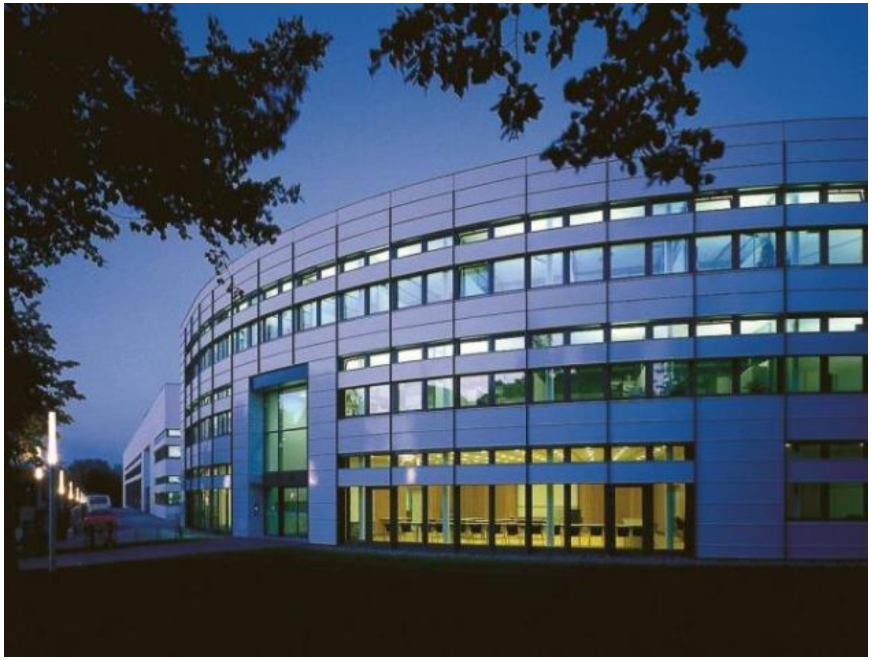
ECOLOGICAL ASSESSMENT OF LIQUID ENERGY CARRIERS

Power-to-Methanol and Oxymethylene Ethers



Christoph Hank

Lukas Lazar, Achim Schaadt,
Robin J. White

Fraunhofer Institute for Solar
Energy Systems ISE

ProcessNet 2018, Aachen

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Introduction
Hydrogen Technologies at Fraunhofer ISE, Freiburg

- H_2-generation by means of *PEM water-electrolysis (1MW PEMEL)*
- Energy storage in H_2-Systems and Redox-Flow-Batteries
- Interconnection of electricity and gas grid, Power-to-H_2

- *PEM Fuel Cell research* and development for mobile applications
- Degradation research (load profile, various climates)
- Customer specific, turn-key ready FC systems to like 20 kW

- *Synthesis of H_2 and CO_2 to liquid energy carriers/fuels* (Methanol, DME, OME); Methanol Miniplant for Carbon2Chem
- Thermochemical H_2-generation from hydrocarbons
- Clean *catalytic evaporation process* of liquid hydrocarbons (CatVap® e.g. for Diesel fuel)

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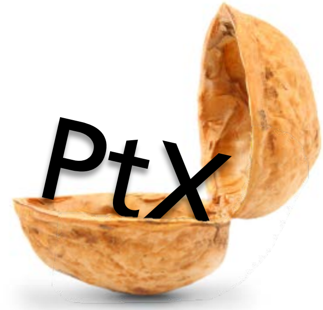
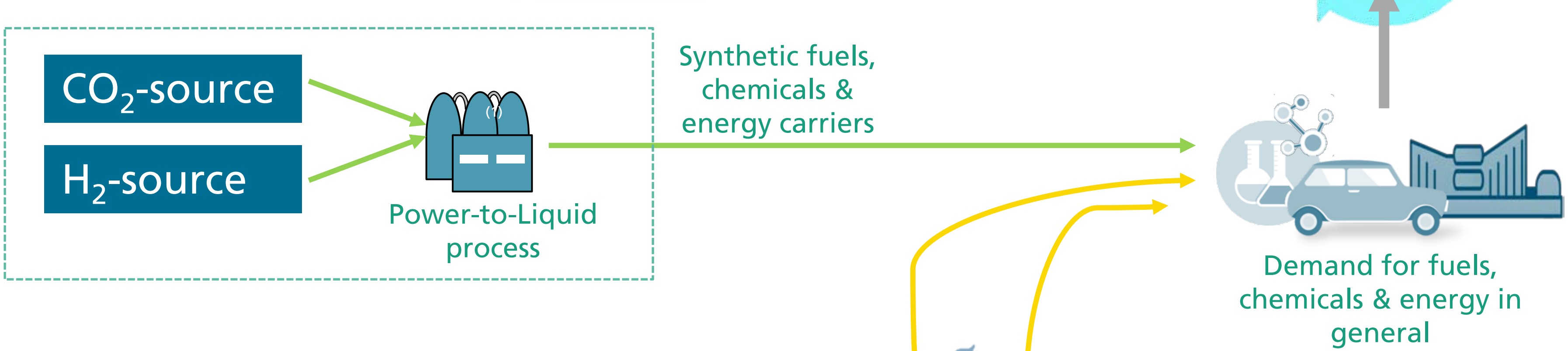
Power-to-X
in a Nutshell



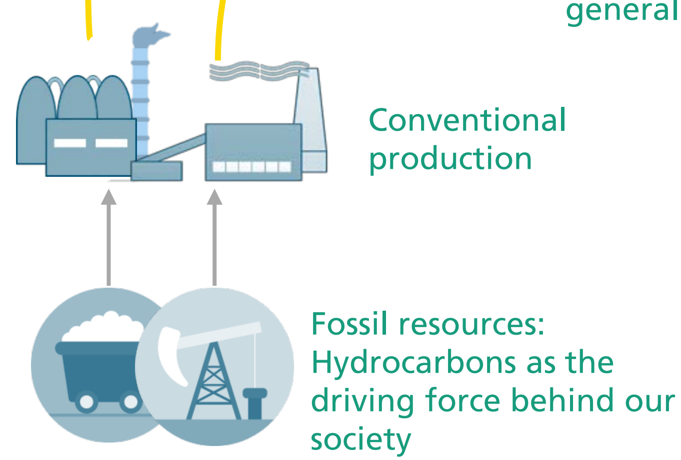


Focus at Fraunhofer ISE:

→ Technically feasible?
Can we do it?

→ Economically feasible?
Can we afford it?

→ Sustainability given?
Is it green((er) than the conventional)?



