CCM-2023

TECHNO- ECONOMIC AND ECOLOGICAL ASSESSMENT OF SYNTHETIC FUELS PRODUCTION USING SUSTAINABLE CARBON AND HYDROGEN

Can e-fuels replace fossil fuels for a future global sustainable transport?

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Simon Maier, Moritz Raab, Yoga Rahmat, Julia Weyand
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DLR

Techno- economic and ecological assessment of synthetic fuels production using sustainable carbon and hydrogen

Agenda

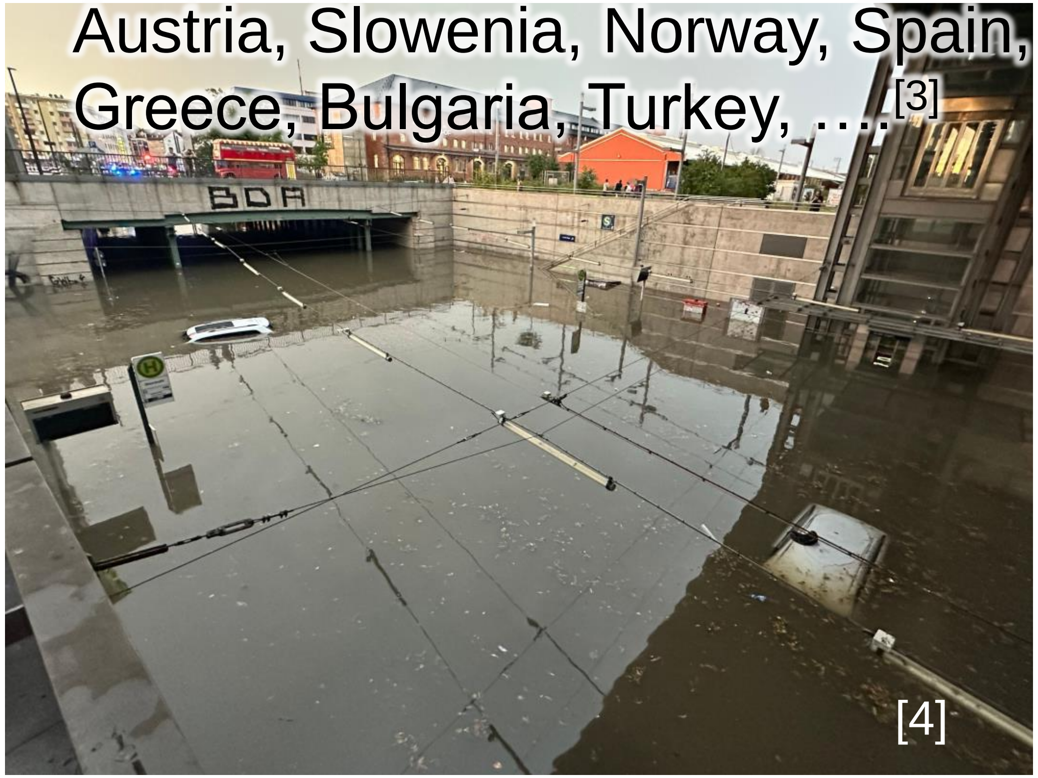
- Motivation
  - Why and how to do techno-economic and –ecological assessment (TEEA) @ DLR
  - TEEA methodology
- Assessment examples
  - Technical
  - Economic
  - Ecological
- Conclusion
  - Global e-fuel assessment for German transport
  - (personal view) Possible e-fuels impact on global transport – Germany as role model?
  - (personal view) Outlook: progress from 2023 onwards?

2023: Climate Change undeniable

- 2023 Wildfires: Canada, Chile, Gran Canary, Greece, Hawaii,….[1]


[2]

- 2023 Flooding (just Europe): Bosnia-Herzeg., Italy, Croatia, Austria, Slowenia, Norway, Spain, Greece, Bulgaria, Turkey, ….[3]


[4]

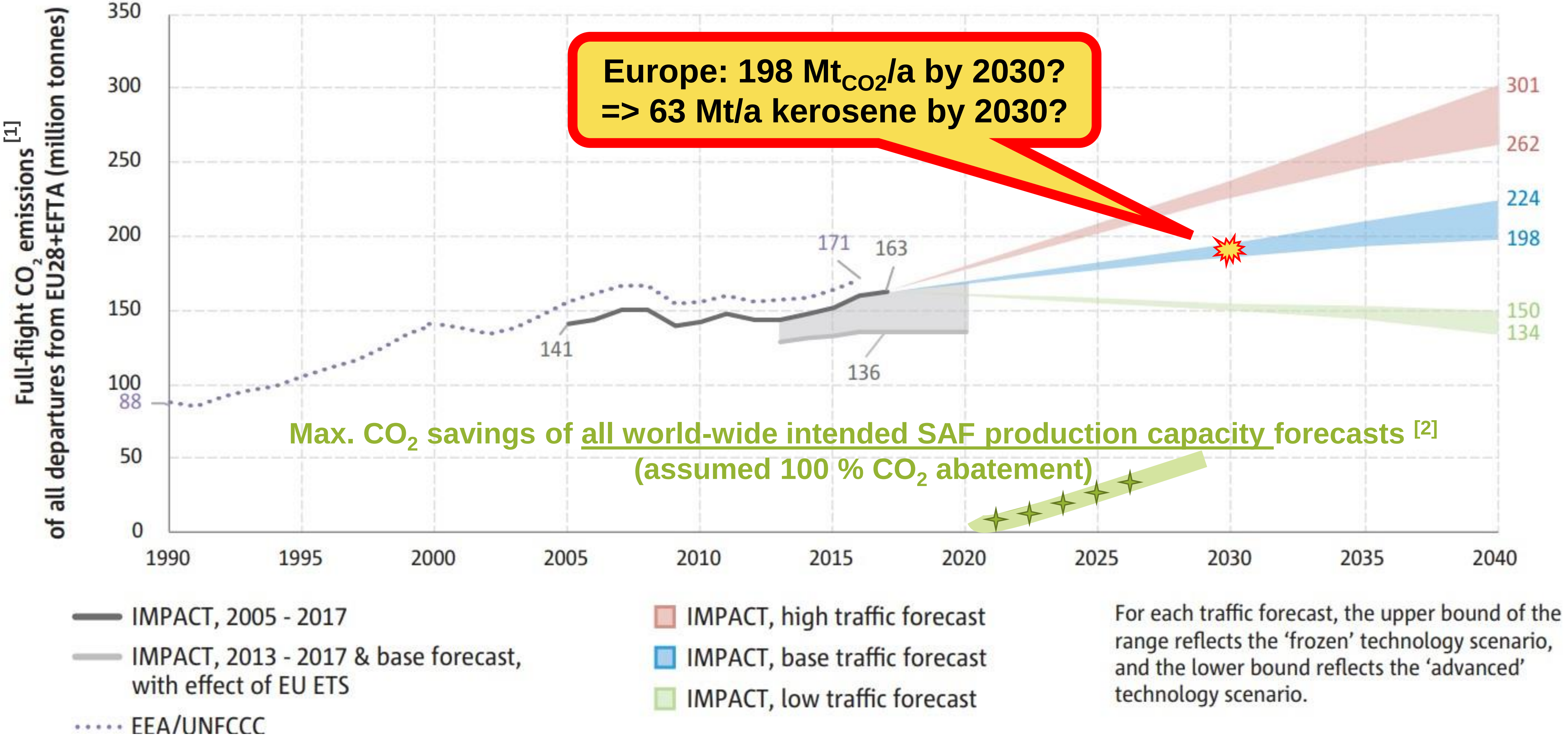
[1] https://en.wikideia.org/wiki/Category:2023_natural_disasters

[2] Photo by: Anthony Quintano/ anthonyquintano.com,
Canada Wildfire Smoke Consumes New Jersey and New York City, June 7 2023,
https://www.flickr.com/photos/quintanomedia/52959378738/ - 52959378738.jpg

[3] https://de.wikipedia.org/wiki/%C3%9Cberschwemmungen_in_Europa_2023

[4] Photo NEWS5/dpa,
Nuremberg, Germany, cars under bridge after flooding August 18 2023,

European aviation CO_2 emissions
Response: SAF for CO_2 abatement



Europe: 198 Mt_{CO2}/a by 2030?
=> 63 Mt/a kerosene by 2030?

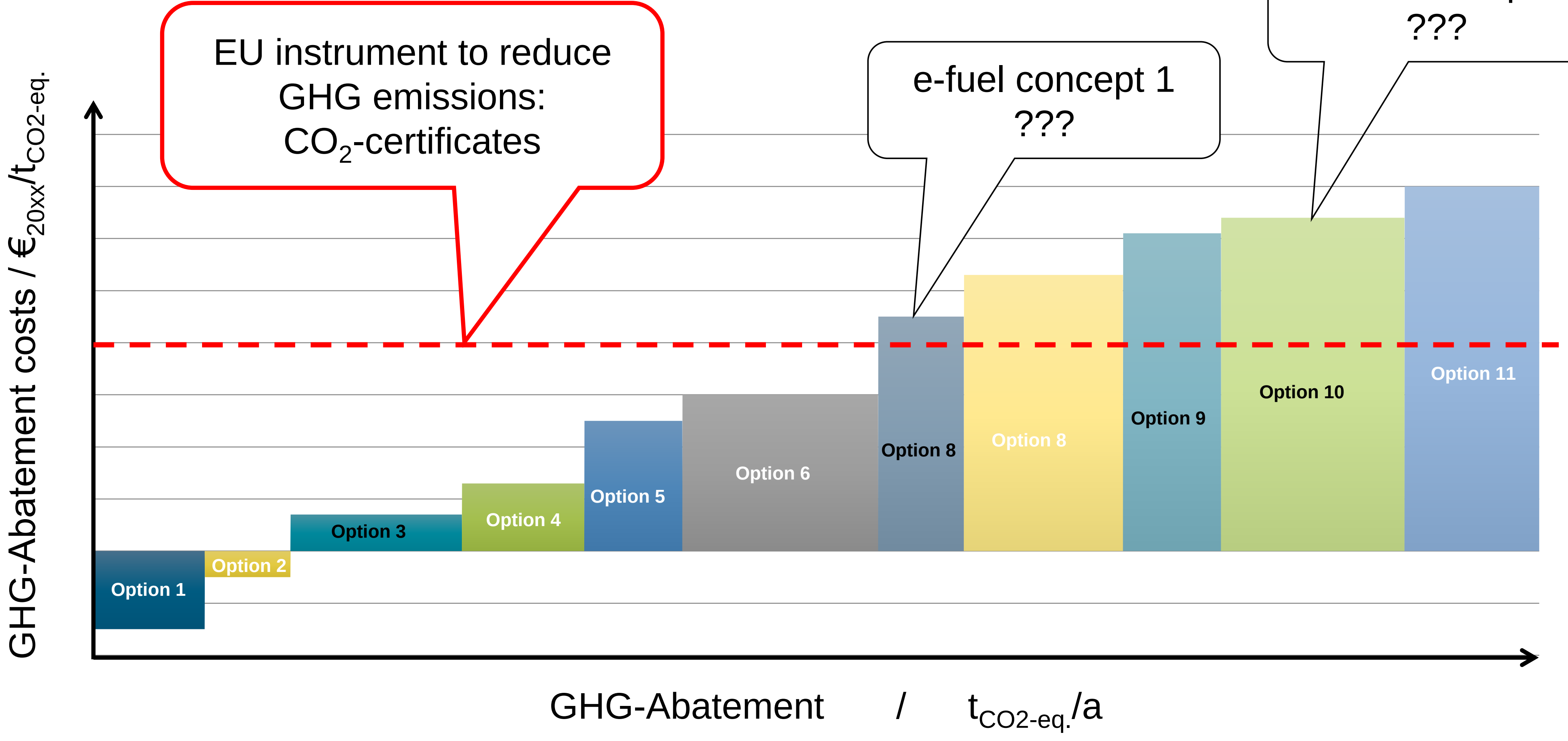
Max. CO_2 savings of <u>all world-wide intended SAF production capacity</u> forecasts [2]
(assumed 100 % CO_2 abatement)

For each traffic forecast, the upper bound of the range reflects the 'frozen' technology scenario, and the lower bound reflects the 'advanced' technology scenario.

[1] European Aviation Environmental Report 2019, https://www.easa.europa.eu/eaer/system/files/usr_uploaded/219473_EASA_EAER_2019_WEB_LOW-RES.pdf
[2] S. Csonka, Aviation's Market Pull for SAF, https://www.caafi.org/focus_areas/docs/CAAFI_SAF_Market_Pull_from_Aviation.pdf.

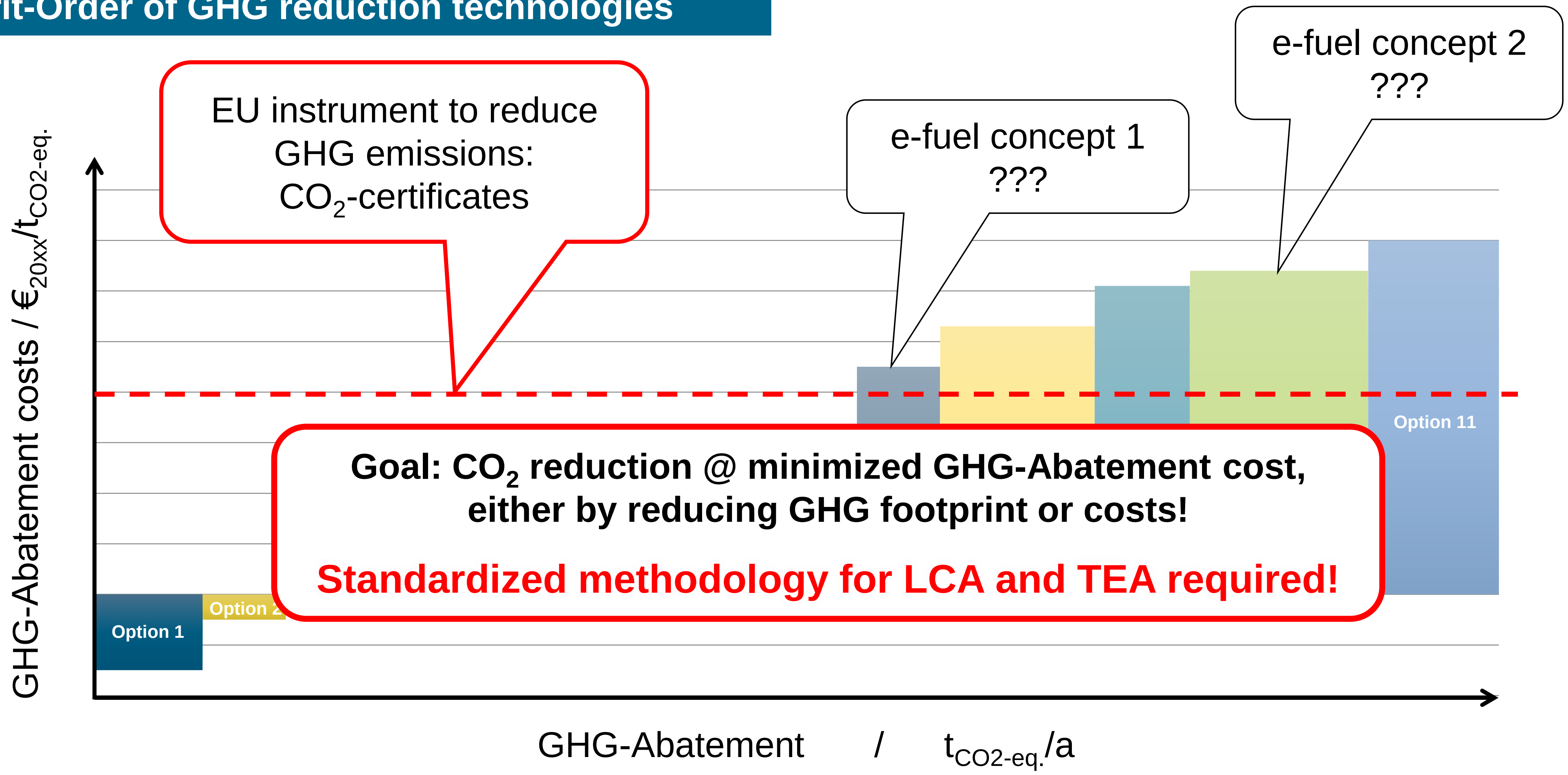
Assessment of e-fuels for sustainable transport sector

Merit-Order of GHG reduction technologies



Assessment of e-fuels for sustainable transport sector

Merit-Order of GHG reduction technologies



EU instrument to reduce GHG emissions: CO_2-certificates

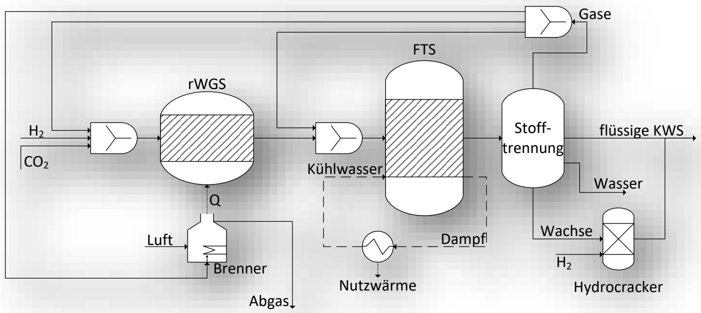
e-fuel concept 1 ???

