@

Application of techno economic and ecological process assessment for cost estimation of renewable fuels

10. ProcessNet annual conference and 34. DECHEMA annual conference for Biotechnology 2020

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F. Habermeyer, S. Maier, M. Raab, J. Weyand,
Ralph-Uwe Dietrich
(DLR e.V., www.DLR.de/tt)

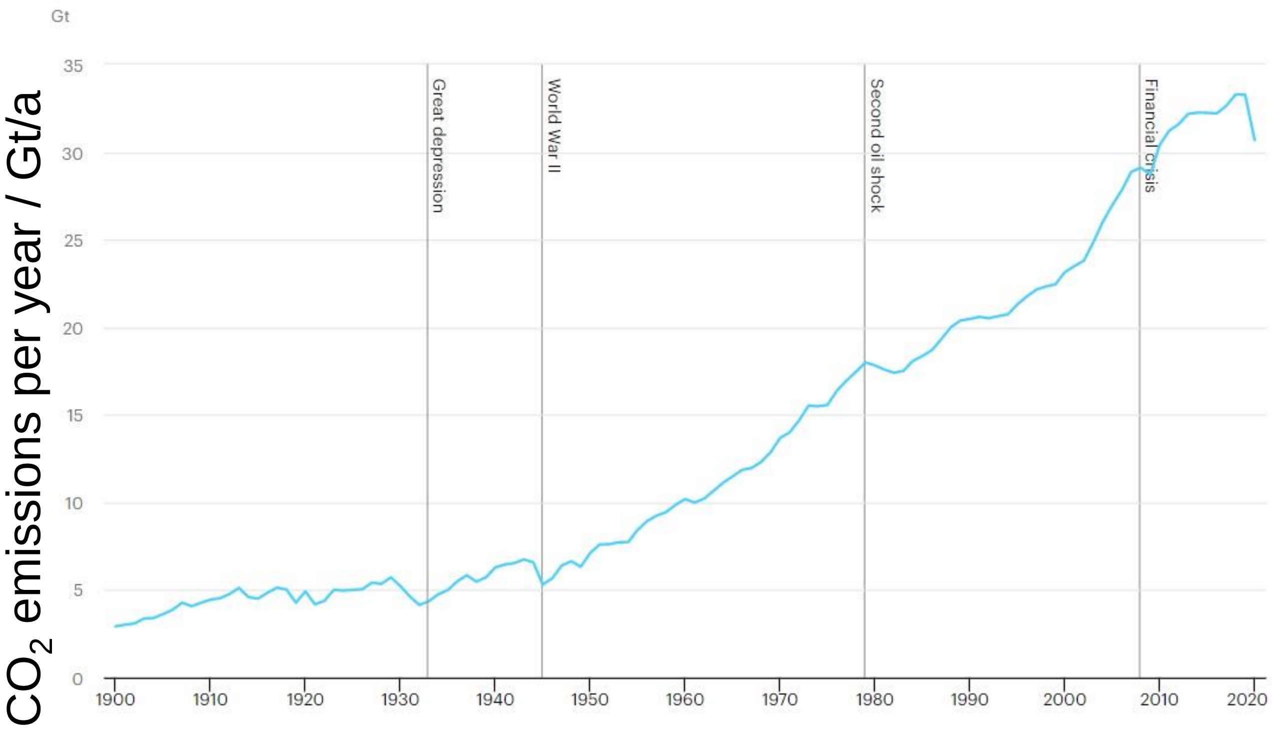
Agenda

1. **Motivation and demand**
2. **Methodology**
3. **Techno-economic & ecological assessment examples**
4. **Summary**

1. Motivation and demand
GHG emissions exceed the 1,5 °C budget

Global energy-related* CO_2 emissions, 1900-2020

IEA, Last updated 30 Apr 2020



https://www.iea.org/data-and-statistics/charts/global-energy-related-co2-emissions-1900-2020

* + deforestation + cement ≈ 40 Gt/a (IPCC)

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1. Motivation and demand

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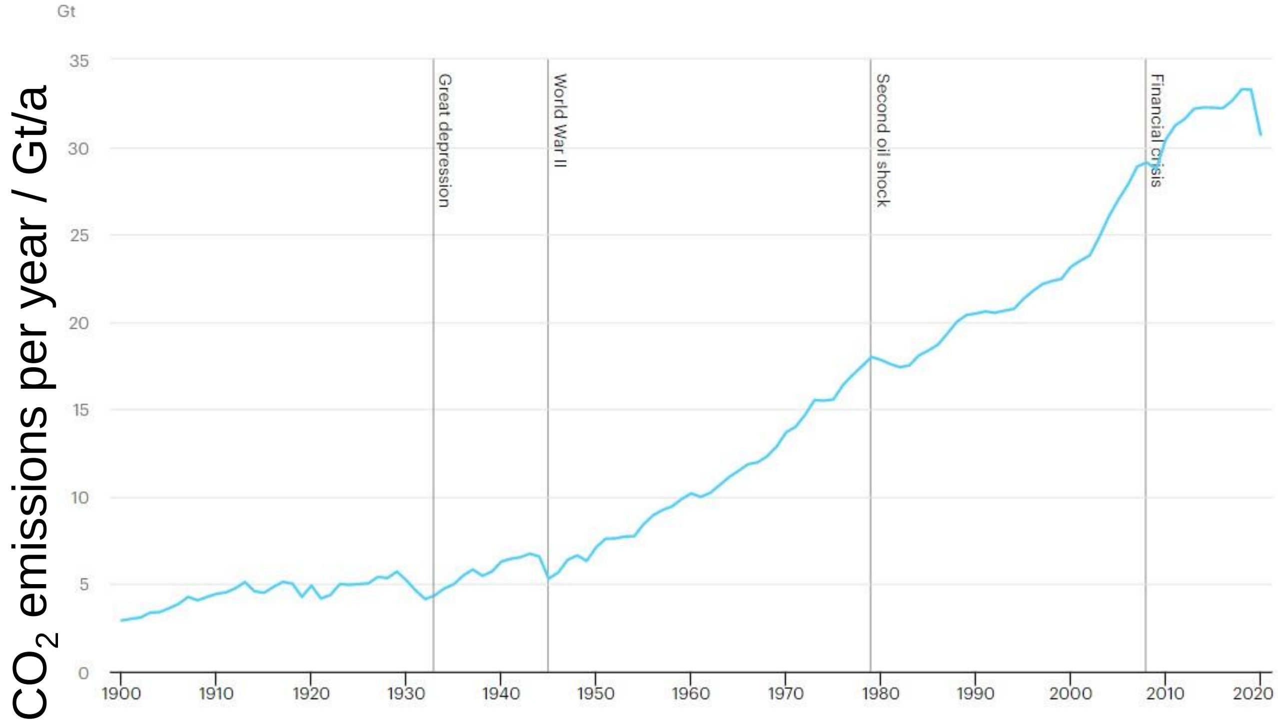
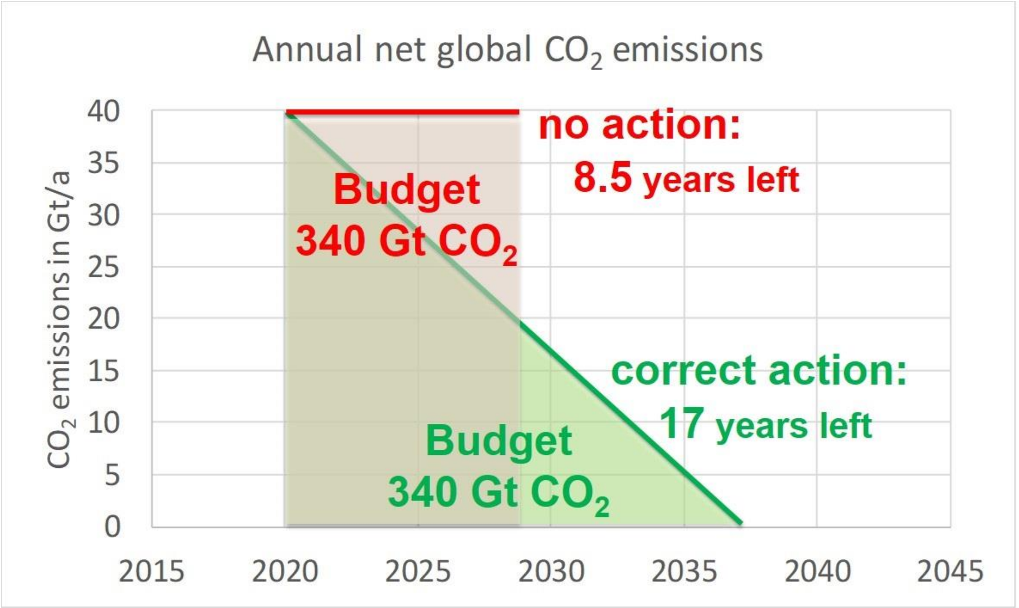


https://www.iea.org/data-and-statistics/charts/global-energy-related-co2-emissions-1900-2020

* + deforestation + cement ≈ 40 Gt/a (IPCC)

Demand: Continuous GHG emissions reduction

- Immediate / permanently / - 2,4 Gt_{CO2}/a



Source: T. Willner: Climate Protection in the Transport Sector – The Key Role of Alternative Fuels. In: J. Werner, N. Biethahn, R. Kolke, E. Sucky and W. Honekamp (Eds.): Mobility in a Globalised World 2019. University of Bamberg Press, ISBN 978-3-86309-731-8, Bamberg, May 2020, pp 261-289

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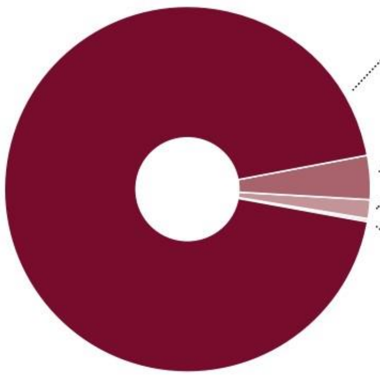
1. Motivation and demand
Transport continues to depend on fossil oil

