DAY 1: Wednesday, June 1st, 2022
Biofuels – a possible solution to decarbonize hard-to-abate sectors

AARHUS POWER-TO-X SYMPOSIUM:

UNITING INDUSTRY AND ACADEMIA ON NEW SOLUTIONS FOR CARBON-NEUTRALITY

1ST – 3RD JUNE 2022, AARHUS, DENMARK

PtX opportunities and challenges for aviation and beyond

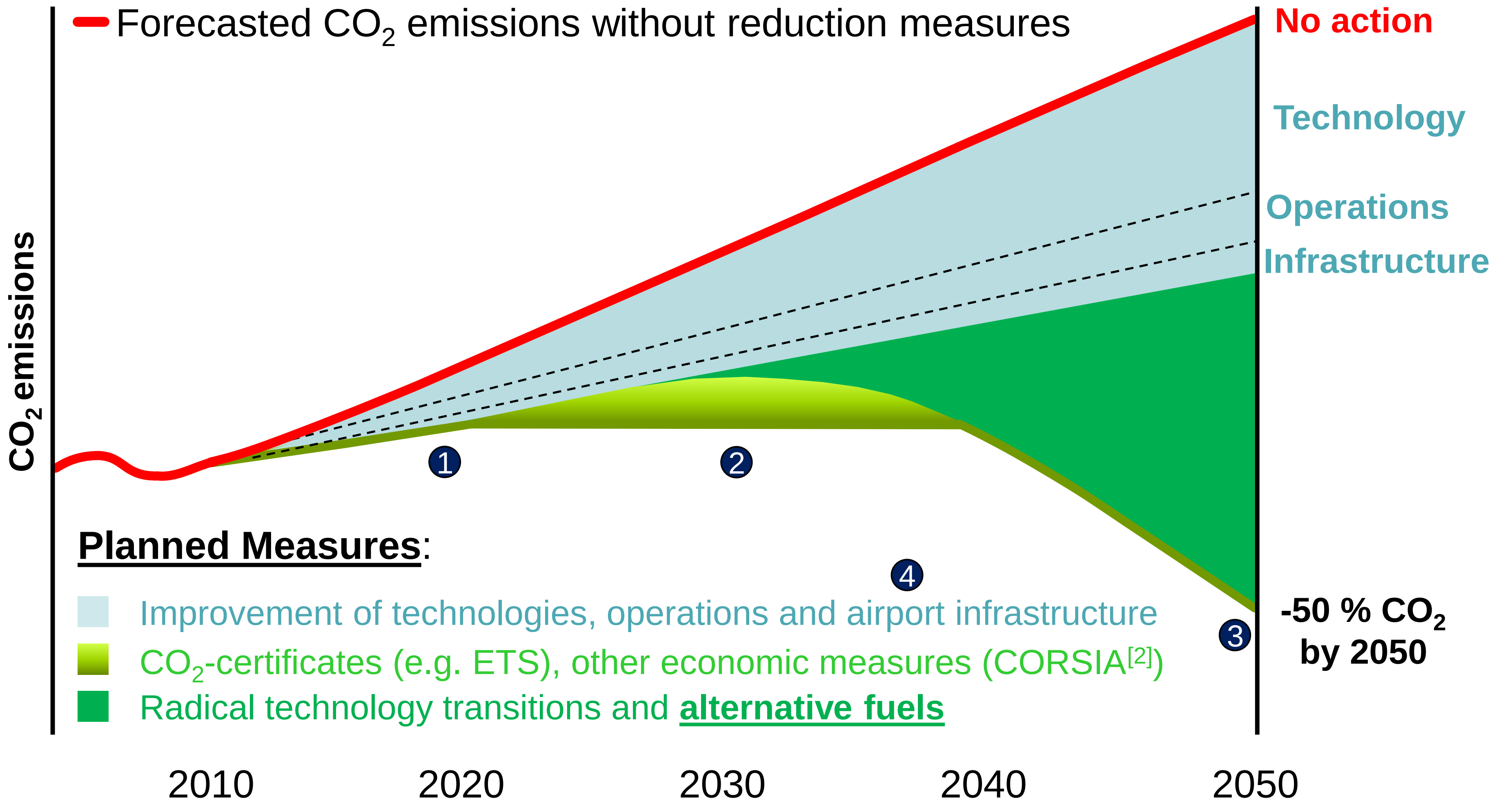
Technical, economic and ecologic evaluation from aviation point of view

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

Global Aviation Industry Response: IATA Technology Roadmap [1] extended [3]

Main goals:

1. Improvement of fuel efficiency about 1,5 % p.a. until 2020
2. Carbon-neutral growth from 2020 onwards
3. CO_2 emissions reduction of 50 % by 2050 (2005 reference)



[1] iata.org, IATA Technology Roadmap 4. Edition, June 2013
[2] ICAO-Resolution A39-3: Carbon Offsetting and Reduction Scheme for International Aviation
[3] www.iata.org/en/programs/environment/flynetzero/

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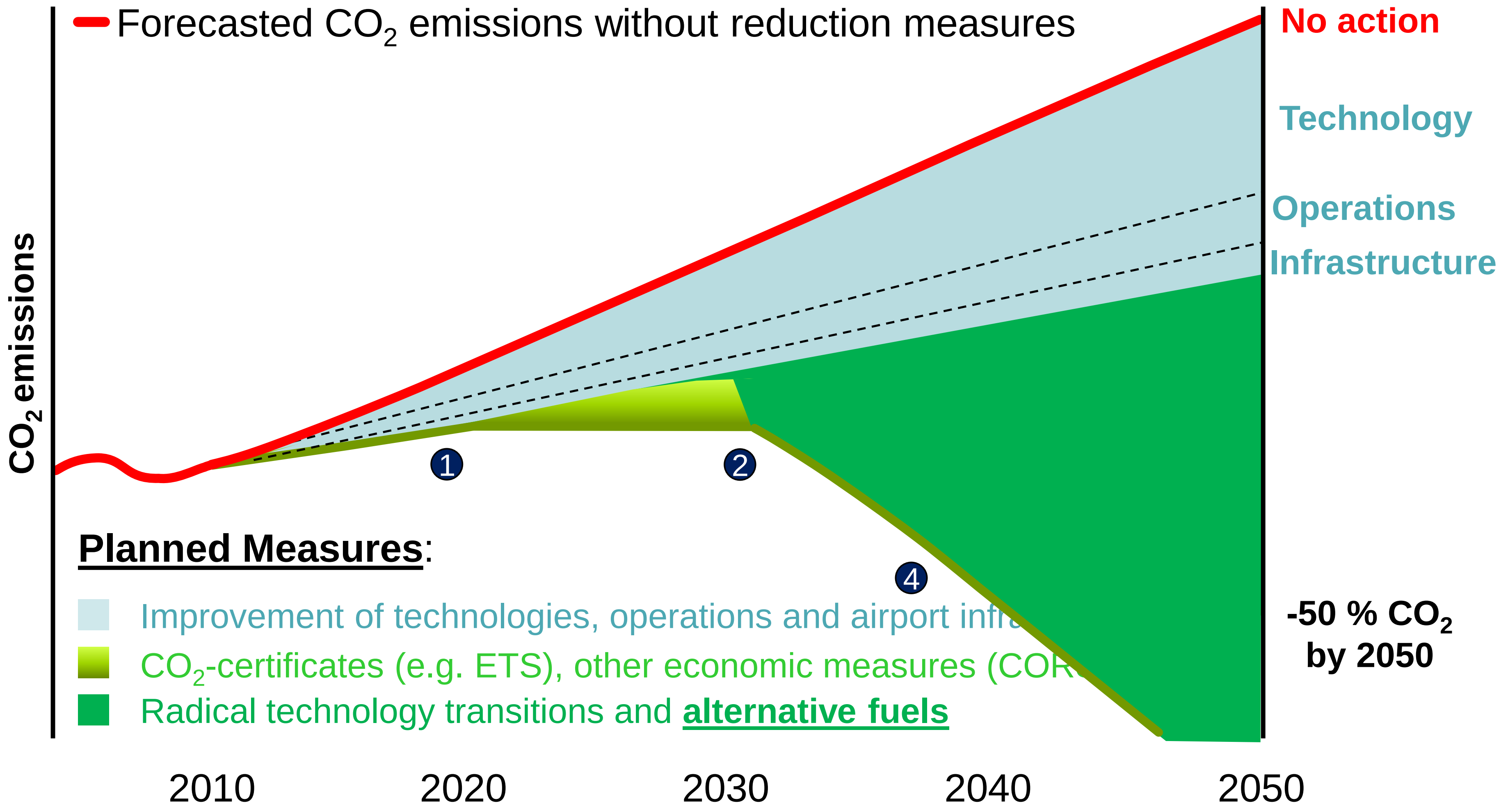

