Nachhaltige Mobilität durch synthetische Kraftstoffe

FINAL MEETING

$OME_{3\text{-}5}$, DMC, MeFo: Techno-economic assessment and conclusion

Ludwigshafen am Rhein, 2 March 2023

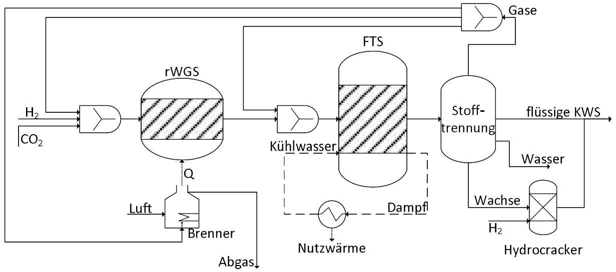
Yoga Rahmat, Sandra Adelung, Cornelie Bänsch, Ralph-Uwe Dietrich

Agenda

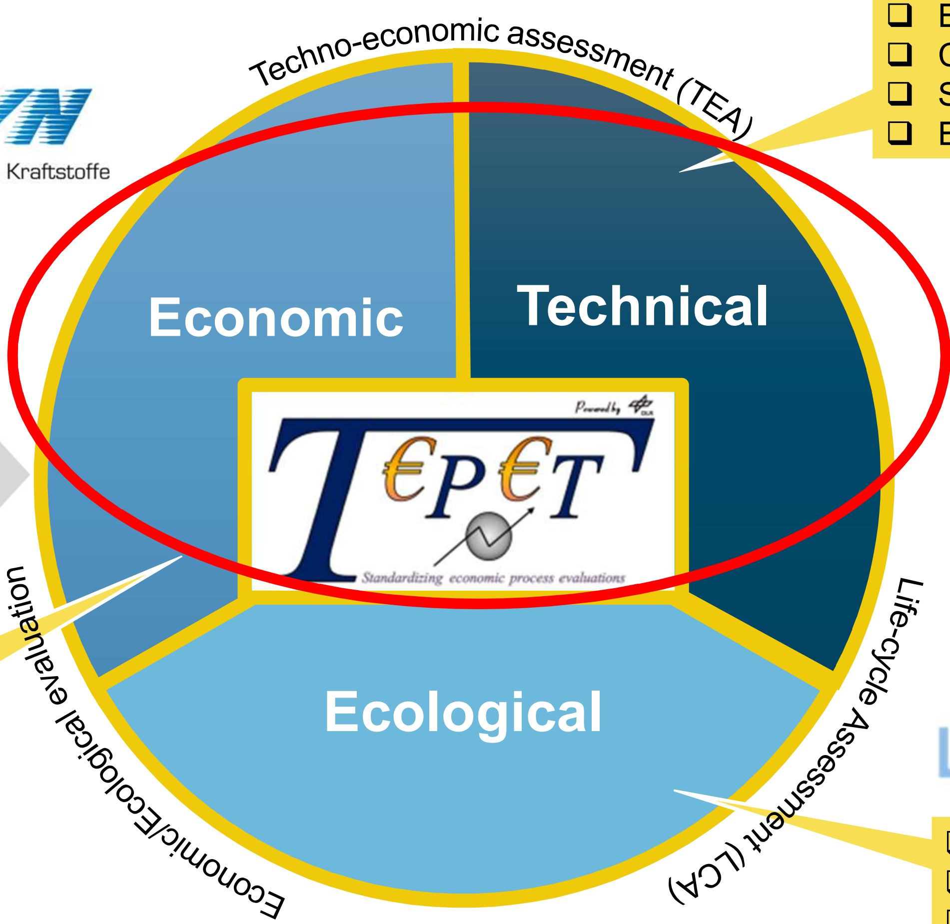
- **T**echno-**E**conomic and **E**cological **A**ssessment @ DLR
  - TEEA methodology
- Techno-economic assessment of German e-fuels transport options
  - Designer fuels: $OME_{3\text{-}5}$, DMC, MeFo
- Conclusion and discussion
  - Possible e-fuels impact on global transport – Germany as role model?
  - How to make progress from 2023 onwards?