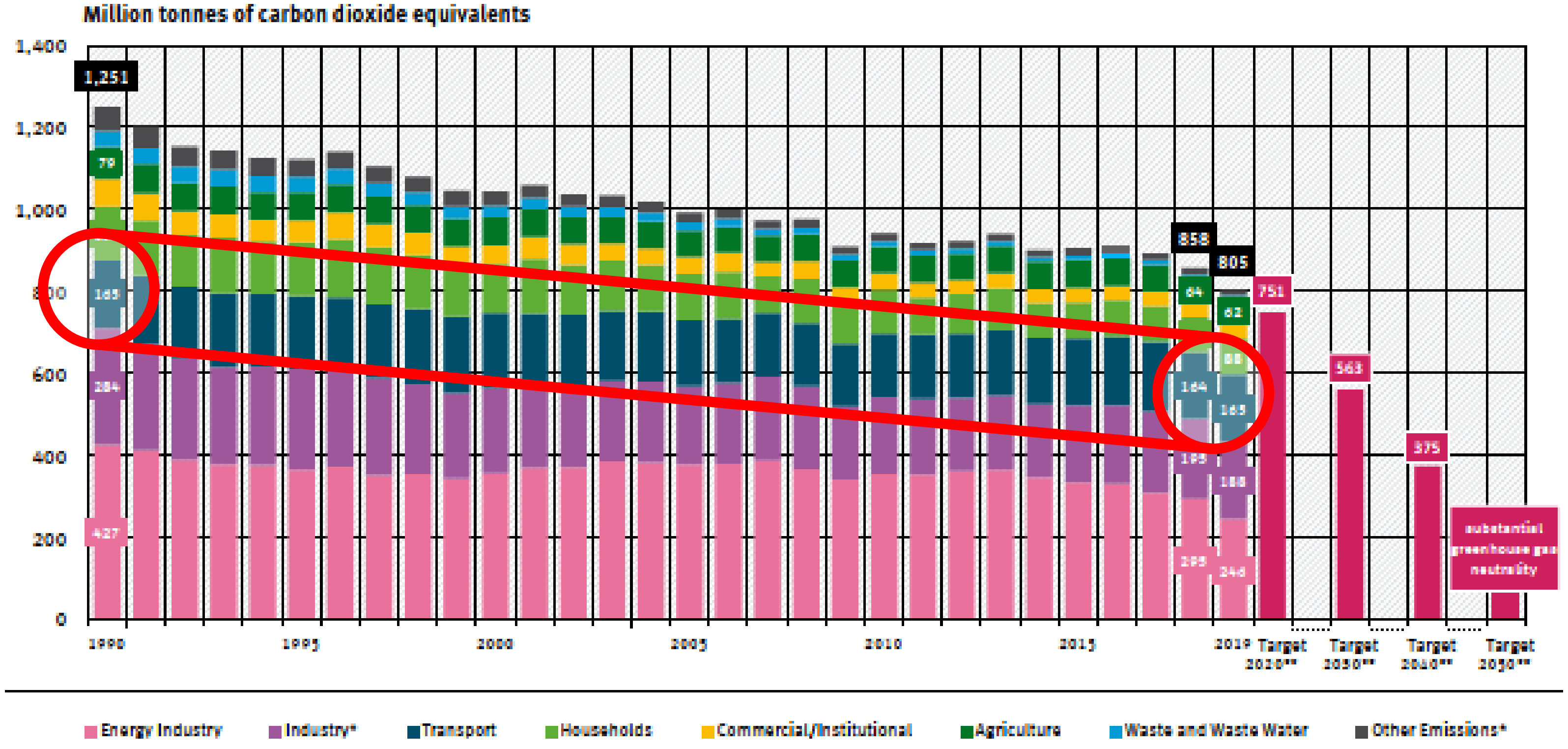
Figure 26: Final energy consumption in the transport sector in 2017



Source: BMWi (2019a)

https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/climate_action__figures_2019_brochure_en_bf.pdf

Emission of greenhouse gases covered by the UN Framework Convention on Climate



Emissions by UN reporting category, without land use, land use change and forestry
* Industry: Energy and process-related emissions from industry (1.A.2 & 2);
Other Emissions: Other combustion (rest of CRF 1.A.4, 1.A.5 military) & fugitive emissions from fuels (1.B)
** Targets 2020 to 2050: Energy Concept of the German Federal Government (2010)
2019: Short-term forecast, emissions from commerce, trade & services contained in Other Emissions

Source: German Environment Agency, National Inventory Reports for the German Greenhouse Gas Inventory 1990 to 2018 (as of 12/2019) and estimate for 2019 from UBA Press Release 15th of march 2020

https://www.umweltbundesamt.de/en/indicator-greenhouse-gas-emissions

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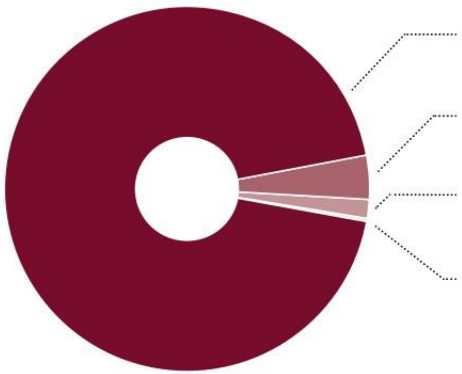
1. Motivation and demand
Transport continues to depend on fossil oil

Figure 26: **Final energy consumption in the transport sector in 2017**



Source: BMWi (2019a)

https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/climate_action__figures_2019_brochure_en_bf.pdf

Options for sustainable transport

- **Electrification?**
  - **Fleet renewal too slow**
  - **Not enough renewable power**
  - **Heavy load, marine, aviation, long distance ignored**
- **Hydrogen?**
  - **Unpredictable FCV development**
- **Crop based biofuels?**
  - **Limited harvest of rape, sugar, corn, …**
  - **Food competition**
  - **Small energetic efficiency**
  - **Inappropriate land use change**
- **New routes?**
  - **Leftover biomass?**
  - **Organic waste?**
  - **Power-to-X?**
  - **Algae based?**

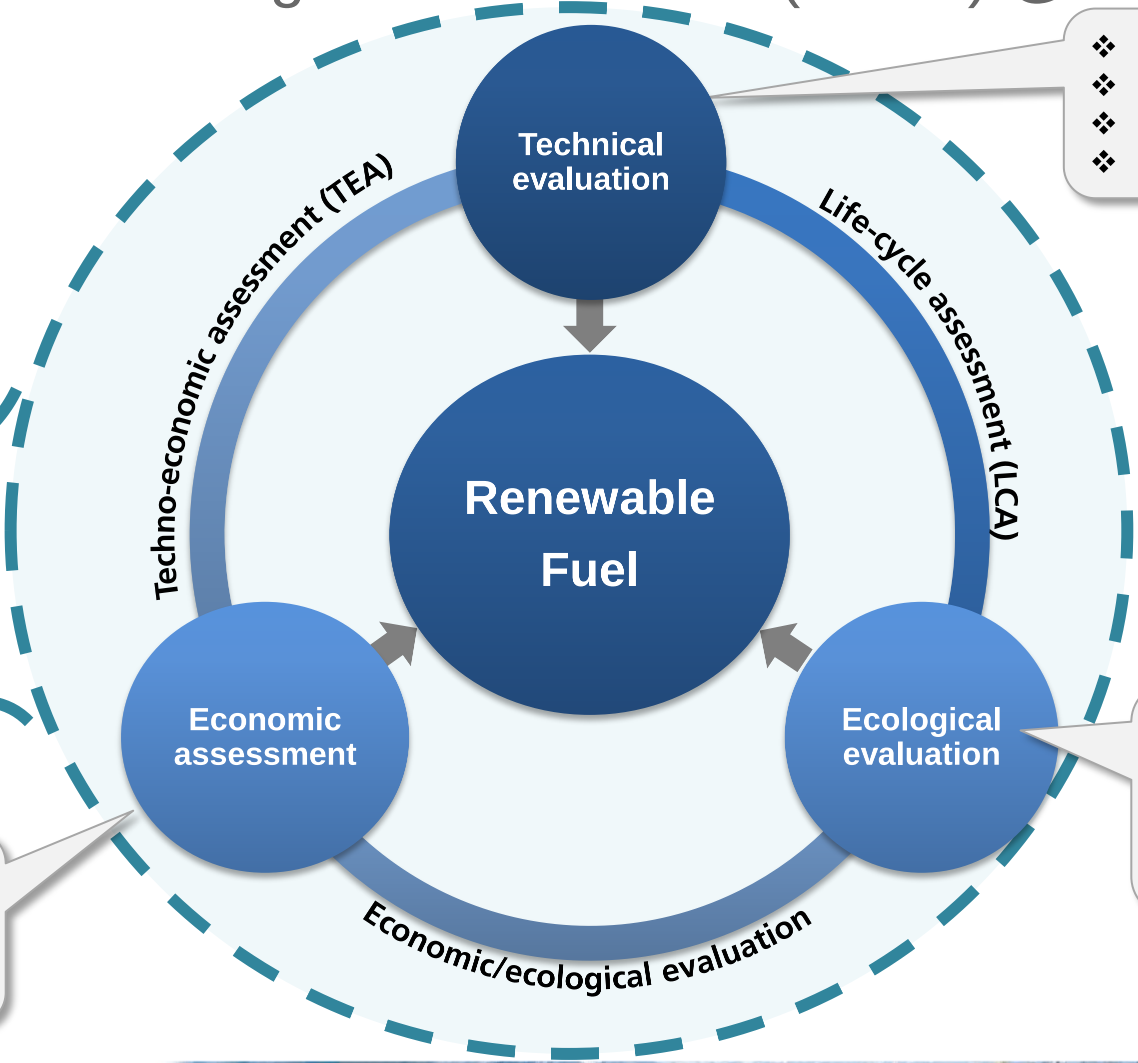
- No Silver bullet
- Low TRL
- Not competitive