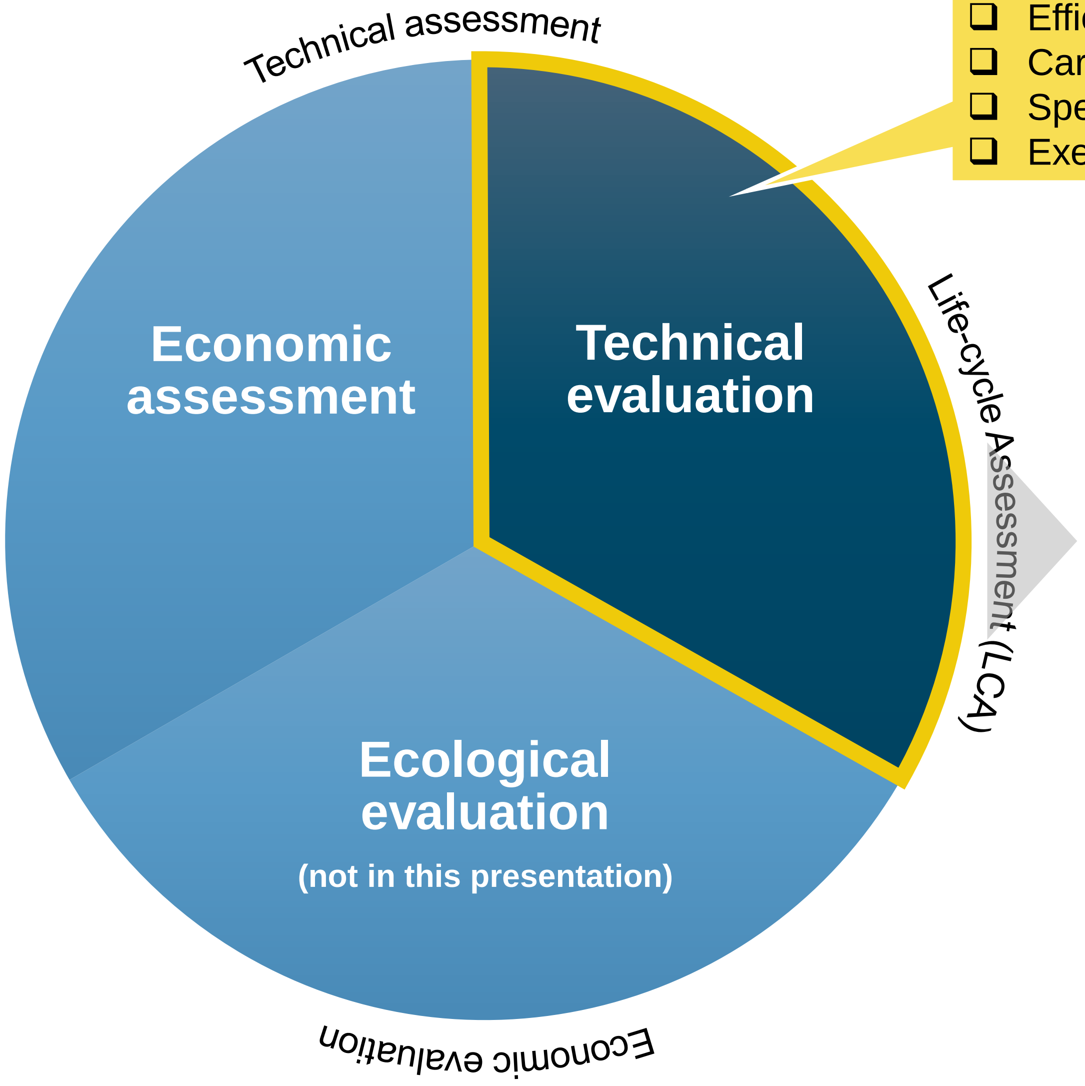
e-fuel concept 2 ???

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) @ DLR





Technical assessment

Economic assessment

Technical evaluation

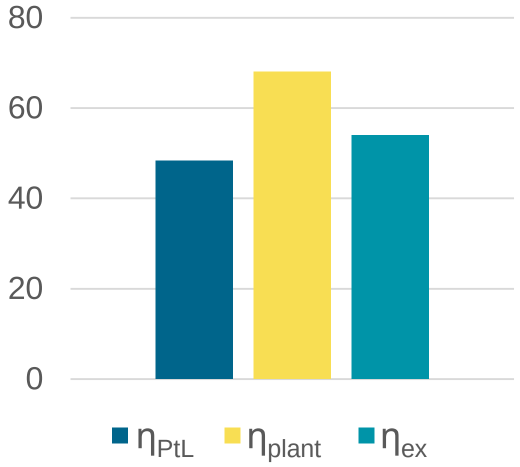
Life-cycle Assessment (LCA)

Ecological evaluation

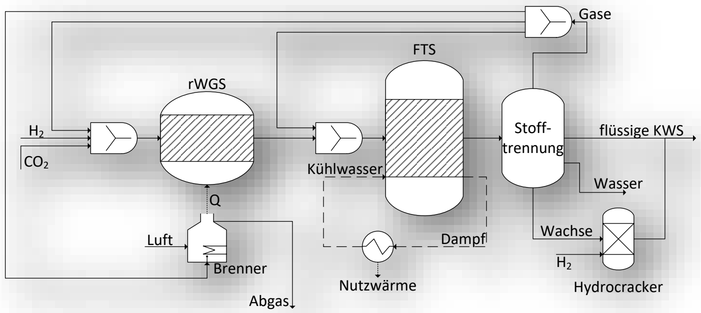
(not in this presentation)

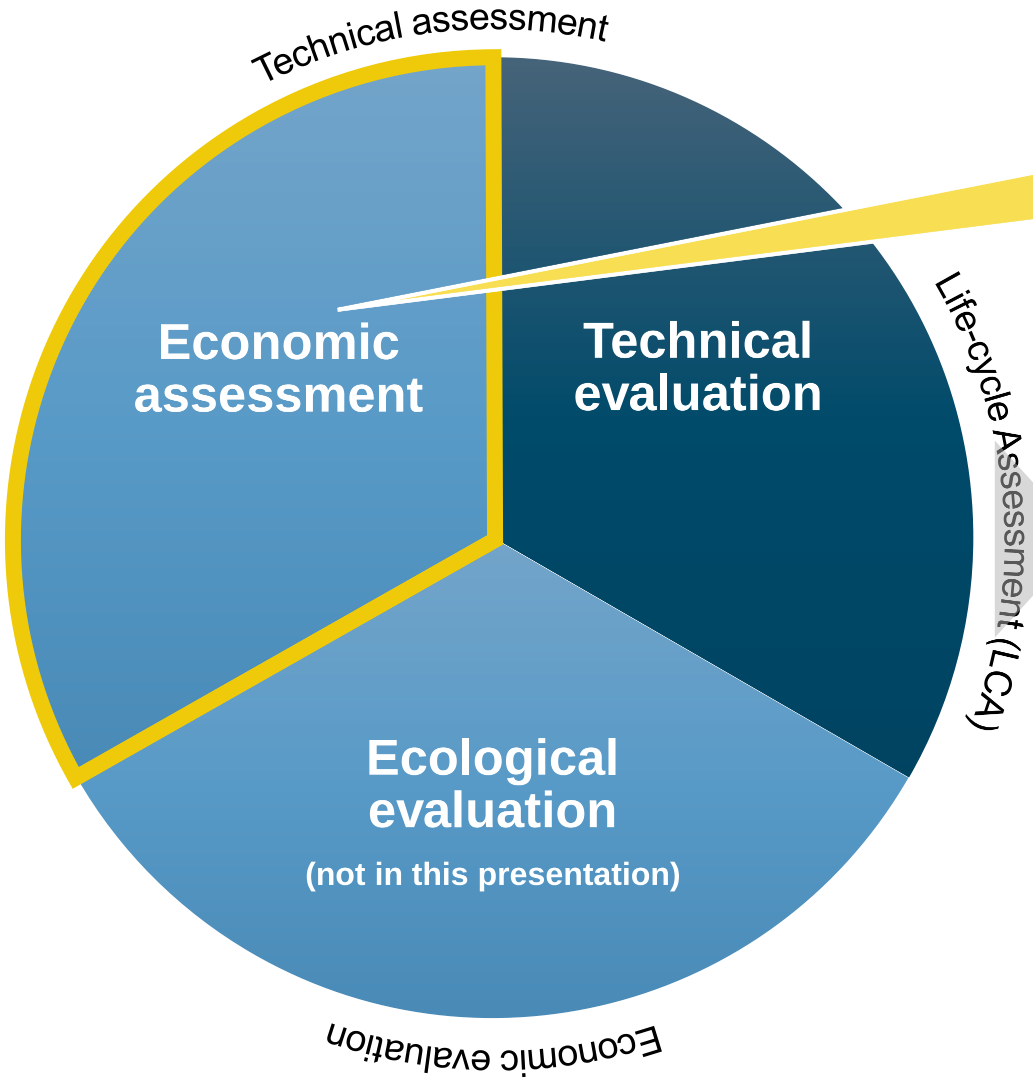
Economic evaluation

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



Techno-economic and ecological assessment (TEEA) @ DLR





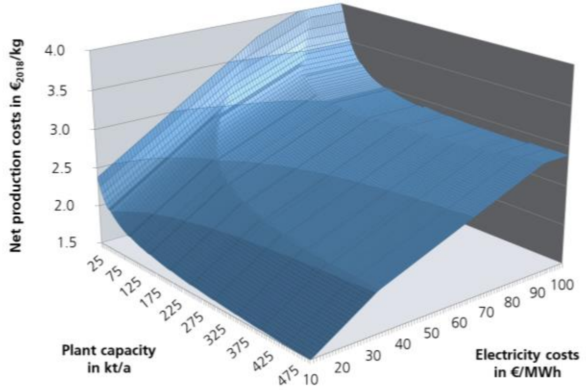
Economic assessment

Technical evaluation

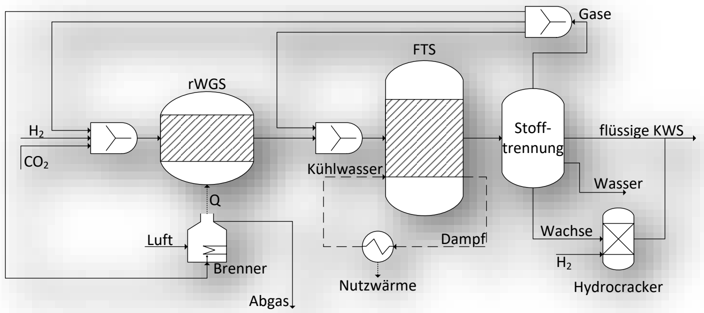
Ecological evaluation

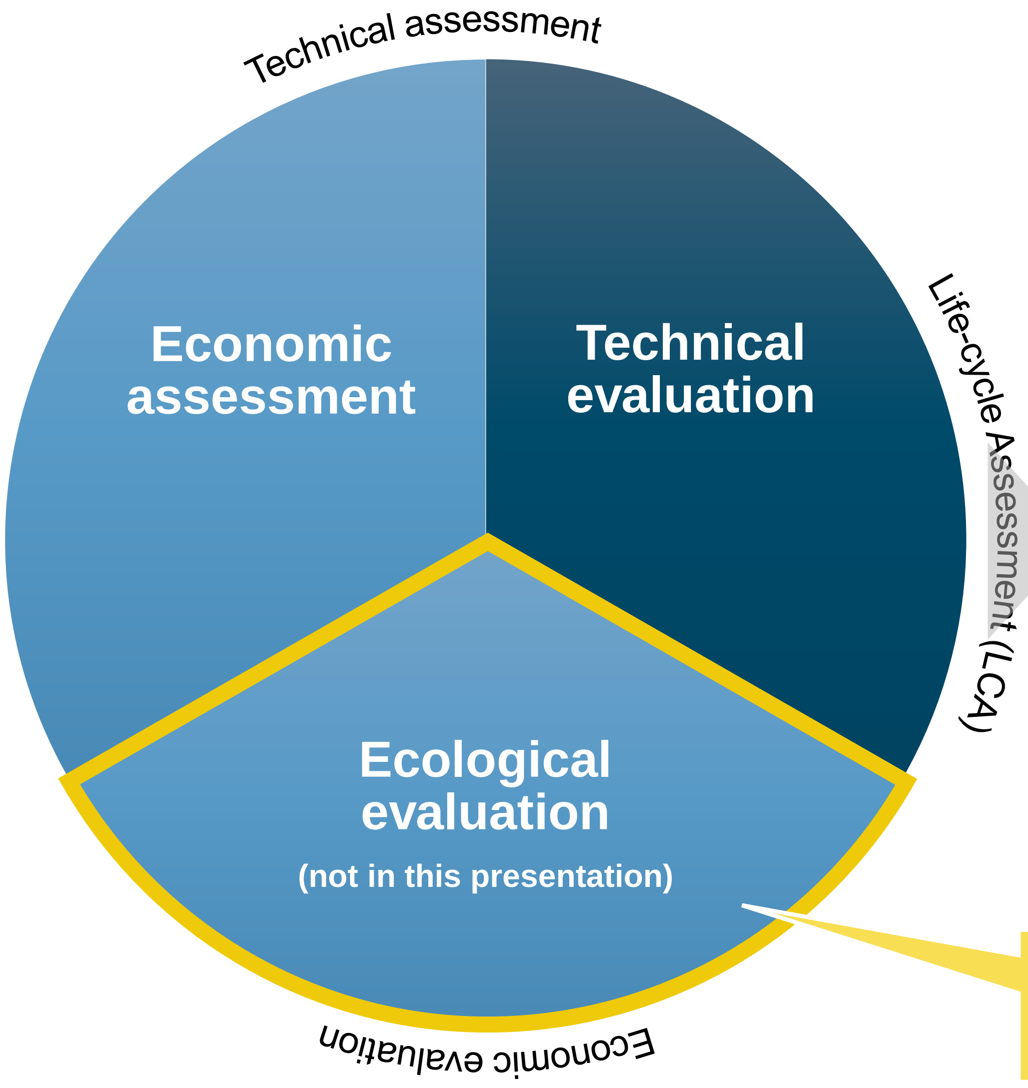
(not in this presentation)