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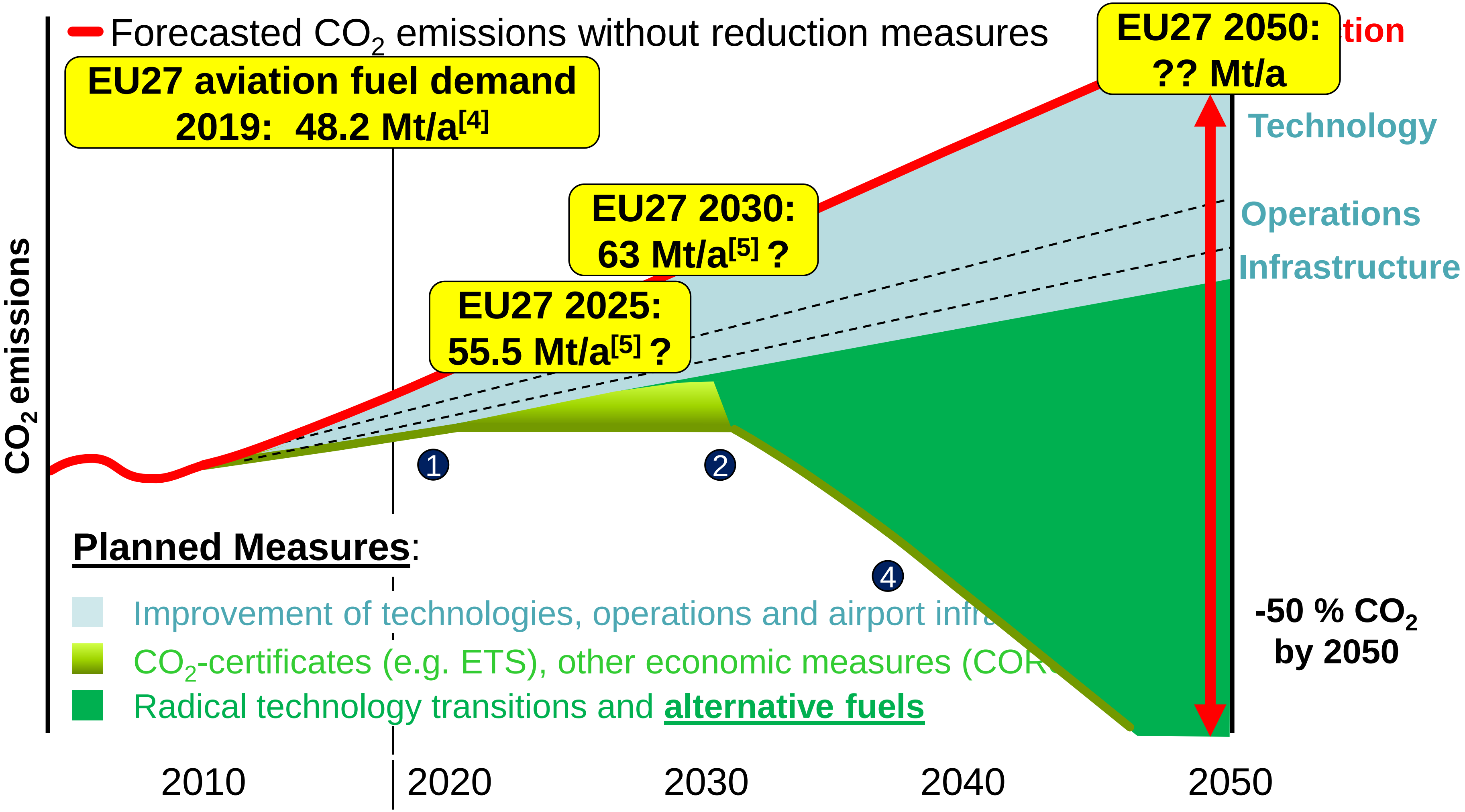

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[3] www.iata.org/en/programs/environment/flynetzero/
[4] ec.europa.eu/eurostat/databrowser/view/NRG_BAL_C
[5] theicct.org, Estimating sustainable aviation fuel feedstock availability to meet growing European Union demand, 08 MAR 2021

Certified Alternative Jet Fuels (ASTM D7566 – 21 [1])

Feedstock	Synthesis technology	Fuel
~~Coal, natural gas~~, biomass, CO_2 & H_2	Fischer-Tropsch (FT) synthesis using Fe or Co catalyst,	Synthetic paraffinic kerosene (FT-SPK)
Non-petroleum derived light aromatics (primarily benzene)	Blend aromatics produced by alkylation to FT-SPK	FT-SPK plus Aromatics (SPK/A)
Biogenic lipids (e.g. algae, soya, palm oil, jatropha)	Hydrogenation and deoxygenation of fatty acids and esters (HEFA) + subsequent hydrocracking, hydroisomerization, isomerization, …	Synthetic paraffinic kerosene (HEFA-SPK)
Additional algae produced oil containing a high percentage of unsaturated hydrocarbons known as botryococcenes,	Blend botryococcenes hydrocarbons prior to hydroprocessing Esters and Fatty Acids (HC-HEFA)	SPK from Hydroprocessed Hydrocarbons, Esters and Fatty Acids (HC-HEFA)
Biogenic lipids (e.g. algae, soya, palm oil, jatropha)	Catalytic hydrothermal conversion of fatty acids and esters	Catalytic hydrothermolysis Jet (CHJ)
Sugar from Biomass	Direct Sugars to Hydrocarbons (DSHC)	Synthetic iso-paraffins (SIP) / Farnesane
Bio-isobutanol (-methanol, -ethanol, -propanol, …)	dehydration+oligomerization+hydration (Alcohol-to-Jet, AtJ)	AD-SPK

[1] ASTM International, „ASTM D7566-21 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons“, 2021

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Additional algae produced oil		
		Synthetic iso-paraffins (SIP) / Farnesane
-ethanol, -propanol, …)	dehydration+oligomerization+hydration (Alcohol-to-Jet, AtJ)	AD-SPK

Crop based SAF won't meet long term aviation demand!

Missing fair assessment of crop based SAF environmental impact!

Fertilizer, harvesting, shipment, …, included?

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		/ Farnesane
Bio-isobutanol (-methanol, -ethanol, -propanol, …)	dehydration+oligomerization+hydration (Alcohol-to-Jet, AtJ)	AD-SPK

Fischer-Tropsch synthesis

- Large scale, commercial technology
- Based on synthesis gas (Available from almost any **green** carbon and hydrogen source)
- Fully synthetic kerosene achievable [2]

Potential for Europe? – e.g. wind power

- Example jet fuel consumption: **63 Mt/a** [3]
- Power demand for exclusively power based kerosene in Europe: **≈ 1,600 TWh$_e$**
- European wind power potential[4]: **12,200 – 30,400 TWh$_e$**
  ≈ 5 - 13 % for power based kerosene?

[1] ASTM International, „ASTM D7566-21 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons", 2021
[2] UK Ministry of Defense, „DEF STAN 91-91: Turbine Fuel, Kerosene Type, Jet A-1", UK Defense Standardization, 2011
[3] theicct.org, Estimating sustainable aviation fuel feedstock availability to meet growing European Union demand, 08 MAR 2021
[4] European Environment Agency, "Europe's onshore and offshore wind energy potential," 2009.

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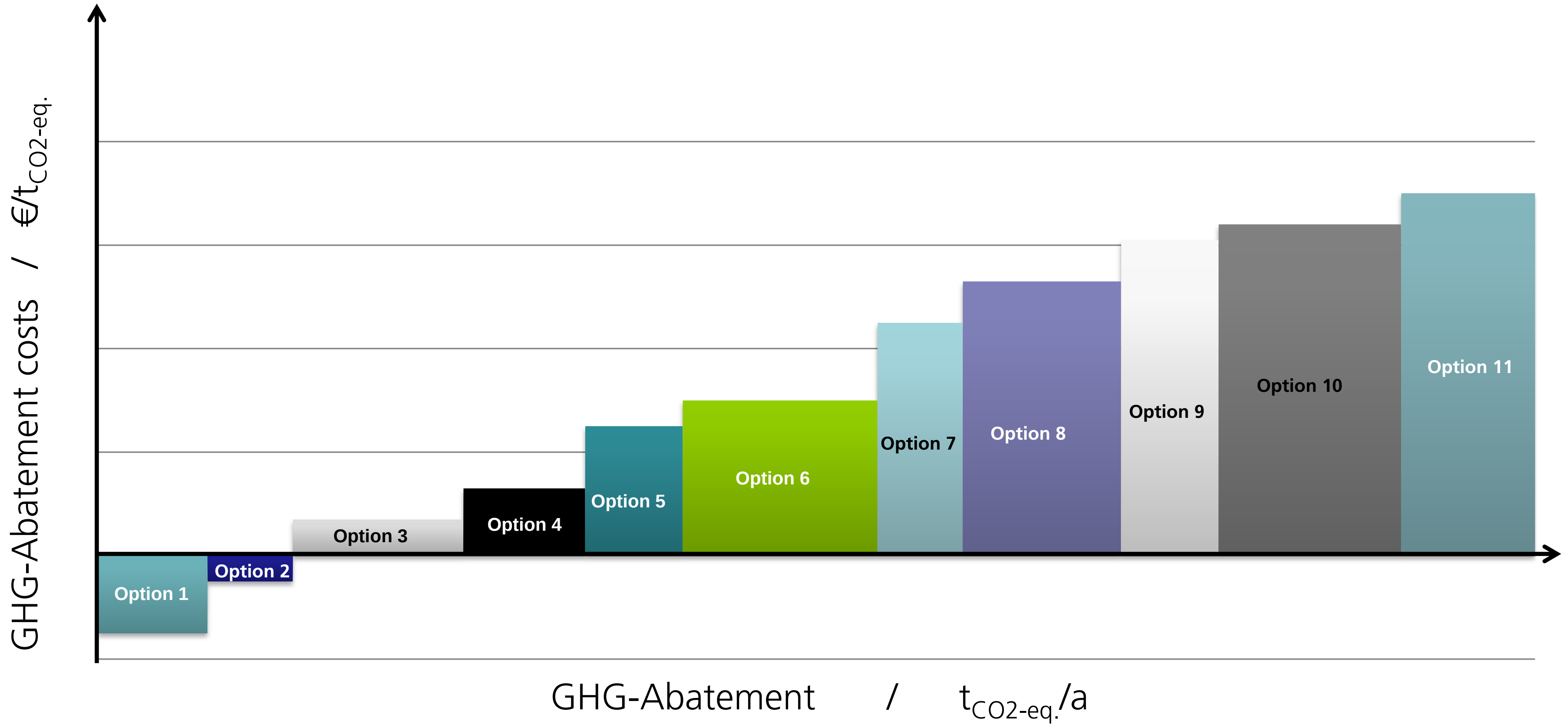
Assessment of SAF Concepts / Options / Configurations / Locations / …