➔ Transparent, fair, neutral assessment

2. Methodology
Techno-economic and ecological assessment (TEEA) @ DLR

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

DLR's evaluation tool

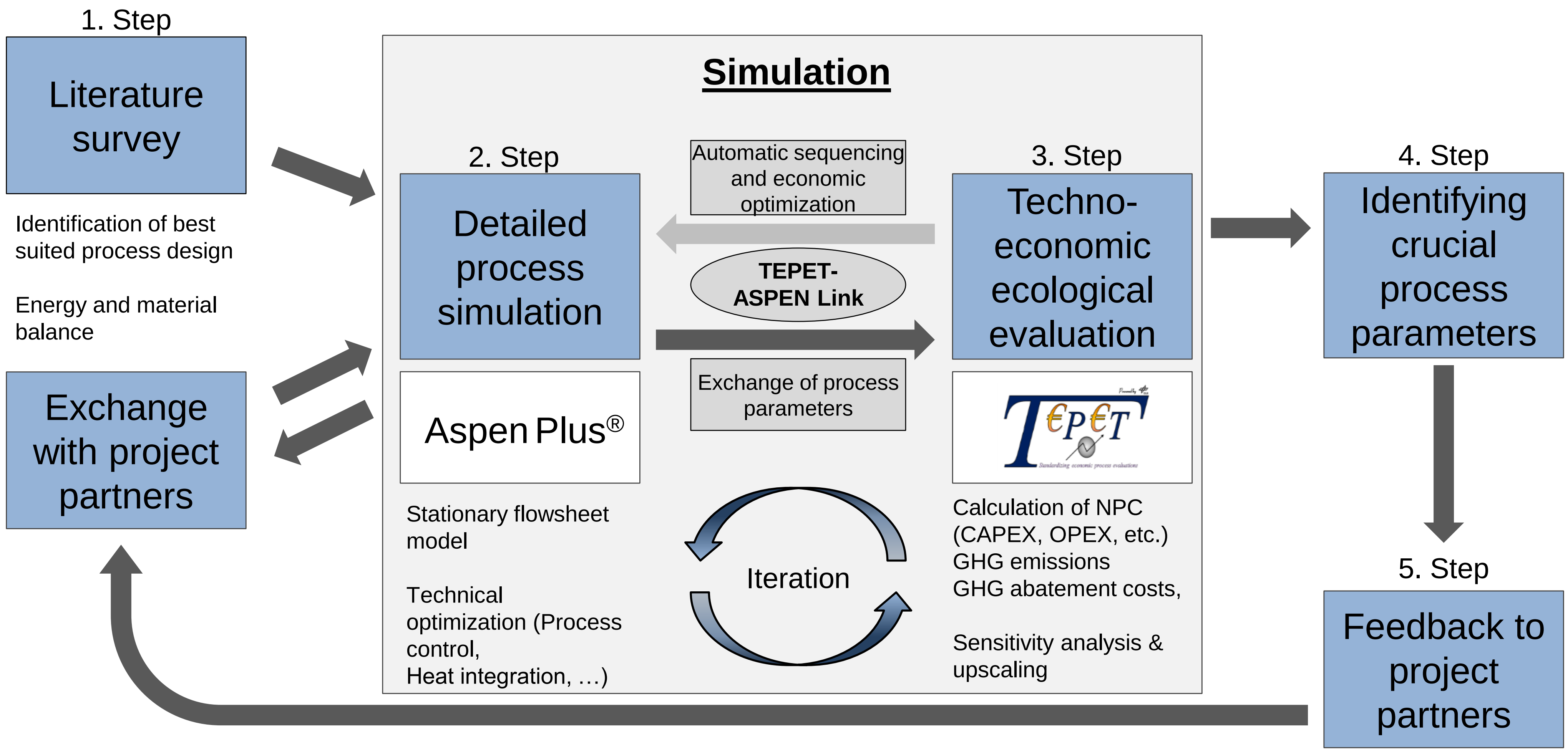


- Global warming potential
- Water consumption
- Soil acidification
- Land use
- …

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

2. Methodology

Techno-economic and ecological assessment (TEEA) @ DLR



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BEniVer
Begleitforschung Energiewende im Verkehr

2. Methodology standardization
TEEA assessment of different fuel options for all transport

- BEniVer – Scientific supervision of „Energy transition in the transport sector (EiV)"

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izes gGmbH Institut für ZukunftsEnergie- und Stoffstromsysteme
FfE
HELMHOLTZ ZENTRUM FÜR UMWELTFORSCHUNG UFZ
DBFZ
GWS SPECIALISTS IN EMPIRICAL ECONOMIC RESEARCH
DECHEMA
DGMK

- EiV funding - 99 Mio. € | 100+ partner
- Renewable electricity based fuels for aviation, road transport and shipping
- BEniVer funding - 9 Mio. €
- Task: Multicriterial assessment of different options for GHG abatement in transport

Cluster (selection)	Application (focus)			Fuels in focus
BEniVer	✈	🚗	🚢	Focus on "technical clusters"
C3-Mobility		🚗		Methanol, DME, OME
CombiFuel		🚗		Hydrogen and methane
E2Fuels		🚗	🚢	Methanol, OME, Hydrogen, Methane
FlexDME		🚗		DME
KEROSyN100	✈			Kerosene
MEEMO		🚗		Methanol
MethQuest		🚗		Methane
Namosyn		🚗		OME, DMC, MF
PlasmaFuel			🚢	Diesel
PowerFuel	✈			Kerosene
Solare Kraftstoffe		🚗		Gasoline, MTBE, Methanol and other alcohols
SynLink	✈	🚗		Gasoline, Diesel, Kerosene, Alcohols

To be updated!

2. Methodology standardization
Setting unified boundary conditions across projects

- General boundary conditions (plant availability, cost for electricity)
- Electrolysis data
- Carbon sources
- Input parameter for utility equipment
- Economic parameters

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BEniVer

Begleitforschung Energiewende im Verkehr

2. Methodology standardization

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- **Input parameter for utility equipment**
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Preliminary dataset

Wärmetauscher			
Rohrbündel			
- ohne Phasenwechsel -			
Gas (1 bar) innen - Gas (1 bar) außen	W/m² K	20	VDI Wärmeatlas - C3
Gas (200 bar) innen - Gas (200 bar) außen	W/m² K	325	VDI Wärmeatlas - C3
Flüssigkeit - Gas (1 bar)	W/m² K	42.5	VDI Wärmeatlas - C3
Gas, Hochdruck (200 bar) innen - Flüssigkeit außen	W/m² K	300	VDI Wärmeatlas - C3
Flüssigkeit innen - Flüssigkeit außen	W/m² K	625	VDI Wärmeatlas - C3
Heizdampf außen - Flüssigkeit innen	W/m² K	750	VDI Wärmeatlas - C3
- Verdampfer -			
Naturumlauf - hohe Viskosität	W/m² K	600	VDI Wärmeatlas - C3
Naturumlauf - niedrige Viskosität	W/m² K	1250	VDI Wärmeatlas - C3
Zwangsumlauf	W/m² K	2000	VDI Wärmeatlas - C3
- Kondensatoren -			
Kühlwasser innen - Dampf außen	W/m² K	750	VDI Wärmeatlas - C3

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BEniVer

Begleitforschung Energiewende im Verkehr

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Preliminary dataset

Faktoren für Ermittlung der Betriebskosten (OPEX)

Indirekte Betriebskosten	Elektrolyse	Rest	**Basis**	**Quelle**	
Versicherung und Steuern	0.02	0.02	FCI	Albrecht 2016	
Maintenance labor (ML)	f (P [kW])	0.01	FCI	Peters Timmerhaus West - Kapitel 6	
Maintenance material (MM)		0.01	FCI	Peters Timmerhaus West - Kapitel 6	
Operating supplies (OS)	0.00	0.15	ML+MM	Albrecht 2016	
Administrative costs	0.25	0.25	PO	Albrecht 2016	
Plant overhead costs (PO)	0.50	0.50	OL+OV+OS	Peters Timmerhaus West - Kapitel 6	
Distribution and selling costs	0.00	0.00	NPC	Raab	Für die TÖA sollen die re
Research and development costs	0.00	0.00	NPC	Raab	Für die TÖA sollen die re
Direkte Betriebskosten	Elektrolyse	Rest	**Basis**	**Quelle**	
Operating Labor (OL)	Selber ausrechner	Selber ausrechnen			
Operating supervision (OV)	0.15	0.15	OL	Albrecht 2016	
Laboratory charges	0.20	0.20	OL	Albrecht 2016	