(1): https://www.convertwithcontent.com

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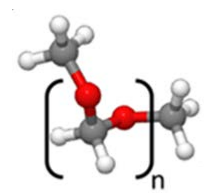
Power-to-Liquid
On the way to economic competitiveness

- CCU & Power-to-X as key elements towards a *defossilised* economy
- Cheap *renewable electricity* as game changer for feasible PtX-processes
- Power-to-Liquid essential for energy-intensive mobility applications…
- …but also for the downstream production of *renewable chemicals*

Polyoxymethylene Dimethyl Ethers –
OME: $H_3CO\text{-}(CH_2O)_n\text{-}CH_3$
as interesting downstream derivate of methanol



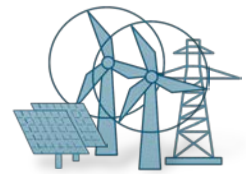
→ *Drop-in substitute for diesel fuel*

→ *Green and (potentially) non-toxic solvent*

→ *Liquid at RT for n = 3 - 5*

Power-to-Liquid
Framework of the presented study

- *Comparative* LCA of *OME_{3-5} when used as 100% diesel substitute*
- OME_{3-5} synthesis based on *direct synthesis* via methanol and anhydrous formaldehyde
- Electricity Scenarios: 2017 & 2050 & Hydro



- CO_2 scenarios: Ammonia & Biogas & Direct Air Capture

- *Well-to-Wheel* system boundaries;
- Exemplify influence of *avoided burden*[1)] approach and *economic allocation*
- *Impact categories:*

Impact category [2)]	Abbrev.	Indicator	Model	Classi-fication
Climate change, GWP 100a	GWP_{100a}	kg CO_{2eq}	IPCC 2007	(I)
Acidification, freshwater and terrestrial	AP	mol H^+_{eq}	ILCD 2016, method by [Seppälä et al.][75] and [Posch et al.][76]	(II)
Ozone layer depletion	ODP	kg $CFC\text{-}11_{eq}$	ILCD 2016, method by [WMO][77]	(I)

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1): Case Ammonia: Production of Urea is substituted; Case Biogas: Production of fossil-based natrual gas is substituted .
2): European Comission, ILCD, International Reference Life Cycle Data System, European plattform on Life Cycle As-sessment

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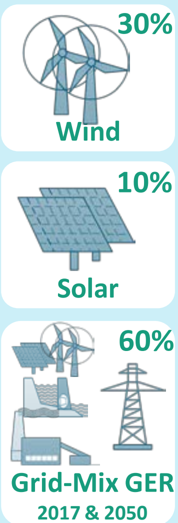
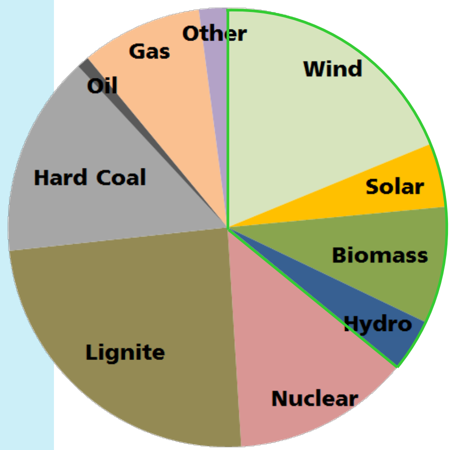
OME via Power-to-Liquid

The assessed PtL process scenarios

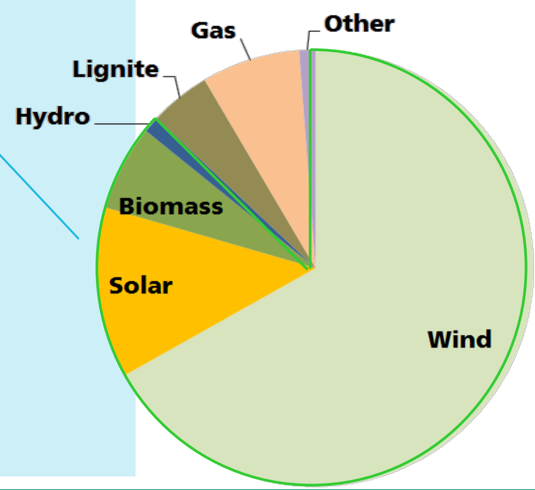
Electricity & CO_2



Germany: 2017 [1)]



Germany: 2050 [2)]



Electricity Scenario	Details	GWP_{el} [g CO_{2eq}/kWh_{el}]
"Grid 2017 + Renw"	60% Grid 2017, 30 % Wind, 10% Solar [DEU]	376
"Grid 2050 + Renw"	60% Grid 2050, 30 % Wind, 10% Solar [DEU]	96
"Hydro"	100% run-of-river [DEU]	4

1): ISE Energy Charts: Germany's Electricity Production 2017, subprocess ecoinvent , 2016
2): German Federal Ministry for Economic Affairs and Energy: Pfluger et al. 2017a, 2017b; subprocess ecoinvent , 2016

