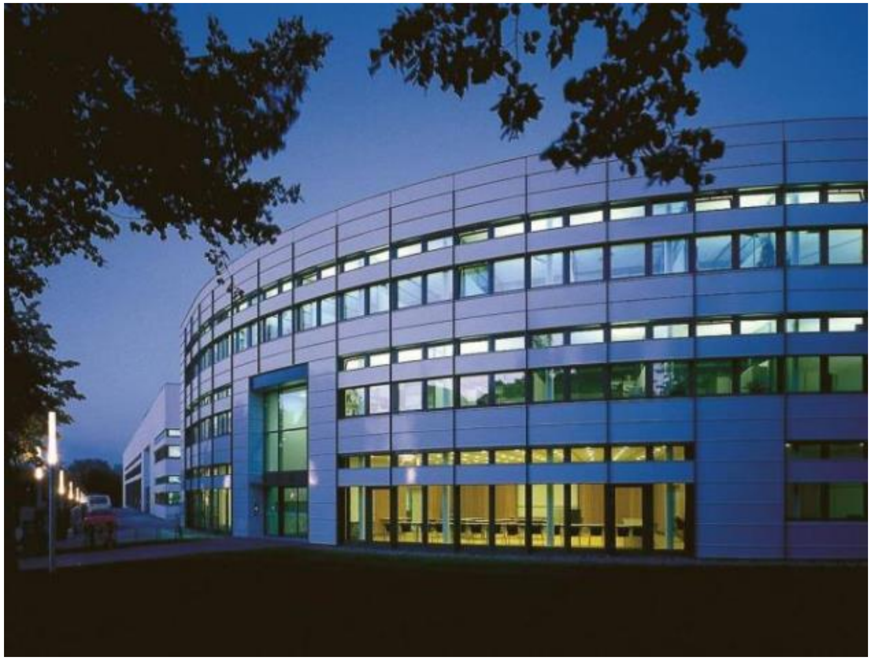
THE POWER-TO-METHANOL PROCESS CHAIN

A Life Cycle Assessment and CO_2 Avoidance Cost Analysis



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Introduction
Power-to-X 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)
- Thermochemical H_2-generation from hydrocarbons
- *Catalytic evaporation process* of liquid hydrocarbons

Introduction
Problem Statement & Goal of the study

- <u>Power-to-Liquid/-Methanol (PtL/M)</u> concept - Combining a multitude of potential sustainable aspects:
  - Capturing of CO_2 from fossil point sources and by this avoiding instant enrichment of the global atmospheric CO_2 content.
  - Capturing of CO_2 from atmosphere (indirect: DAC / direct: biomass)

    → Key role for the next step towards a '*Circular Economy*'.
  - Production of renewable high-density energy carriers ('*Solar Fuels* *') and polymers (*Power-to-Chemicals*).
  - *Substitution* of fossil based & CO_2 intensive production processes.
  - Intrinsic incentive for production facilities to reinterpret CO_2 from 'cost intensive waste' to '*feedstock with a possible business case*'.

P_tM as a **sustainable** way for substitution of fossil methanol and fuels??

*R.Schlögl: ‚Sustainbable Energy Systems: The Strategic Role of Chemical Energy Conversion', Topics in Catalysis, Springer, 2016

Introduction
Problem Statement & Goal of the study

Molecular binding of 1.4 t CO_2/ t MeOH, unless…

$$CO_2 + 3H_2 \rightleftharpoons CH_3OH + H_2O$$

Only in case of Direct Air Capture or Biomass-CO_2

…utilization of the MeOH-based product releases molecular CO_2*

$$CH_3OH + \frac{3}{2}O_2 \Rightarrow CO_2 + 2H_2O$$

- In a *stoichiometric manner*:
  - PtM based on CO_2 from atmosphere or biomass ‚CO_2-neutral'.

*Complete oxidation of MeOH assumed

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But

- Production of H_2 as energy intensive PtM process step.
- Catalytic activation of CO_2 under high pressure.

$+XCO_{2eq}$?

→ Goal: Environmental evaluation of the PtM process also accounting for material & energy flows (*where possible*)