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BEniVer

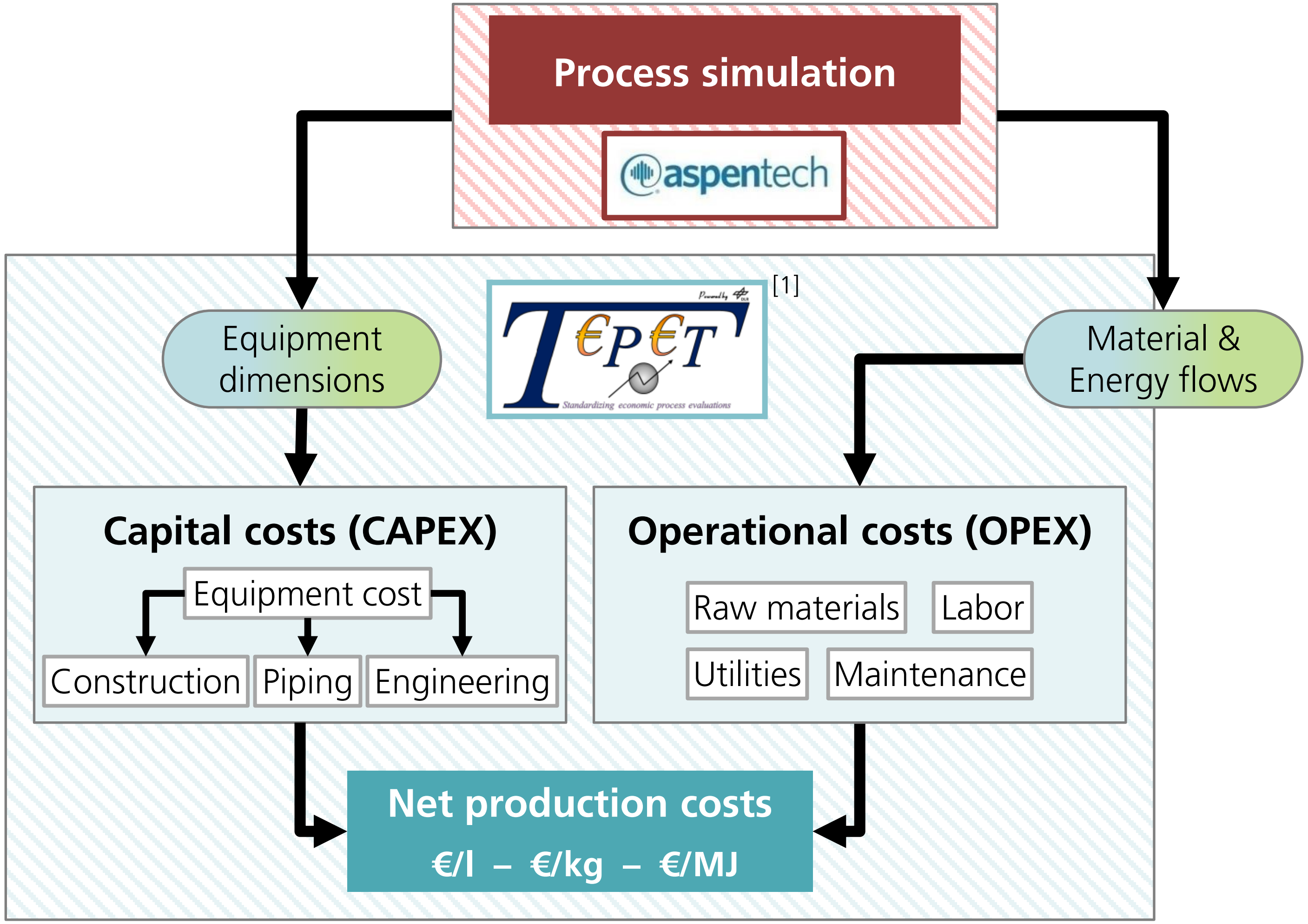
Begleitforschung Energiewende im Verkehr

2. Methodology standardization
Setting unified boundary conditions across projects

- General boundary conditions (plant availability, cost for electricity)
- Electrolysis data
- Carbon sources
- Input parameter for utility equipment
- Economic parameters

➢ **Standardized boundary conditions enable transparent techno-economic assessment**
   ➢ **Fair comparison between different fuel production routes and concepts**

2. Methodology - TEPET tool extension for seamless environmental impact assessment



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

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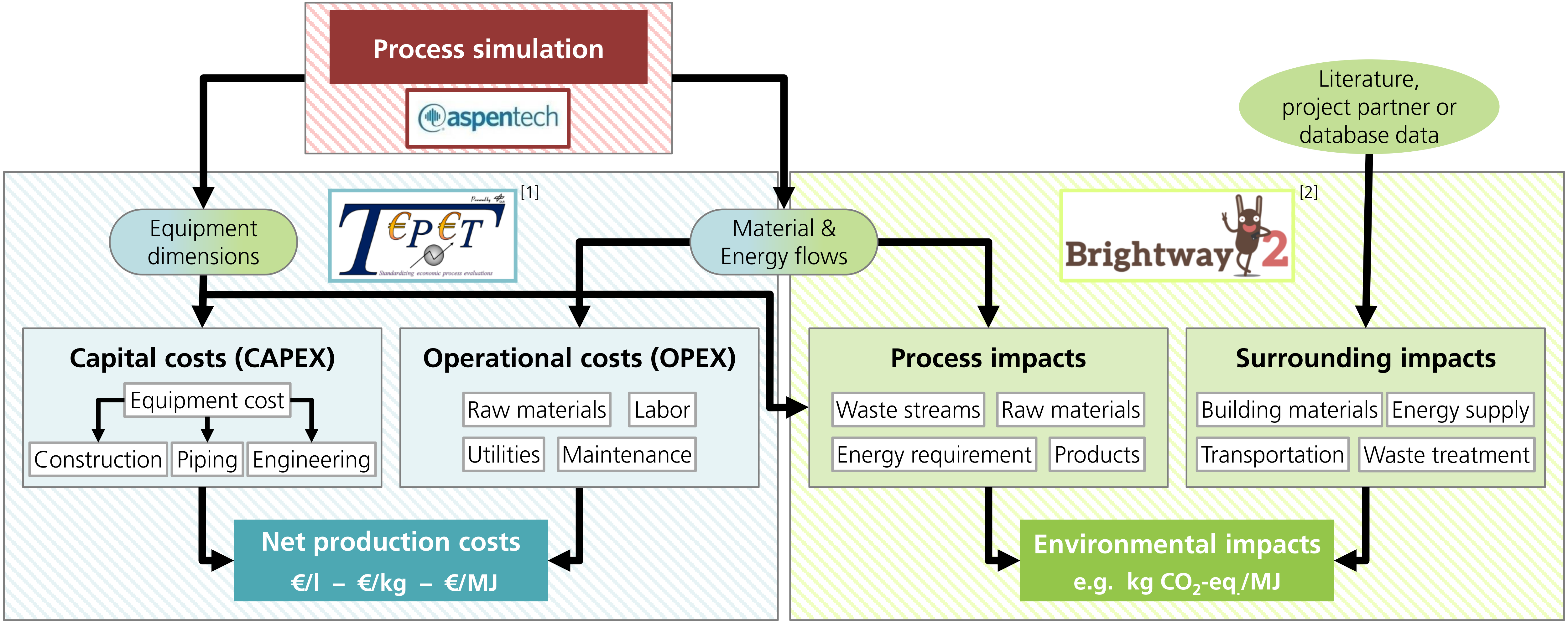
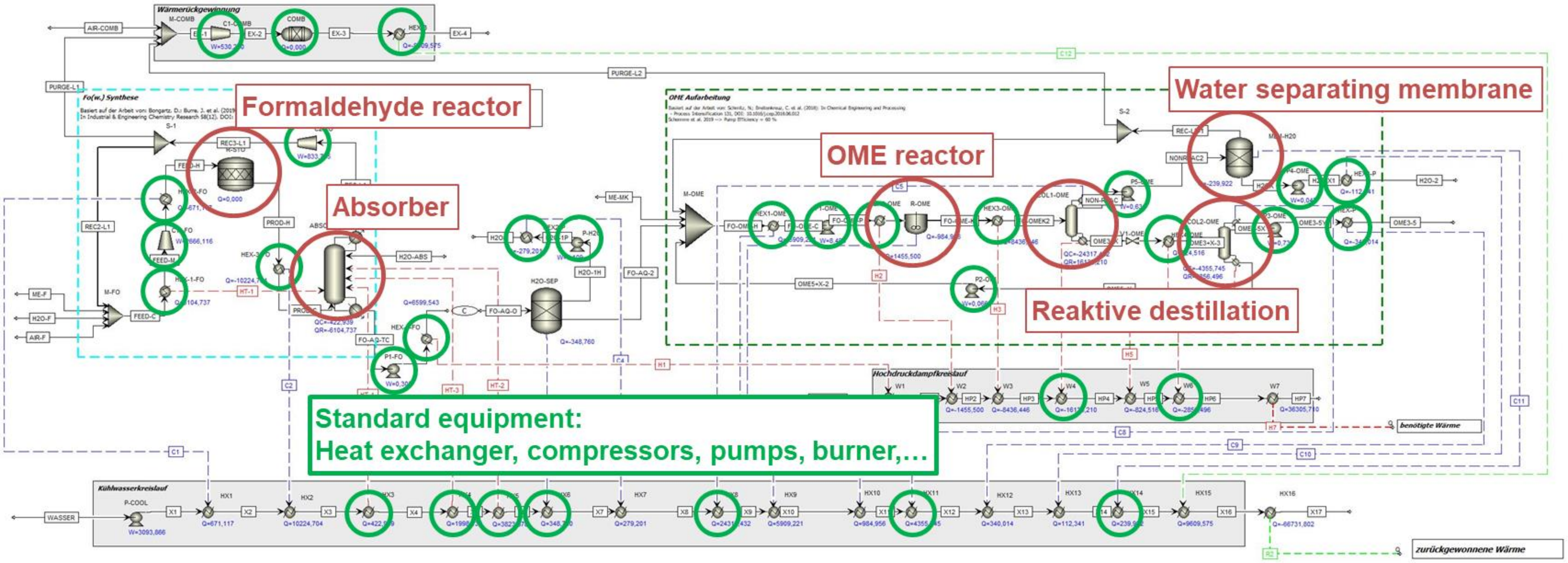


[1] Albrecht et al. (2016) - A standardized methodology for the techno-economic evaluation of alternative fuels – A case study, Fuel, 194: 511-526
[2] Mutel (2017) - Brightway: An open source framework for Life Cycle Assessment, Journal of Open Source Software, 2(12): 236

NAMOSYN – Nachhaltige Mobilität durch synthetische Kraftstoffe

2. Methodology

Equipment Costs for process units: example OME_{3-5}



Source: ASPEN plus process simulation by Fraunhofer ISE for exemplary OME synthesis process with MeOH and aqueous FA as feedstock. Annual productivity considered OME3-5 of 100 kt.

2. Methodology

Equipment Costs for process units: example OME_{3-5}

Nachhaltige Mobilität durch synthetische Kraftstoffe

Equipment	Sizing	€ Ref.
Formaldehyde reactor	Based on GHSV from [1]	[2]
OME reactor	Fraunhofer ISE, process data sheet	[2]
Reactive distillation	Fraunhofer ISE, process data sheet	[3]
Water separating membrane	Based on [4]	[5]
Absorber	Packing height based on [6], height of internals estimated	[3]
XXX	???	[???]
Burner	Fraunhofer ISE, process data sheet	[3]
Heat exchanger (shell-and-tube)	Heat transfer coefficients from BEniVer project V1.2 incl. absorber cooling, evaporator, condenser	[3]
Pumps, compressors	Fraunhofer ISE, process data sheet	[3]

[1] M. Qian, M. A. Liauw, G. Emig, *Appl. Catal.* **2003**, *238*, 211.
[2] D. R. Woods, *Rules of Thumb in Engineering Practice* **2007**, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim.
[3] M. S. Peters, K. D. Timmerhaus, R. E. West, *Plant Design and Economics for Chemical Engineers* **2003**, McGraw-Hill Higher Education, New York.
[4] N. Schmitz, *Production of polyoxymethylene dimethyl ethers from formaldehyde and methanol* **2018**, Dissertation, TU Kaiserslautern.
[5] R. W. Baker, *Membrane Technology and Applications* **2012**, John Wiley and Sons Ltd, Chichester.
[6] S. Hall, *Rules of Thumb for Chemical Engineers* **2012**, Elsevier, Oxford.