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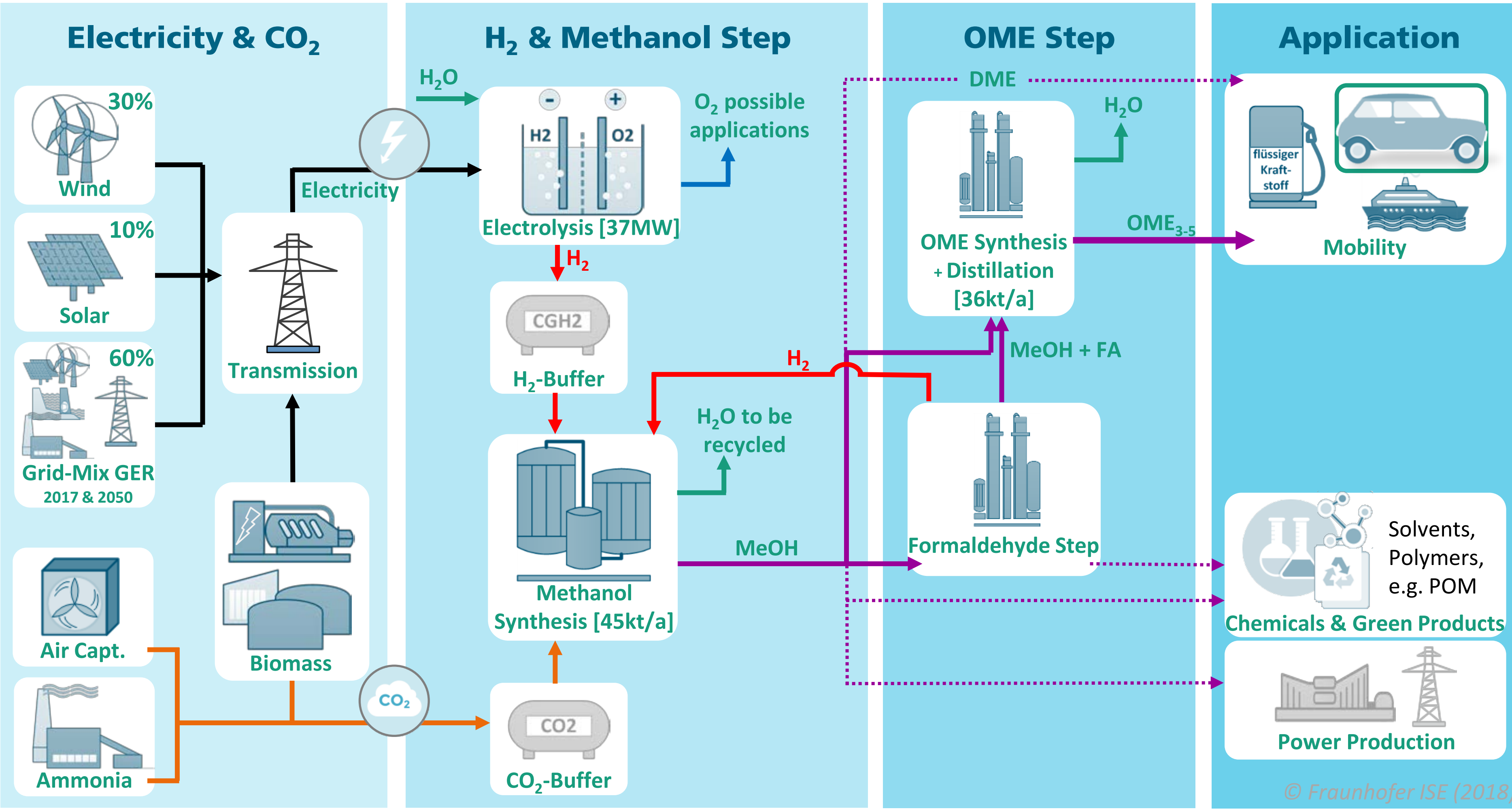
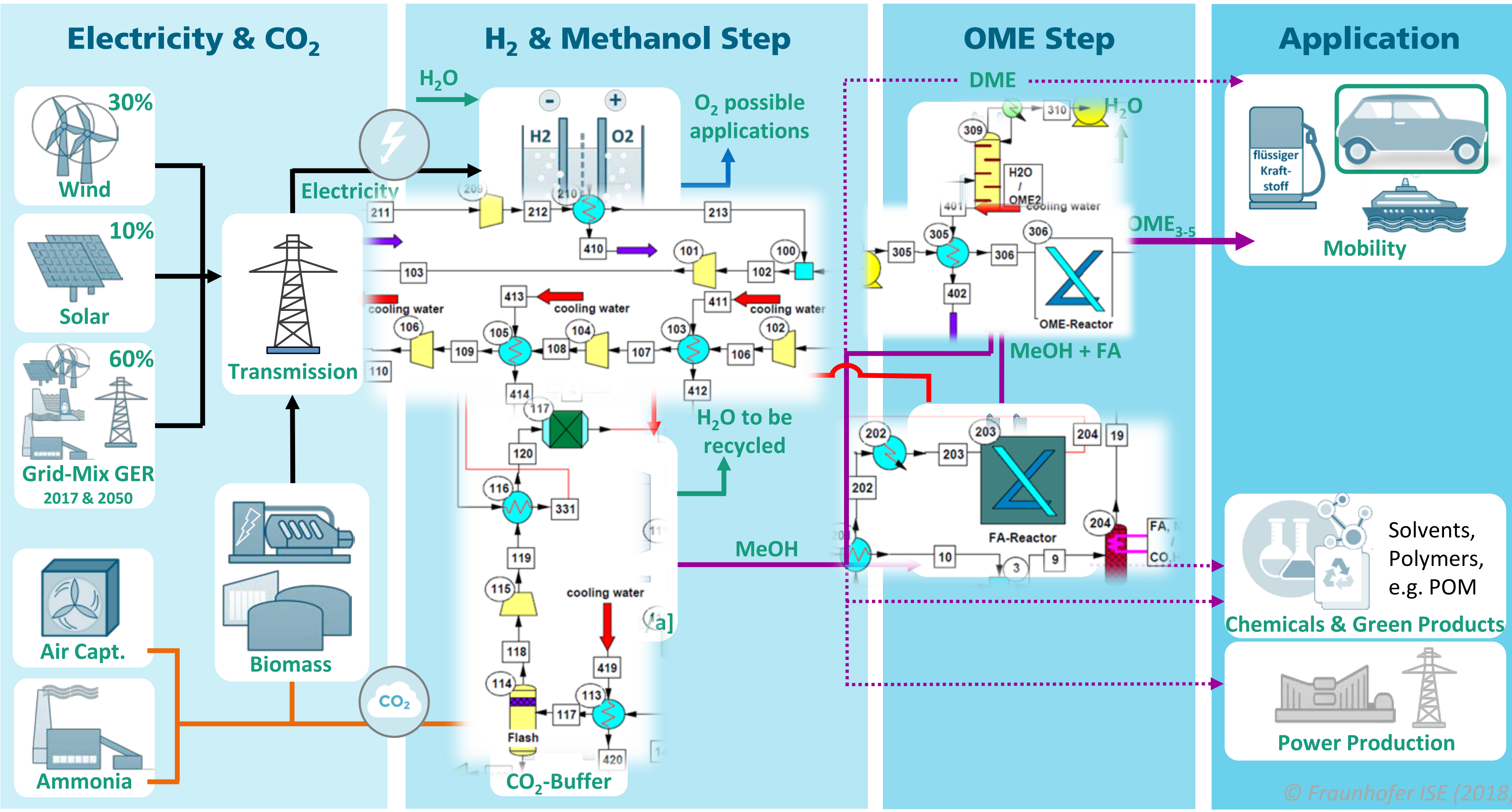
OME via Power-to-Liquid
The assessed PtL process scenarios