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



Techno-economic and ecological assessment (TEEA) @ DLR





Technical assessment

Economic assessment

Technical evaluation

Life-cycle Assessment (LCA)

Ecological evaluation

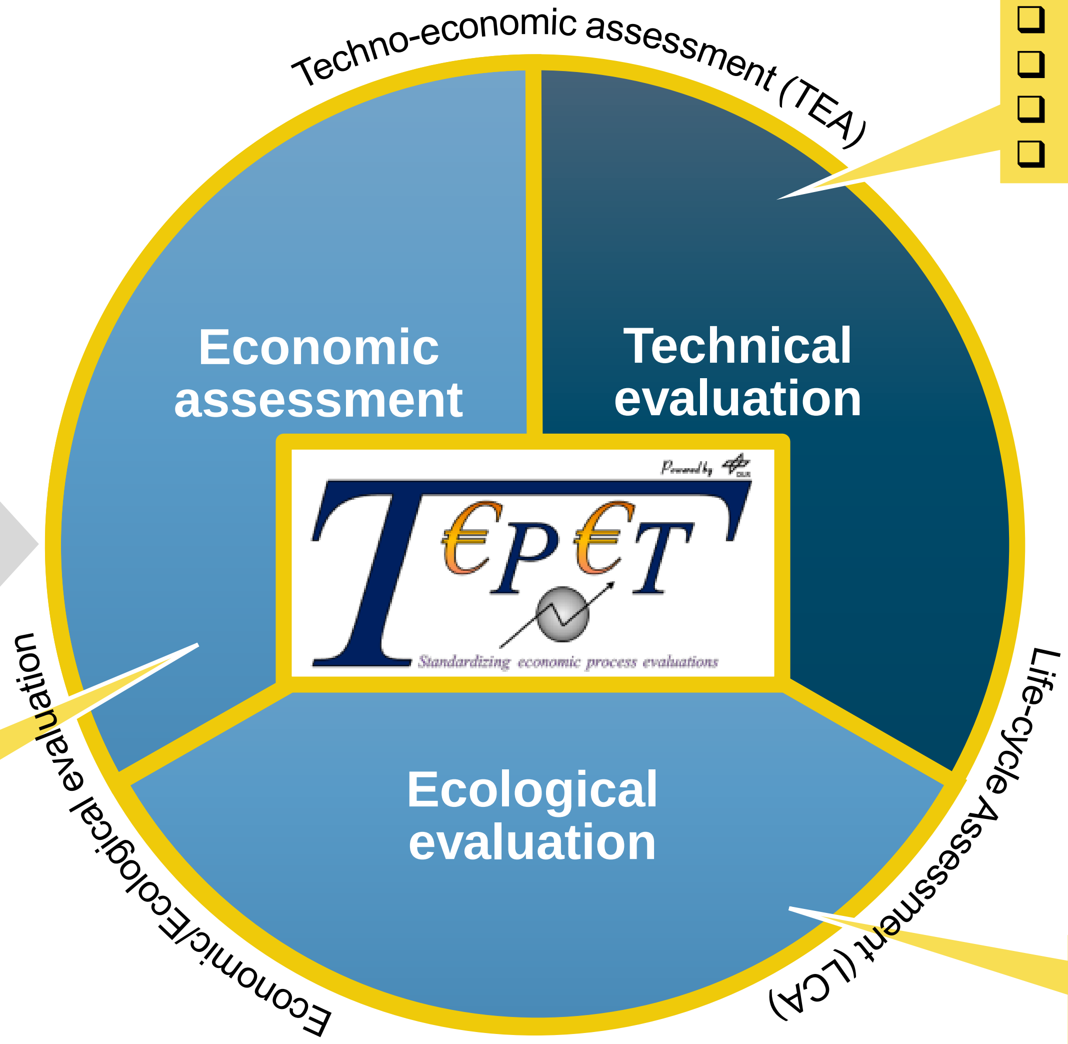
(not in this presentation)

Economic evaluation

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

Techno-economic and ecological assessment (TEEA) @ DLR

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



Techno-economic assessment (TEA)

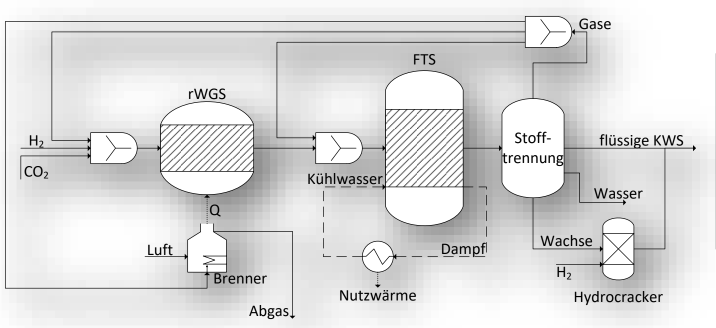
Economic assessment

Technical evaluation

Ecological evaluation

Economic/Ecological evaluation

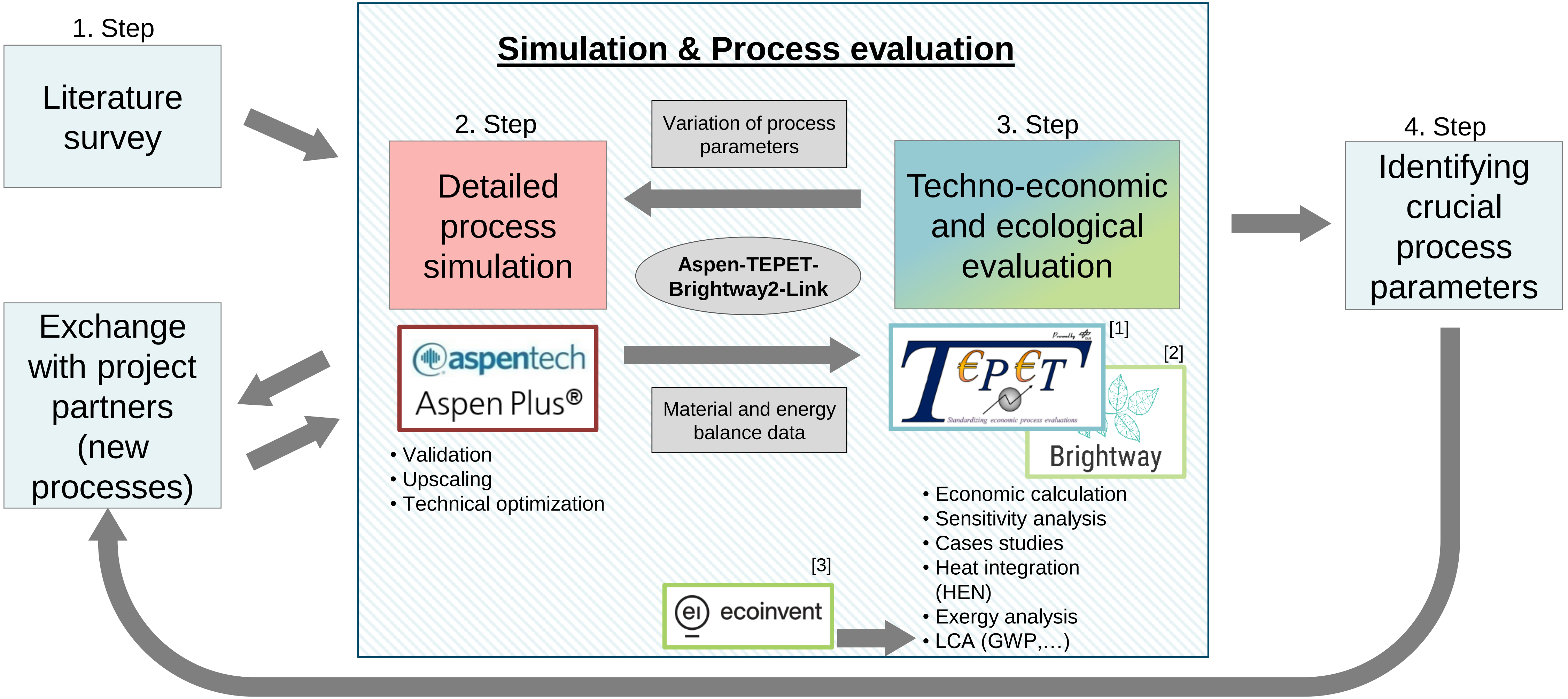
Life-cycle Assessment (LCA)



- ☐ CAPEX, OPEX, NPC
- ☐ Sensitivity analysis
- ☐ 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 (new processes)

Simulation & Process evaluation

2. Step

Detailed process simulation

- Validation
- Upscaling
- Technical optimization

Variation of process parameters

Aspen-TEPET-Brightway2-Link

Material and energy balance data

[3]

3. Step

Techno-economic and ecological evaluation

[1]

[2]

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

4. Step

Identifying crucial process parameters

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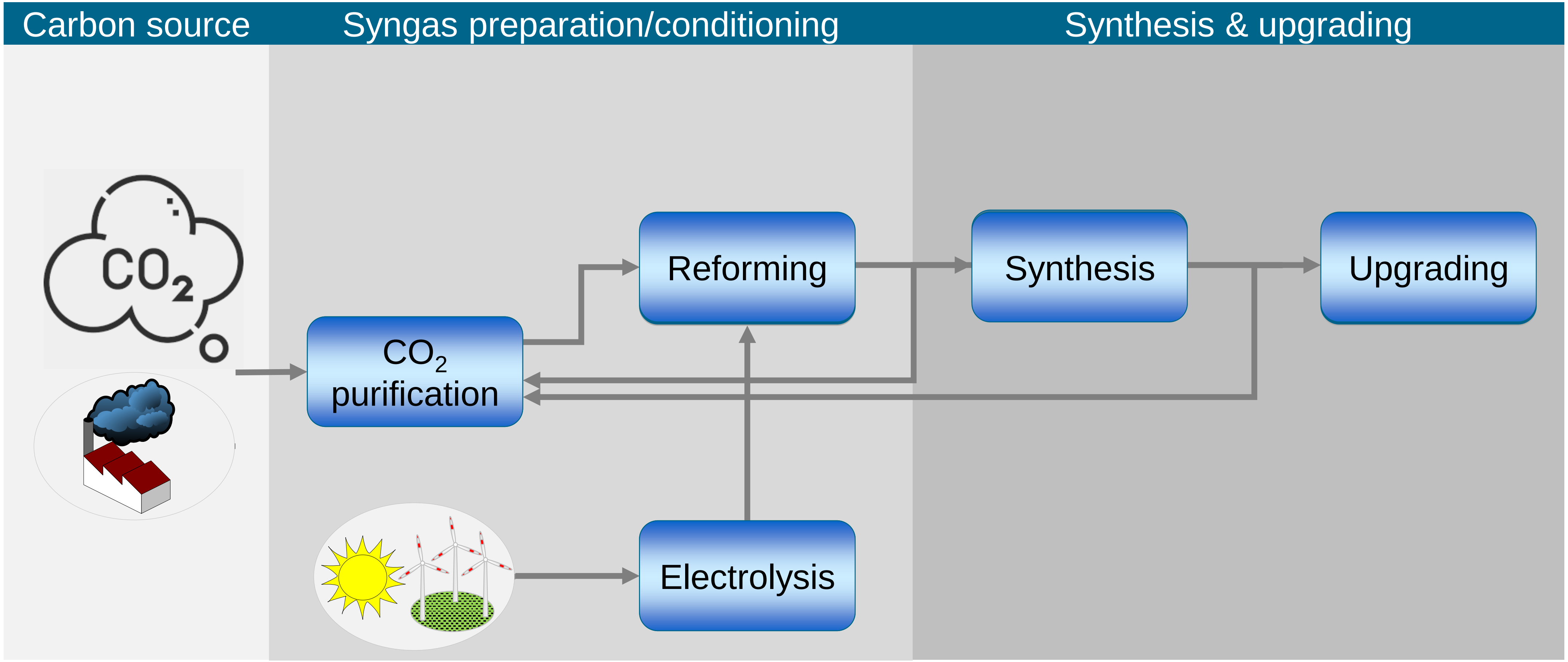
[1] Albrecht et al. (2016) A standardized methodology for the techno-economic evaluation of alternative fuels – A case study, Fuel, 194: 511-526
[2] Mutel (2017) - Brightway: An open source framework for Life Cycle Assessment, Journal of Open Source Software, 2(12): 236
[3] Wernet, G et al. (2016) The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