Agenda

1. **Motivation and demand**

2. **Methodology**

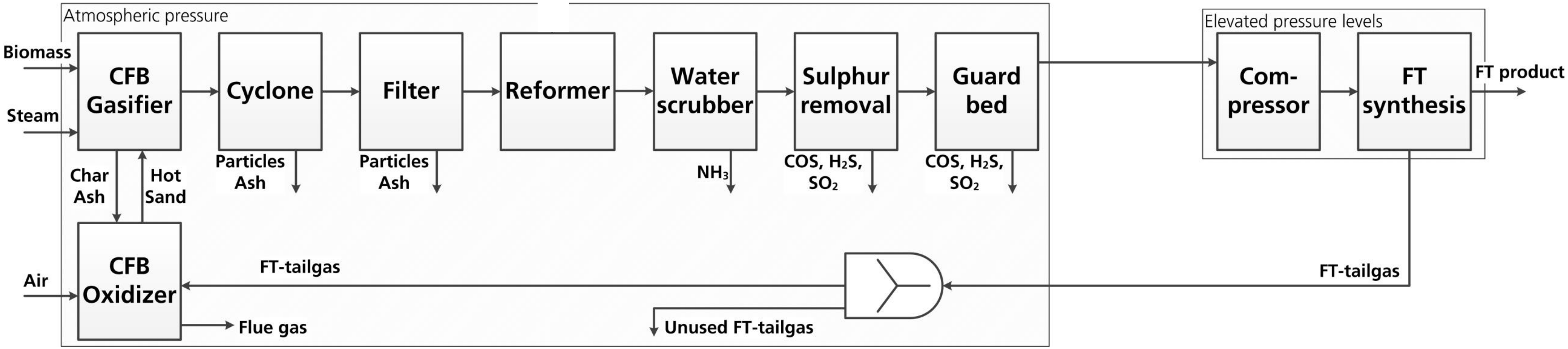
3. Techno-economic & ecological assessment examples

- Compare different process configurations
- Impact of seasonal operation
- Different renewable fuel options for the entire transport sector
- Nationwide Usage of Renewables for Transport

4. **Summary**

3. Techno-economic & ecological assessment examples
Compare different process configurations: example BtL

COMSYN project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 727476



Case 1

- Base case
- Autothermal reforming with air

3. Techno-economic & ecological assessment examples

Compare different process configurations: example BtL

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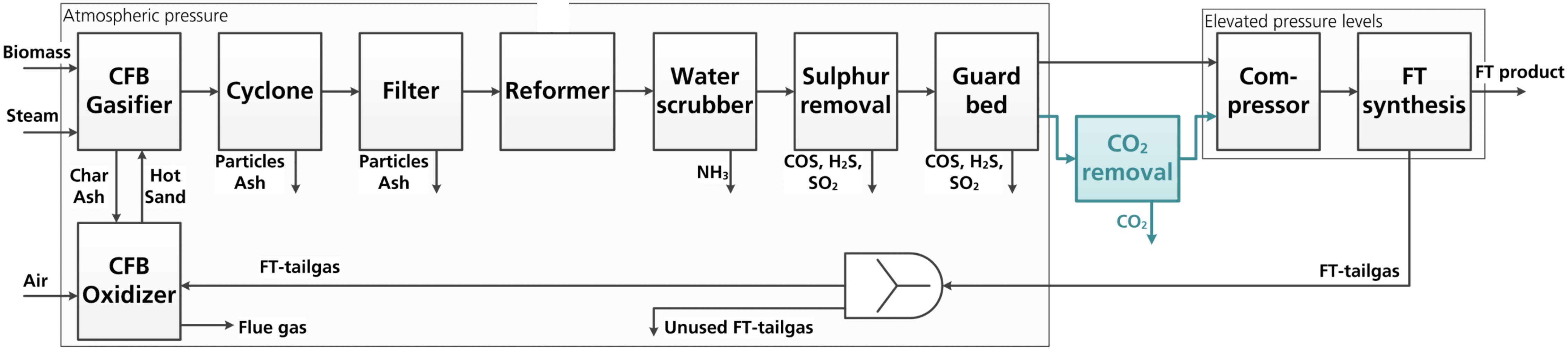

Case 1	Case 2
• Base case • Autothermal reforming with air	• Autothermal reforming with air • **CO_2 removal** after guard bed ➢ Operating at 5 bar ➢ 80 % CO_2 is removed

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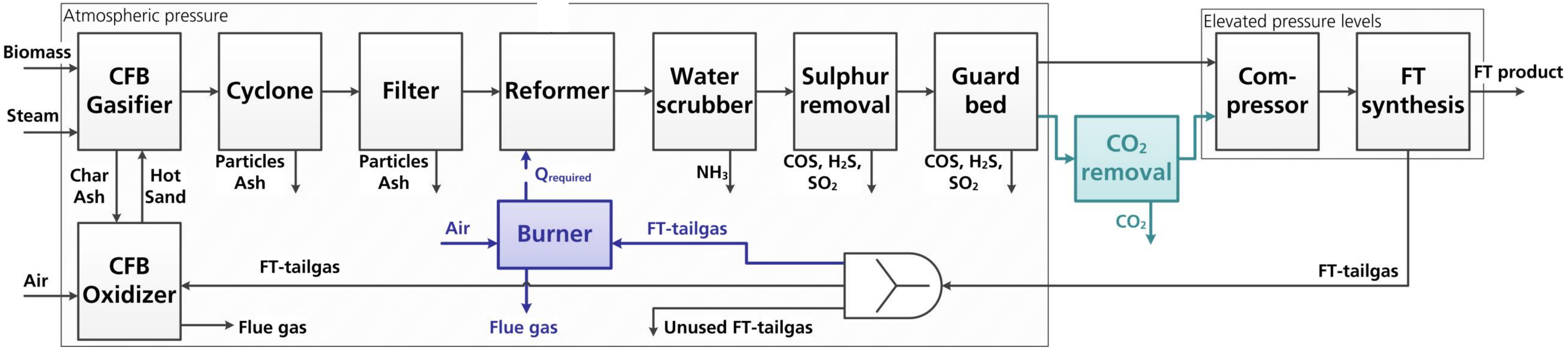
3. Techno-economic & ecological assessment examples

Compare different process configurations: example BtL

COMSYN

COMSYN project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 727476



Case 1	Case 2	Case 3
• Base case • Autothermal reforming with air	• Autothermal reforming with air • **CO_2 removal** after guard bed ➢ Operating at 5 bar ➢ 80 % CO_2 is removed	• **Allothermal** reforming ➢ Required heat is provided by an additional burner ➢ No air is led into the reformer

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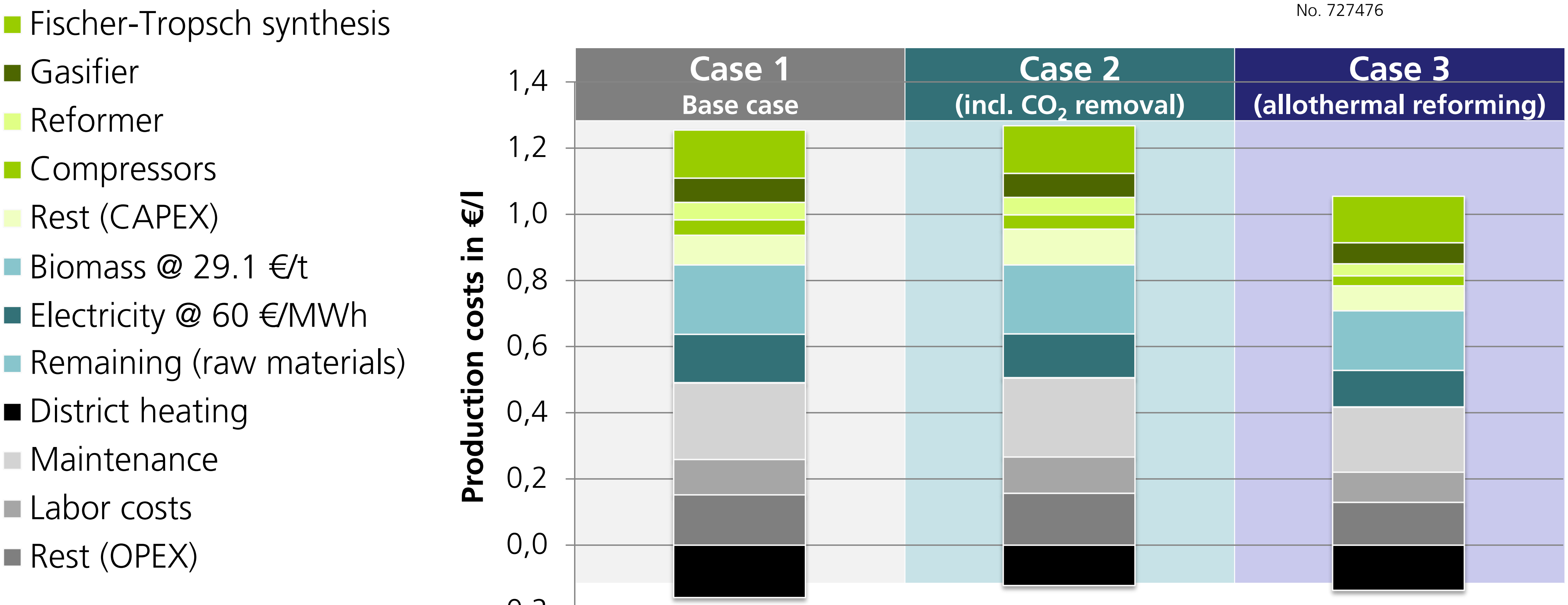
3. Techno-economic & ecological assessment examples