OME via Power-to-Liquid

Background CHEMCAD Simulation



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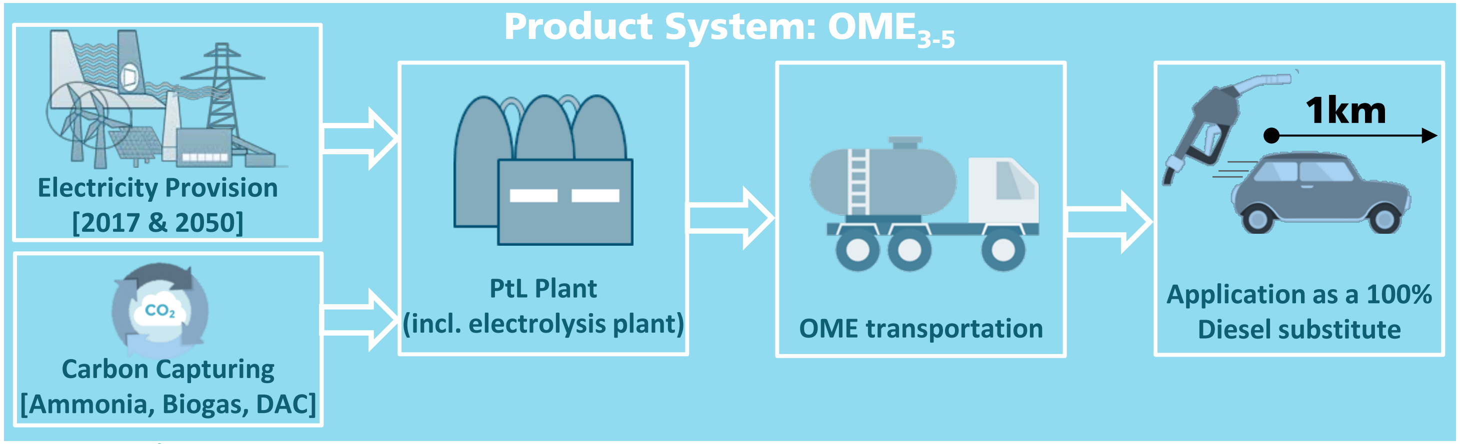
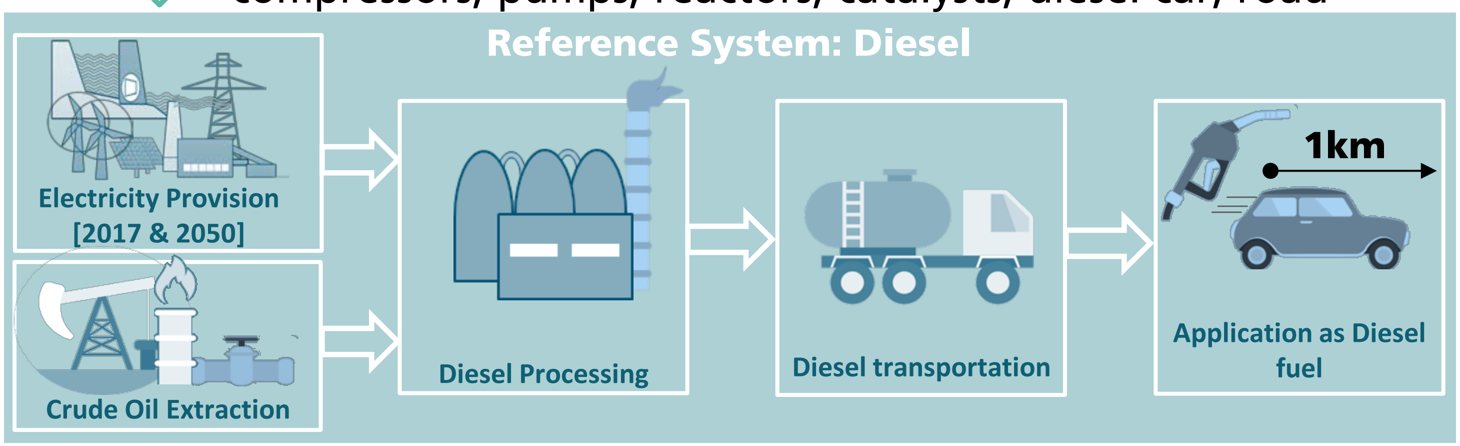
LCA of OME

System Boundaries and Functional Unit



Process energies: electricity, heat, steam, “cooling” from water, transportation

Equipment & materials: power plants, chemical facilities (approx.), compressors, pumps, reactors, catalysts, diesel car, road

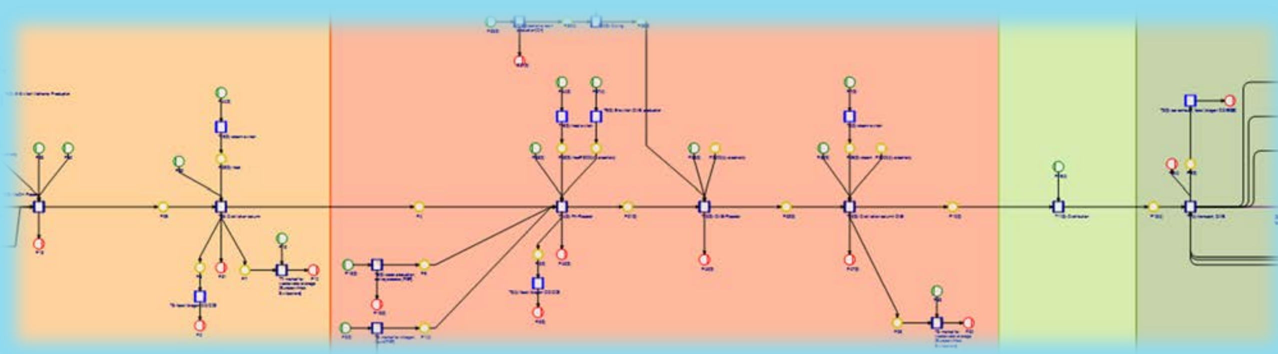


Christoph Hank, ProcessNet 2018

LCA of OME

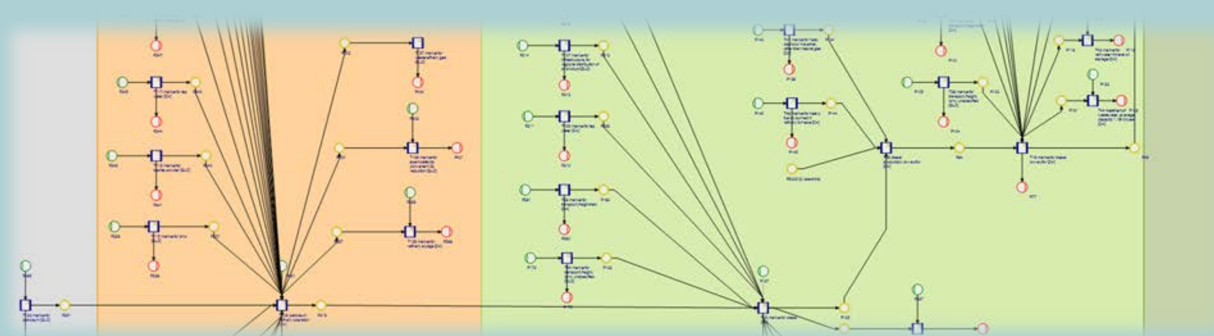
System Boundaries and Functional Unit

Product System: $OME_{3\text{-}5}$



Transfer of the resulting Life-Cycle-Inventory -Data to the LCA-software Umberto NXT

Reference System: Diesel



Multifunctionality in Case of CCU
Different methods lead to different Impacts

- Multifunctional Processes: Delivering more than one product
- In case of CCU: Waste CO_2 becomes a feedstock
- Different methods recommended (ISO14044, EU ILCD, other[1)]) in hierarchical order:
  - *I.: Subdivision*
  - *II.: System Expansion [x kg CO_{2eq} / km driving distance & x kg urea]*
  - *III.: System Expansion and Avoided Burden*

$$Impact_{Product\ specific} = Impact_{combined\ production} - Impact_{substituted\ conventional\ production}$$

  - *IV.: Allocation with physical / economical relationship of products*

➡ **Following slides**: Exemplified influence of *system expansion and av. burden* & *allocation* on LCIA results.