*Complete oxidation of MeOH assumed

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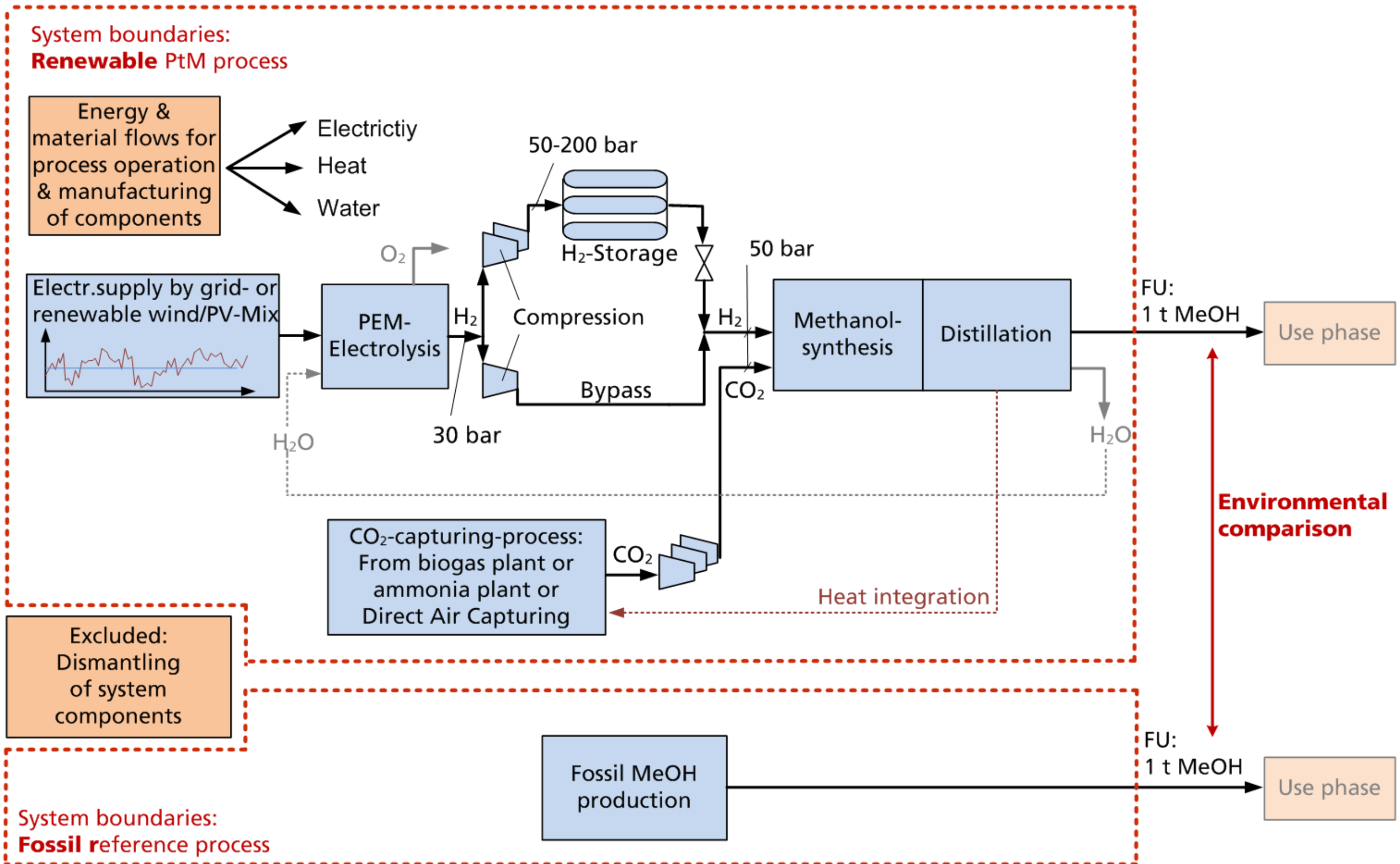
Product System Studied

System Boundaries: Cradle-to-Gate



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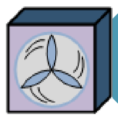
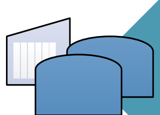
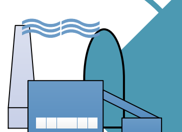
Product System Studied
Cases Analysed & Allocation



Case DAC:
- CO_2 from Direct Air Capturing Plant
- Carbon capturing process with impact
- Mono-functional: No allocation necessary



Case Biogas:
- CO_2 from biogas purification plant
- Carbon capturing process without impact
- Mono-functional: No allocation necessary