Net Production Costs for different process configurations

COMSYN project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 727476

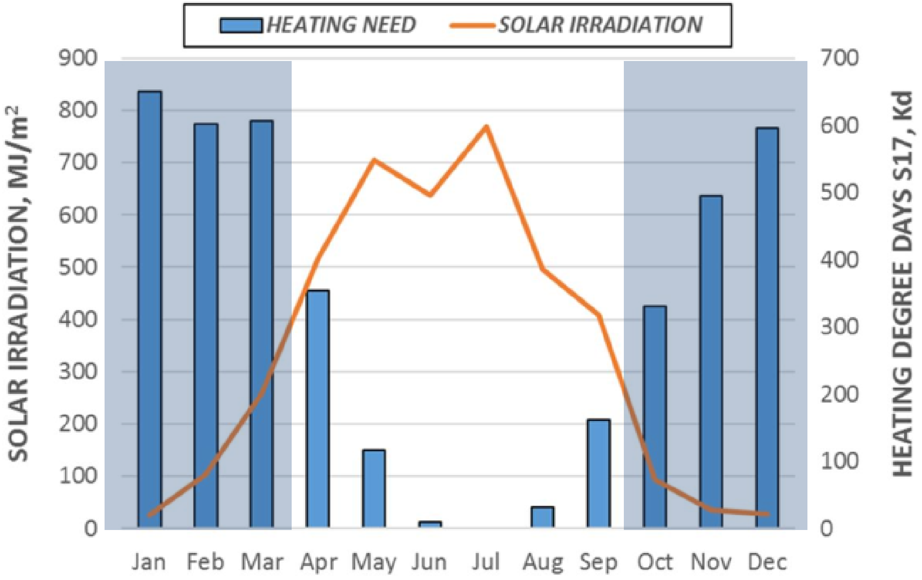


Base year:	2018	Plant lifetime:	30 years	Full load hours:	8.260 h/a	Interest rate:	5 %

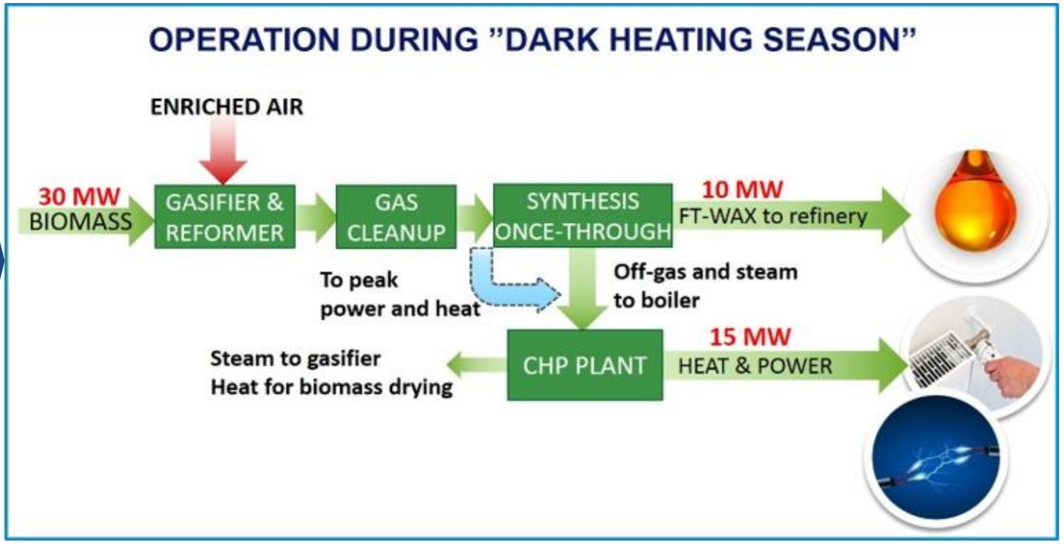
FLEXCHX project has received funding from the European Union's Horizon 2020 research and innovation Programme under Grant Agreement No 763919.

3. Techno-economic & ecological assessment examples

Impact of seasonal operation: example BtL / PBtL



High heat demand & Low renewable electricity availability



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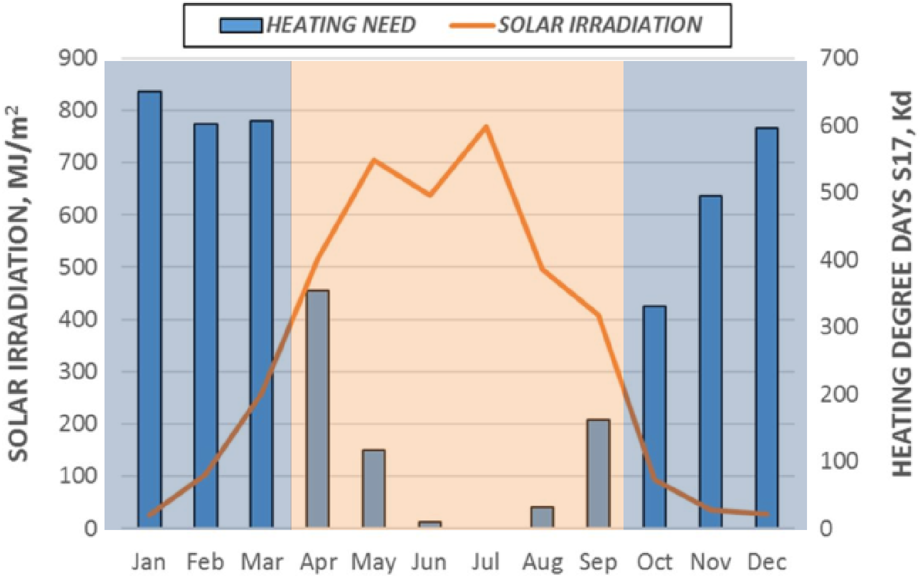
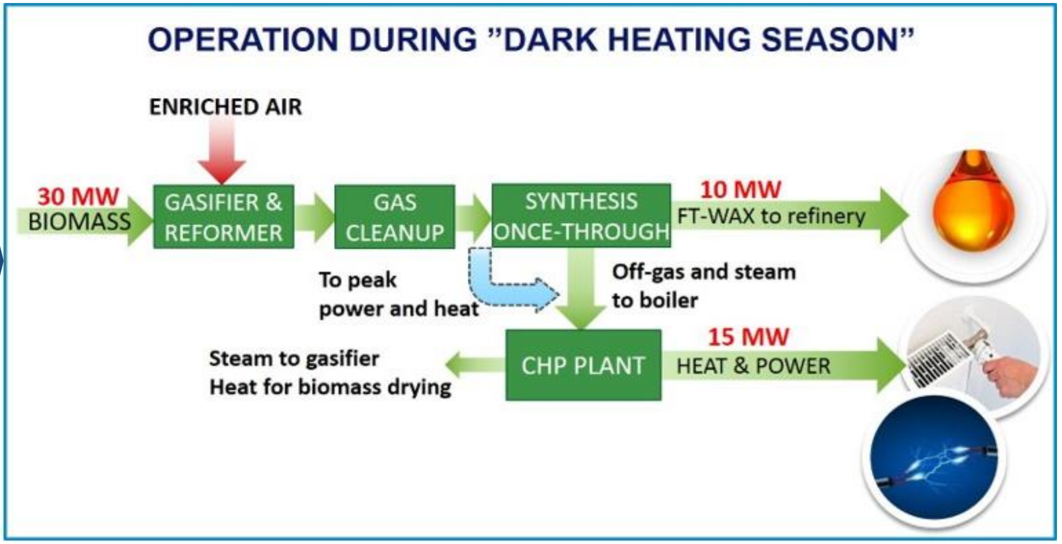
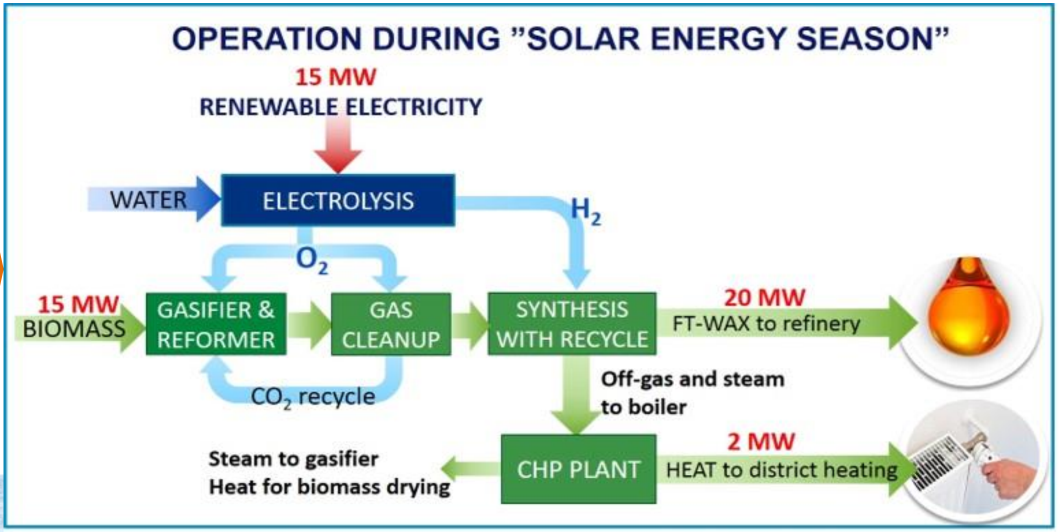


High heat demand & Low renewable electricity availability



Low heat demand & High renewable electricity availability



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3. Techno-economic & ecological assessment examples