Merit-Order of GHG reduction technologies



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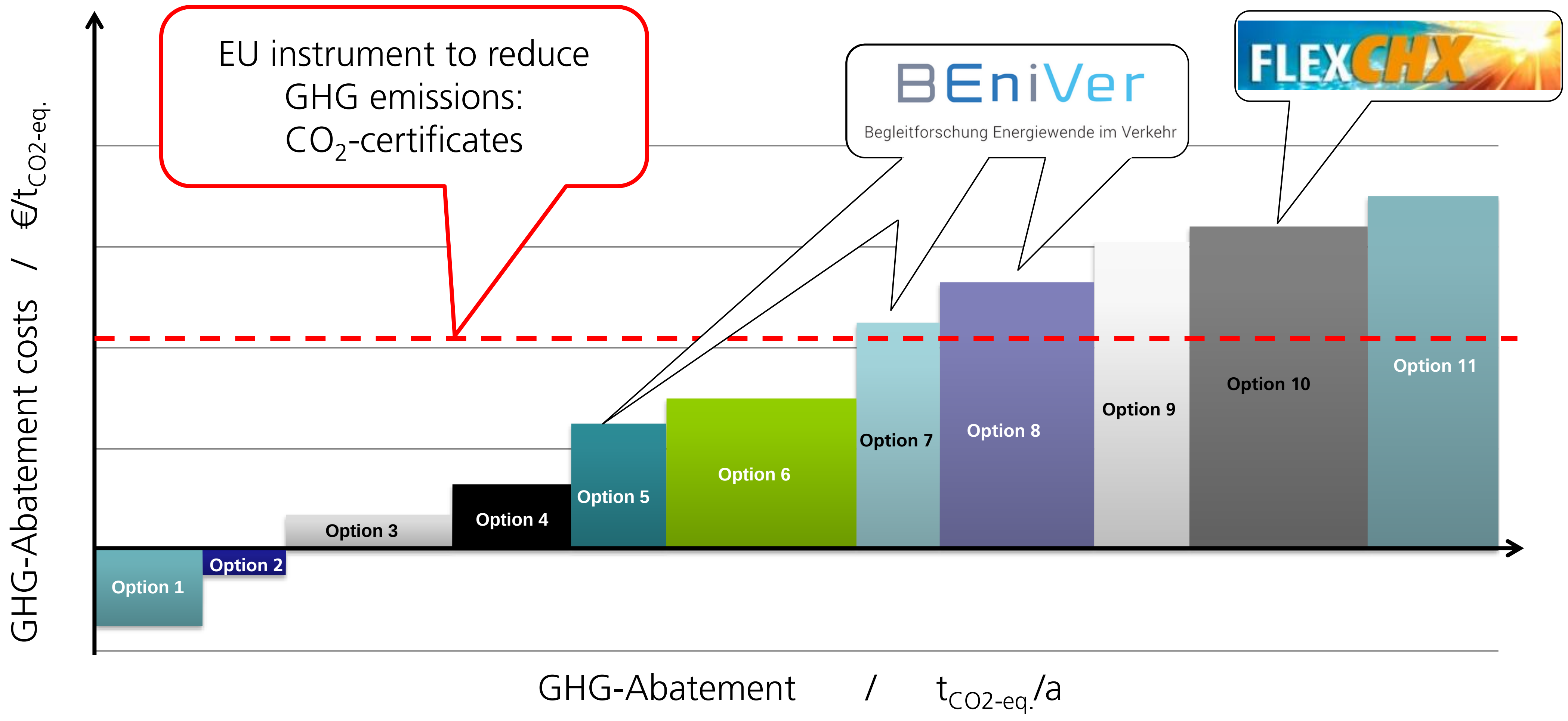

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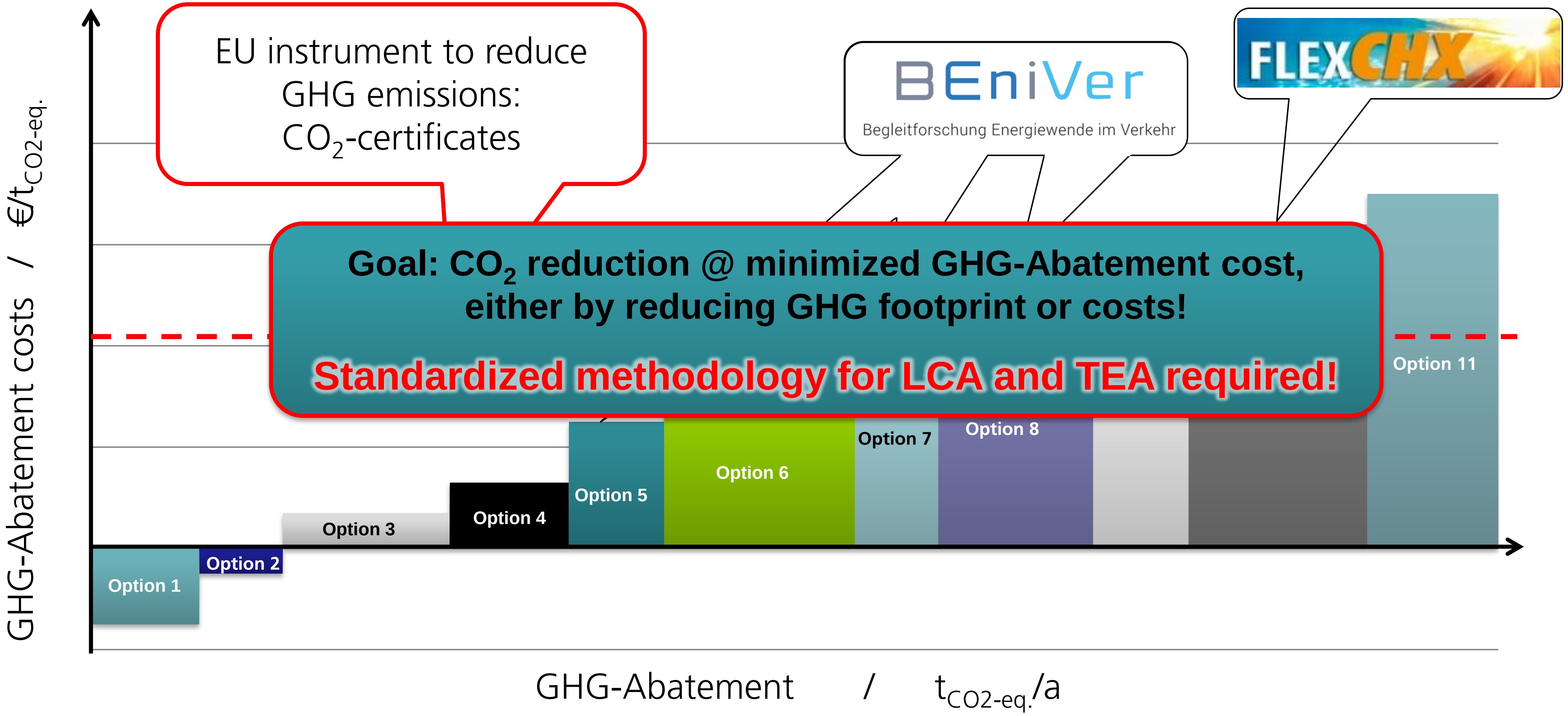

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Techno-Economic and Ecological Assessment (TEEA) @ DLR

1. Step
Literature survey

Exchange with project partners

Simulation & Process evaluation

2. Step
Detailed process simulation

aspentech
Aspen Plus®

- Upscaling
- Technical optimization

Variation of process parameters

Aspen-TEPET-Brightway2-Link

Material and energy balance data

3. Step
Techno-economic and ecological evaluation

TEPET [1]
Brightway2 [2]

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

ecoinvent [3]

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.