1): Techno-Economic Assessment & Life-Cycle Assessment Guidelines for CO2 Utilization, TU Berlin, RWTH Aachen, Univ. Sheffield, 2018

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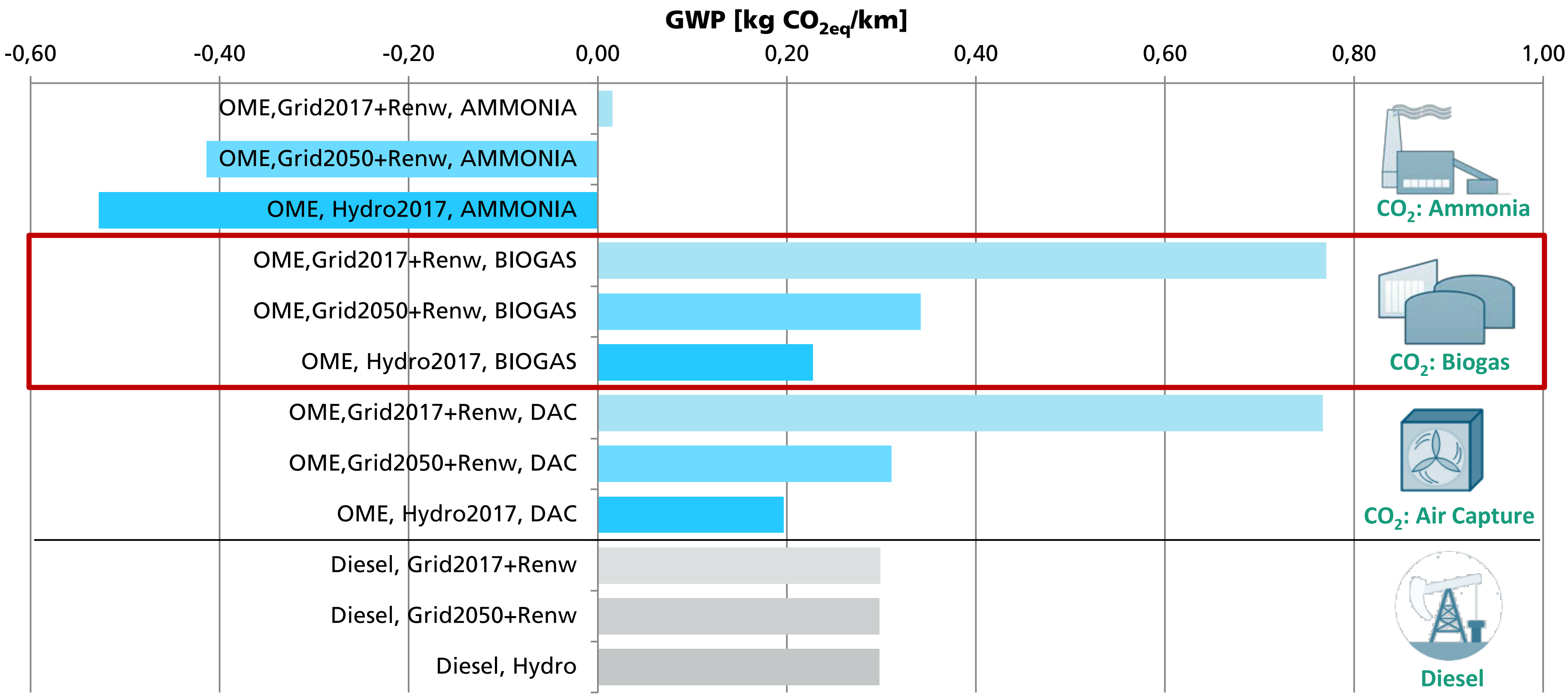
Life Cycle Impact Assessment Results

Global Warming Potential – *Avoided Burden Approach*

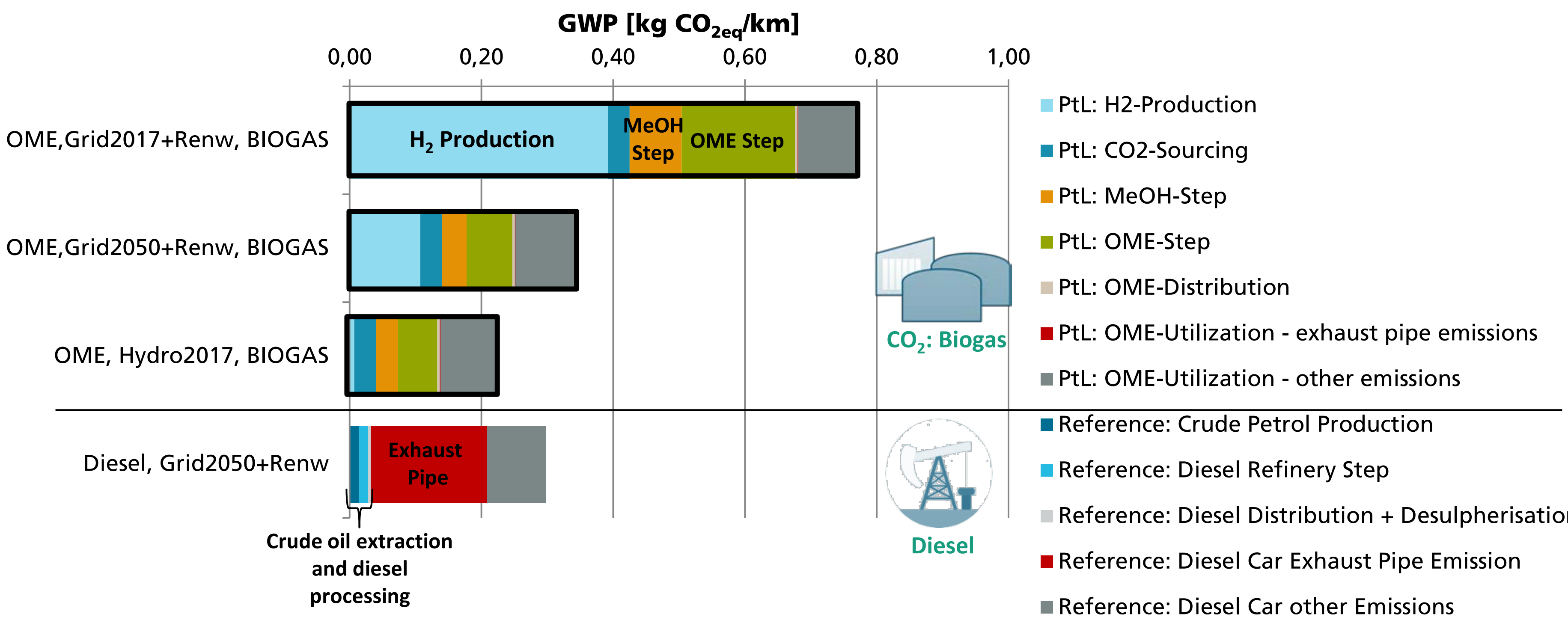
- Global Warming Potential for a driving distance of 1km:



Life Cycle Impact Assessment Results

Global Warming Potential – *Avoided Burden Approach*

- Contribution of Life Cycle Phases: Case CO_2 from Biogas



- Electrolytic H_2 production and thermal intensity of the OME step as the main drivers for the OME's overall GWP.