Techno-economic and ecological assessment @ DLR
TEEA methodology

Nachhaltige Mobilität durch synthetische Kraftstoffe



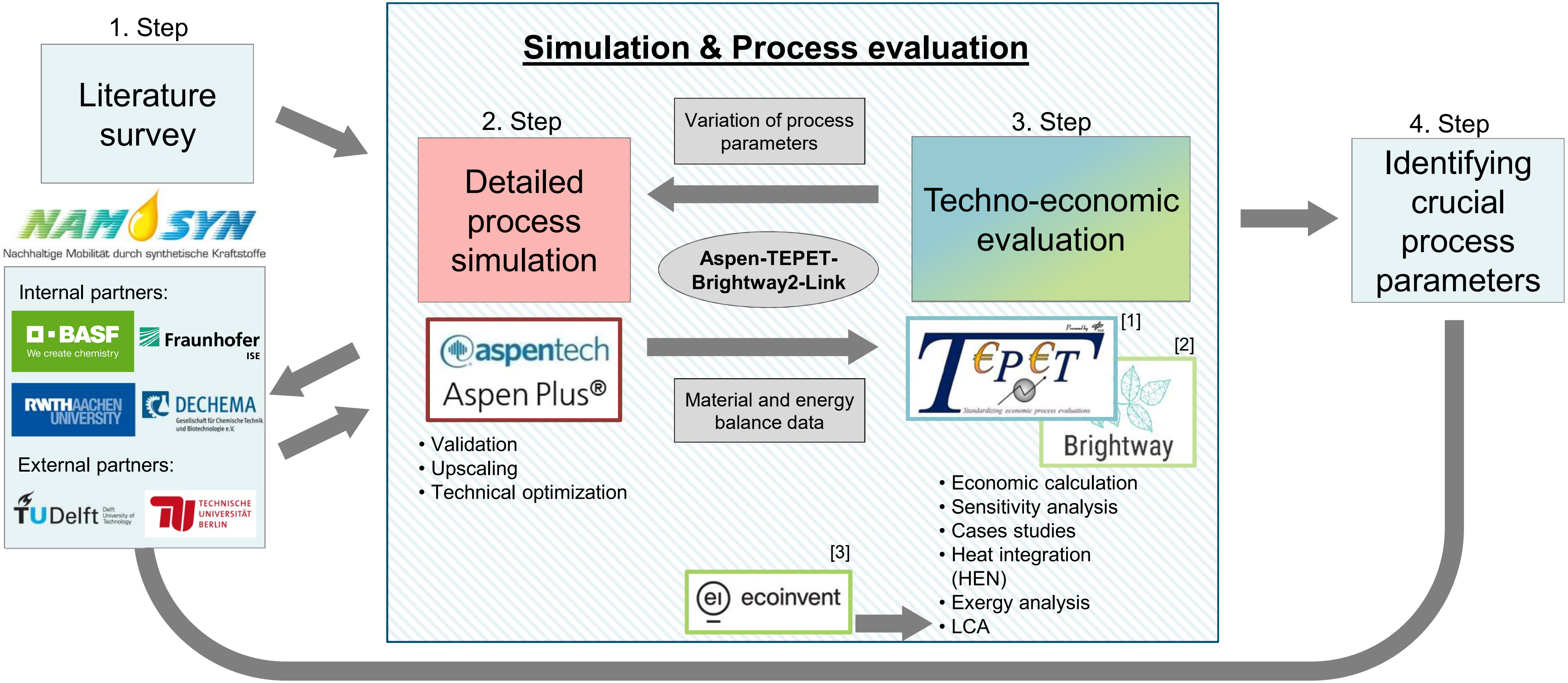
- ❑ Efficiencies (X-to-Liquid, Overall)
- ❑ Carbon conversion
- ❑ Specific feedstock demand
- ❑ Exergy analysis



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

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

TEEA @ DLR



[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.

TEA OF DESIGNER FUELS

Designer fuels: $OME_{3\text{-}5}$, DMC, MeFo

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Oxygenates from MeOH

H_2

CO_2

MeOH synthesis

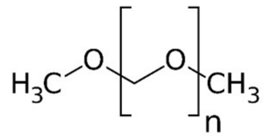
Process simulation in Aspen Plus

Technical analysis

Net production costs in TEPET

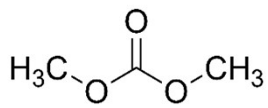
Economic analysis

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



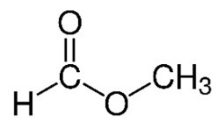
DMC synthesis

Cooperation with TU Delft



MeFo synthesis

BASF patent[1]

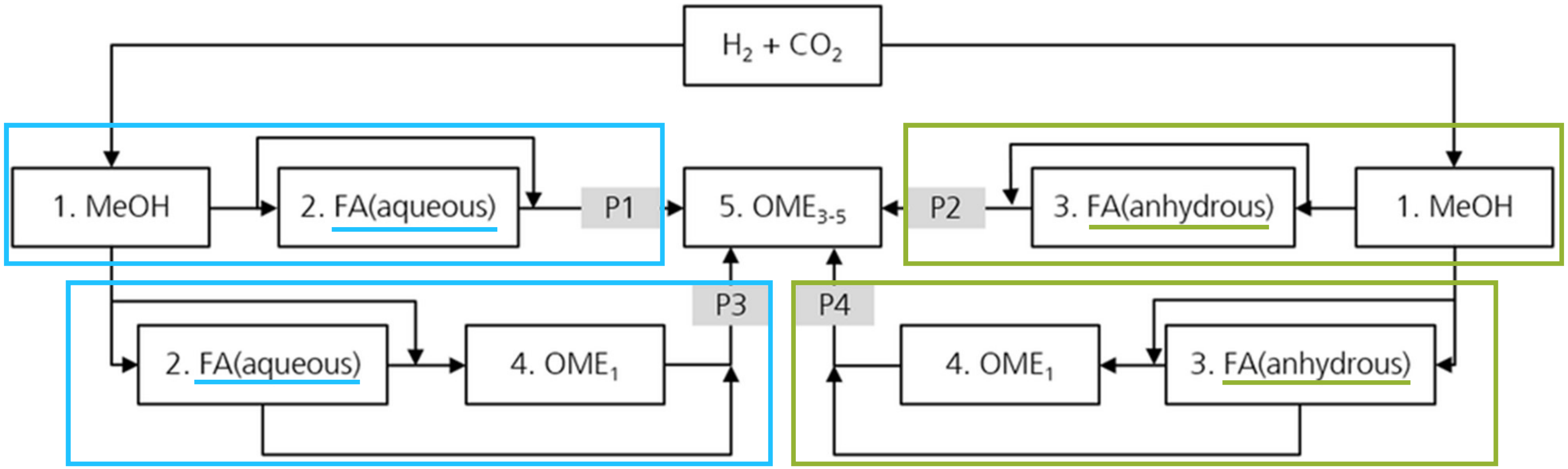


[1] BASF SE – Patent Nr. EP2922815B1

P-t-OME_{3-5} : The observed routes

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)