3 generic Fischer-Tropsch based Sustainable Aviation Fuels (SAF) concepts

Power-to-Liquid



Carbon source

Syngas preparation/conditioning

Synthesis & upgrading

CO_2 purification

Reforming

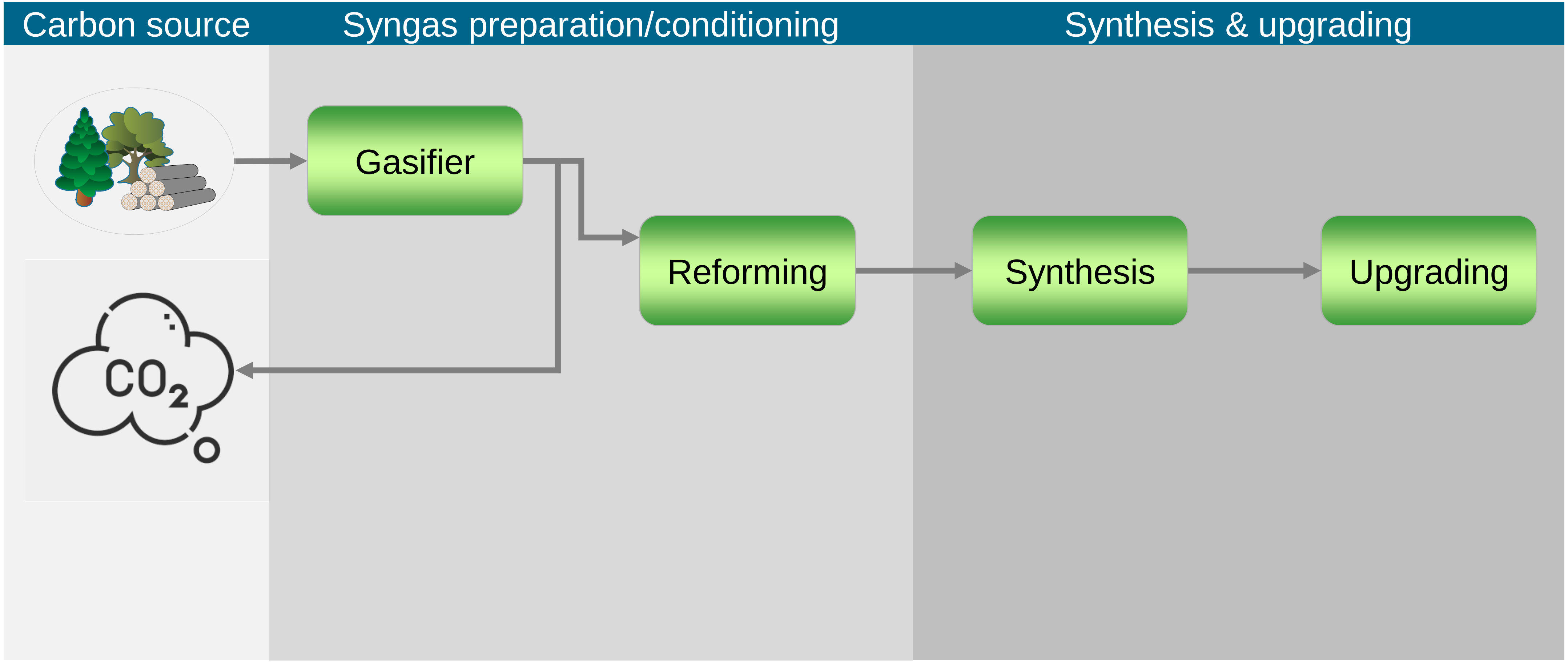
Synthesis

Upgrading

Electrolysis

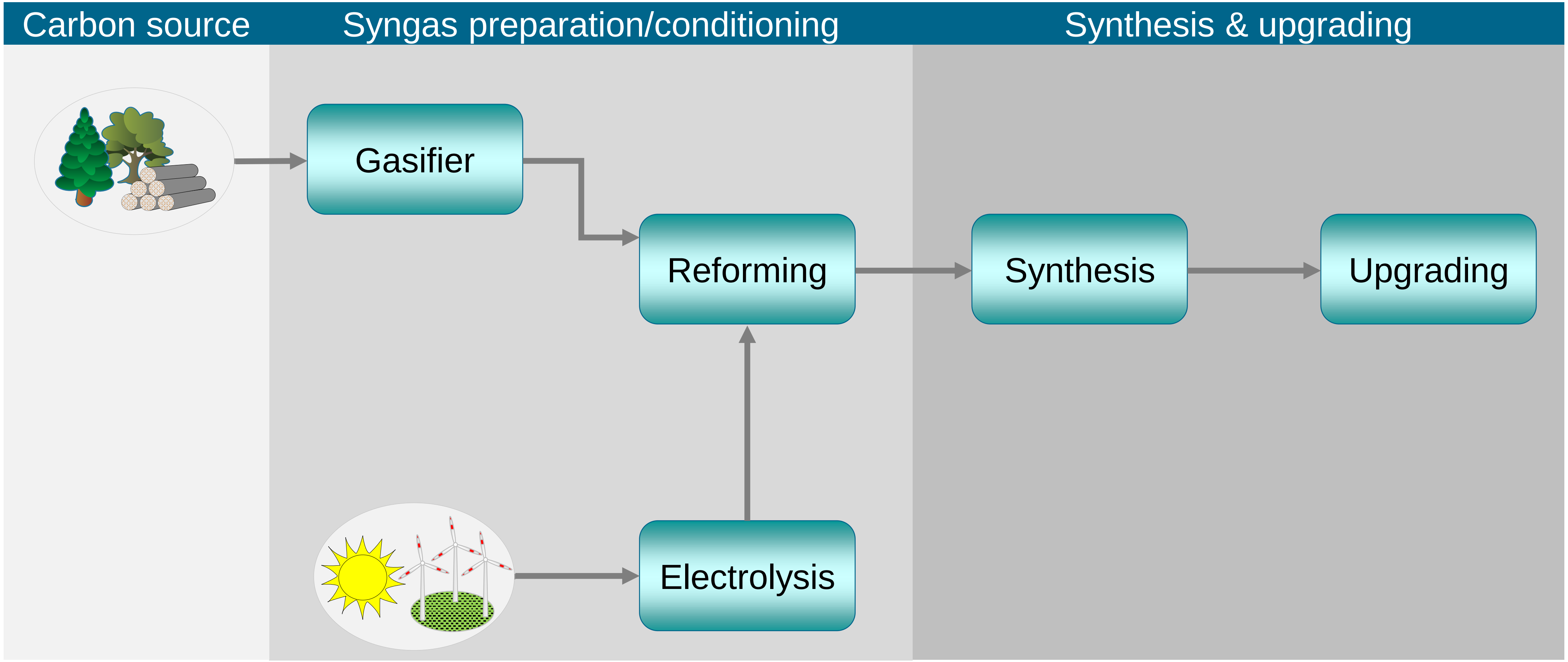
3 generic Fischer-Tropsch based Sustainable Aviation Fuels (SAF) concepts

Biomass-to-Liquid



3 generic Fischer-Tropsch based Sustainable Aviation Fuels (SAF) concepts

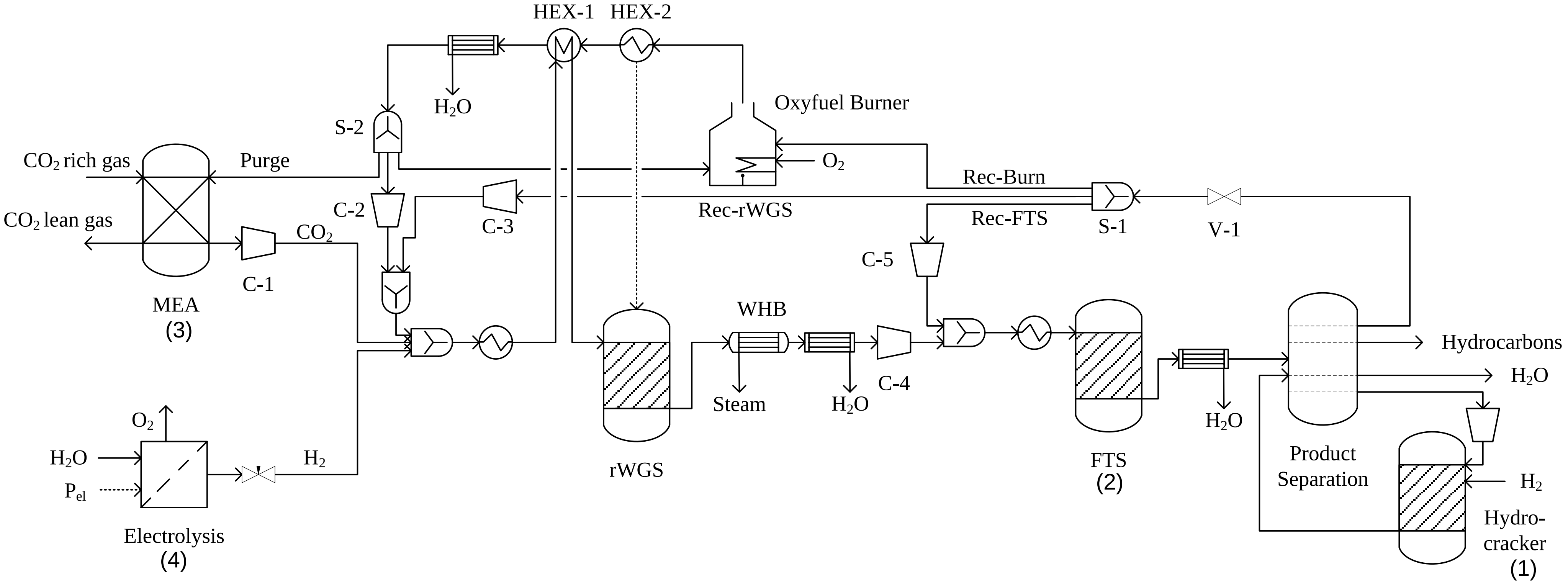
Power&Biomass-to-Liquid



TECHNICAL ASSESSMENT OF SAF (PTL)

Technical Assessment: Power-to-Liquid

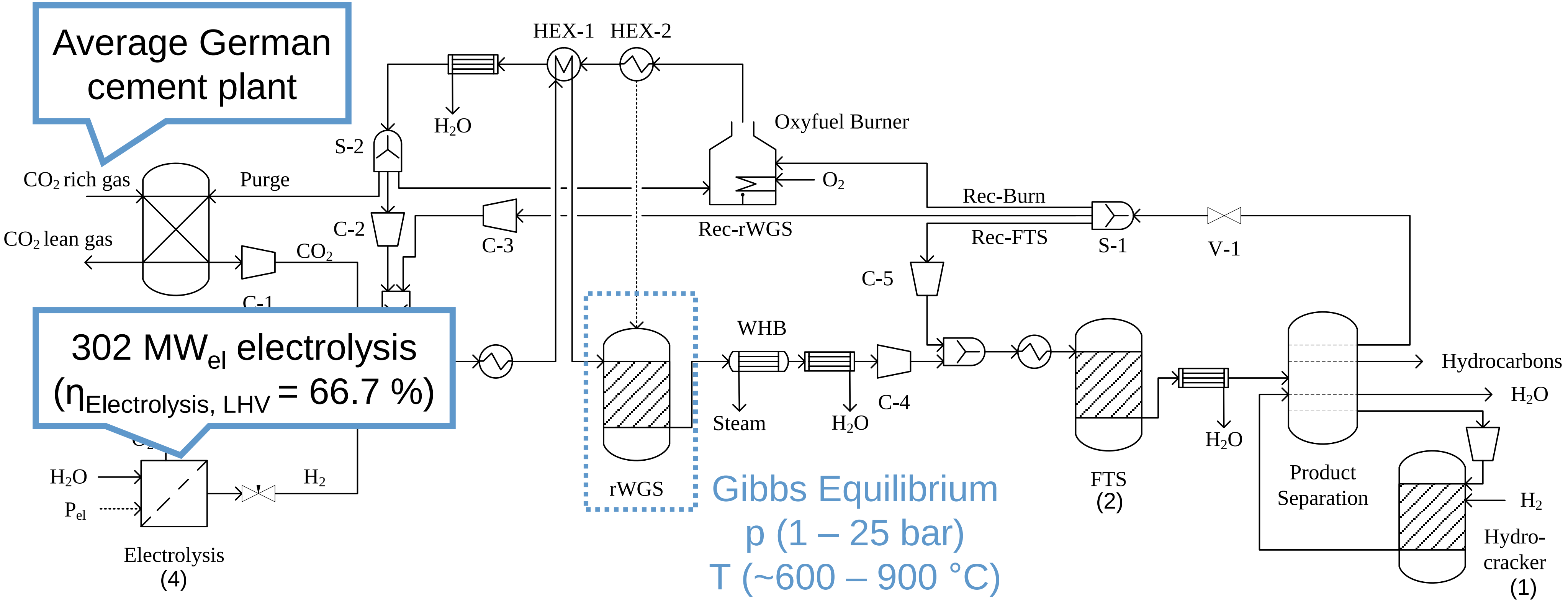
Methodology: Experimentally validated flowsheet (5)



(1) D. Leckel, M. Liwanga-Ehumbu (2006): Diesel-Selective Hydrocracking of an Iron-Based Fischer−Tropsch Wax Fraction (C 15 −C 45) Using a MoO 3 -Modified Noble Metal Catalyst
(2) D. Vervloet et al. (2012): Fischer–Tropsch reaction–diffusion in a cobalt catalyst particle: aspects of activity and selectivity for a variable chain growth probability
(3) Roussanaly et al. (2017):Techno-economic analysis of MEA CO2 capture from a cement kiln– impact of steam supply scenario
(4) Schmidt et al. (2017): Future cost and performance of water electrolysis:: An expert elicitation study
(5) Adelung and Dietrich, R.-U. (2022). Impact of the reverse water-gas shift operating conditions on the Power-to-Liquid process efficiency

Technical Assessment: Power-to-Liquid

Methodology: Experimentally validated flowsheet (5)



Average German cement plant

302 MW_{el} electrolysis ($\eta_{Electrolysis, LHV}$ = 66.7 %)

Gibbs Equilibrium
p (1 – 25 bar)
T (~600 – 900 °C)

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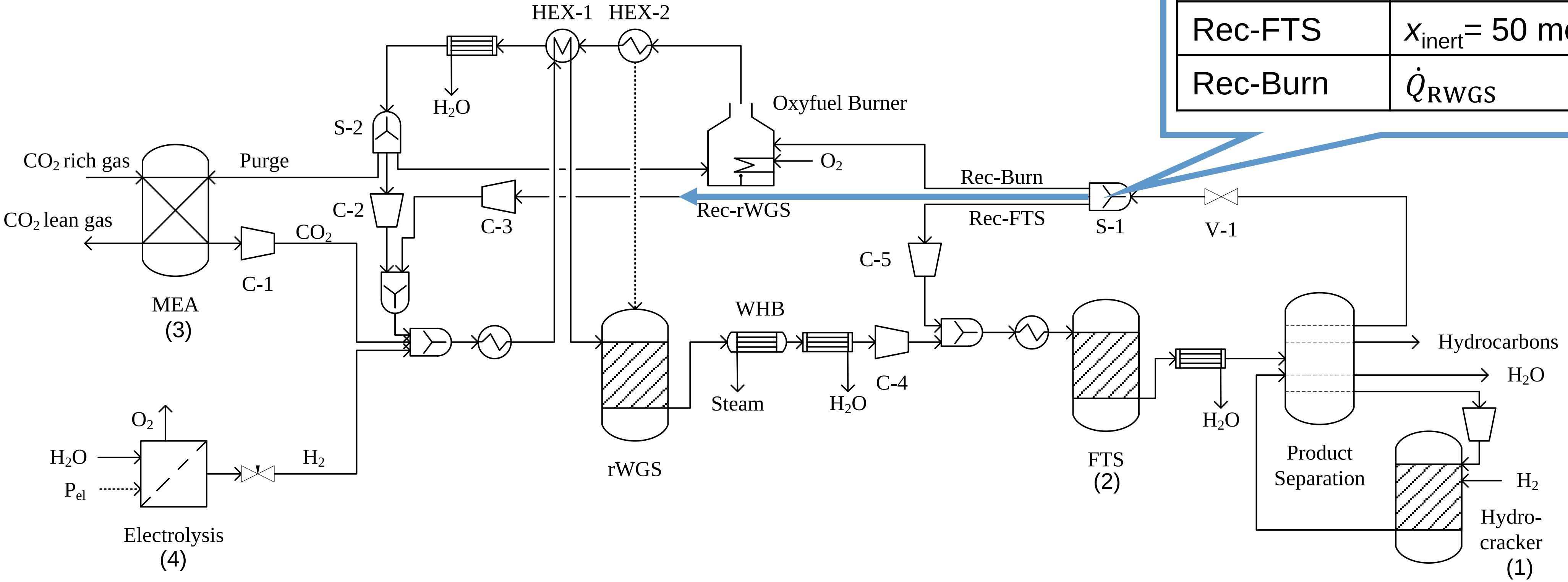
Technical Assessment: Power-to-Liquid

Methodology: Experimentally validated flowsheet (5)