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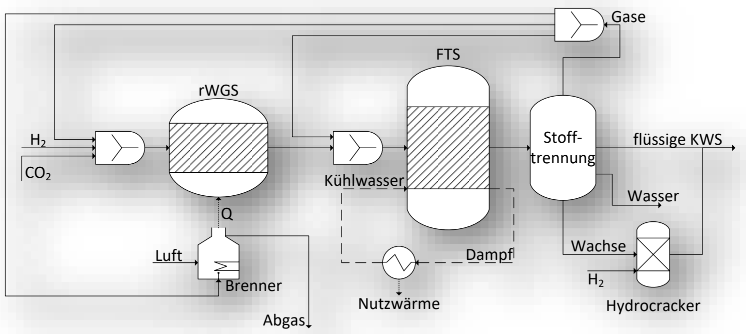
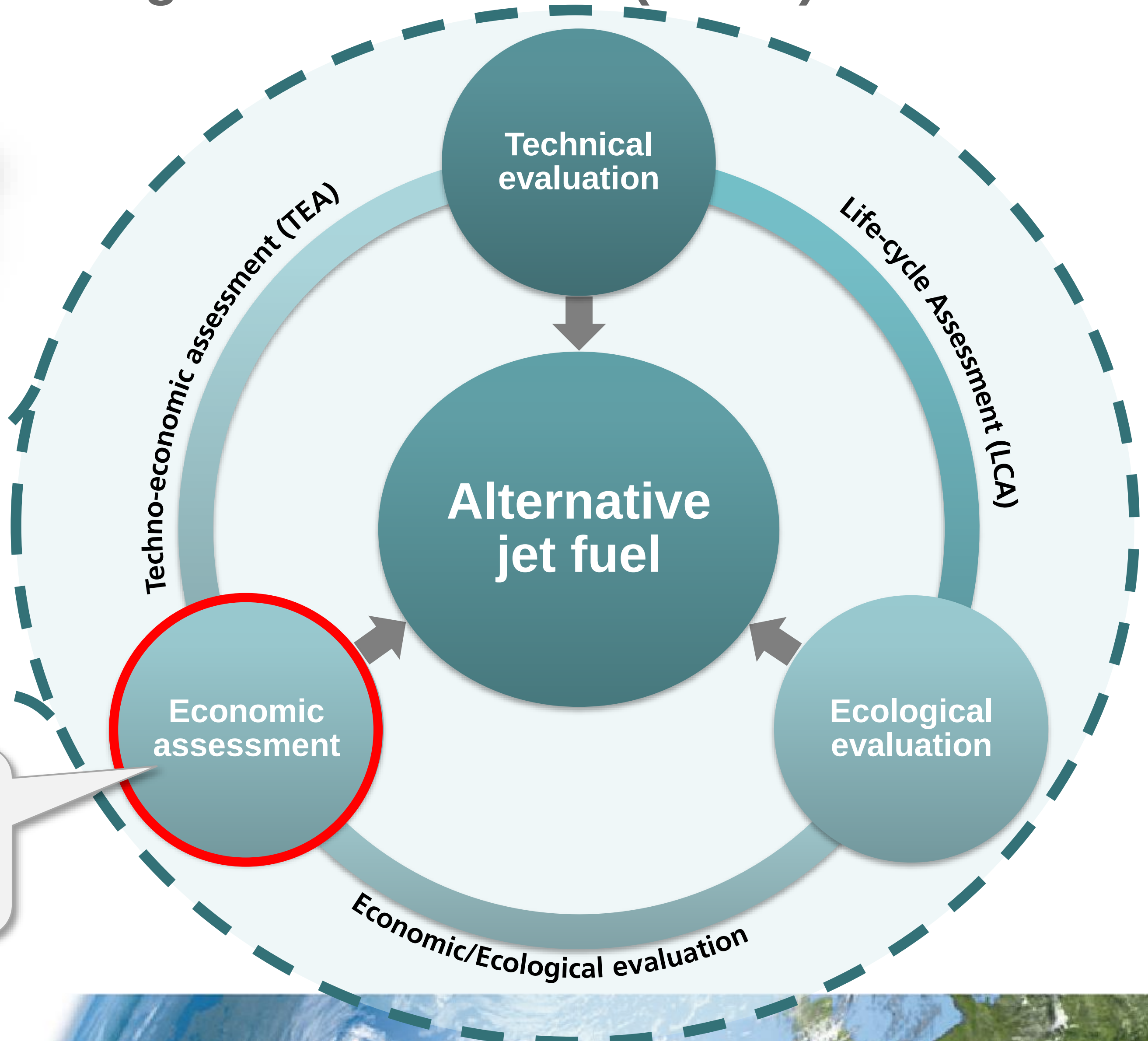
Techno-Economic and Ecological Assessment (TEEA) of renewable jet fuel



DLR's Techno economic process evaluation tool

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



Power-to-Liquid process: Detailed techno-economic assessment

Technical Analysis [1]

Process modelling, efficiency analysis

[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,
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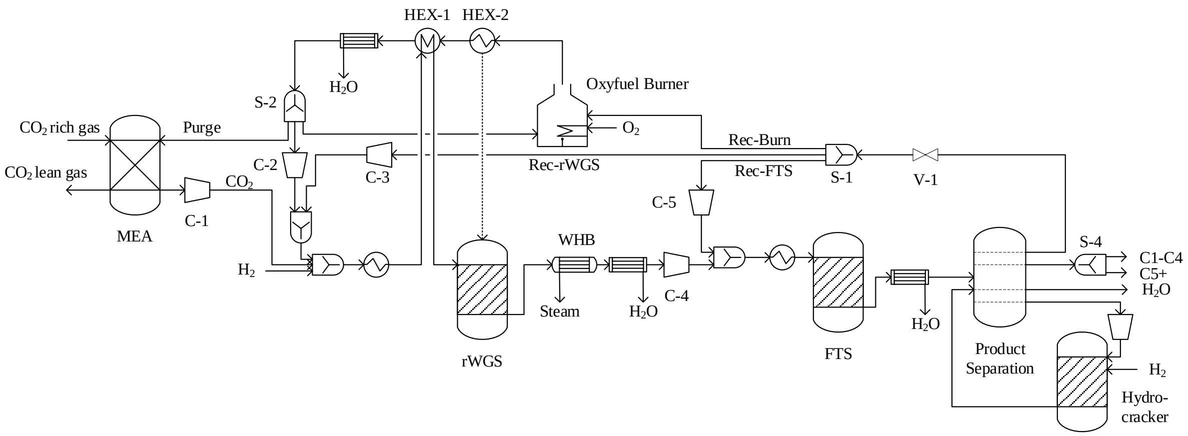

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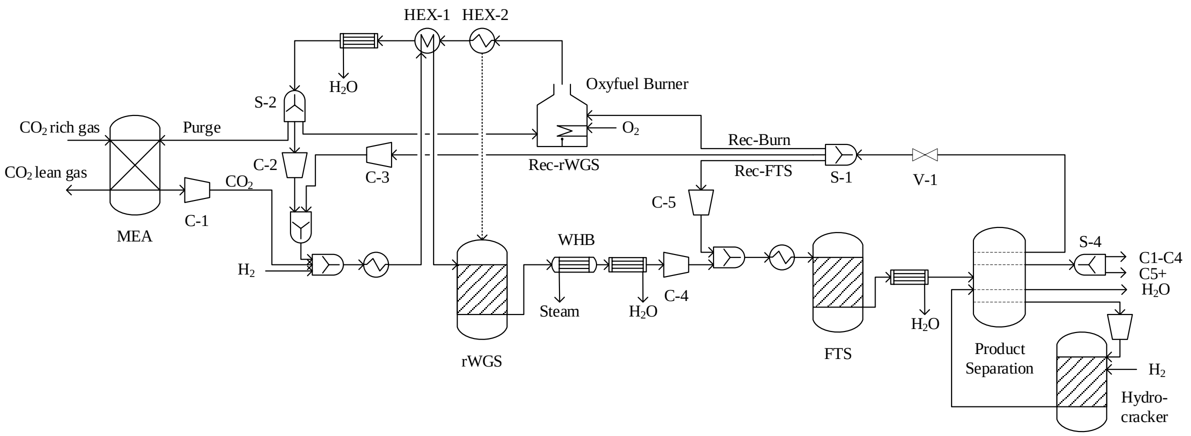

RWGS @ 5 bar and 825 °C

$\eta_{PtL,SCR}$ ≤ 41 % [1]

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Economic Analysis [2]