P-t-$OME_{3\text{-}5}$: Technical assessment

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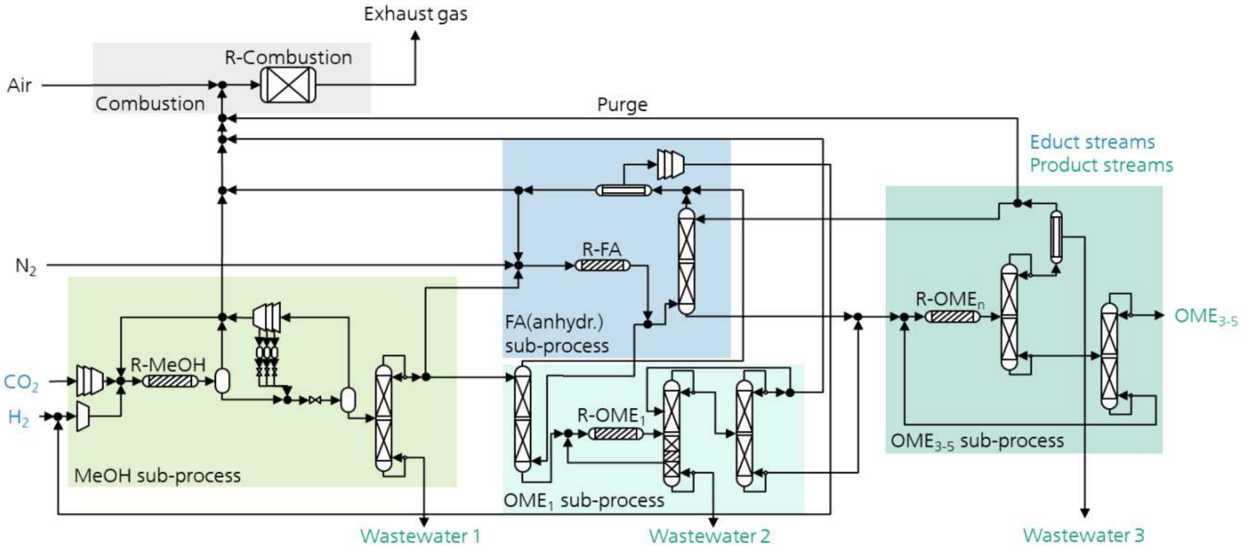
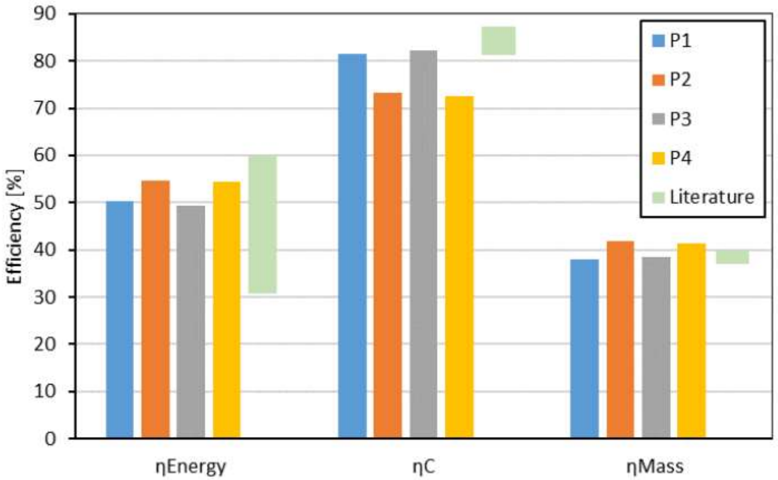
Simplified process flow diagram of P4, derived from Fraunhofer ISE factsheet[1]





$$\eta_{Energy} = \frac{\dot{m}_{OME_{3-5}} \cdot LHV_{OME_{3-5}}}{\sum_k \dot{Q}_k + \sum_l \dot{W}_l + \sum_i \dot{m}_i \cdot LHV_i}$$

$$\eta_C = \frac{C_{OME_{3-5}}}{\sum_i C_i}$$

$$\eta_{Mass} = \frac{\dot{m}_{OME_{3-5}}}{\sum_i \dot{m}_i}$$

	P1	P2	P3	P4
η_{Energy} [%]	50.3	54.6	49.3	54.4
η_C [%]	81.6	73.2	82.1	72.5
η_{Mass} [%]	38.1	41.9	38.5	41.4

[1] 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)

P-t-OME$_{3-5}$: Economic assessment

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CAPEX: Equipment costs

Equipment type Red: special equipment Green: standard equipment	Characteristics	Literature source (Standard: [1])
Reactors	FA-synthesis (hydrous/anhydrous): fixed bed reactor Remaining type : multi-tubular reactor	[2] (improper capacity range in [1])
Membrane	Water separation: plate membrane, dimensioning [3] H_2 separation: hollow fiber membrane, dimensioning [4]	[4] (not available in [1])
Film evaporators		[2] (improper capacity range in [1])
Heat exchangers, columns, compressors, pumps, burner, flash drums	Standard equipment according to Peters *et al.* [1], available in TEPET database	[1]

[1] M. S. Peters, K. D. Timmerhaus, R. E. West, *Plant Design and Economics for Chemical Engineers* **2003**, McGraw-Hill Higher Education, New York.
[2] D. R. Woods, *Rules of Thumb in Engineering Practice* **2007**, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim.
[3] N. Schmitz, *Production of polyoxymethylene dimethyl ethers from formaldehyde and methanol* **2018**, Dissertation, TU Kaiserslautern.
[4] R. W. Baker, *Membrane Technology and Applications* **2012**, John Wiley and Sons Ltd, Chichester.