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Life Cycle Impact Assessment Results

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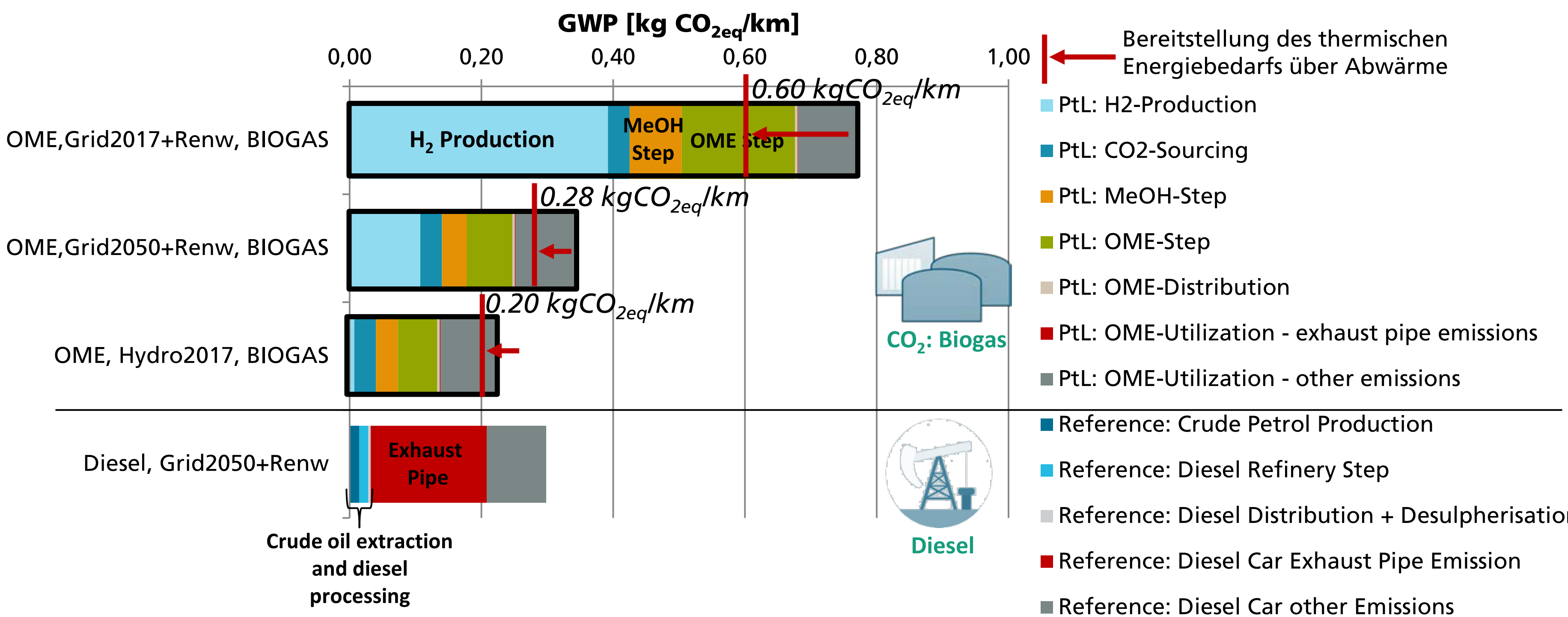
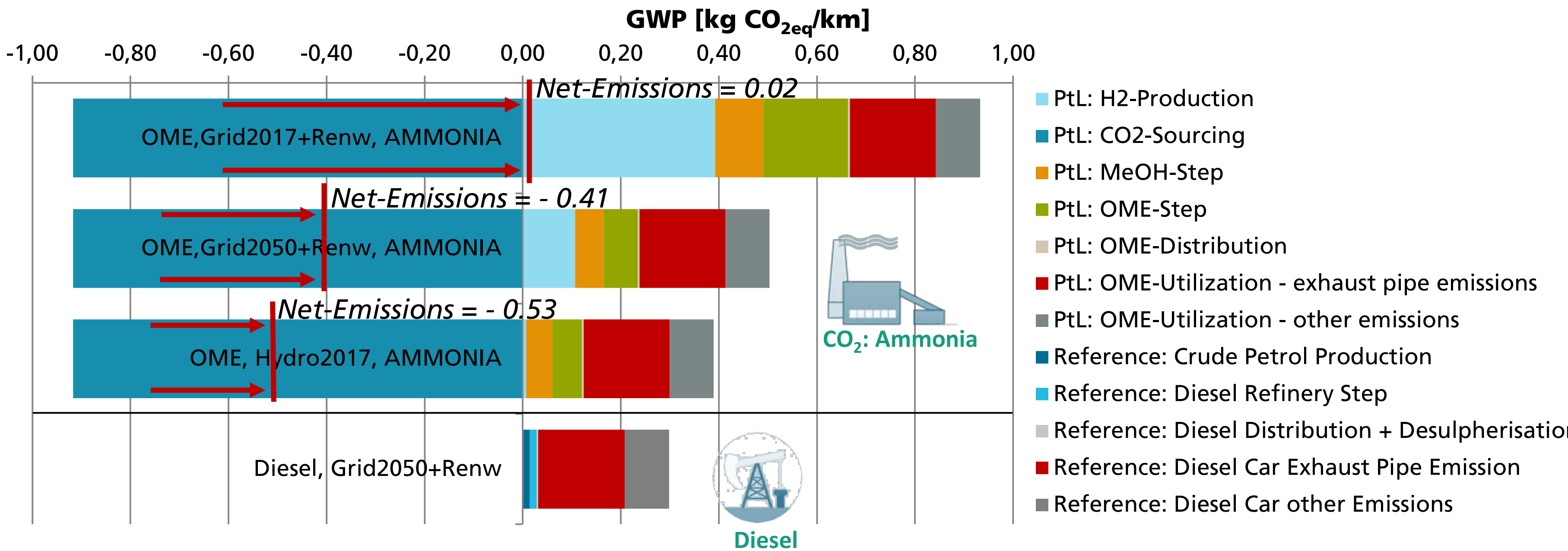


- Electrolytic H_2 production and thermal intensity of the OME step as the main drivers for the OME's overall GWP.