Recycle	**Specification**
Rec-FTS	x_{inert}= 50 mol %
Rec-Burn	$\dot{Q}_{RWGS}$



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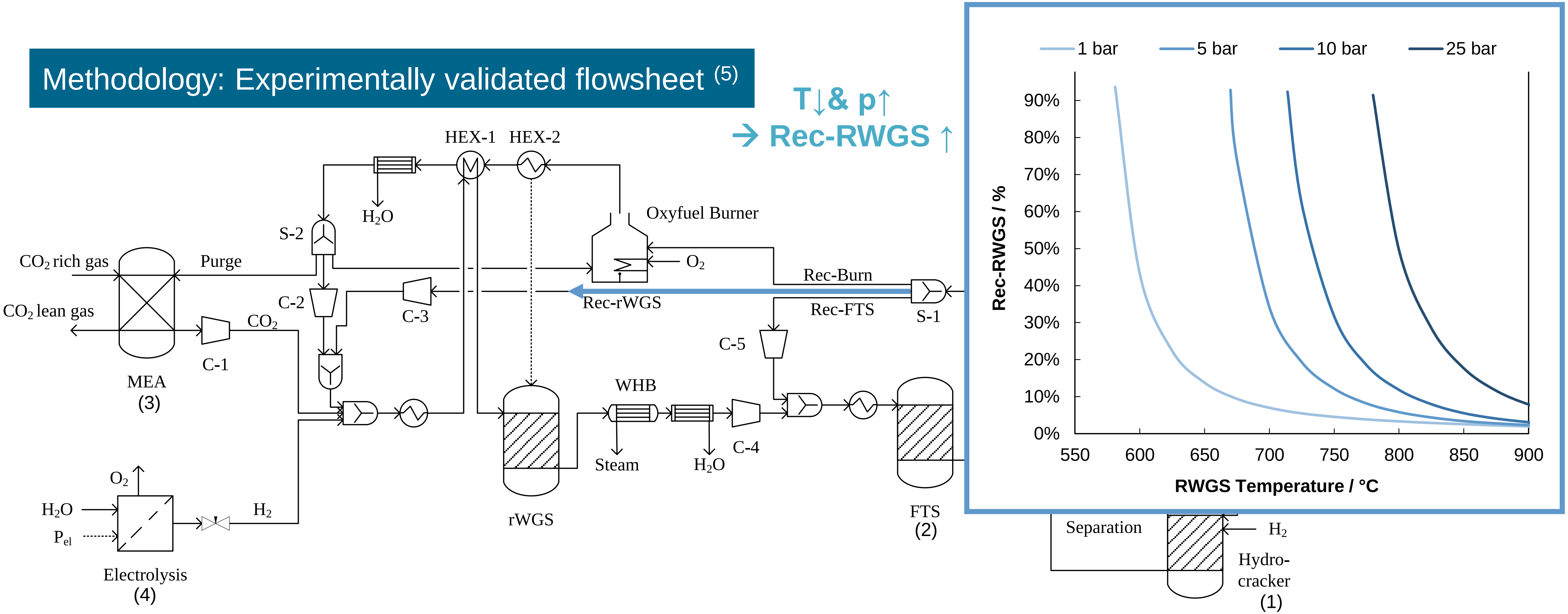
Technical Assessment: Power-to-Liquid

Methodology: Experimentally validated flowsheet (5)

T↓& p↑

→ Rec-RWGS ↑



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Technical Assessment: Power-to-Liquid

Process Parameter dependent Material / Energy Efficiency (5)

■ = Highest efficiency

$$\eta_{\mathrm{C}} = \frac{\dot{n}_{\mathrm{C,C5+}}}{\dot{n}_{\mathrm{C,feedstock}}}$$

RWGS Temperatur / °C	1	5	10	25
900	82.2%	82.2%	82.4%	83.7%
875	82.3%	82.4%	82.8%	84.5%
850	82.4%	82.6%	83.1%	85.1%
825	82.5%	82.8%	83.7%	85.8%
800	82.5%	83.1%	84.3%	86.7%
775	82.8%	83.7%	85.1%	
750	82.9%	84.3%	85.9%	
725	83.2%	85.1%	86.7%	
700	83.4%	86.0%		
675	83.9%	86.8%		
650	84.5%			
625	85.3%			
600	86.3%			

RWGS press. / bar

Higher recycle rate to RWGS increases C efficiency

$$\eta_{\mathrm{H}} = \frac{\dot{n}_{\mathrm{H,C5+}}}{\dot{n}_{\mathrm{H},elektrolysis}}$$

	1	5	10	25
900	23.6%	23.6%	23.6%	23.1%
875	23.8%	23.7%	23.6%	22.8%
850	23.9%	23.9%	23.7%	22.2%
825	24.0%	23.9%	23.6%	21.1%
800	24.2%	24.0%	23.4%	19.0%
775	24.3%	24.0%	22.8%	
750	24.4%	23.8%	21.6%	
725	24.5%	23.3%	19.0%	
700	24.6%	22.0%		
675	24.6%	18.8%		
650	24.5%			
625	24.0%			
600	22.5%			

RWGS press. / bar

Less water formation increases H efficiency

$$\eta_{\mathrm{PtL}} = \frac{\dot{m}_{\mathrm{C5+}} LHV_{\mathrm{C5+}}}{P_{elektrolysis} + P_{\mathrm{MEA}} + P_{\mathrm{compressor}}}$$

	1	5	10	25
900	35.3%	36.1%	36.2%	35.8%
875	35.5%	36.2%	36.3%	35.5%
850	35.7%	36.4%	36.4%	34.6%
825	35.8%	36.5%	36.3%	32.8%
800	36.0%	36.6%	36.0%	29.7%
775	36.2%	36.5%	35.0%	
750	36.3%	36.2%	33.1%	
725	36.4%	35.2%	29.0%	
700	36.4%	33.1%		
675	36.3%	28.0%		
650	36.0%			
625	34.9%			
600	32.0%			

RWGS press. / bar

High H efficiency plus low compression demand maximizes PtL efficiency

[1] Adelung, S. and Dietrich, R.-U. (2022). Impact of the reverse water-gas shift operating conditions on the Power-to-Liquid fuel production cost. *Fuel.*

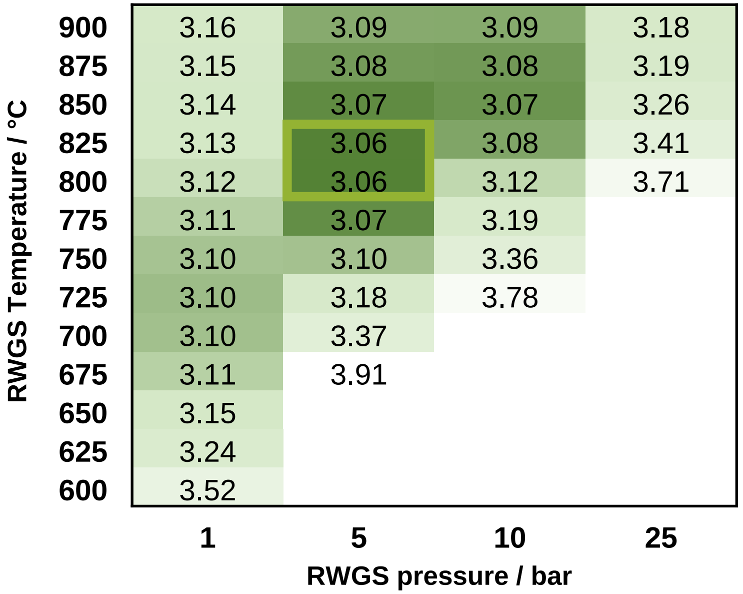
ECONOMICAL ASSESSMENT OF SAF (PTL)

Economical Assessment of **Power-to-Liquid** process

Process Parameter dependent Net Production Costs [1] / NPC in $€_{2019}/kg_{C5+}$

🟩 = lower NPC

H_2-Input: 4.1€/kg_{H2}



RWGS Temperature / °C	1	5	10	25
900	3.16	3.09	3.09	3.18
875	3.15	3.08	3.08	3.19
850	3.14	3.07	3.07	3.26
825	3.13	3.06	3.08	3.41
800	3.12	3.06	3.12	3.71
775	3.11	3.07	3.19	
750	3.10	3.10	3.36	
725	3.10	3.18	3.78	
700	3.10	3.37		
675	3.11	3.91		
650	3.15			
625	3.24			
600	3.52			

RWGS pressure / bar

Minimum

[1] Adelung, S. and Dietrich, R.-U. (2022). Impact of the reverse water-gas shift operating conditions on the Power-to-Liquid fuel production cost. *Fuel.*

Economical Assessment of **Power-to-Liquid** process

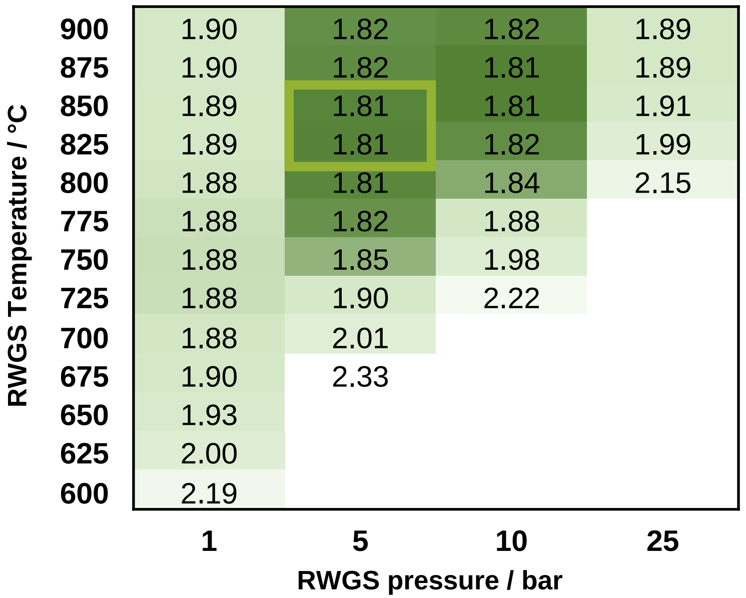
CCM-2023

DLR

Process Parameter dependent Net Production Costs [1] / NPC in $€_{2019}/kg_{C5+}$

🟩 = lower NPC

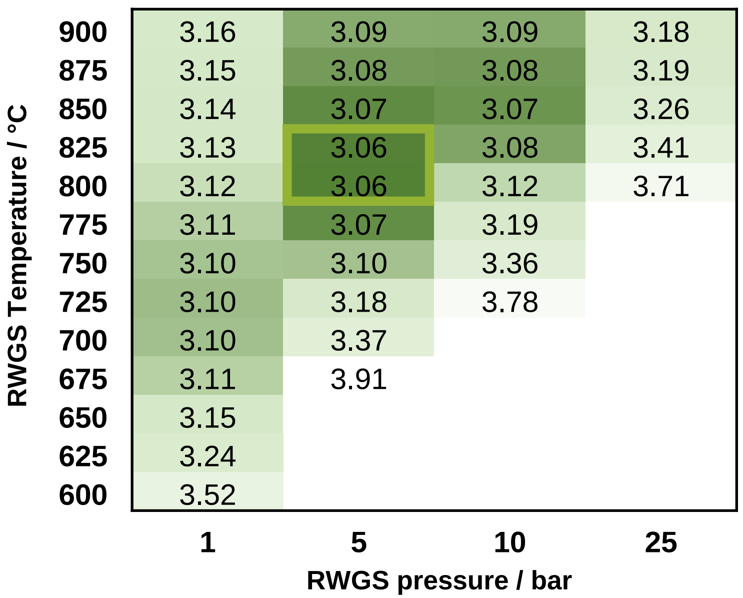
H_2-Input: 2.3 $€/kg_{H2}$



RWGS Temperature / °C	1	5	10	25
900	1.90	1.82	1.82	1.89
875	1.90	1.82	1.81	1.89
850	1.89	1.81	1.81	1.91
825	1.89	1.81	1.82	1.99
800	1.88	1.81	1.84	2.15
775	1.88	1.82	1.88	
750	1.88	1.85	1.98	
725	1.88	1.90	2.22	
700	1.88	2.01		
675	1.90	2.33		
650	1.93			
625	2.00			
600	2.19			

RWGS pressure / bar

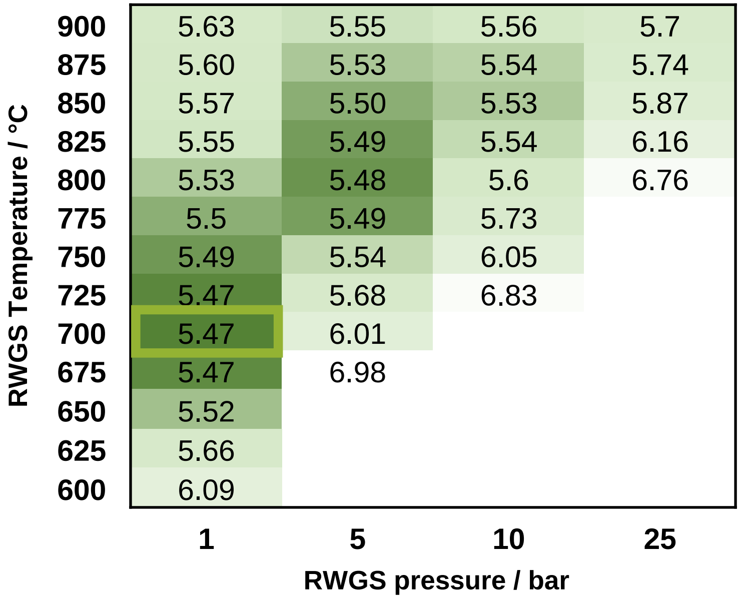
H_2-Input: 4.1$€/kg_{H2}$



RWGS Temperature / °C	1	5	10	25
900	3.16	3.09	3.09	3.18
875	3.15	3.08	3.08	3.19
850	3.14	3.07	3.07	3.26
825	3.13	3.06	3.08	3.41
800	3.12	3.06	3.12	3.71
775	3.11	3.07	3.19	
750	3.10	3.10	3.36	
725	3.10	3.18	3.78	
700	3.10	3.37		
675	3.11	3.91		
650	3.15			
625	3.24			
600	3.52			

RWGS pressure / bar

H_2-Input: 7.6 $€/kg_{H2}$



RWGS Temperature / °C	1	5	10	25
900	5.63	5.55	5.56	5.7
875	5.60	5.53	5.54	5.74
850	5.57	5.50	5.53	5.87
825	5.55	5.49	5.54	6.16
800	5.53	5.48	5.6	6.76
775	5.5	5.49	5.73	
750	5.49	5.54	6.05	
725	5.47	5.68	6.83	
700	5.47	6.01		
675	5.47	6.98		
650	5.52			
625	5.66			
600	6.09			

RWGS pressure / bar

Minimum

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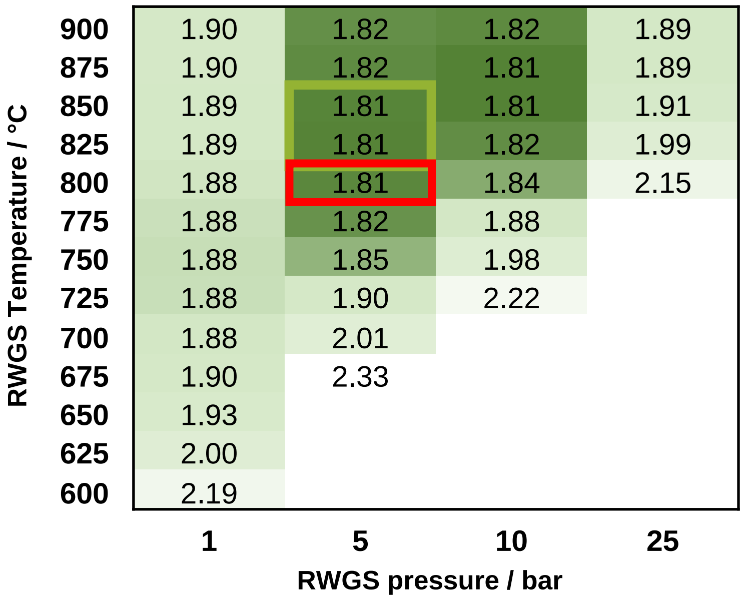
[1] Adelung, S. and Dietrich, R.-U. (2022). Impact of the reverse water-gas shift operating conditions on the Power-to-Liquid fuel production cost. *Fuel.*

Economical Assessment of **Power-to-Liquid** process

Process Parameter dependent Net Production Costs [1] / NPC in $€_{2019}/kg_{C5+}$