Net production costs, CAPEX, OPEX, sensitivity analysis

[2] Adelung, S.; Dietrich, R.-U. (2022)
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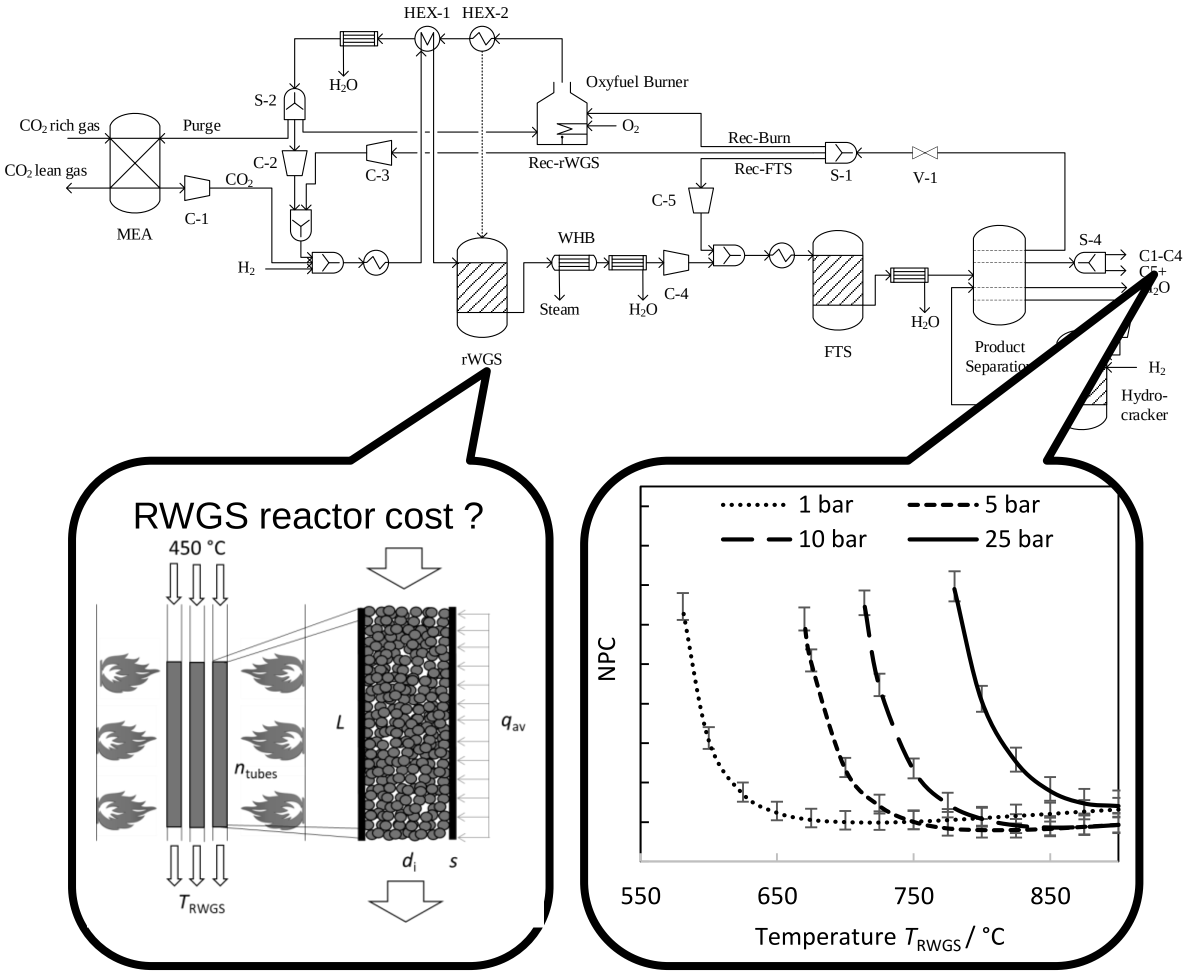

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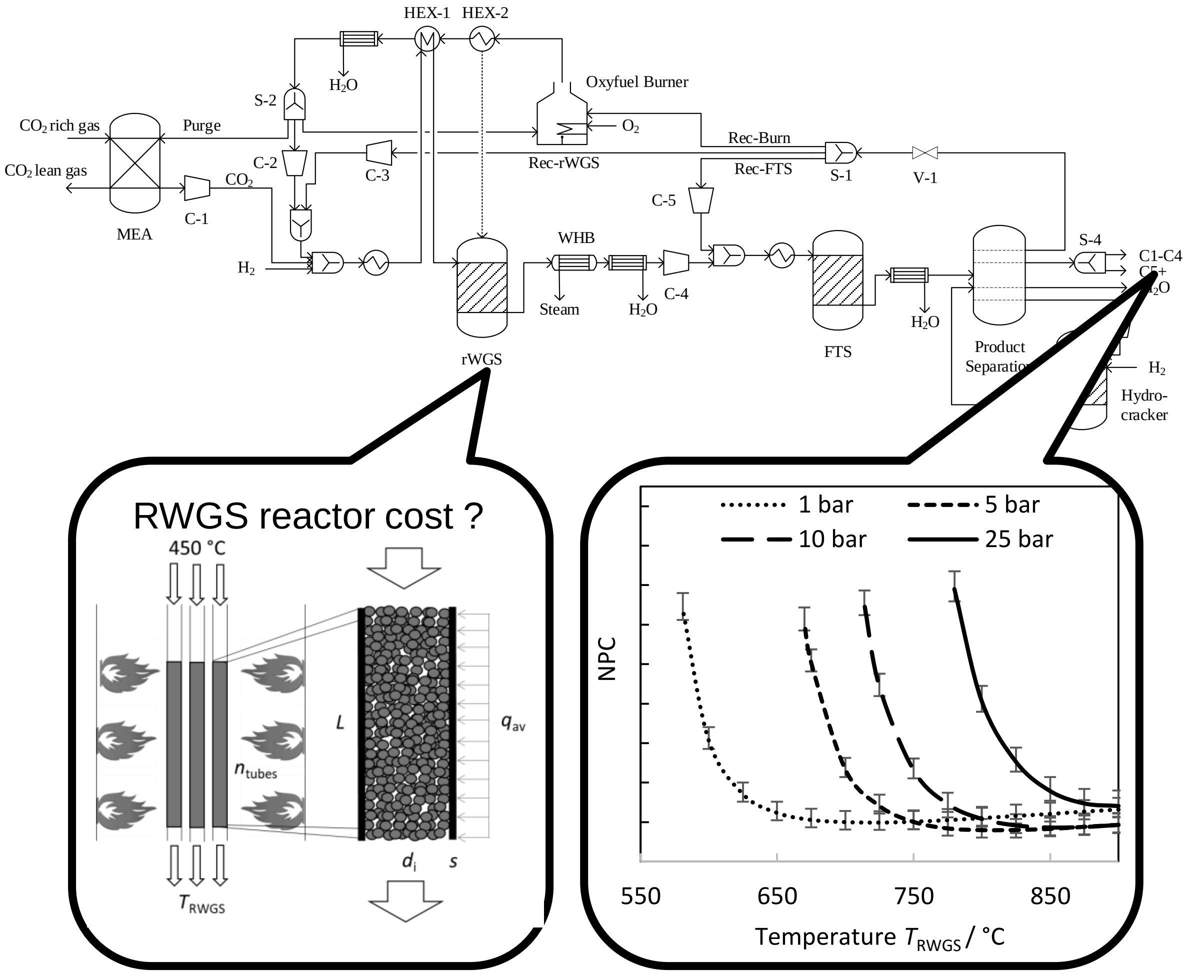
Fuel, Vol. 317, 2022, 123440, doi.org/10.1016/j.fuel.2022.123440

Uncertainty and Global Sensitivity Analysis [3]

Major contributors to the uncertainty of the PtL net production cost

[3] Adelung, Sandra (2022)
"*Global sensitivity and uncertainty analysis of a Fischer-Tropsch based Power-to-Liquid process*", Journal of Energy Chemistry, submitted



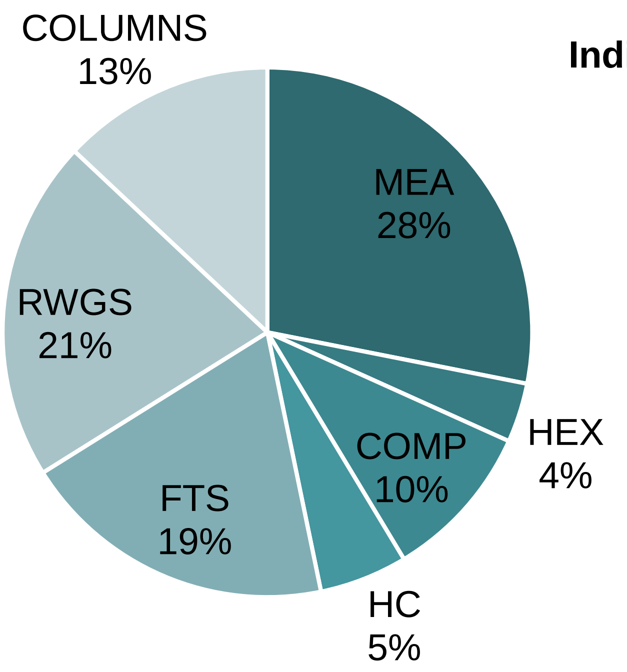
Power-to-Liquid process: Detailed techno-economic assessment [1]

Cost breakdown at RWGS cond. 800 °C & 5 bar and H_2 cost of 4.1 $€_{2019}$/kg

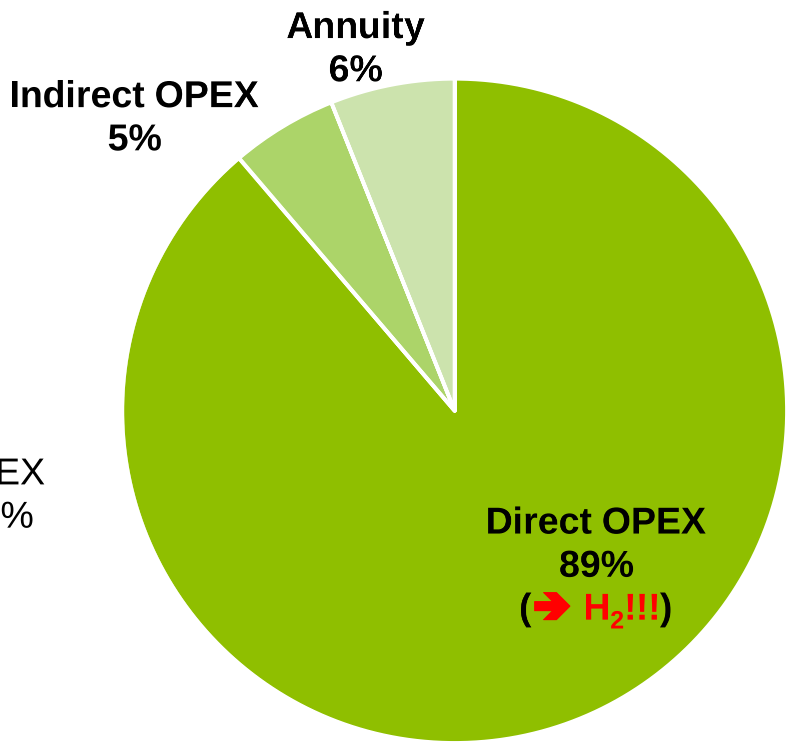
General Plant Assumptions	
Plant capacity	6.05 t/h H_2 input
Full load hours	8,000 hours/a
Operating time of plant y	20 years
Interest rate IR	7 %
Base year	2019
Location	Germany
Site	Brownfield

Hydrogen Cost Cases [2]	
Low	2.3 €/kg_{H2}
Base	4.1 €/kg_{H2}
High	7.6 €/kg_{H2}

FCI: 136 $M€_{2019}$



NPC: 229 $M€_{2019}$/a, 75 kt_{C5+}/a



[1] Adelung, S. et al., *Impact of the reverse water-gas shift operating conditions on the Power-to-Liquid fuel production cost*, Fuel, Vol. 317, 2022, 123440
[2] Bertuccioli, L., et al., *Development of Water Electrolysis in the European Union*. 2014, Fuel Cells and Hydrogen Joint Undertaking: Lausanne.

