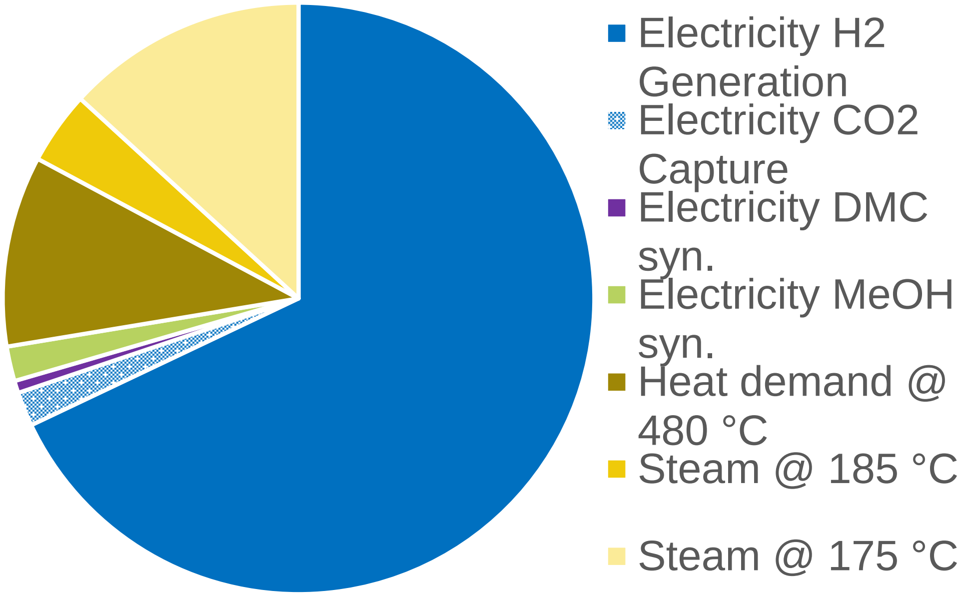
Nachhaltige Mobilität durch synthetische Kraftstoffe

DMC from MeOH *



Energy demand : 91.6 MW_{el} + 34.9 MW_{th}

DMC prod. : 50.1 MW_{LHV}



$$\eta_{PtL} = \frac{50.1\ MW_{LHV}}{91.6\ MW_e} = \mathbf{54.7}\ \%$$

$$\eta_{XtL} = \frac{50.1\ MW_{LHV}}{91.6\ MW_e + 34.9\ MW_{th}} = \mathbf{51.4}\ \%$$