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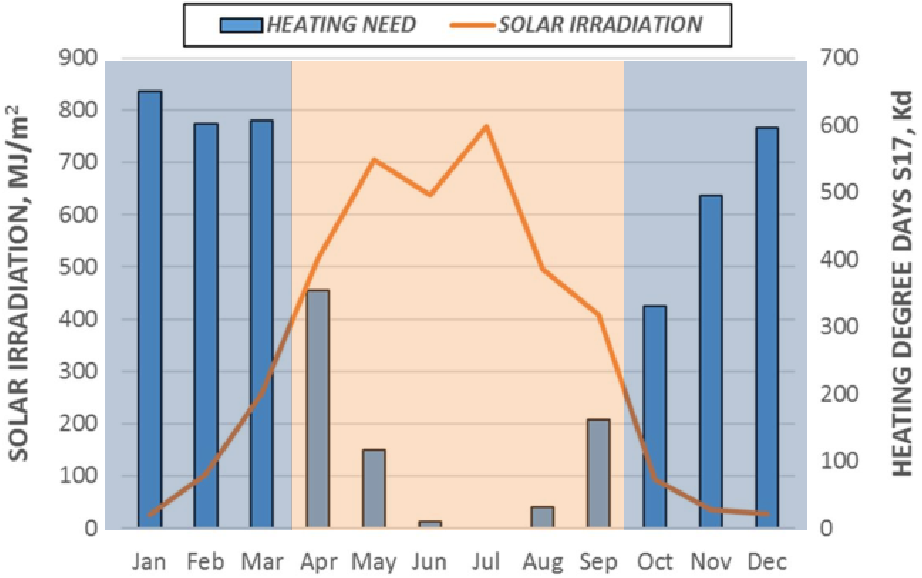

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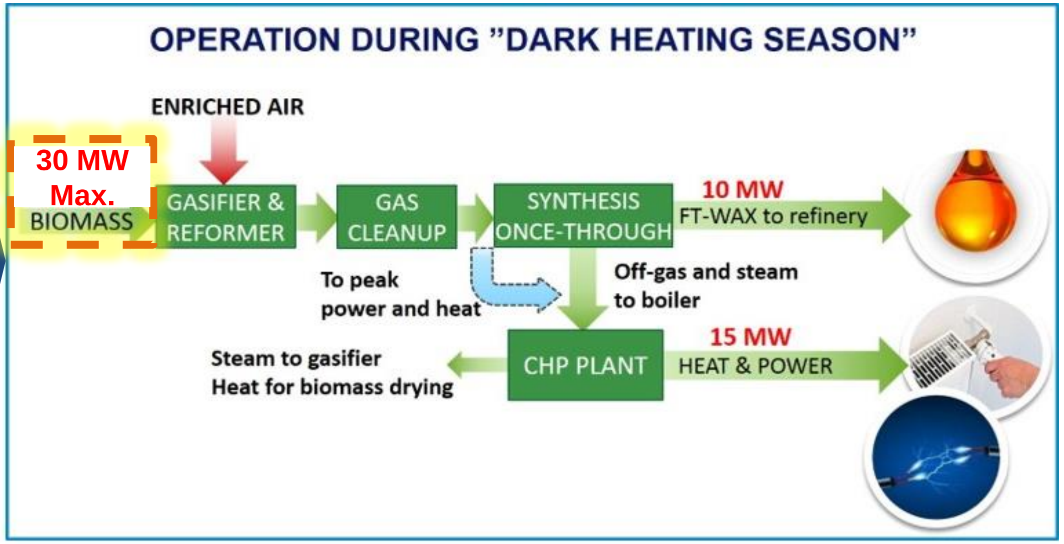
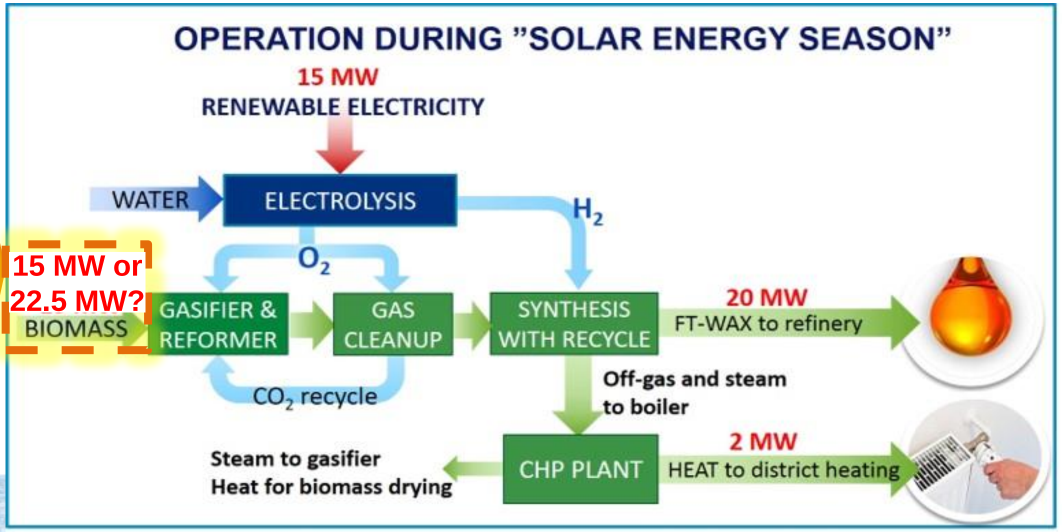


Crucial design parameter:

Biomass input ratio

- Higher ratio:
  - \+ Better utilization of investment
  - – Higher investment cost for electrolyzer

Low heat demand & High renewable electricity availability



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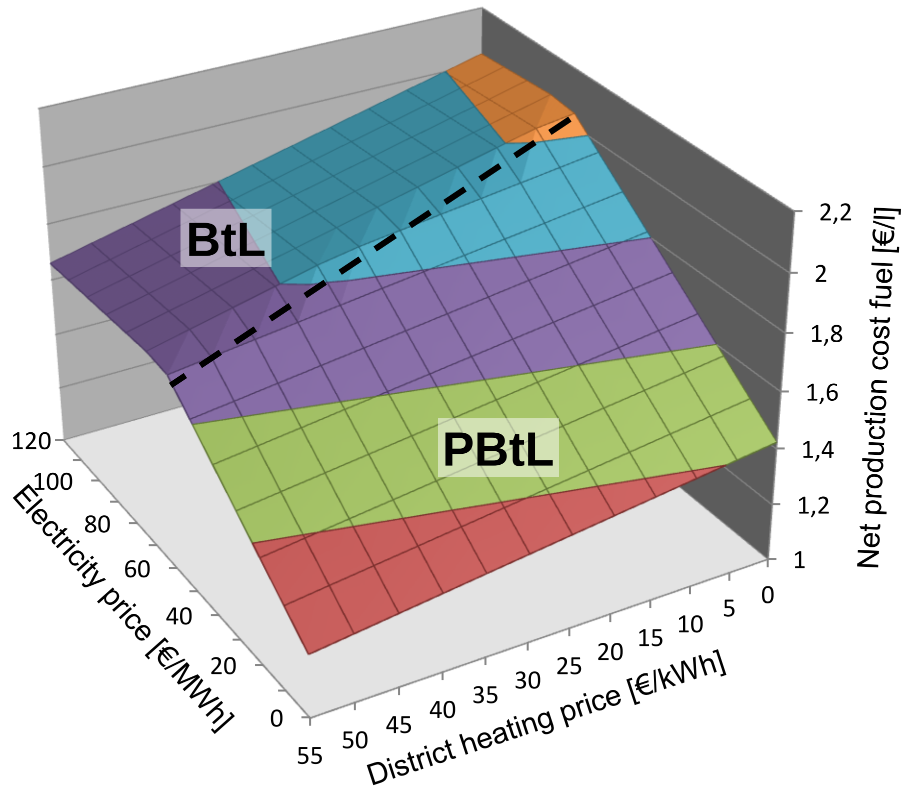
FLEXCHX

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

3. Techno-economic & ecological assessment examples

Impact of seasonal operation: example BtL / PBtL

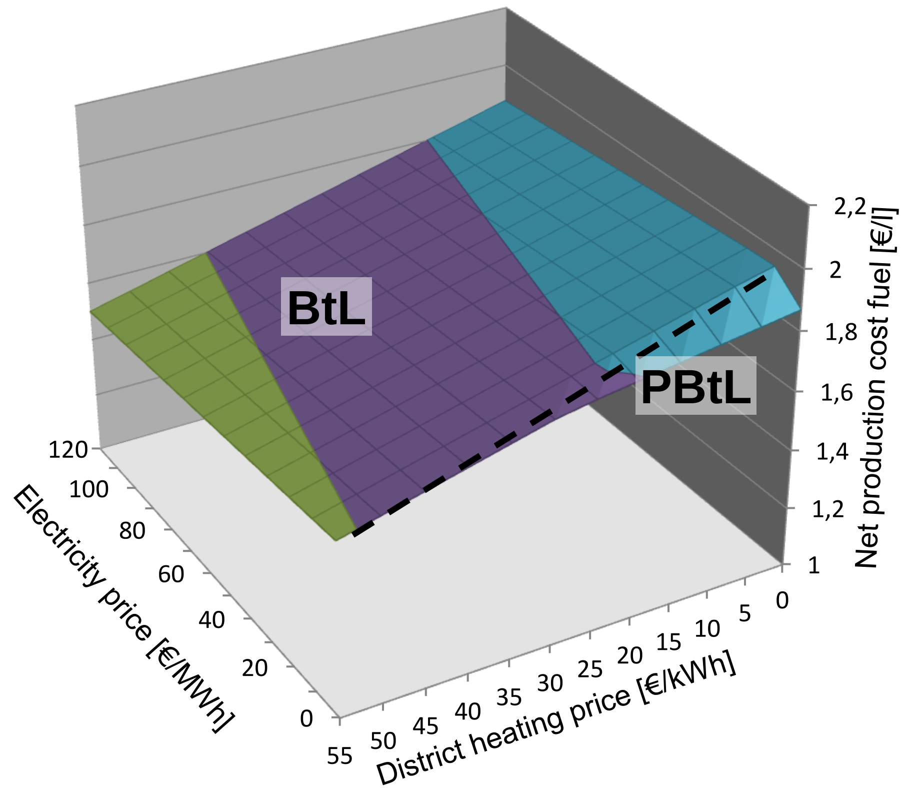
22.5 MW biomass input PBtL (75 % part load)