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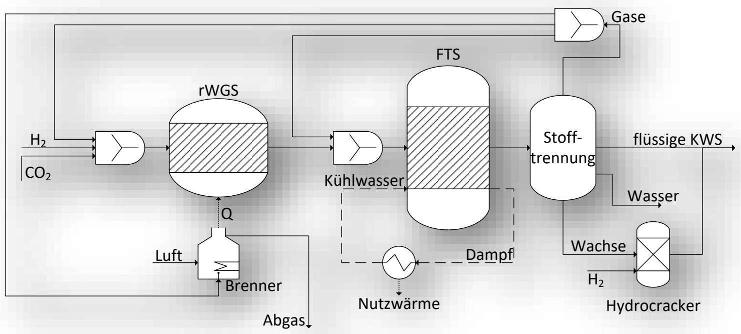
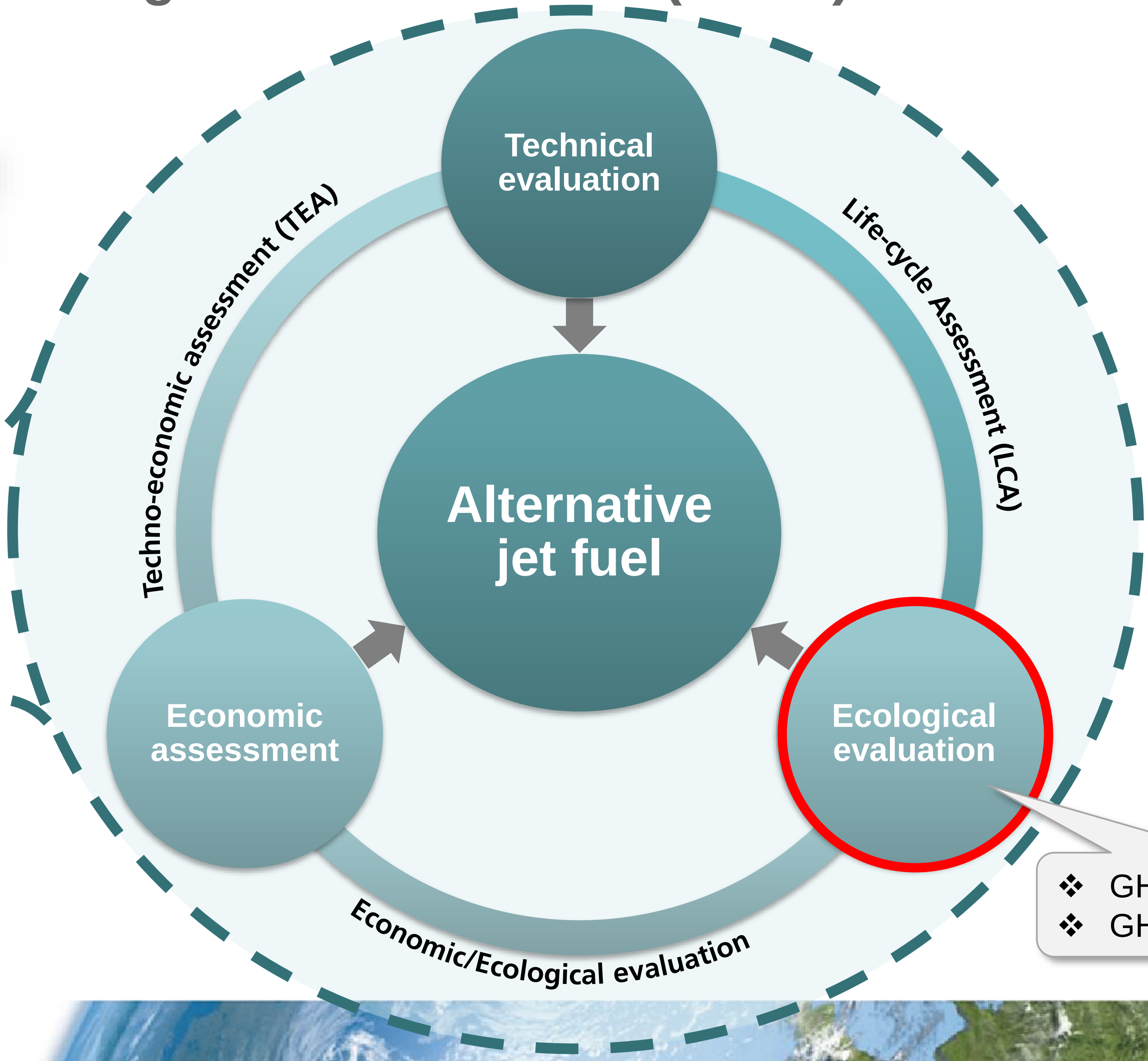


DLR's Techno economic process evaluation tool

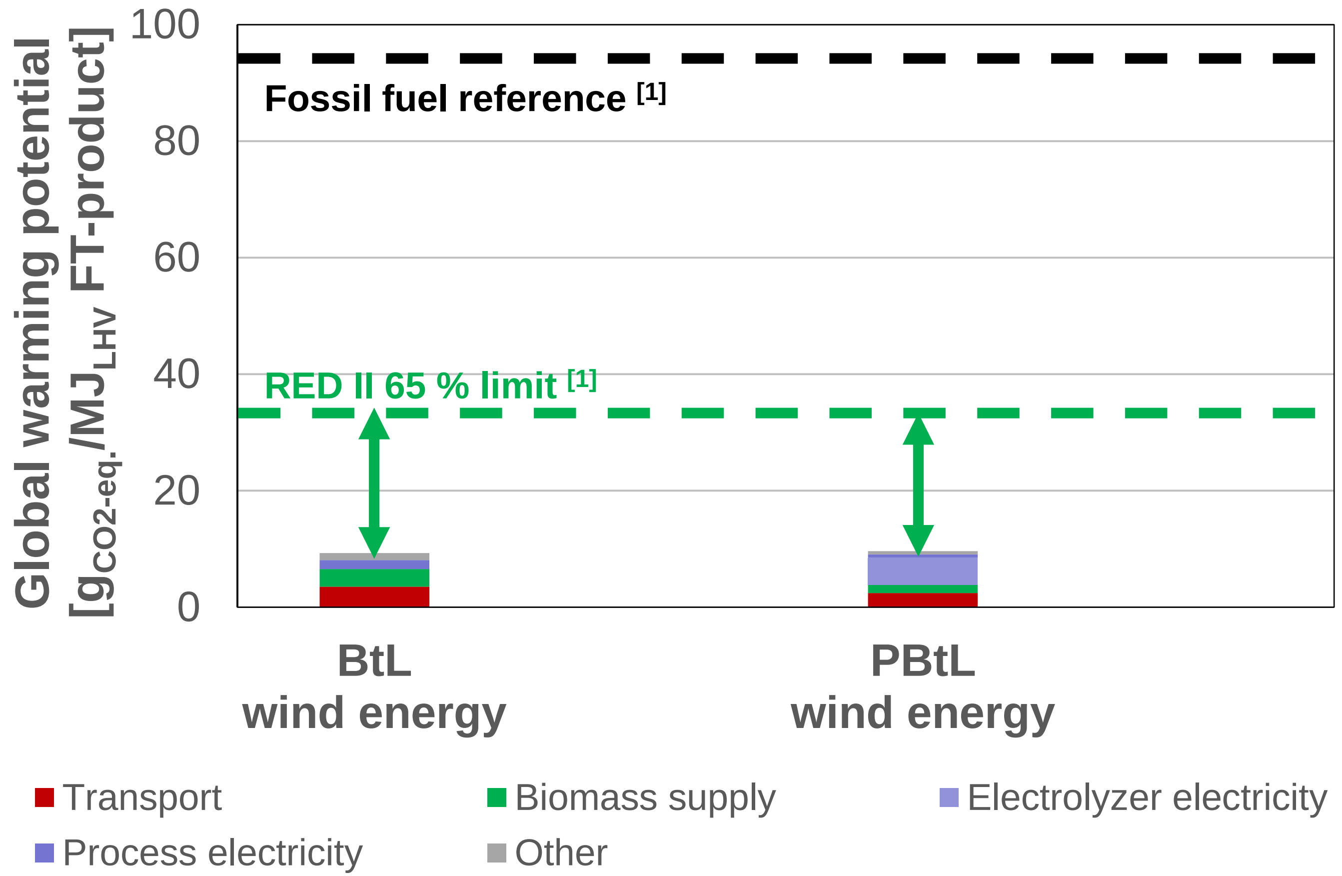


- GHG-footprint
- GHG-abatement costs

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

Life Cycle Assessment Example Results

Global warming potential in FLEXCHX cases BtL and PBtL (50 MW_{th})