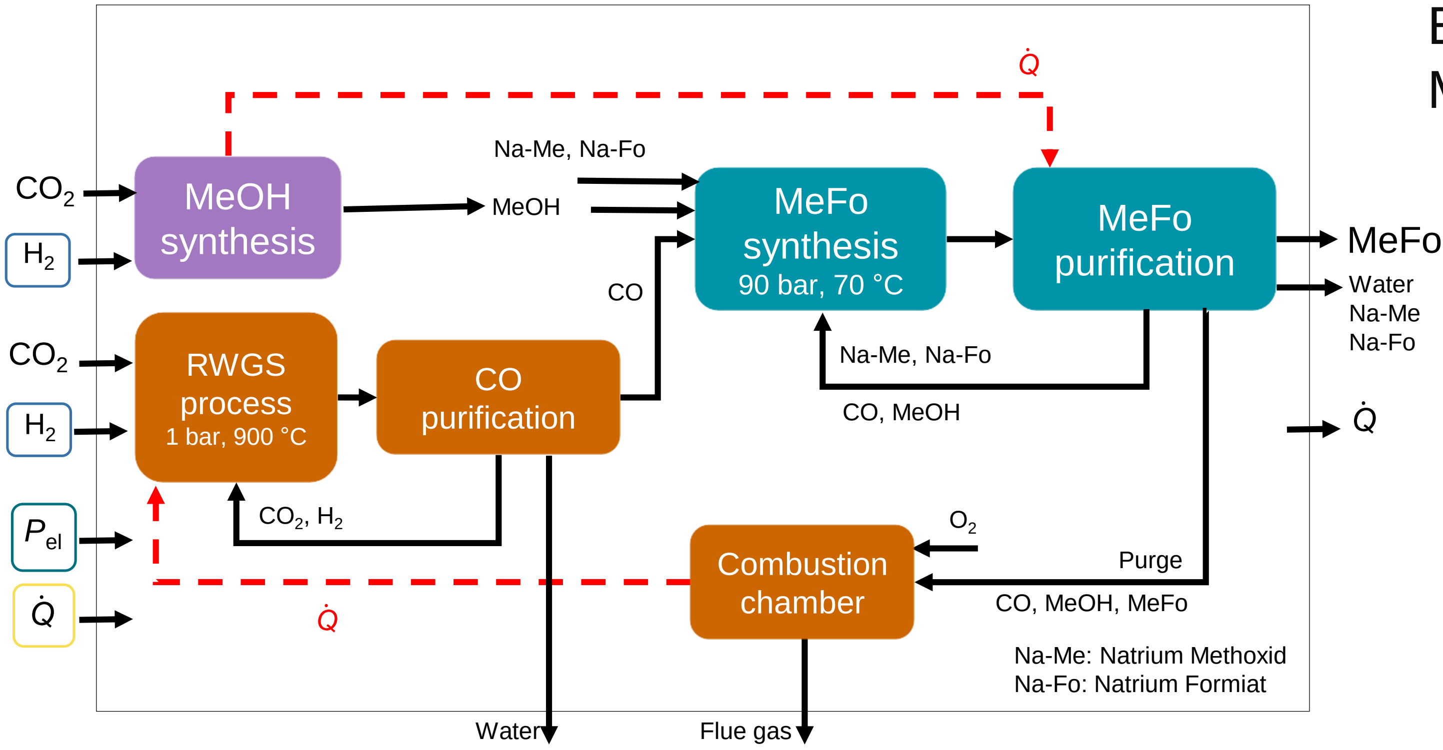
* Innovative lab scale process of TU Delft, publication pending

Techno-Economic and ecological assessment

NAMOSYN Nachhaltige Mobilität durch synthetische Kraftstoffe

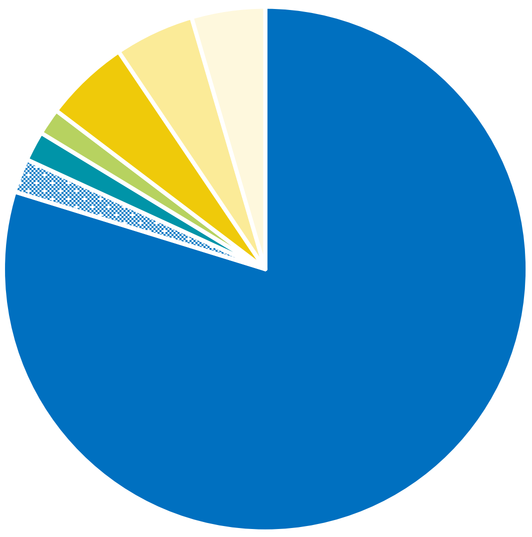
DLR

MeFo from MeOH *



Energy demand : 102.9 MW_{el} + 17.7 MW_{th}

MeFo prod. : 55 MW_{LHV}



$$\eta_{PtL} = \frac{55\ MW_{LHV}}{102.9\ MW_e} = \mathbf{53.4}\ \%$$

$$\eta_{XtL} = \frac{55\ MW_{LHV}}{102.9\ MW_e + 17.7\ MW_{th}} = \mathbf{45.6}\ \%$$