P-t-OME_{3-5} : Economic assessment

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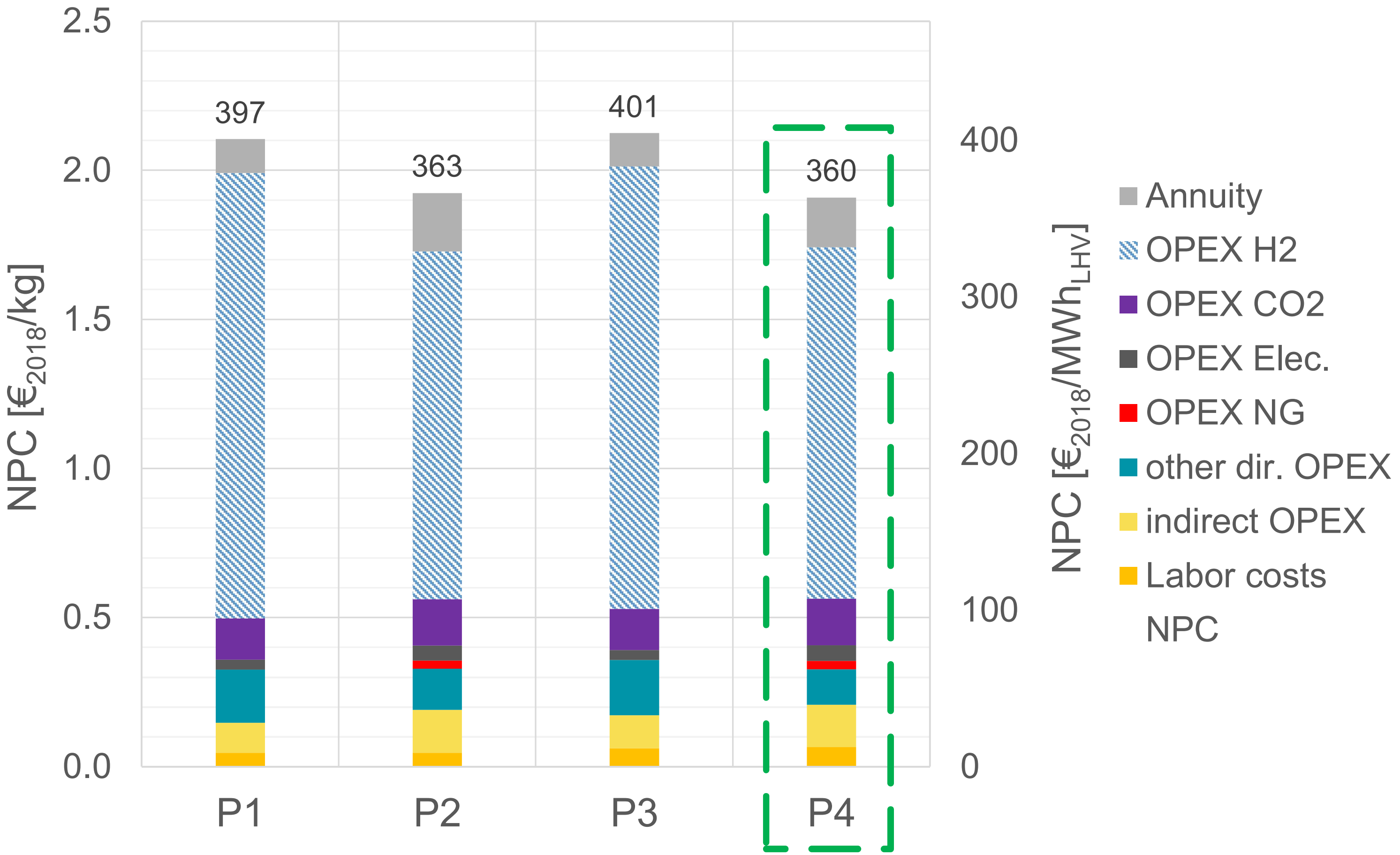
BEniVer Begleitforschung Energiewende im Verkehr



Assumptions		V3.2*
Basis year		2018
Full-load hours		8 000
CO_2	€/t	71
H_2	€/t	5 586
Electricity	€/MWh	71.5

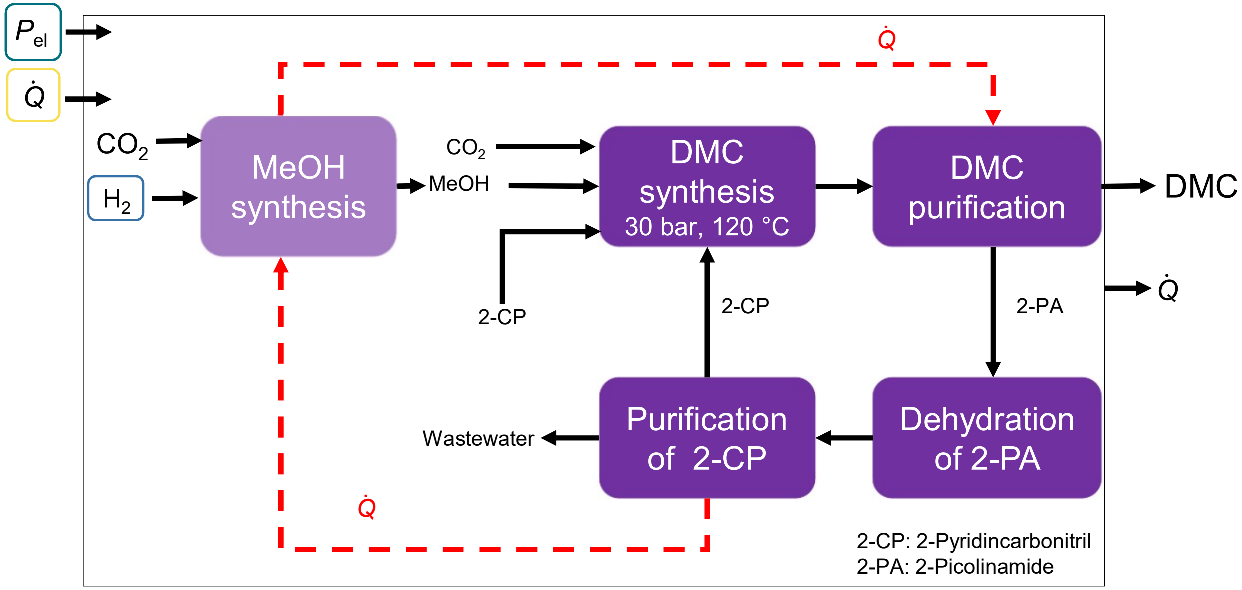
*BEniVer general assumptions:
- 300 MW_e power input
- generic costs - minimum 2018