- **Transportation: truck** (size: >32 t / 16-32 t)
  - **100 km biomass** (90.9 $g_{CO2\text{-}eq.}$/(t*km) [2])
  - **200 km FT-products** (166.8 $g_{CO2\text{-}eq.}$/(t*km) [2])
- **Biomass: Harvesting woody residues (bark, saw dust, wood chips)** (13.8 $g_{CO2\text{-}eq.}$/kg [2])
- **Electricity: Finnish onshore wind energy** (17.2 $g_{CO2\text{-}eq.}$/kWh [2])

Conclusion

- REDII target accomplished @ Finnish FLEXCHX base case assumptions

[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
[2] 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] Online https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-6 [Accessed 14.9.21]

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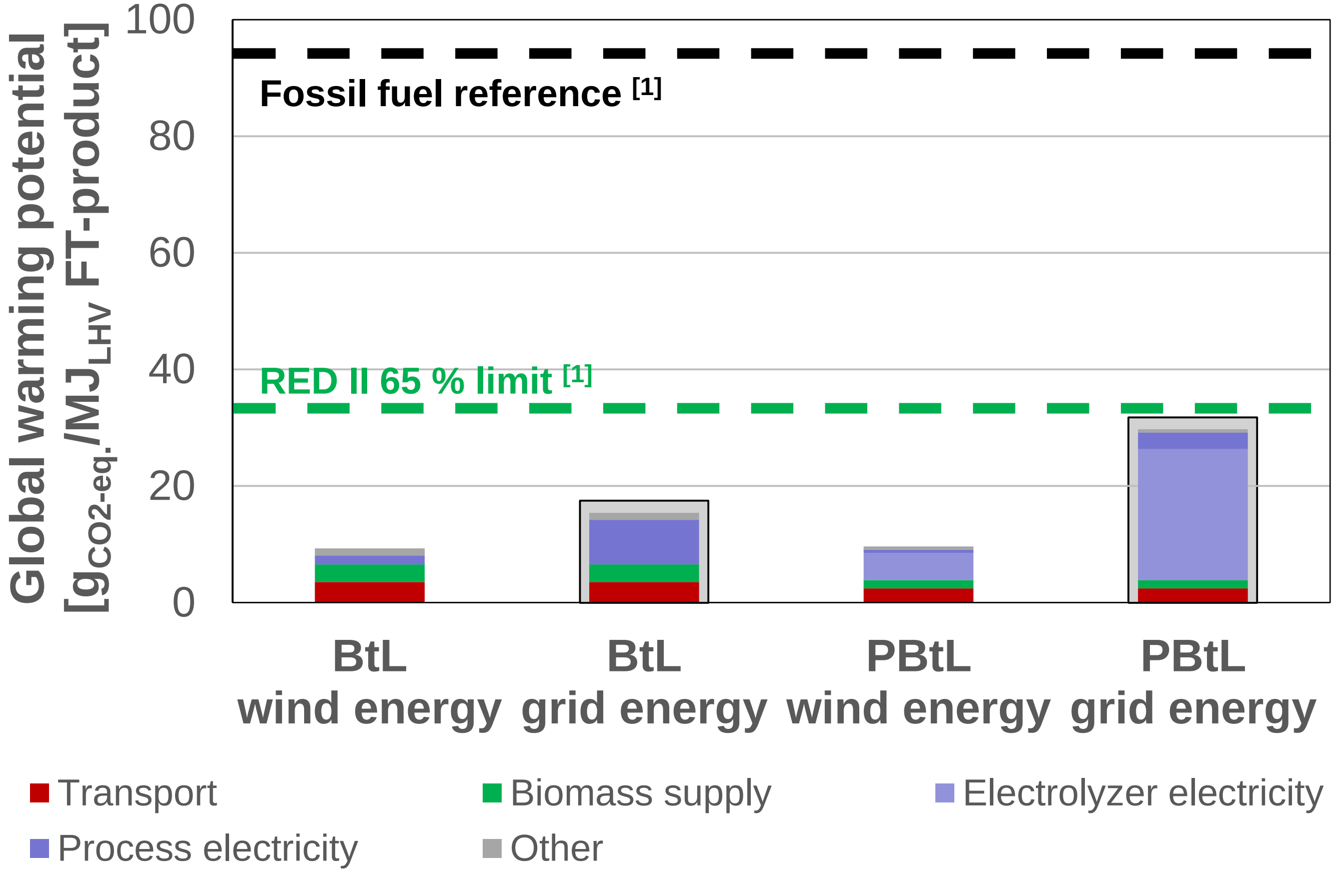

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- **Electricity: Finnish grid mix** (86 $g_{CO2-eq.}$/kWh [3])

Conclusion

- REDII target accomplished @ Finnish FLEXCHX base case assumptions
- REDII target **only slightly** accomplished for PBtL @ Finnish grid mix electricity

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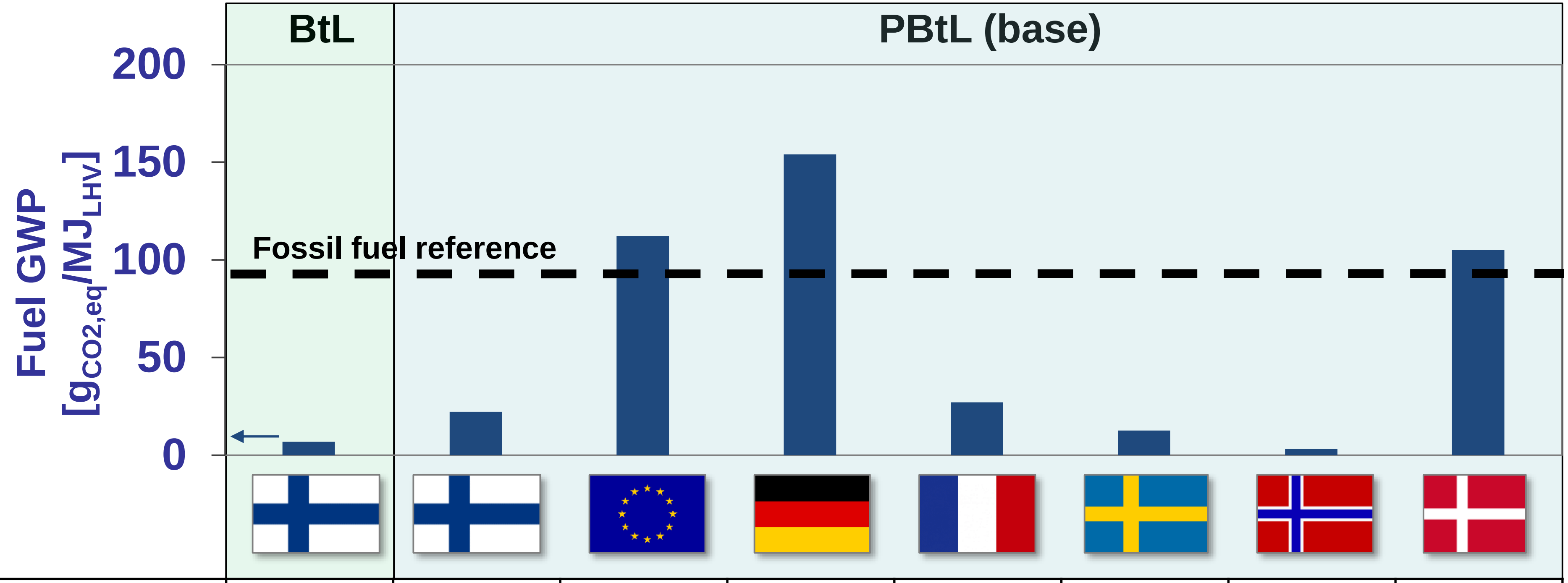
Life Cycle Assessment Example Results

Global warming potential in FLEXCHX case PBtL (50 MW_{th}) w. national grid power



Grid power price [$€_{2017}/MWh_e$] [1]		61	101	132	79	58	72	235
Grid power emission [$kg_{CO2,eq}/MWh_e$] [2]		86	447	615	105	47	9	377