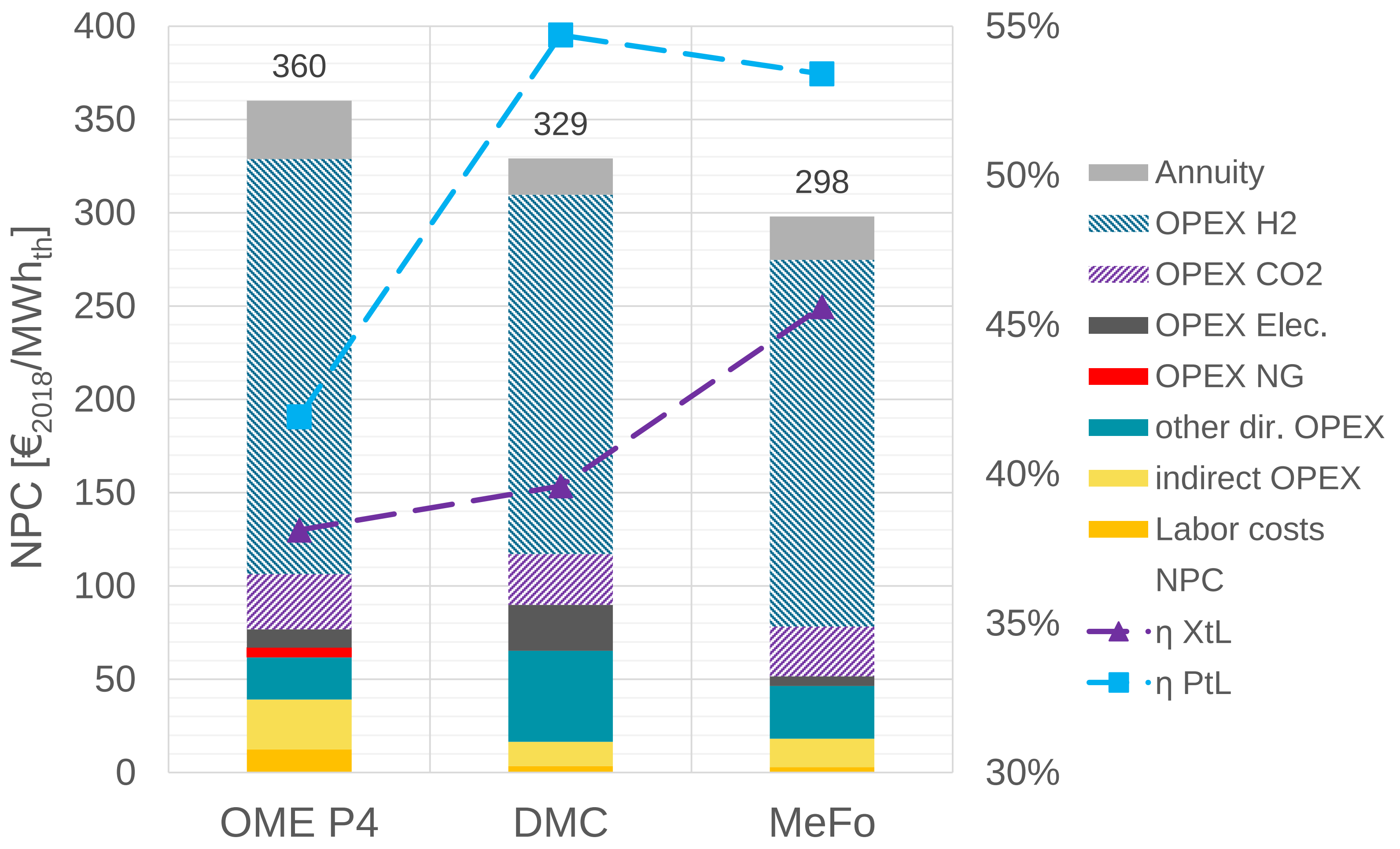
* state-of-the-art BASFprocess, taken from patent Nr. EP2922815B1

Techno-Economic and ecological assessment

NAMOSYN
Nachhaltige Mobilität durch synthetische Kraftstoffe

DLR

Oxygenate from MeOH



Assumptions		V3.2*
Basis year		2018
Full-load hours		8000
CO_2	€/t	71
H_2	€/t	5 586
Electricity €/MWh		71.5