🟩 = lower NPC

H_2-Input: 2.3 €/kg_{H2}

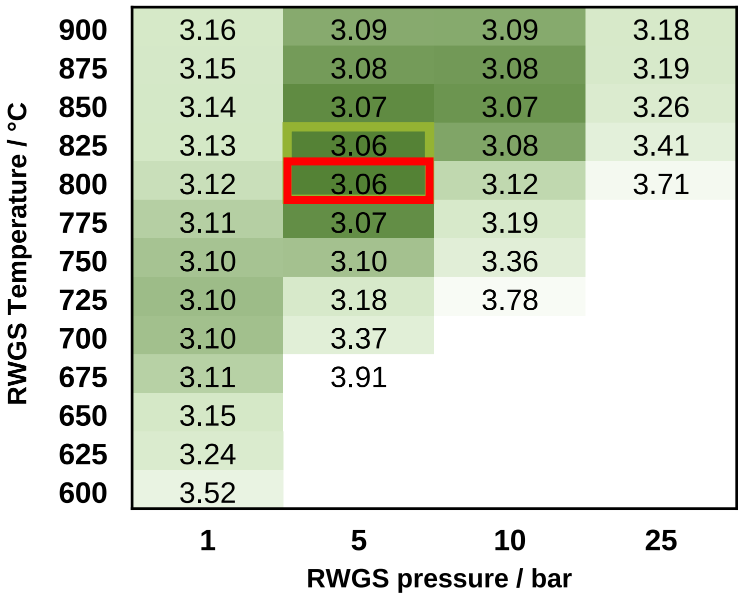


RWGS Temperature / °C

	1	5	10	25
900	1.90	1.82	1.82	1.89
875	1.90	1.82	1.81	1.89
850	1.89	1.81	1.81	1.91
825	1.89	1.81	1.82	1.99
800	1.88	1.81	1.84	2.15
775	1.88	1.82	1.88	
750	1.88	1.85	1.98	
725	1.88	1.90	2.22	
700	1.88	2.01		
675	1.90	2.33		
650	1.93			
625	2.00			
600	2.19			

RWGS pressure / bar

H_2-Input: 4.1€/kg_{H2}

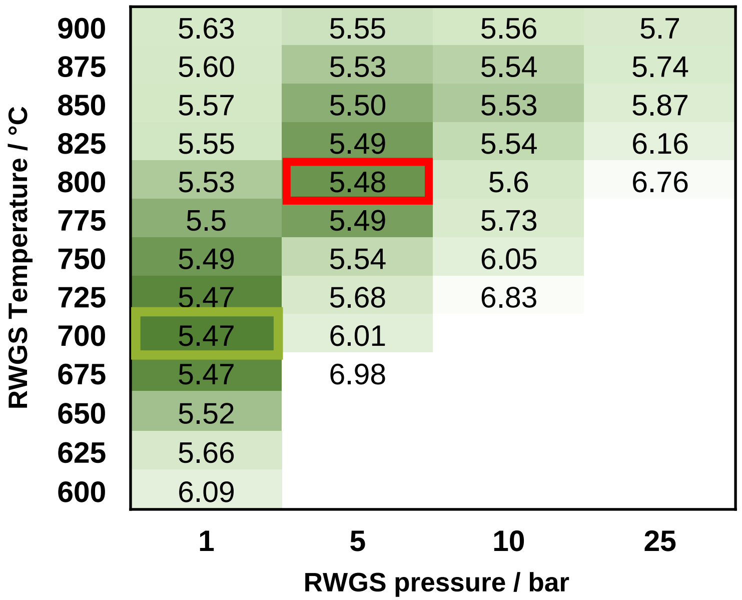


RWGS Temperature / °C

	1	5	10	25
900	3.16	3.09	3.09	3.18
875	3.15	3.08	3.08	3.19
850	3.14	3.07	3.07	3.26
825	3.13	3.06	3.08	3.41
800	3.12	3.06	3.12	3.71
775	3.11	3.07	3.19	
750	3.10	3.10	3.36	
725	3.10	3.18	3.78	
700	3.10	3.37		
675	3.11	3.91		
650	3.15			
625	3.24			
600	3.52			

RWGS pressure / bar

H_2-Input: 7.6 €/kg_{H2}



RWGS Temperature / °C

	1	5	10	25
900	5.63	5.55	5.56	5.7
875	5.60	5.53	5.54	5.74
850	5.57	5.50	5.53	5.87
825	5.55	5.49	5.54	6.16
800	5.53	5.48	5.6	6.76
775	5.5	5.49	5.73	
750	5.49	5.54	6.05	
725	5.47	5.68	6.83	
700	5.47	6.01		
675	5.47	6.98		
650	5.52			
625	5.66			
600	6.09			

RWGS pressure / bar

Minimum

5 bar and 800 °C: low cost, robust NPC optimum for all H_2 feedstock costs

---

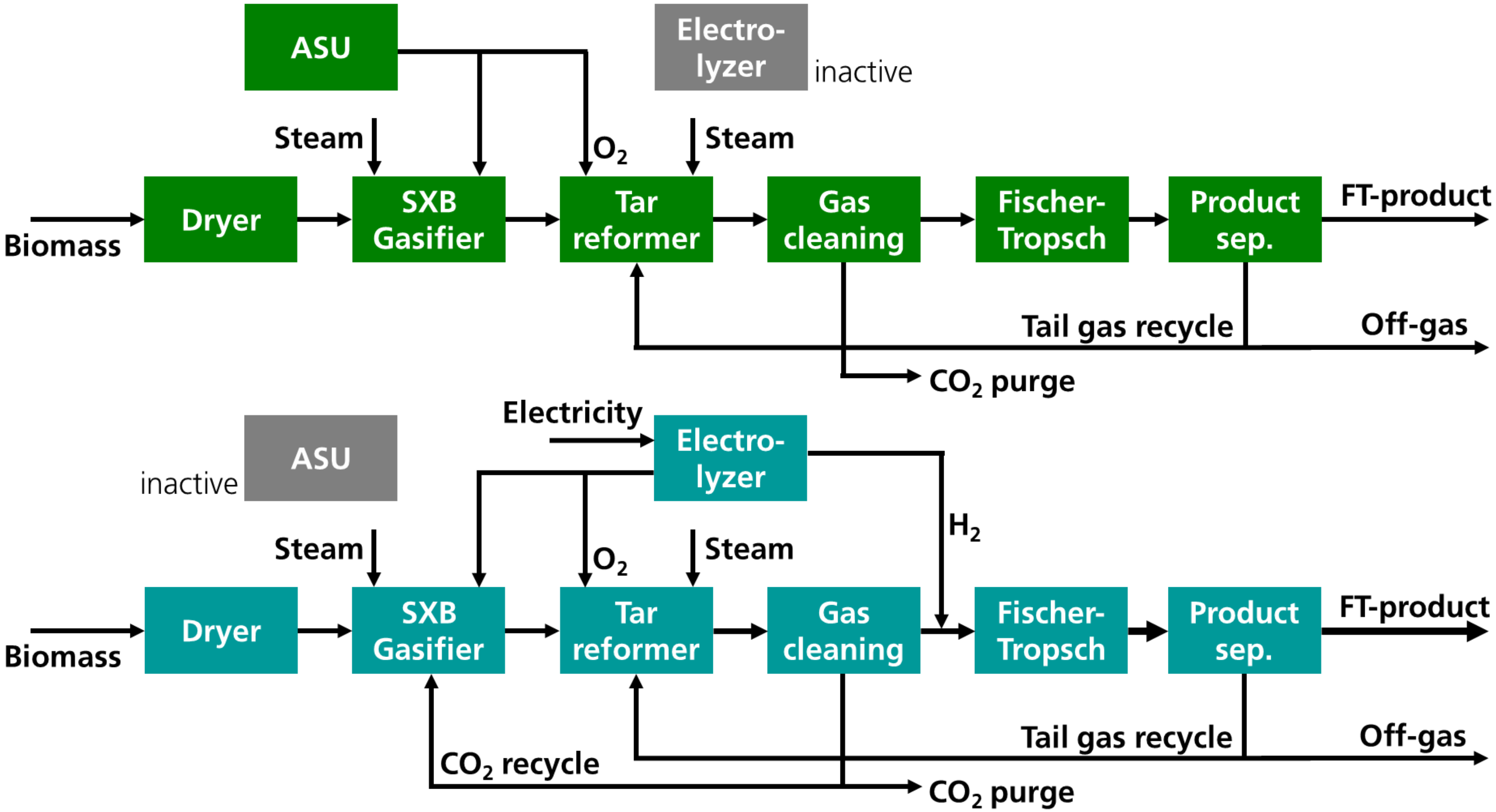
[1] Adelung, S. and Dietrich, R.-U. (2022). Impact of the reverse water-gas shift operating conditions on the Power-to-Liquid fuel production cost. *Fuel.*

ENVIRONMENTAL ASSESSMENT OF SAF (PBTL)

Environmental Assessment of Biomass-to-Liquid versus Power&Biomass-to-Liquid Application

Dual configuration concept [1] :

FlexCHX project has received funding from the European Union's Horizon 2020 research and innovation Programme under Grant Agreement No 763919



ASU
Electro-lyzer
inactive
Steam
O_2
Steam
Biomass
Dryer
SXB Gasifier
Tar reformer
Gas cleaning
Fischer-Tropsch
Product sep.
FT-product
Tail gas recycle
Off-gas
CO_2 purge

Electricity
Electro-lyzer
inactive
ASU
H_2
Steam
O_2
Steam
Biomass
Dryer
SXB Gasifier
Tar reformer
Gas cleaning
Fischer-Tropsch
Product sep.
FT-product
Tail gas recycle
Off-gas
CO_2 recycle
CO_2 purge

BtL with ASU:

- high heat demand
- low renewable power

PBtL with electrolyzer :

- no heat demand
- Low GWP power available

[1] Habermeyer, et. al (2021). Techno-economic analysis of a flexible process concept for the production of transport fuels and heat from biomass and renewable electricity. Front. Energy Res., Nov. 2021 | Volume 9 | Article 723774

Environmental Assessment of **Biomass-to-Liquid** versus **Power&Biomass-to-Liquid** Application

Global Warming Potential (GWP) [1]

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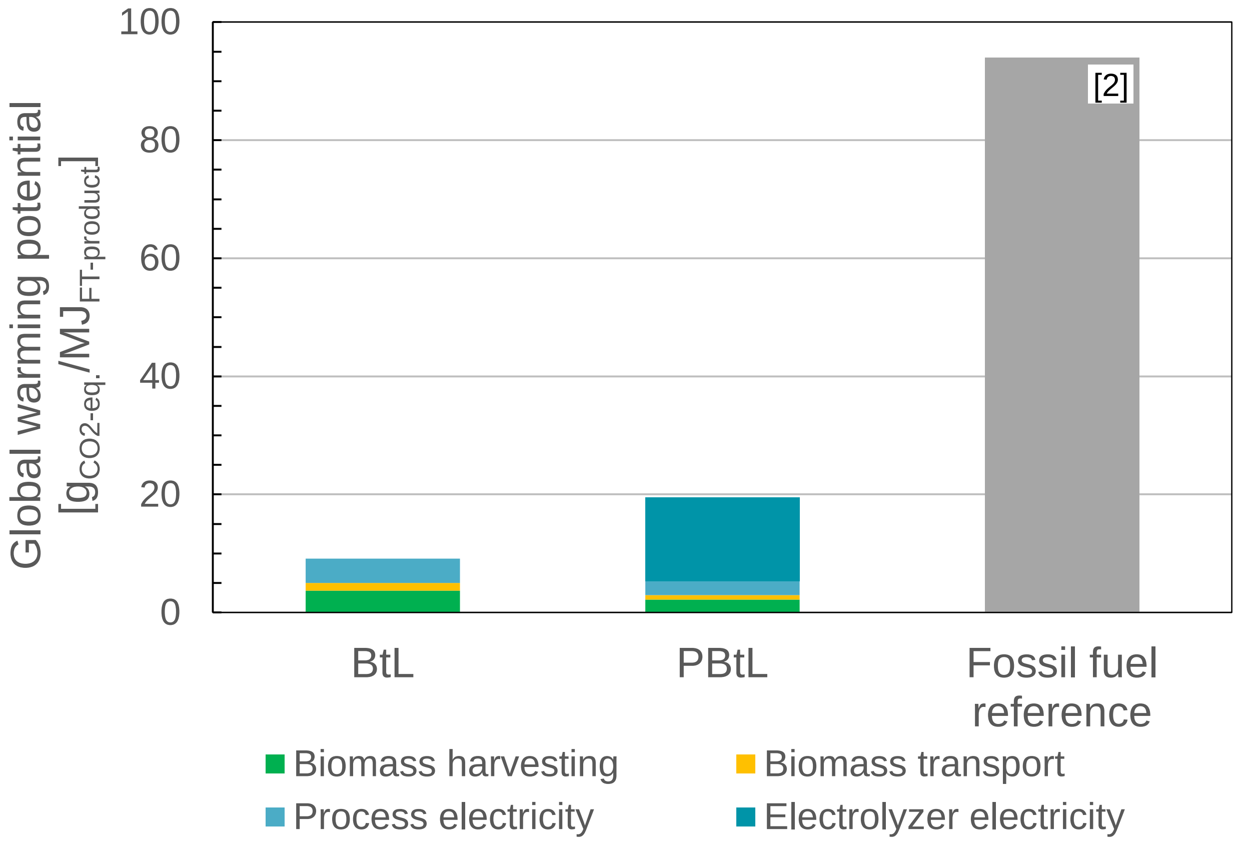

- **Transportation: 100 km (one-way) by truck (69 $g_{CO2\text{-}eq.}$/(t*km))**
- **Biomass: Harvesting forest residues (19.7 $g_{CO2\text{-}eq.}$/kg)**
- **Electricity: Finnish grid (68.6 $g_{CO2\text{-}eq.}$/kWh)**

[1] Habermeyer, et. al (2021). Techno-economic analysis of a flexible process concept for the production of transport fuels and heat from biomass and renewable electricity. Front. Energy Res., Nov. 2021 | Volume 9 | Article 723774

[2] European Union (2018) “Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)”, Official Journal of the European Union

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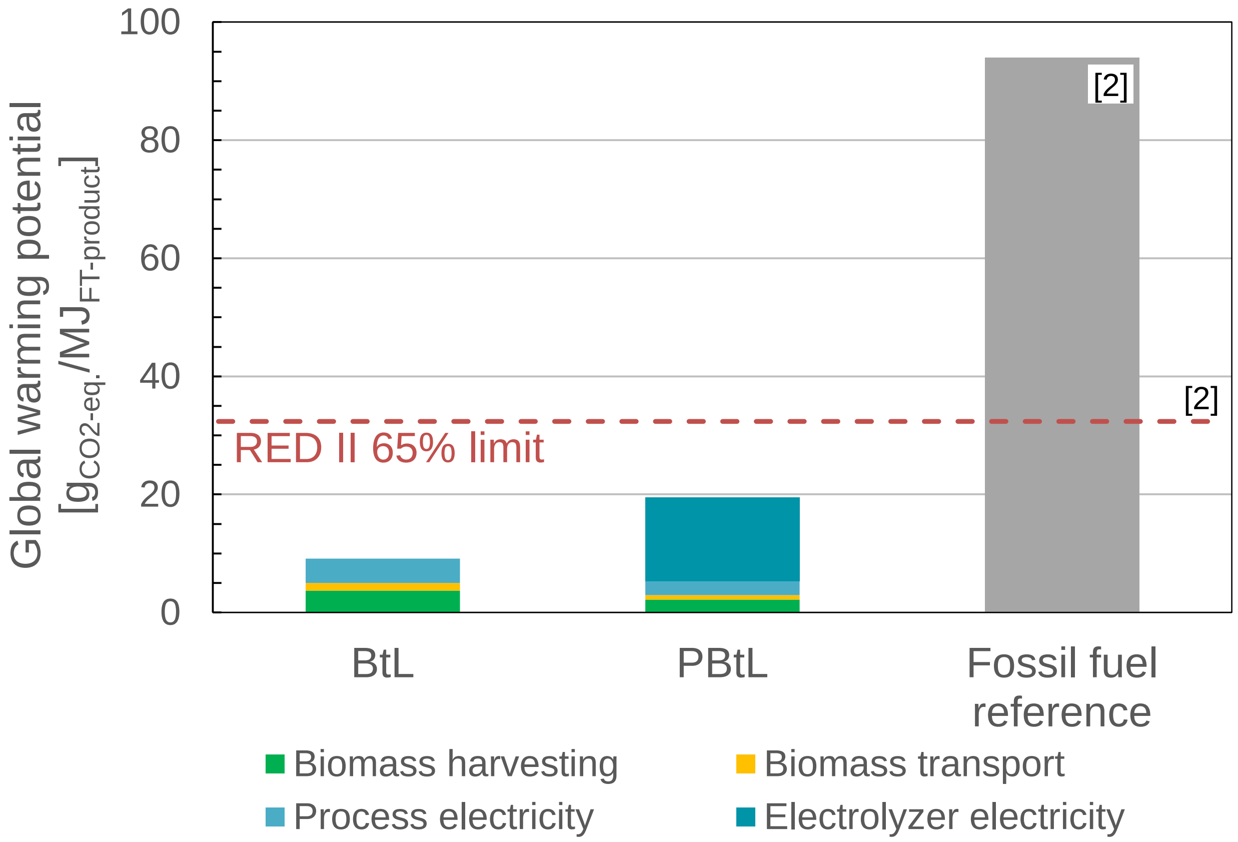