Life Cycle Impact Assessment Results

Global Warming Potential – *Avoided Burden Approach*

- Contribution of Life Cycle Phases: Case CO_2 from Ammonia



- Avoided Burden Approach leads to very low overall GWP
- Ecologic efficiency of most CCU reduction pathways are strongly dependent on the way of solving multi-functionality

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Life Cycle Impact Assessment Results
Global Warming Potential – *Economic Allocation*

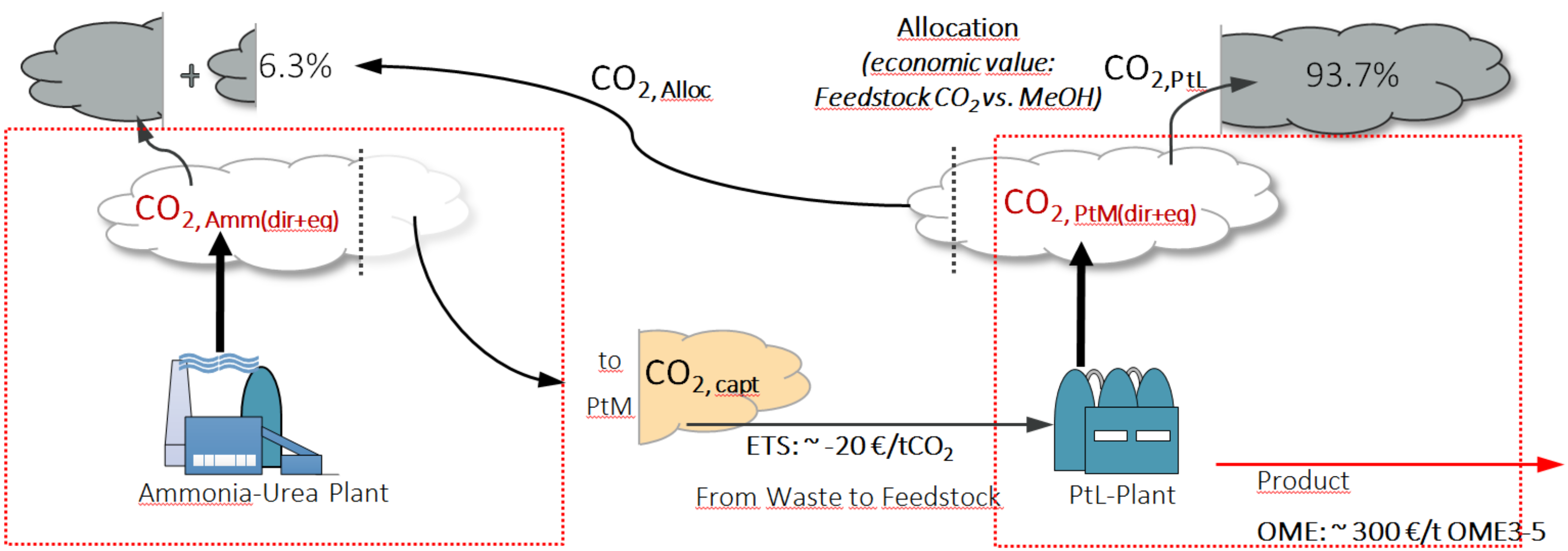
- Economic Allocation:
  - Case Biogas:
    - Biogenic CO_2: 5 €/t CO_2 (incl. Desulphurisation) [1)] → 0.5%
    - Biomethane: 1078 €/t $BioCH_4$ [2)] → 99.5%

1) Runte, 2017, Master-Thesis: Technoökonomische Bewertung von auf Wasserstoff basierenden Erneuerbaren kraftstoffen, Fraunhofer ISE
2) Deutsche Energie-Agentur GmbH (dena), 2013: Branchenkompass Biomethan

Life Cycle Impact Assessment Results

Global Warming Potential – *Economic Allocation*

- Economic Allocation:
  - Case Ammonia:
  - Captured CO_2: -20 €/t CO_2
    (ETS-Certificate negative market price rates captured CO_2 as "waste"
    → CCU-process becomes multi-functional
    → partial allocation of CCU-impact to emitting process



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Life Cycle Impact Assessment Results

Global Warming Potential – *Economic Allocation*

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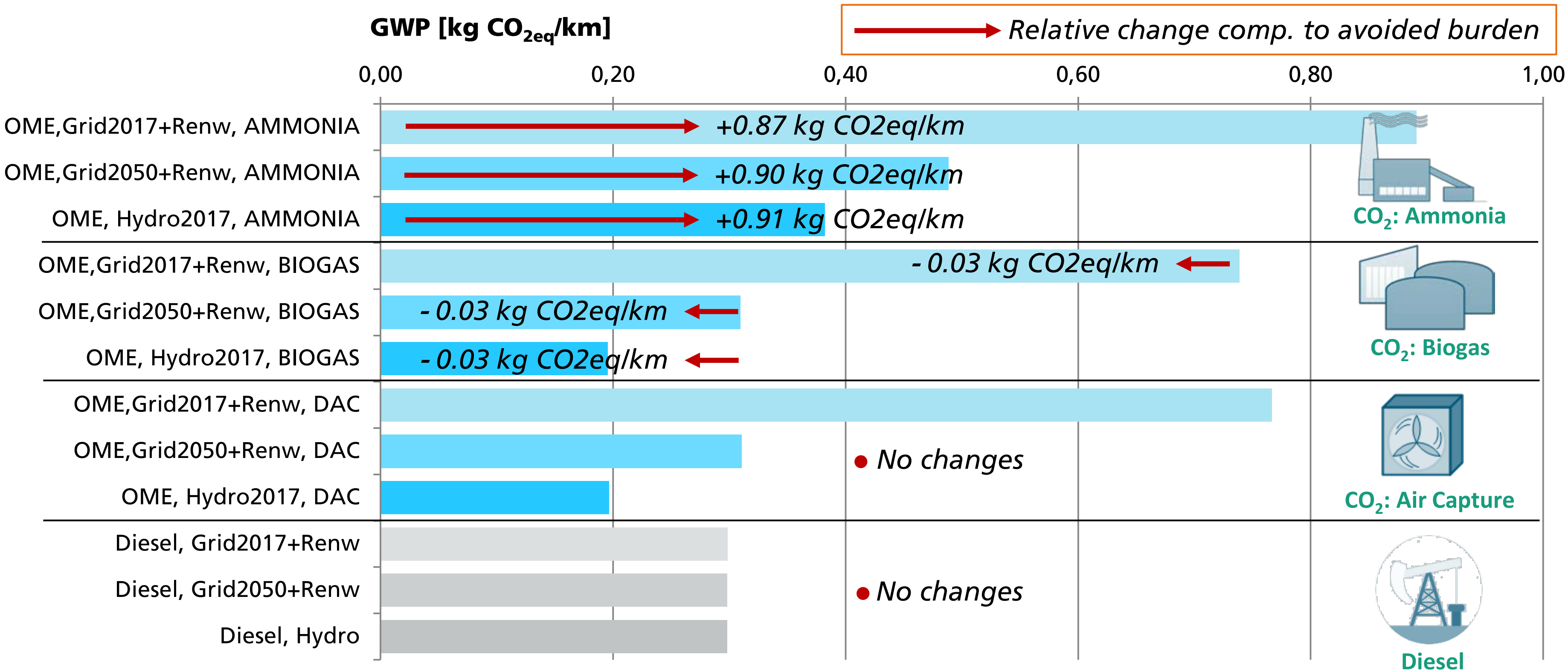