*BEniVer general assumptions: generic costs - average 2018

- Similar magnitude of NPC
- H_2 is the cost driver
- OME P4 → lowest efficiencies
- DMC → highest η_{PtL}
- MeFo → highest η_{XtL}
- **Application as drop-in fuels?**

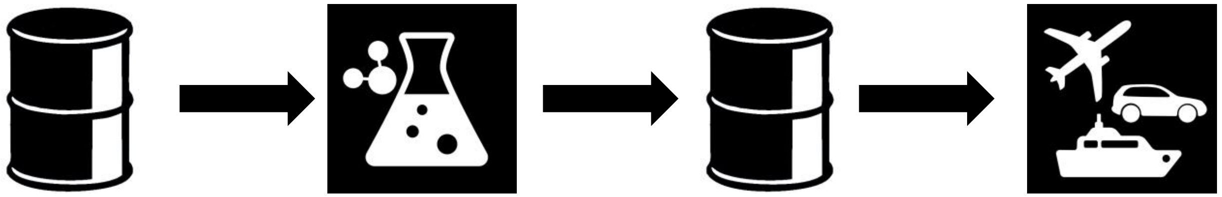
TEEA @ DLR

CONCLUSION: PTX FOR TRANSPORT?

Conclusion for e-fuels options in private transport

Simple pictograms

- Present (2022)

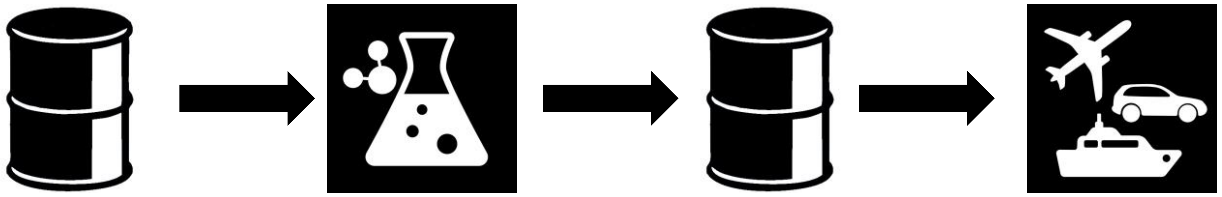


- Future Dream (2018)

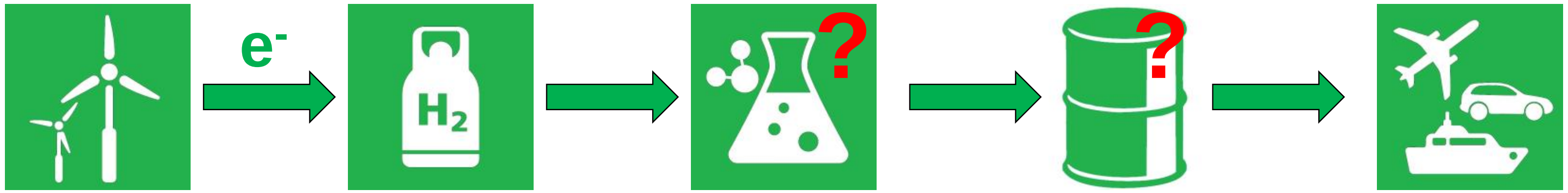
Conclusion for e-fuels options in private transport

Simple pictograms

- Present (2022)