- Transportation: 100 km (one-way) by truck (69 $g_{CO2\text{-}eq.}/(t*km)$)
- Biomass: Harvesting forest residues (19.7 $g_{CO2\text{-}eq.}/kg$)
- Electricity: Finnish grid (68.6 $g_{CO2\text{-}eq.}/kWh$)

Conclusion

REDII target accomplished
@ FLEXCHX base case

[1] Habermeyer, et. al (2021). Techno-economic analysis of a flexible process concept for the production of transport fuels and heat from biomass and renewable electricity. Front. Energy Res., Nov. 2021 | Volume 9 | Article 723774

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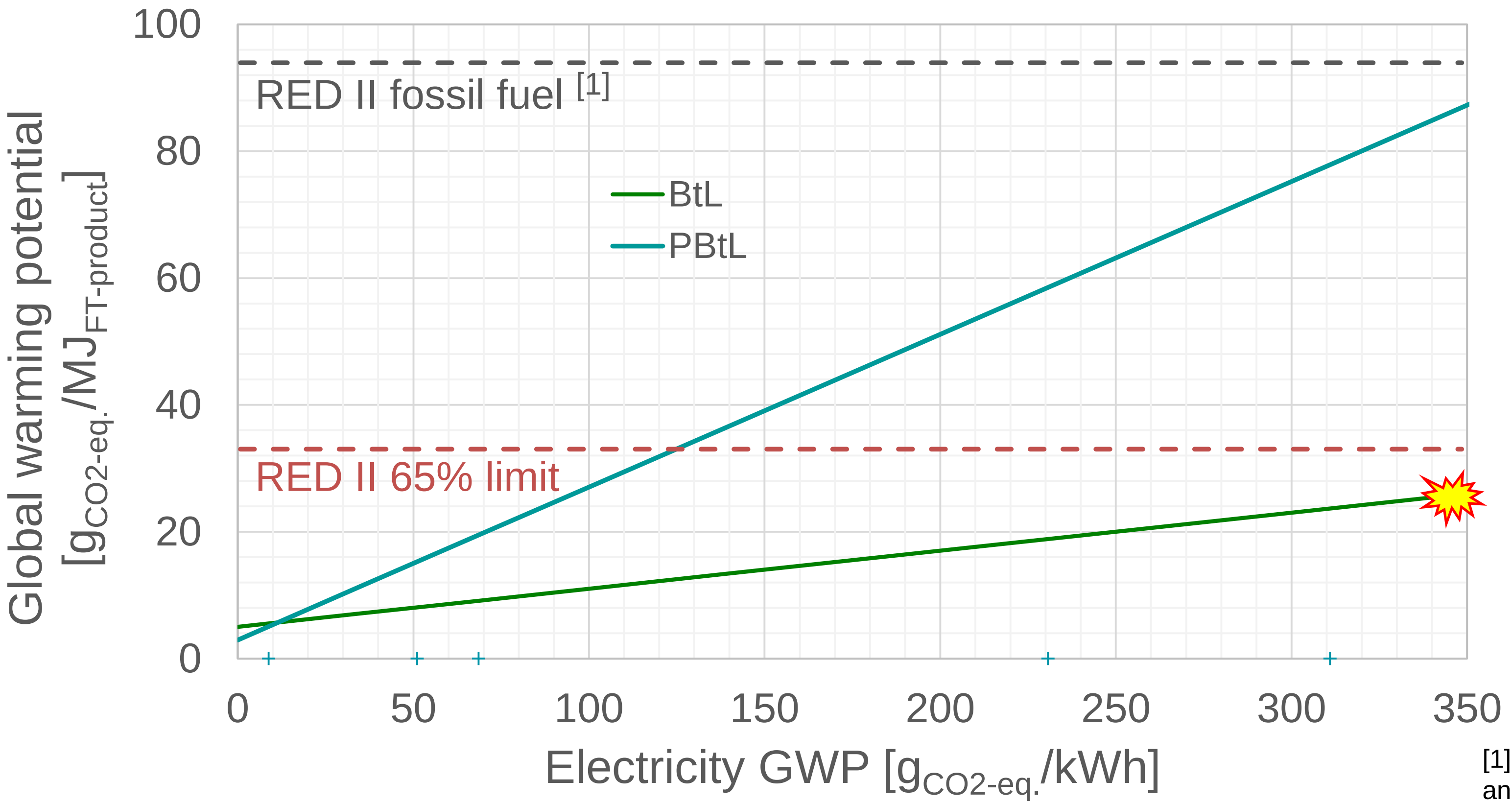

- REDII 65 % limit can be reached for all depicted electricity grid mixes for BtL

Biomass: (19.7 $g_{CO2\text{-}eq.}$/kg)
Transport: 69 $g_{CO2\text{-}eq.}$/(t*km)

[1] European Union (2018) "Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)", Official Journal of the European Union

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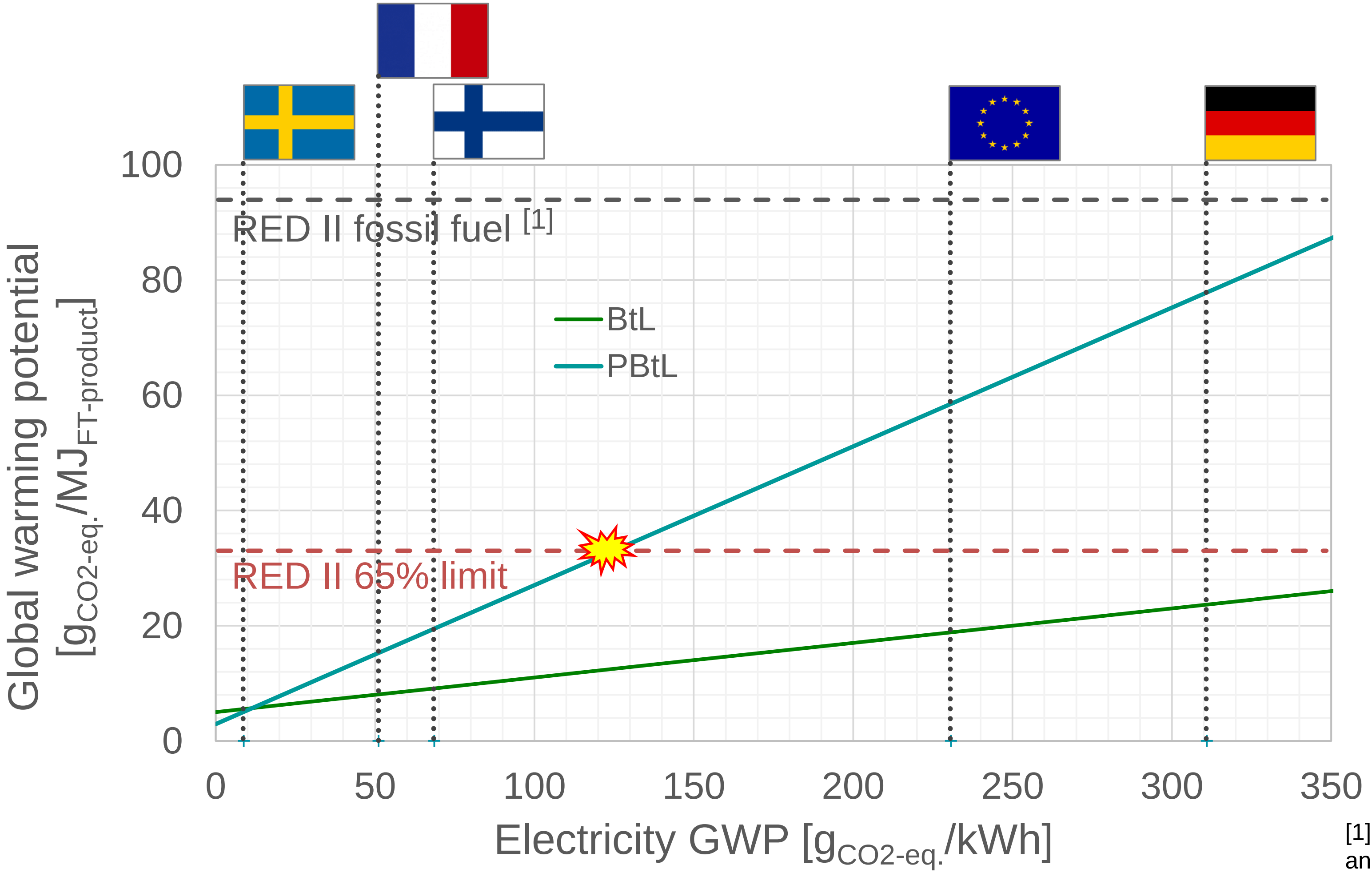

- ➢ REDII 65 % limit can be reached for all depicted electricity grid mixes for BtL
- ➢ PBtL requires electricity with GWP <120 $g_{CO2\text{-}eq.}$/kWh to reach REDII 65 % limit

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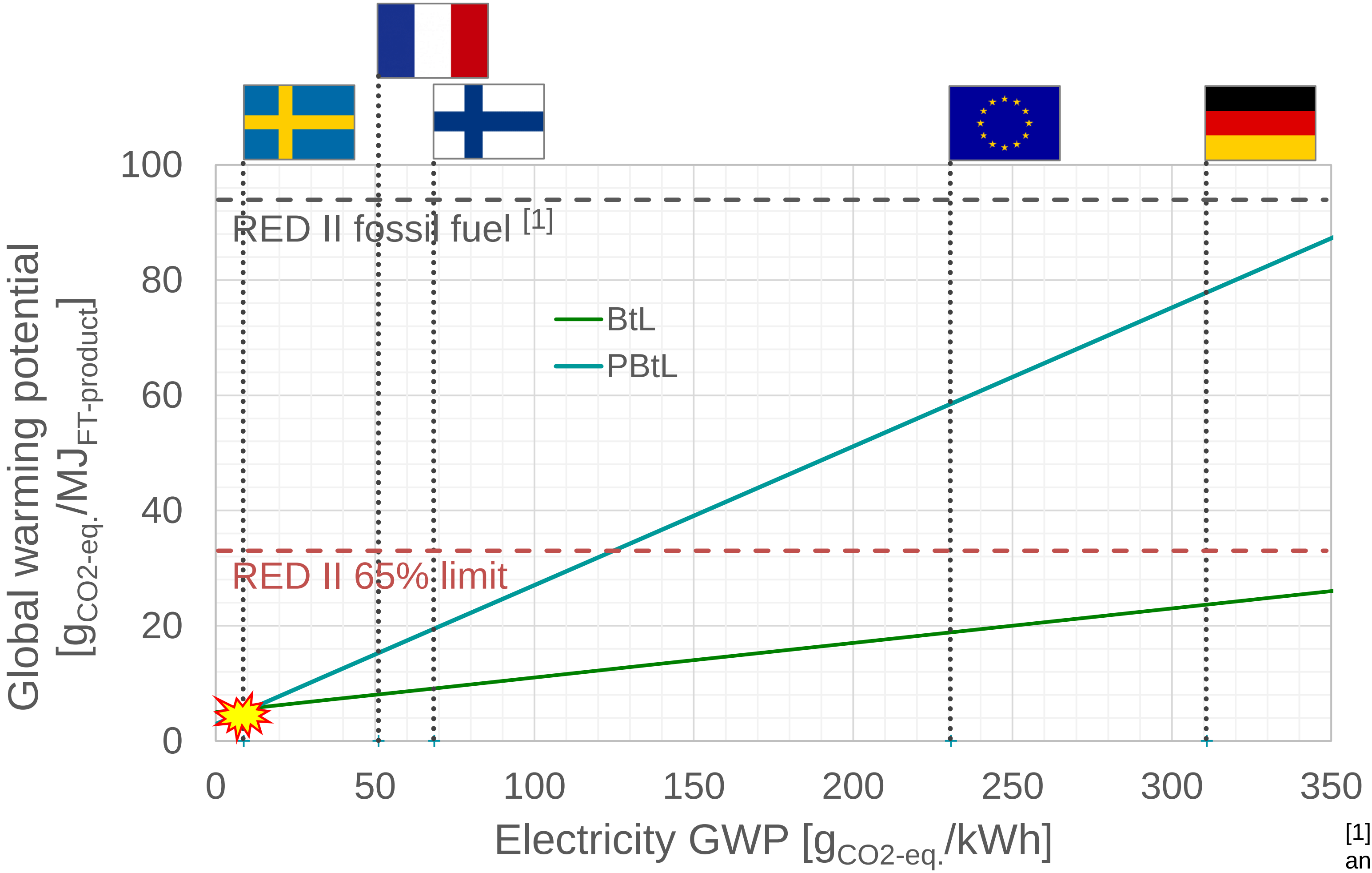

- REDII 65 % limit can be reached for all depicted electricity grid mixes for BtL
- PBtL requires electricity with GWP <120 $g_{CO2\text{-}eq.}$/kWh to reach REDII 65 % limit
- PBtL could have lower GWP than BtL with Swedish grid mix

[1] European Union (2018) “Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)”, Official Journal of the European Union

FINDINGS: E-FUELS COMPETITIVENESS

Global e-fuel assessment for German transport

Energy transition In the Transport sector (EiT) – Beniver: Scientific supervision

BEniVer
Begleitforschung Energiewende im Verkehr

- EiT: 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	🚗 ✈ 🚢

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

Standardization efforts – Make e-fuel options comparable

TE(E)A framework (comparing “apples with apples”) [1]

- (Renewable) Electricity
  - Production cost, taxes, fees
  - Availability, fluctuation
- H_2
  - Type of electrolyzer, efficiency, investment costs
- CO_2
  - Source, capture process, availability
- General plant / economic parameters
  - Size, location, year of construction, lifetime
  - Equipment cost data base, cost factors (FCI, OPEX, …), CEPCI, interest rate
  - …

BEniVer

Begleitforschung Energiewende im Verkehr

Assumptions		V3.2*
Base year		2018
Electricity	€/MWh	55.7
H_2	€/t	4’742
CO_2	€/t	69
Power	MW_e	300
Full-load hours		8’000

[1] Heimann, N. et al (2023) Contribution to a standardized economical and ecological analysis for carbon-based e-fuel production in Germany, rontiers in Energy Research Process and Energy Systems Engineering, submitted

Global e-fuel assessment – technical efficiencies

EiT: Comparing generic fuels / designer fuels

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

CCM-2023

DLR

Global e-fuel assessment – Summary

EiT: Comparing generic fuels / designer fuels

	SNG	MeOH	FT	OME$_{3-5}$	DMC	MeFo
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Production: economics & environment						
NPC [€$_{2018}$/MWh$_{LHV}$]	192	204	321	360	329	298
GHG (and more environmental impact criteria): provided by FfE (BEniVer Begleitforschung Energiewende im Verkehr), LTT Lehrstuhl für Technische Thermodynamik RWTH AACHEN UNIVERSITY (NAMOSYN Nachhaltige Mobilität durch synthetische Kraftstoffe)						
Application: too 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? • …

Global e-fuel assessment – Summary

CCM-2023

DLR

EiT: Comparing generic fuels / designer fuels

	SNG	MeOH	FT	$OME_{3\text{-}5}$	DMC	MeFo
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App … arameters, no systematic, no monetary assessment						
Application parameter examples	• • •	Europe? • …			n atio?	• Better combustion • Blending ratio? • …

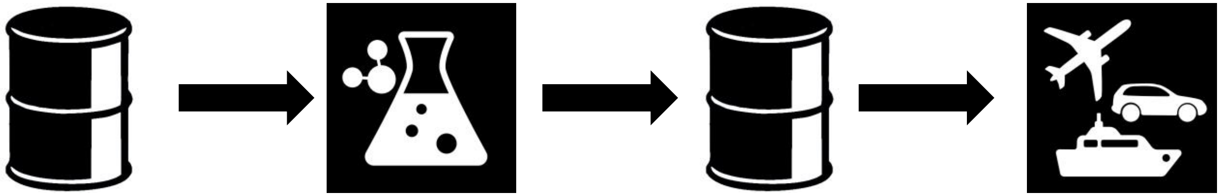
Even if e-methane, e-methanol are somewhat cheaper to produce, there will be no competitiveness with fossil fuels
(compare ≈ 5 €/MWh crude oil)
CO_2-certificates prizes need to reach 1’000+ €/t

CONCLUSION: E-FUELS FOR TRANSPORT?