- The anhydrous processes (P2 & P4) form less water out of H_2
- Higher η_{PtL} in P2 & P4
- Lower NPC in P2 & P4
- P4 is the slightly better OME_{3-5} production option

P-t-DMC : Technical assessment

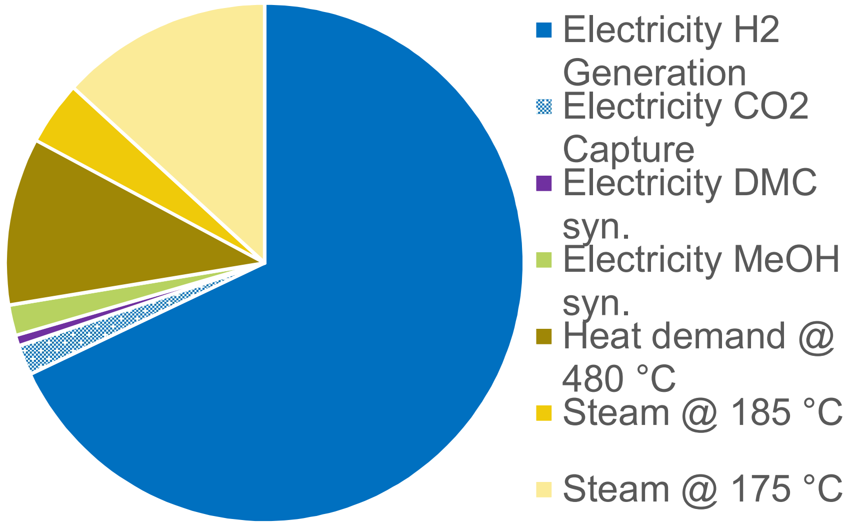
Nachhaltige Mobilität durch synthetische Kraftstoffe

DMC from MeOH*



Energy demand : 105.8 MW_e + 21.7 MW_{th}

DMC prod. : 50.1 MW_{LHV}



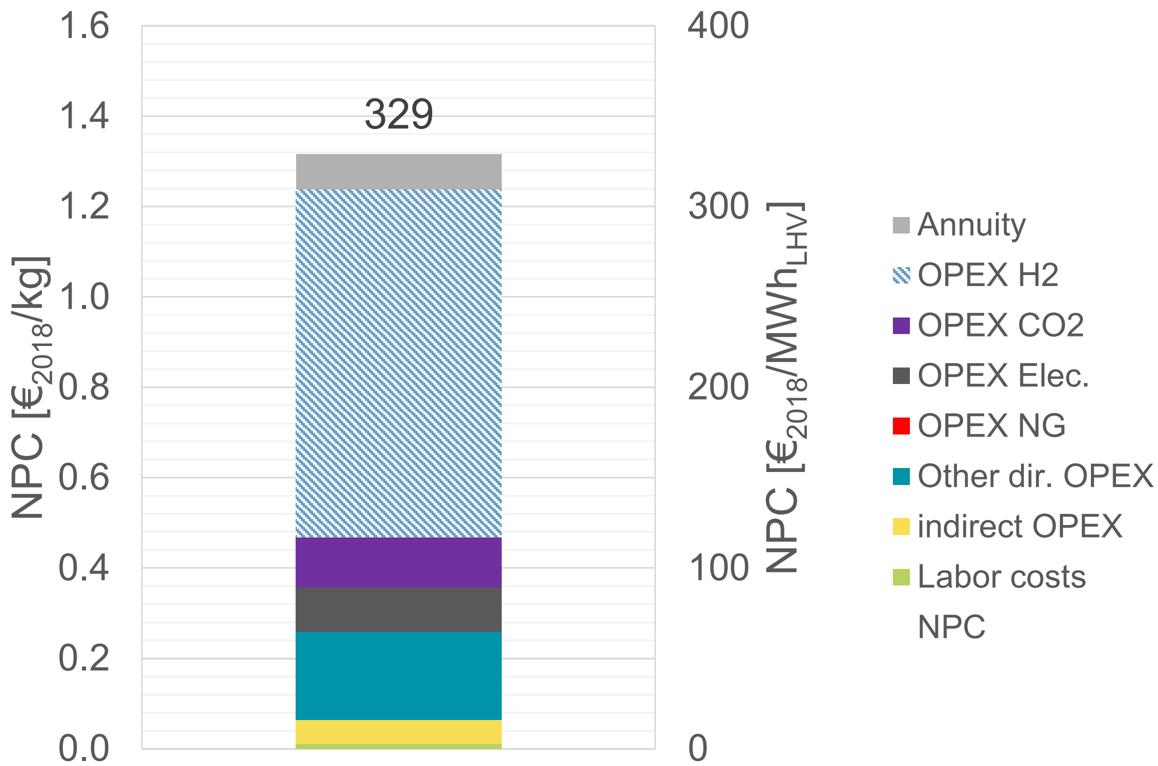
$$\eta_{PtL} = \frac{50.1\ \mathrm{MW}_{LHV}}{105.8\ \mathrm{MW_e}} = \mathbf{47.3}\ \%$$

$$\eta_{EtL} = \frac{50.1\ \mathrm{MW}_{LHV}}{105.8\ \mathrm{MW_e} + 21.7\ \mathrm{MW_{th}}} = \mathbf{39.3}\ \%$$

* Innovative lab scale process of TU Delft, publication pending, project results corrected with MeOH production assessment of Rahmat et al.