- Higher fuel production cost for BtL

+ Larger PBtL operation window

15 MW biomass input PBtL (50 % part load)



+ Overall lower production costs for BtL

- Marginal PBtL operation window

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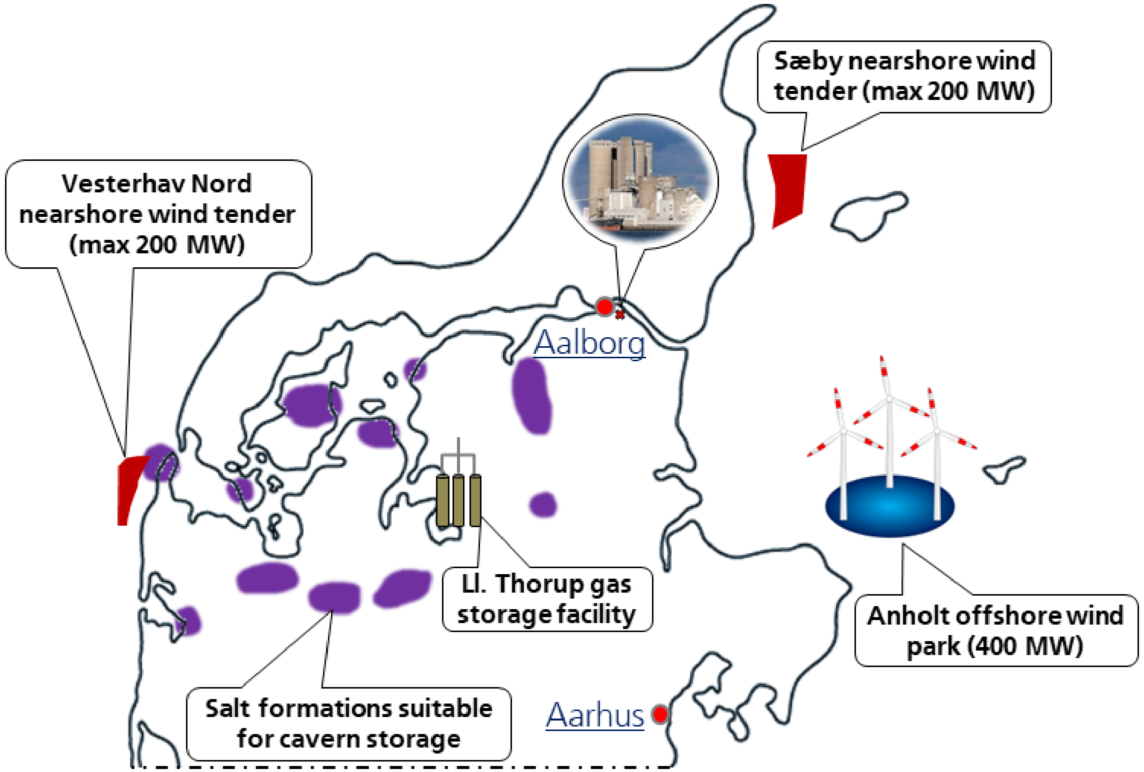
3. Techno-economic & ecological assessment examples
Nationwide Usage of Renewables for Transport: example Denmark



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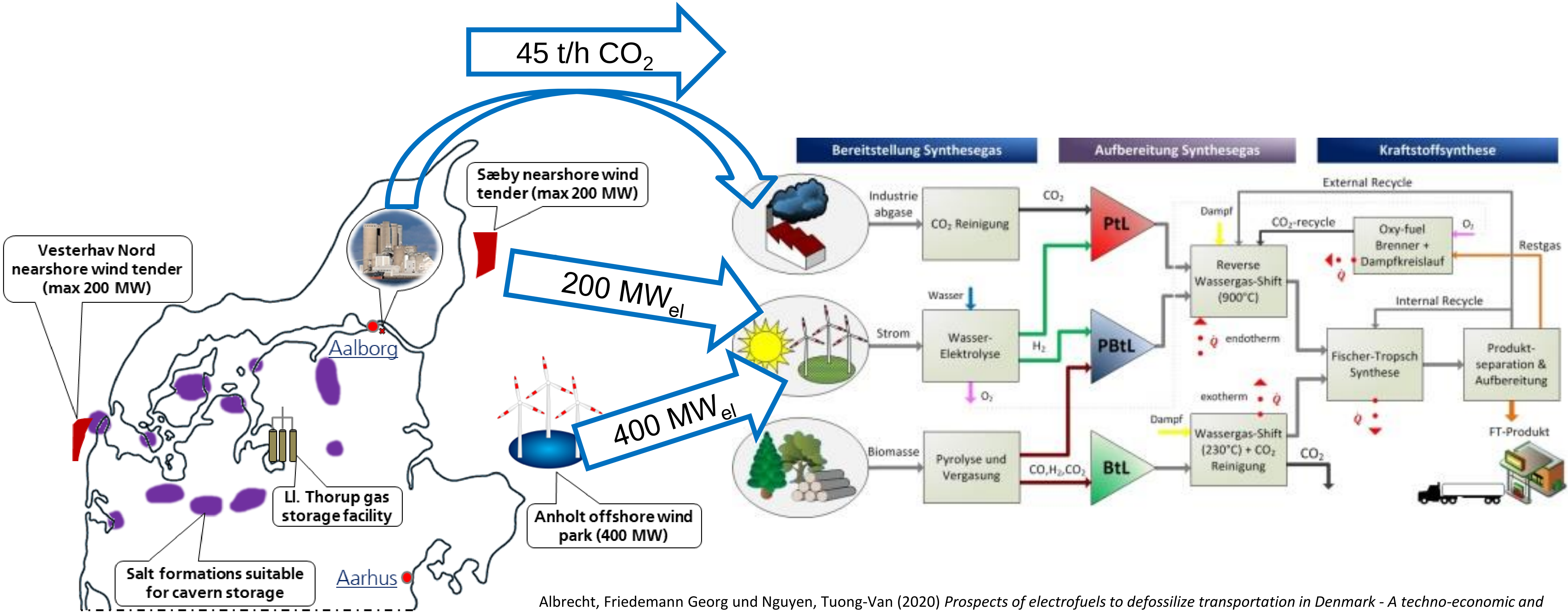
Nationwide Usage of Renewables for Transport: example Denmark



Albrecht, Friedemann Georg und Nguyen, Tuong-Van (2020) *Prospects of electrofuels to defossilize transportation in Denmark - A techno-economic and ecological analysis*. **Energy**, 192, Seiten 116511-116533.Elsevier.DOI: 10.1016/j.energy.2019.116511ISSN 0360-5442.

4. Techno-economic & ecological assessment summary

- Sustainable transport is a key element of the global climate change mitigation
  ➔ Paris Agreement of UNFCCC (2016) ➔ European Green Deal (2019)
- Renewable fuels production options have to be assessed transparent, even at low TRL
- Techno-economic & ecological assessment can be used for different questions on the way towards market introduction like
  - Type of fuels
  - New Production route
    - E.g. Sustainable Chemical Production with Electricity

See poster P05.74 **CHEMampere: Sustainable Chemical Production with Electricity**
E. Klemm[1]; C. Lobo[2]; [1] Universität Stuttgart/D; [2] Universität Stuttgart, Institut für Technische Chemie, Stuttgart/D

4. Techno-economic & ecological assessment summary

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- Renewable fuels production options have to be assessed transparent, even at low TRL
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  - Type of fuels
  - New Production route
    - E.g. Sustainable Chemical Production with Electricity
  - Operation modes
  - Site location
  - Transport system transition
  - …
- DLR’s TEPET tool enables standardized scientific assessment for sustainable production
  ➔ fair, transparent, comprehensible and convincing decisions

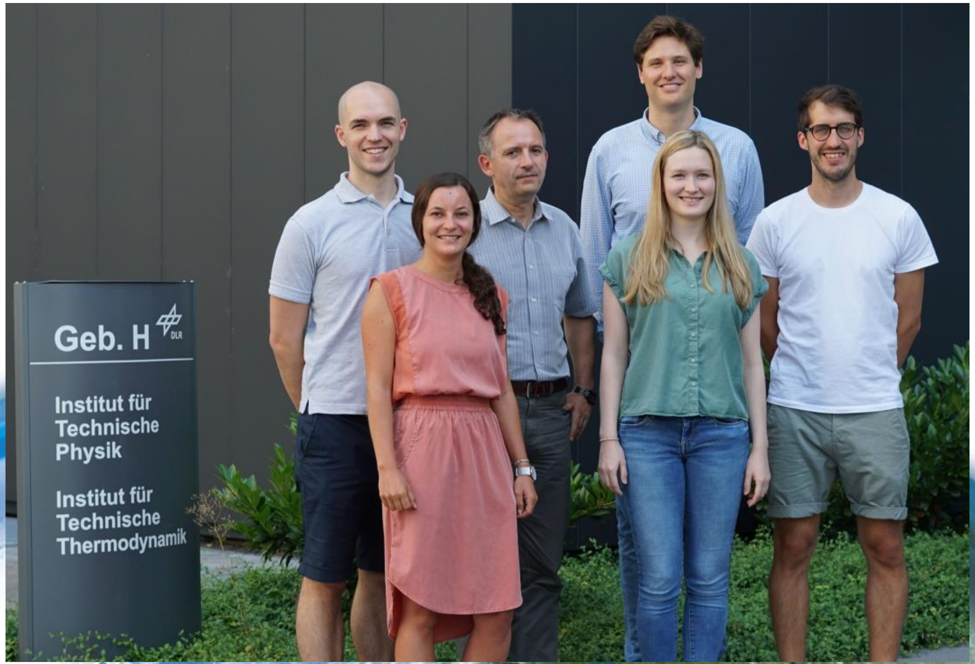
DLR @ PROCESSNET
EINE INITIATIVE VON DECHEMA UND VDI-GVC

10. ProcessNet annual conference and 34. DECHEMA annual conference for Biotechnology 2020

Thank you for your attention!

Ralph-Uwe Dietrich
ralph-uwe.dietrich@dlr.de

German Aerospace Center /
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)
Institute of Engineering Thermodynamics
Research Area Manager of:
Techno-Economic Analysis



Knowledge for Tomorrow