E-fuels options for global transport

Simple pictograms

- Present (2018 ➔ 2023)

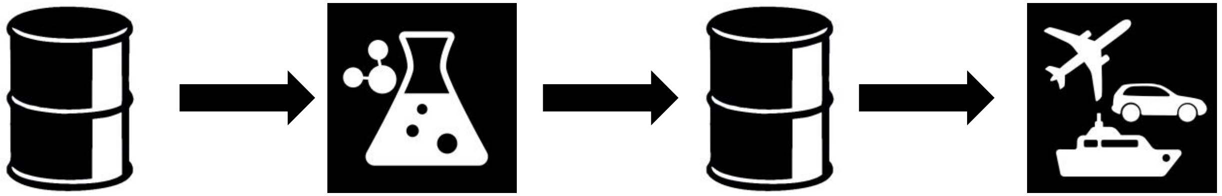


- Future Dream (2018)

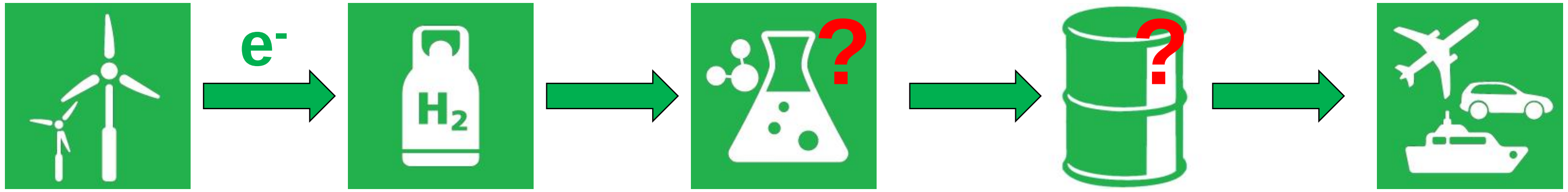
E-fuels options for global transport

Simple pictograms

- Present (2018 ➔ 2023)



- Future Dream (2018)
  EiT Questions



E-fuels options for global transport

Simple pictograms

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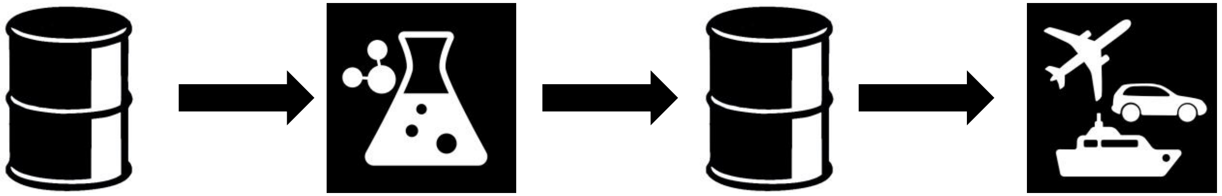

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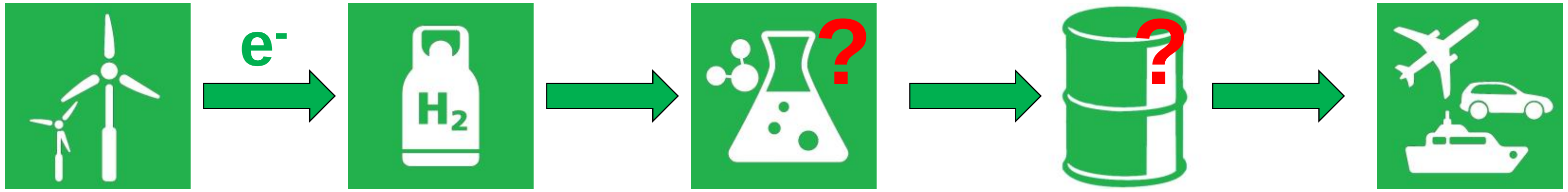
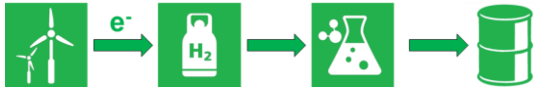


- Reality Check 2023



E-fuels options for global transport

Simple pictograms

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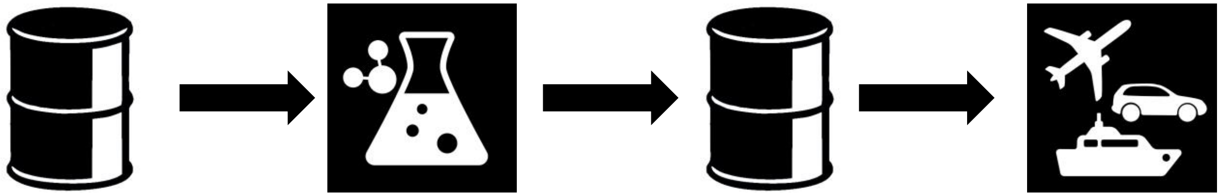
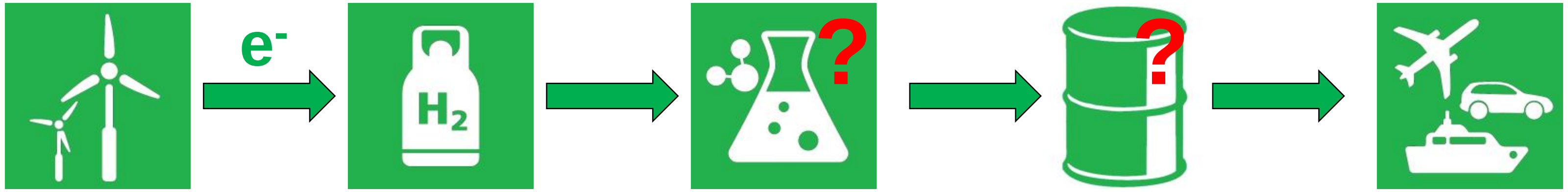


- Future Dream (2018)

  EiT Questions



- Reality Check 2023

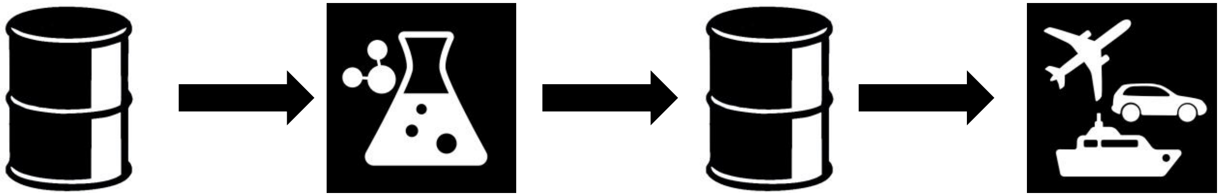
  EiT Q&A

€€€€$_{2018/2023}$

E-fuels options for global transport

Simple pictograms

- Present (2018 ➔ 2023)



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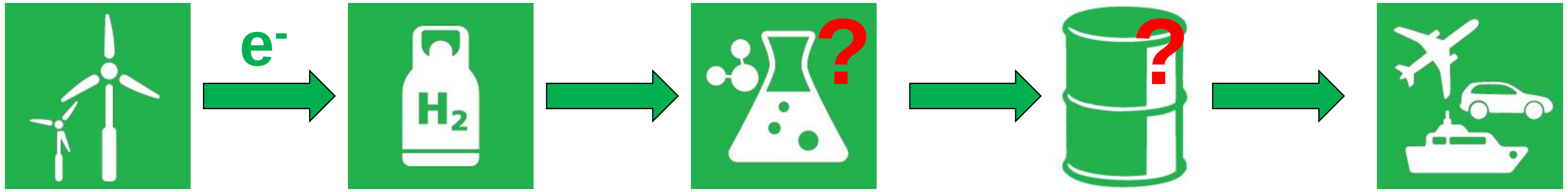

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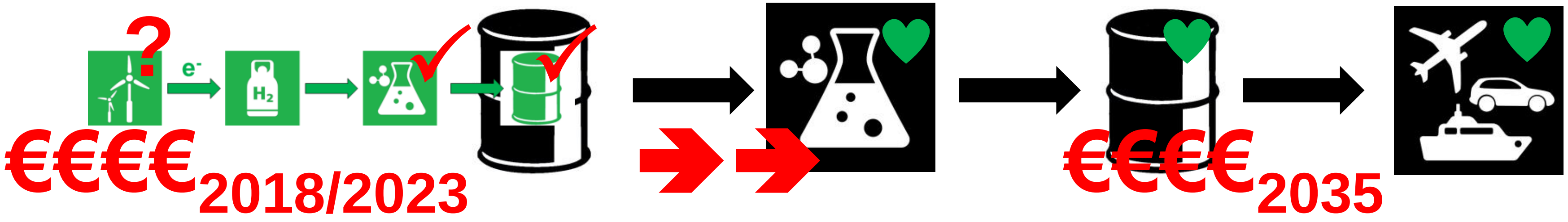
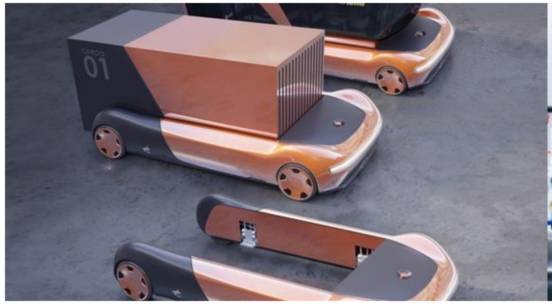


Outlook: Transport beyond 2023

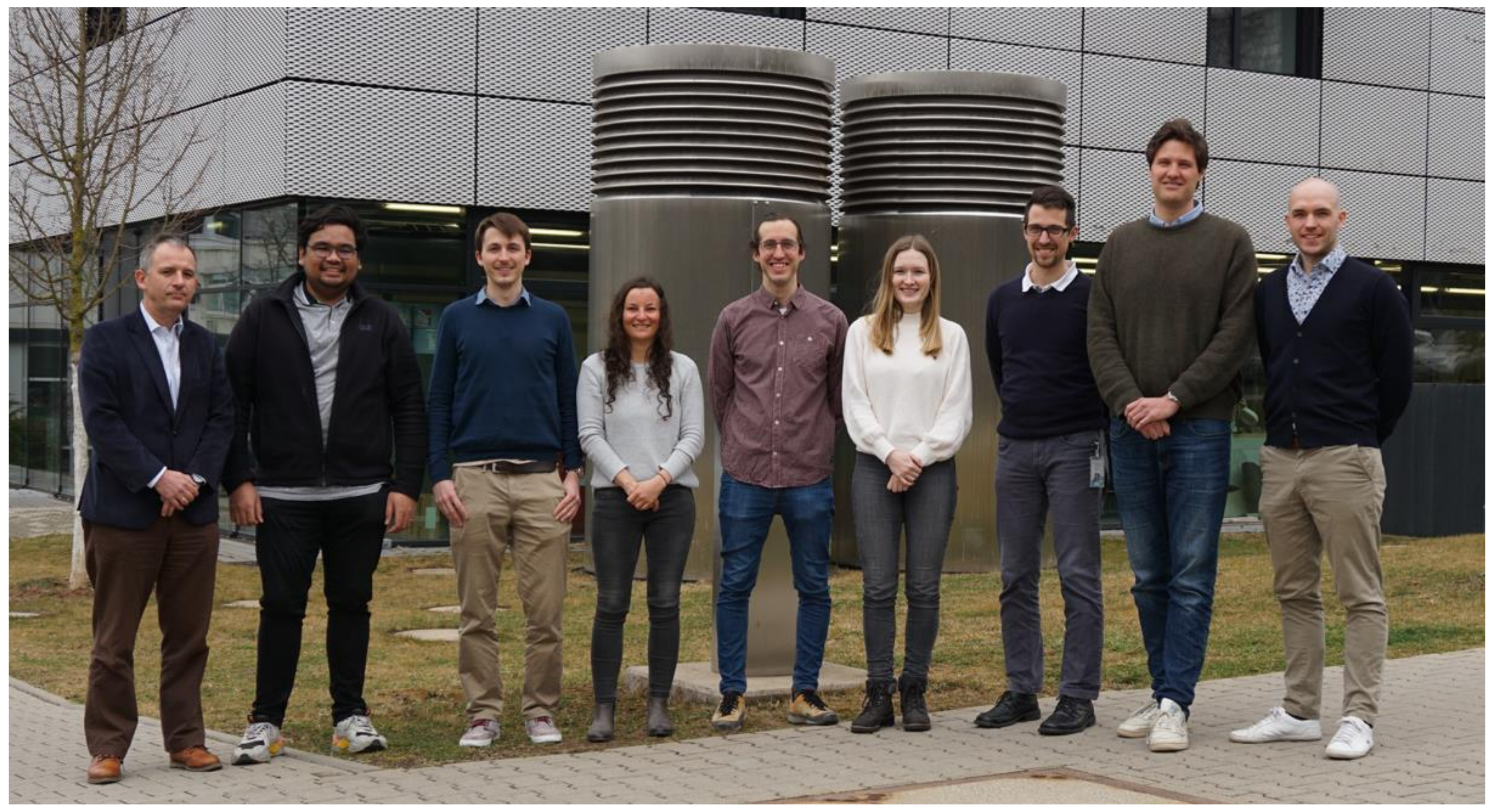
- Maximize mileage from green electrons
  - Favor public over private transport
  - Favor rail over road / air transport
  - Favor electric over hydrogen over ICE

- 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
  - Instant drop-in fuels blending mandate
  - Little electrification in marine and aviation
  - Maximize GHG abatement at minimal cost

THANK YOU FOR YOUR ATTENTION !
Questions?



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