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Summary & Outlook

- *CO_2-based fuels can offer a reduction in GWP* when sourced from mainly renewable energies (*H_2-content* / upstream electricity critical component)
- OME and other synthetic fuels with *promising cost reduction potential*: regions with *low RE cost* (e.g. Chile, South Africa, Maghreb states)
- *Integration* of HT-excess heat (e.g. steel mills) with great potential; consideration of side products beneficial for TEA & LCA
- OME synthesis process *development towards less energy intensive pathways* and selective catalysts for further improvements
- Results for ecologic efficiency of $OME_{3\text{-}5}$ production (and other CCU processes) are *highly dependent on solving of multi-functionality*
- If possible: *apply ISO 14044 hierarchy* for solving of multi-functionality (otherwise, as shown, results can be distorted)
- *Further Impact Categories remain critically* and depend on intensive defossilisation of upstream manufacturing processes[1)]

1): Hank et al., 2019: Comparative well-to-wheel Life Cycle Assessment of $OME_{3\text{-}5}$ synfuels production via the Power-to-Liquids pathway; submitted 20.05.2019

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Thank you for your attention

christoph.hank@ise.fraunhofer.de

Hydrogen Technologies at the Fraunhofer Institute for Solar Energy Systeme ISE

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& the German Federal Ministry of Education and Research

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The city of Freiburg from the ‚Schauinsland‘
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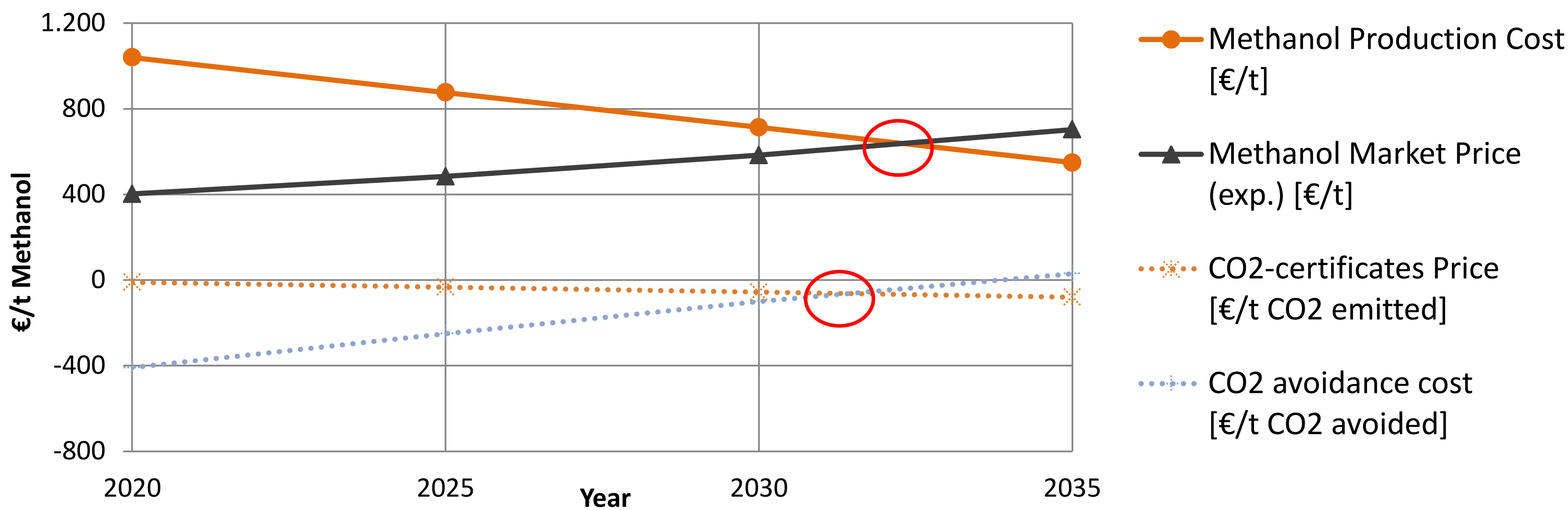
Starting Point[1)]

LCA & CO_2 Avoidance Cost of Power-to-*Methanol*

- Power-to-Methanol (PtM) can be *environmentally advantageous* compared to fossil based methanol production for specific cases
- But as *yet* not economically competitive (high capital expenditures & cheap fossil competitors)



1): Hank, 2017: The power-to-methanol process chain - a life cycle assessment and CO2 avoidance cost analysis, 15th International Conference on Carbon Dioxide Utilization, Shanghai, China, July, 17th-21st, 2017
Hank et al., 2018: Economics & carbon dioxide avoidance cost of methanol production based on renewable hydrogen and recycled carbon dioxide – power-tomethanol

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CO_2 Avoidance Cost
For the assessed OME pathway

- Interlinkage of economic and ecologic efficiency
- Cost comparison between two systems, both delivering the same product (or service), for the reduction of $CO_{2\ (Equivalents)}$

$$CO_2\ Avoidance\ Cost = \frac{Production\ Cost_{CCU\ product} - Production\ Cost_{fossil\ product}}{GWP_{fossil\ product,C2G} - GWP_{CCU\ product,C2G}}$$

- Applicable to other impact categories (“impact avoidance cost”)

Hank et al., 2018: Economics & carbon dioxide avoidance cost of methanol production based on renewable hydrogen and recycled carbon dioxide – power-tomethanol

CO_2 Avoidance Cost
For the assessed OME pathway

- Cost calculations for the production of „green OME“ based on:
  - CO_2: Ammonia-Urea plant, Electricity: Renewables-Grid-Mix
  - CAPEX, OPEX (incl. maintenance & replacements) considered
  - Steady-state process; ~36 kt OME_{3-5}/a (pilot plant scale)
- Costs calculation:

CO2 Avoidance Cost[1)]	Green OME 2017	Diesel	Green OME 2050?
Fuel Production Cost [€/t]	1045	291	620
Specific Cost [€/km]	0.13	0.02	0.08
Global Warming Potential [kgCO_{2eq}/km]	0.06	0.30	- 0.36
CO_{2eq} Avoidance Cost	**458 €/t CO_{2eq}**		**90 €/t CO_{2eq}**

→ Future: Power-to-Liquids for countries with very low RE-generation cost? (Price bids for PV already @2.5ct€/kWhel and below[2)])

1) Lazar, 2018, Master-Thesis: Environmental performance of liquid energy carriers and fuels based on renewable hydrogen and recycled carbon dioxide (Power-to-Liquid), Fraunhofer ISE
2) https://www.bloomberg.com/news/articles/2016-05-03/solardevelopers-undercut-coal-with-another-record-set-in-dubai, last accessed March 2018. & https://economictimes.indiatimes.com/industry/energy/power/chile-breaks-dubais-record-of-solar-power-output-at-low-cost/articleshow/53932595.cms

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