P-t-DMC : Economic assessment

DMC from MeOH*



Nachhaltige Mobilität durch synthetische Kraftstoffe

BEniVer

Begleitforschung Energiewende im Verkehr

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- 300 MW_e power input
- generic costs - minimum 2018

- H_2 is the cost driver
- CAPEX annuity does not play significant role
- Techno-economic comparison on the slide 15

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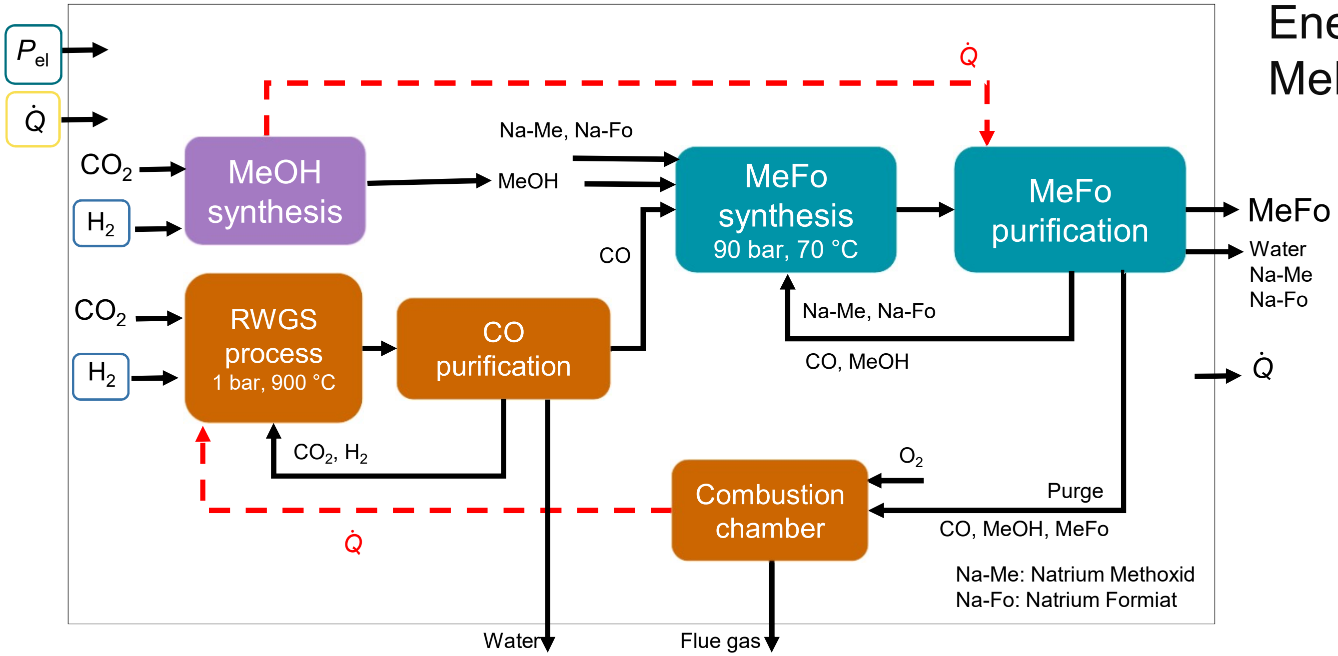
P-t-MeFo : Technical assessment

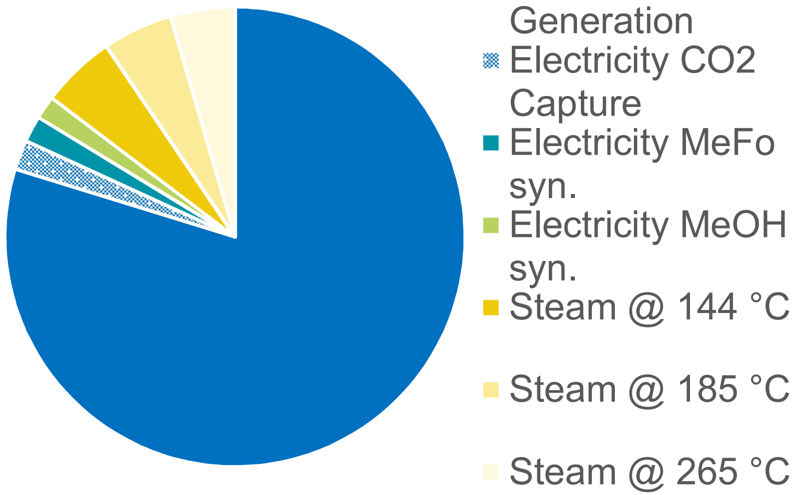
Nachhaltige Mobilität durch synthetische Kraftstoffe

MeFo from MeOH*



Energy demand : 102.5 MW_e + 13.8 MW_{th}

MeFo prod. : 55 MW_{LHV}



$$\eta_{PtL} = \frac{55\ \mathrm{MW}_{LHV}}{102.5\ \mathrm{MW_e}} = \mathbf{52.5}\ \%$$

$$\eta_{EtL} = \frac{55\ \mathrm{MW}_{LHV}}{102.5\ \mathrm{MW_e} + 13.8\ \mathrm{MW_{th}}} = \mathbf{46.4}\ \%$$