- Future Dream (2018)
  E&V Questions



Conclusion for e-fuels options in private transport

Simple pictograms

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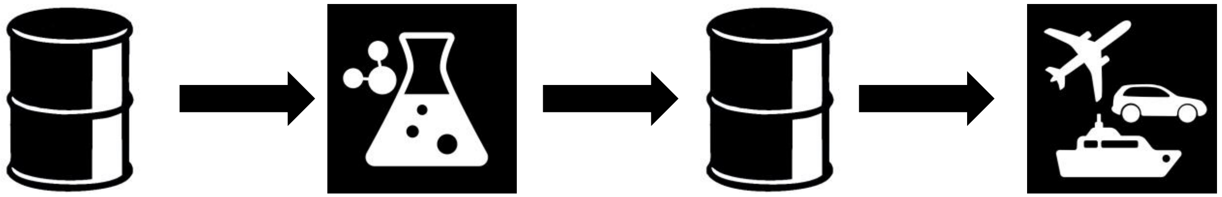
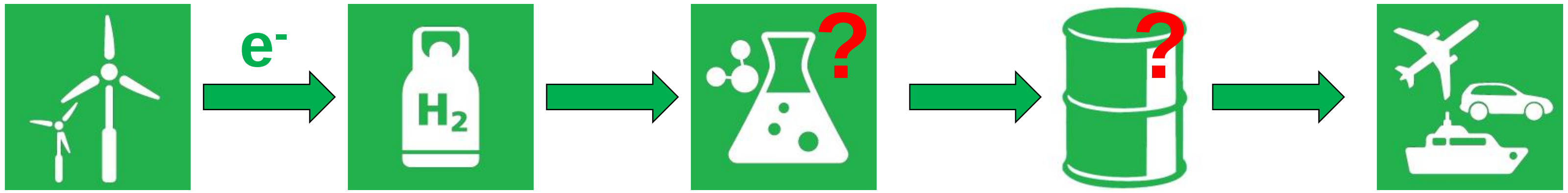
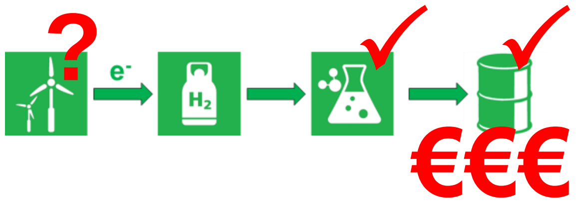


- Future Dream (2018)
  E&V Questions



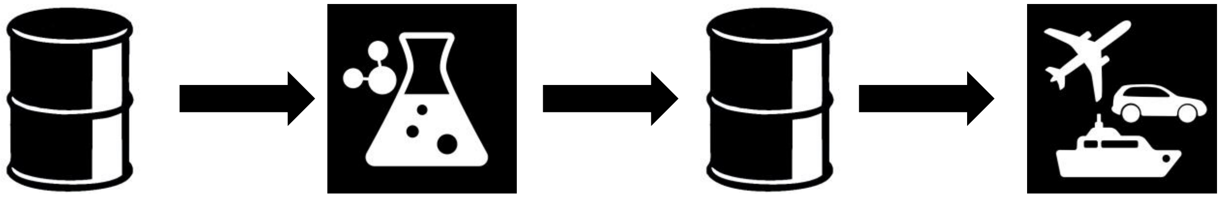
- Reality Check 2022
  Q&A



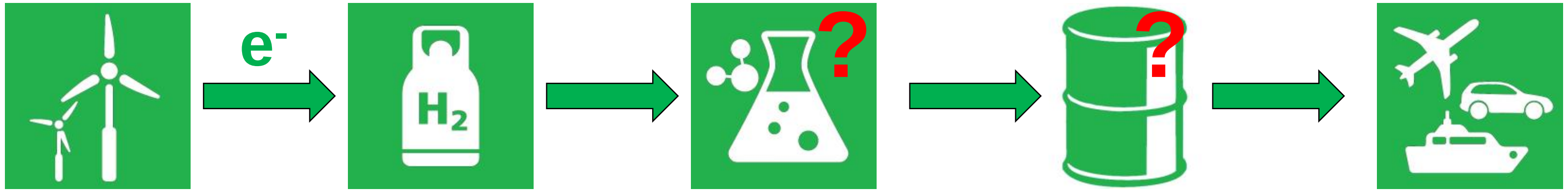
Conclusion for e-fuels options in private transport