[1] Hannula, I., & Reiner, D. M. (2019). Near-term potential of biofuels, electrofuels, and battery electric vehicles in decarbonizing road transport. *Joule*, *3*(10), 2390-2402.
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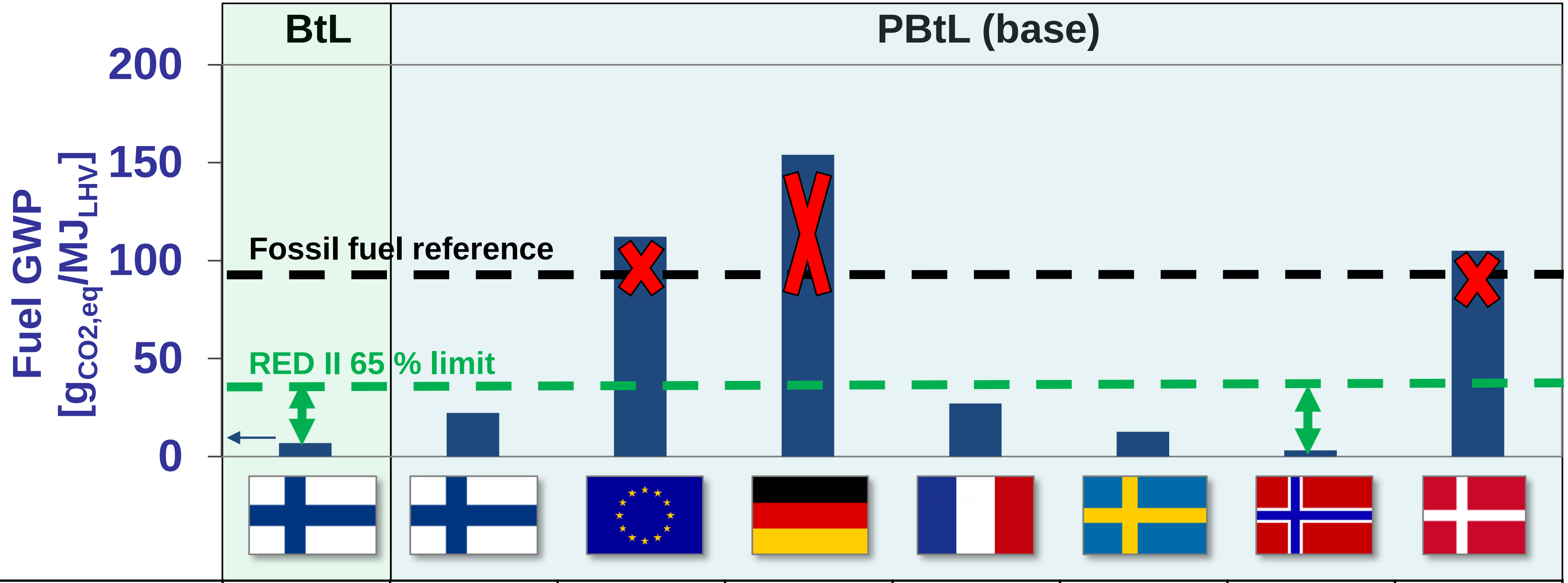

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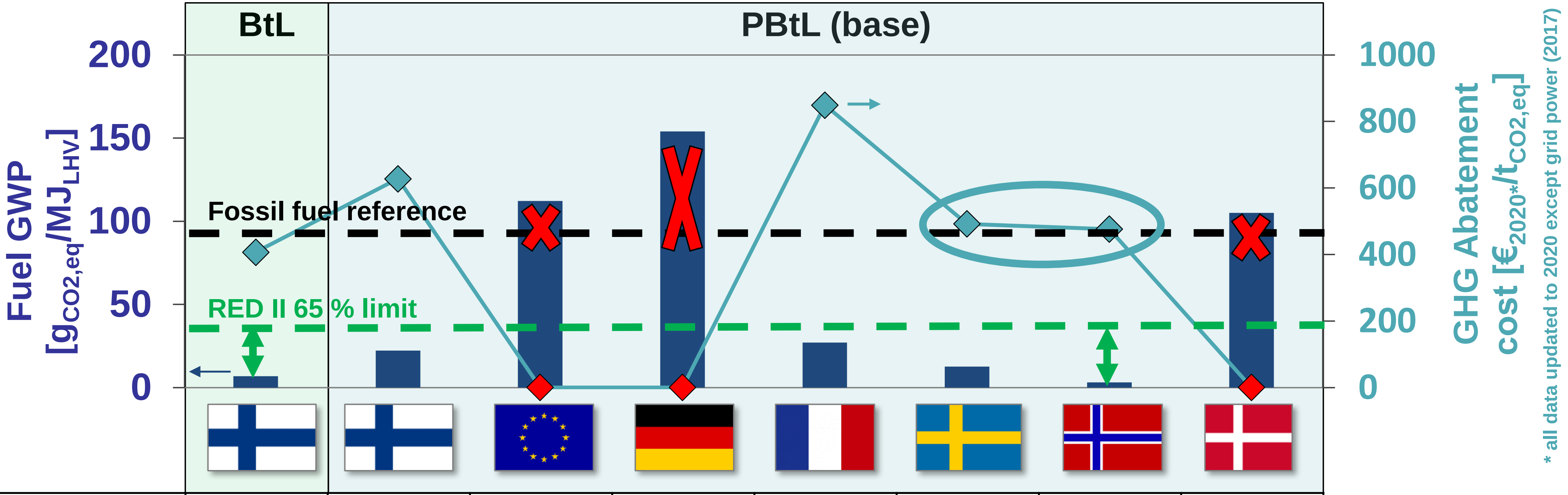

	BtL	PBtL (base)						
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PtX beyond aviation: New fuels for sustainable transport?

Beniver - Scientific supervision of „Energy transition in the transport sector (EiV)”

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

BEniVer
Begleitforschung Energiewende im Verkehr

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
- BEniVer funding - 9 Mio. € (8 partner)

- Goal: **Multicriterial assessment of different options for GHG abatement in transport**

Conclusions: PtX opportunities and challenges for aviation and beyond?

- **Opportunity 1**: Promised enormous increase in renewable energy generation
  - German coalition agreement (government): +300 - 350 TWh renewable electricity by 2030
  - New RE capacity implementation: 35 - 40 TWh p.a.?
  - 10 % for aviation: 3.5 – 4.0 TWh ➔ **+100 - 200 kt/a SAF addition each year?**

- **Opportunity 2**: Promised short term SAF pull (aviation industry) and push (expected deployment policies)
  - Immediate utilization of „low hanging fruits“: e.g. stop burning industrial H_2, explore **cheap** green carbon

- **Challenge 1:** underdeveloped European SAF industry (compared to GWP saving request)
  - Mandatory: reliable, permanent market for SAF – e.g., year-on-year growth rate of blending until 2030?
  - Investor certainty crucial

Promise 100 % SAF within 3 decades?

Fair share: 33 % supply in this decade?

➔ ⅓ of 63 Mt/a [1] ➔ 21 Mt/a SAF by 2030 !!!

[1] theicct.org, Estimating sustainable aviation fuel feedstock availability to meet growing European Union demand, 08 MAR 2021

Thank you for your attention!

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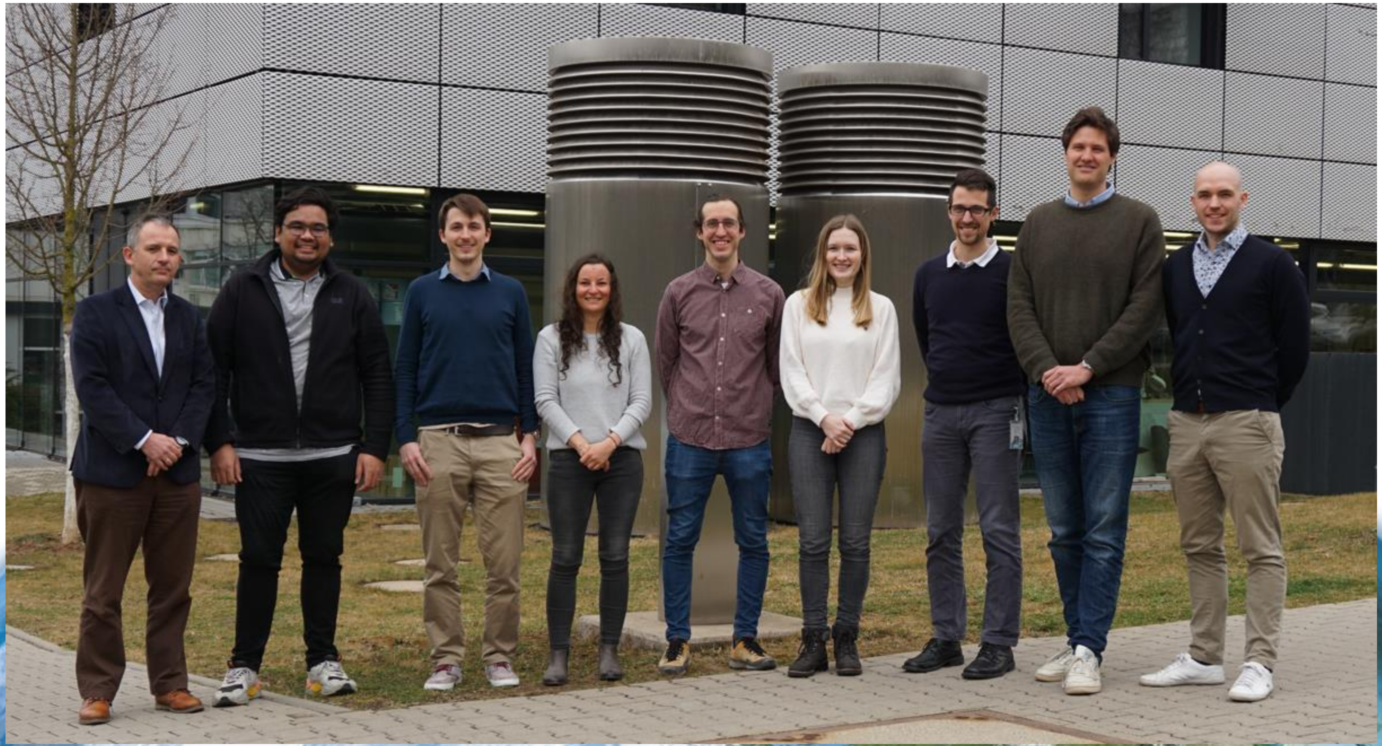

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