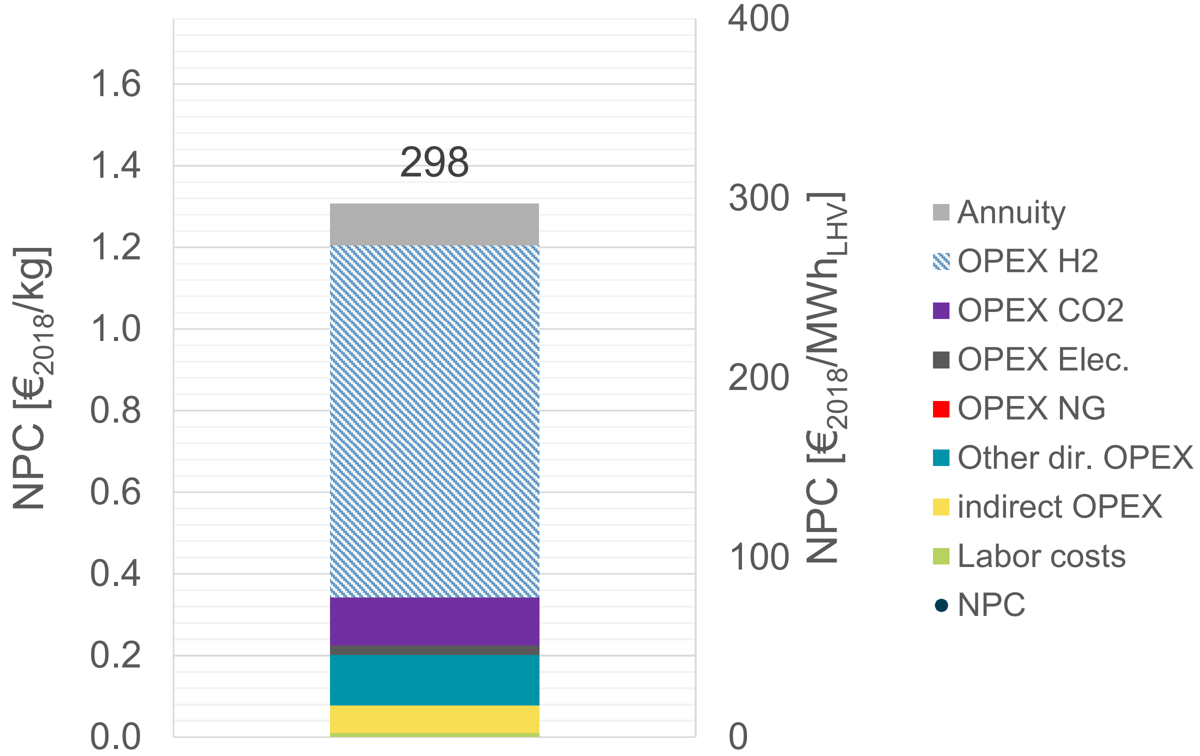
* state-of-the-art BASF process, taken from patent Nr. EP2922815B1, project results corrected with MeOH production assessment of Rahmat et al.

P-t-MeFo : Economic assessment

Nachhaltige Mobilität durch synthetische Kraftstoffe

Begleitforschung Energiewende im Verkehr

MeFo from MeOH*



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* state-of-the-art BASF process, taken from patent Nr. EP2922815B1, project results corrected with MeOH production assessment of Rahmat et al.

Designer fuels : Techno-economic assessment

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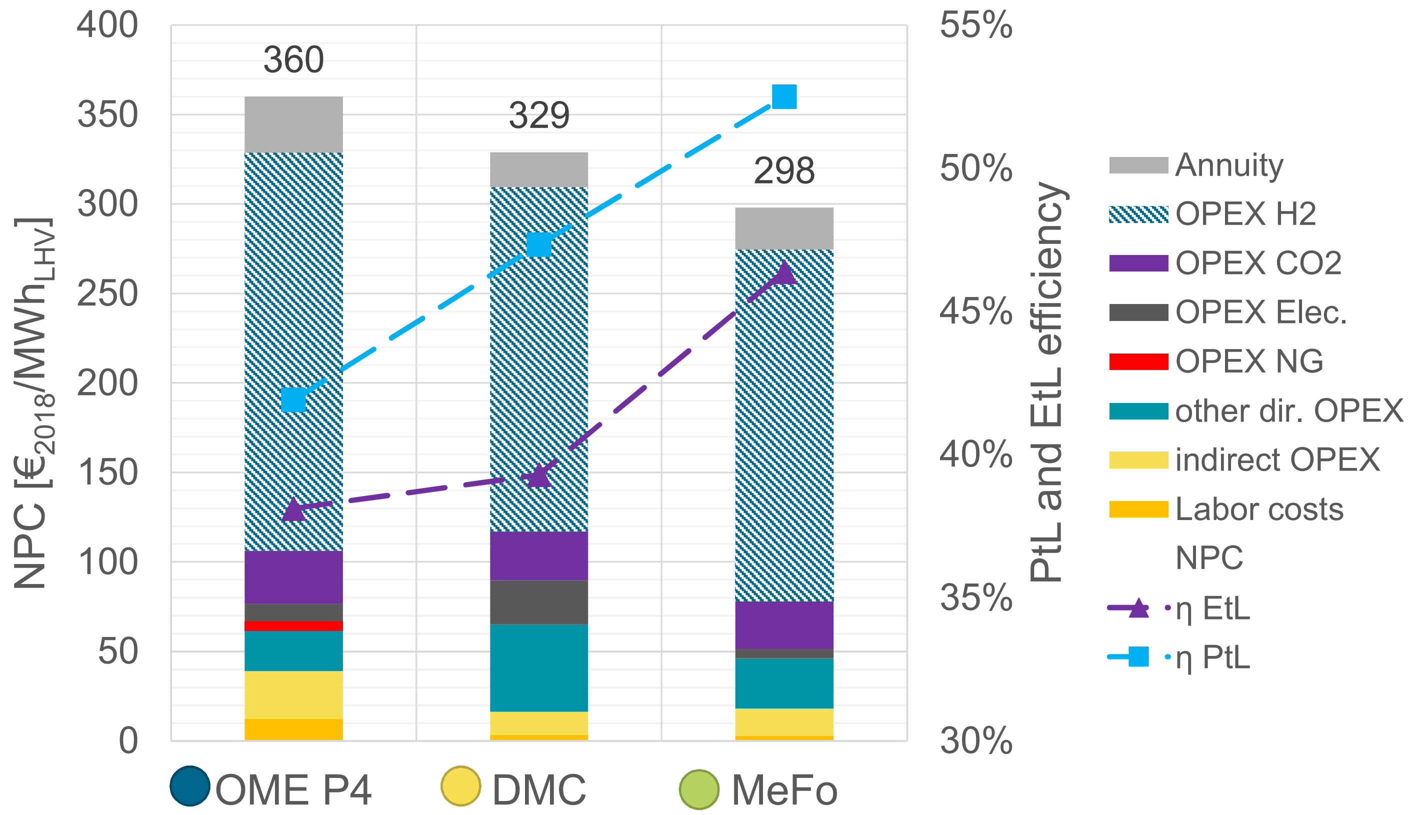
Oxygenates from MeOH : $OME_{3\text{-}5}$, DMC, MeFo