Simple pictograms

- Present (2022)



- Future Dream (2018)
  E&V Questions



- Reality Check 2022
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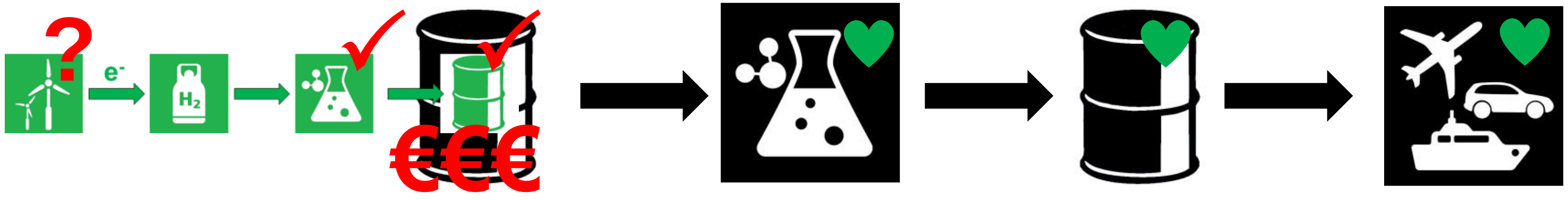
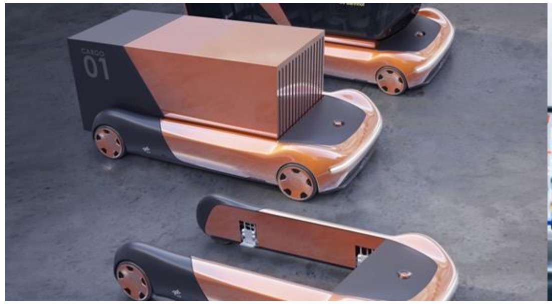


Outlook: Transport beyond 2022

- Maximize mileage from green electrons
  - Favor public over private transport
  - Favor rail over road / air transport
  - Favor electric over hydrogen over ICE

- Invent new / better electric locomotion
  - Efficient public transport
  - New e-bikes, -cars, -trucks, -planes, -ships
  - Smart connection between transport options



- Don’t ignore the legacy fleet
  - Instant drop-in fuels blending mandate
  - Little electrification in marine and aviation
  - Maximize GHG abatement at minimal cost

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

E-Fuel options in private transport, aviation and shipping

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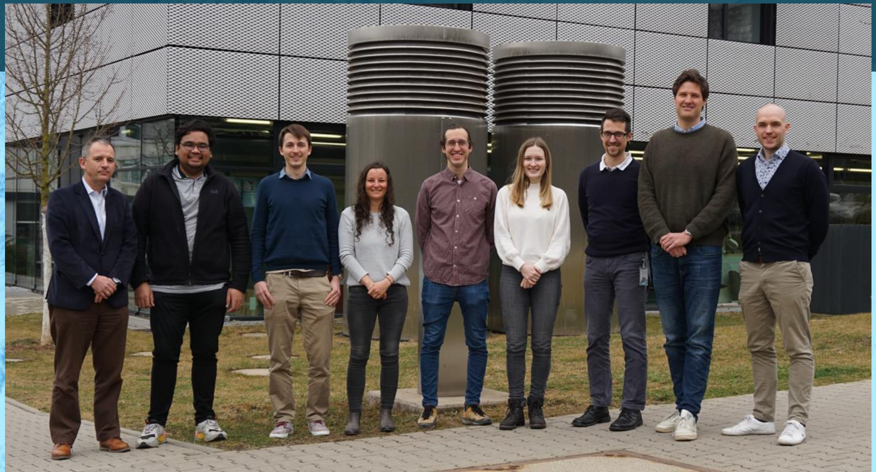
Francisco Moser, Moritz Raab,
Yoga Rahmat, Julia Weyand,
Ralph-Uwe Dietrich



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