BEniVer
Begleitforschung Energiewende im Verkehr

Assumptions		V3.2*
Basis year		2018
Full-load hours		8 000
CO_2	€/t	71
H_2	€/t	5 586
Electricity	€/MWh	71.5

*BEniVer general assumptions: generic costs - average 2018

- $OME_{3\text{-}5}$ through the route P4 is not the winner
- MeFo has the lowest NPC due to its relatively high efficiency
- **Application as drop-in fuels?**

R-U. Dietrich, Y. Rahmat, DLR-TT, 2 March 2023

CONCLUSION: PTX FOR TRANSPORT?

Global e-fuel assessment – initial contribution

Comparing generic / designer fuels

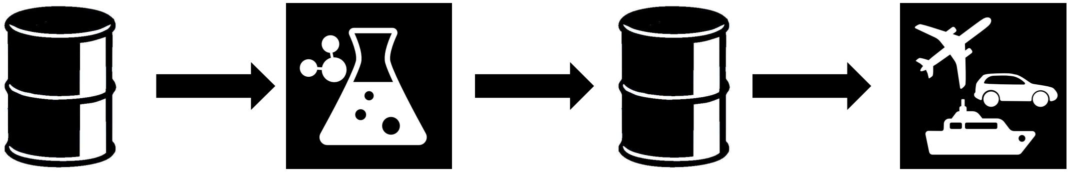
	SNG	MeOH	FT	$OME_{3\text{-}5}$	DMC	MeFo
Production: technical						
η_{PtX} [%]	59	53	40	42	47	52
η_{EtX} [%]	exotherm.	51	41	38	39	46

$$\boldsymbol{\eta_{PtX}} = \frac{\dot{\boldsymbol{m}}_{fuel} \cdot L\dot{H}V_{fuel}}{\sum \dot{\boldsymbol{P}}_{el}}$$

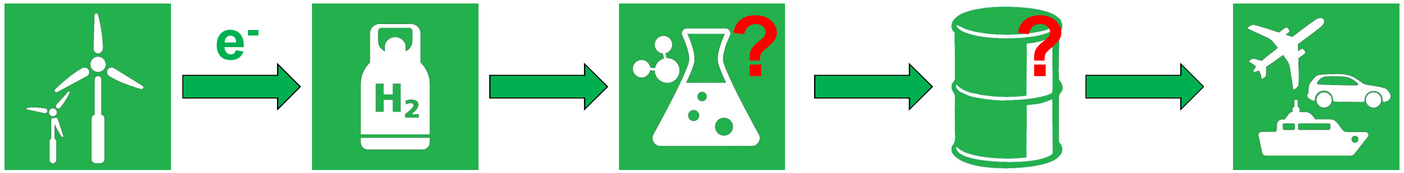
$$\boldsymbol{\eta_{EtX}} = \frac{\dot{\boldsymbol{m}}_{fuel} \cdot L\dot{H}V_{fuel}}{\sum \dot{\boldsymbol{P}}_{el} + \sum \dot{Q}}$$

Conclusion for e-fuels options in global transport
Simple pictograms

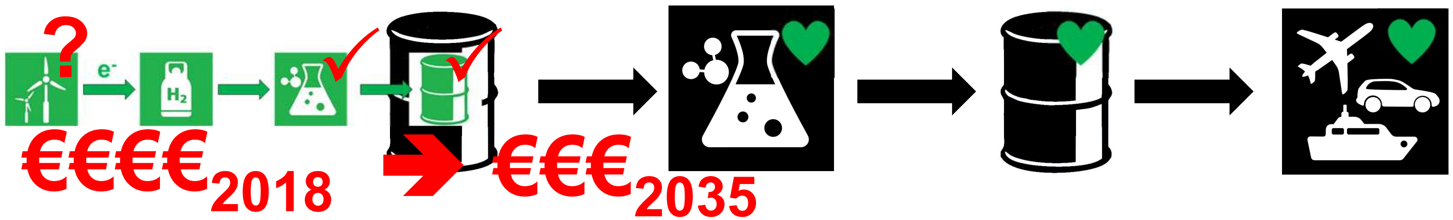
- Present (2018 ➔ 2023)



- Future Dream (2018)
  E&V Questions

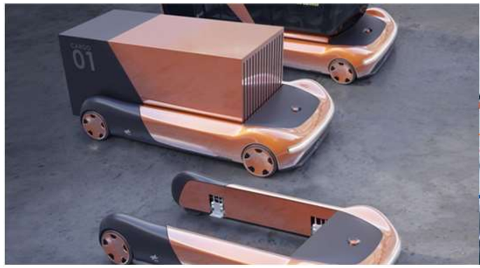


- Reality Check 2023
  Q&A



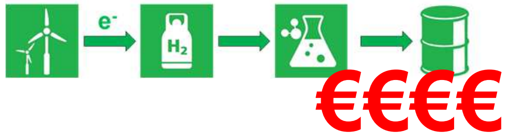
Outlook: Transport beyond 2023

- 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 (short-term response?)
  - Instant drop-in fuels blending mandate
  - Little electrification in marine and aviation
  - Maximize GHG abatement at minimal cost



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THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?

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