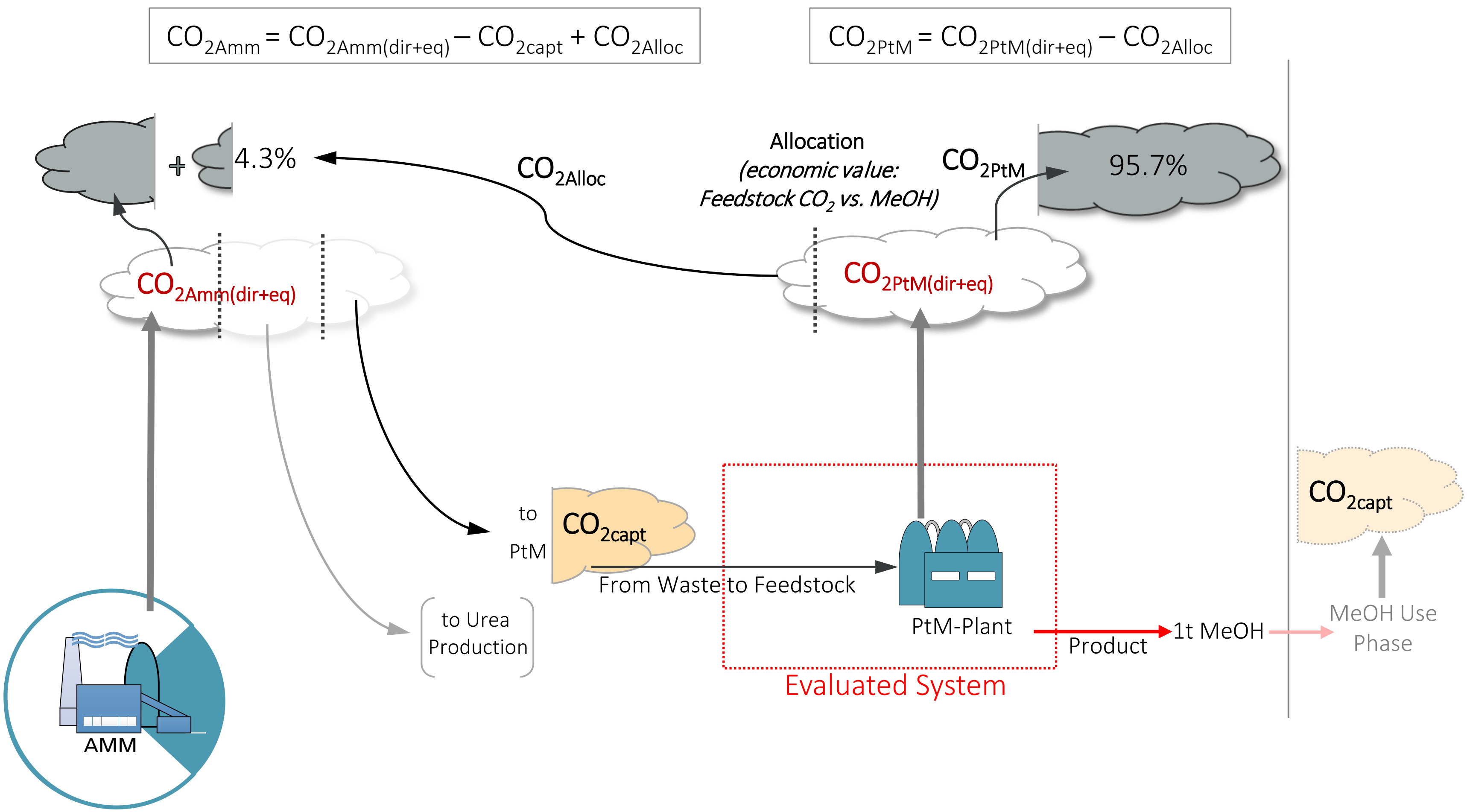


Case Ammonia:
- CO2 from ammonia plant
- Ammonia Plant is delivering NH_3 + CO_2
- PtM Plant recycles CO_2 (from waste to feedstock)
- Multi-Functional: Allocation necessary

- *Multi-functional processes*: require a partitioning of their resulting in-/outputs.
- *System Expansion* approach: not justifiable for every multi-functional process.
- *Allocation* approach: one way to solve multi-functionality.

Product System Studied

Cases Analysed & Allocation – Case Ammonia



Product System Studied
Methodology of Assessment & Impact Categories

- Methodical approach for PtM system evaluation:

1. *One year renewable energy data: Wind-/PV-Mix, 15 min-steps, ~12 GWh/a*
2. *Dynamic Simulation in MATLAB® /Simulink® (Material & Energy flows)*
3. *Thermodynamical simulation via CHEMCAD (Heating and cooling loads)*
4. *Impact Assessment in Umberto® NXT Universal (Ecoinvent V3.3)*

Group	Impact Category	Name	Unit
CML 2001	**climate change**	**GWP 100a**	**kg CO_{2eq}**
CML 2001	eutrophication potential	EP, average european	kg NO_{xeq}
CML 2001	acidification potential	AP, average european	kg SO_{2eq}
CML 2001	photochemical oxidation (summer smog)	POCP, high NO_X	kg C_2H_{4eq}
CED_F	cumulated energy demand fossil	non-renewable energy resources, fossil	MJ_{eq}
CED_S	cumulated energy demand solar	renewable energy resources, solar, converted	MJ_{eq}
CED_W	cumulated energy demand wind	renewable energy resources, wind, converted	MJ_{eq}

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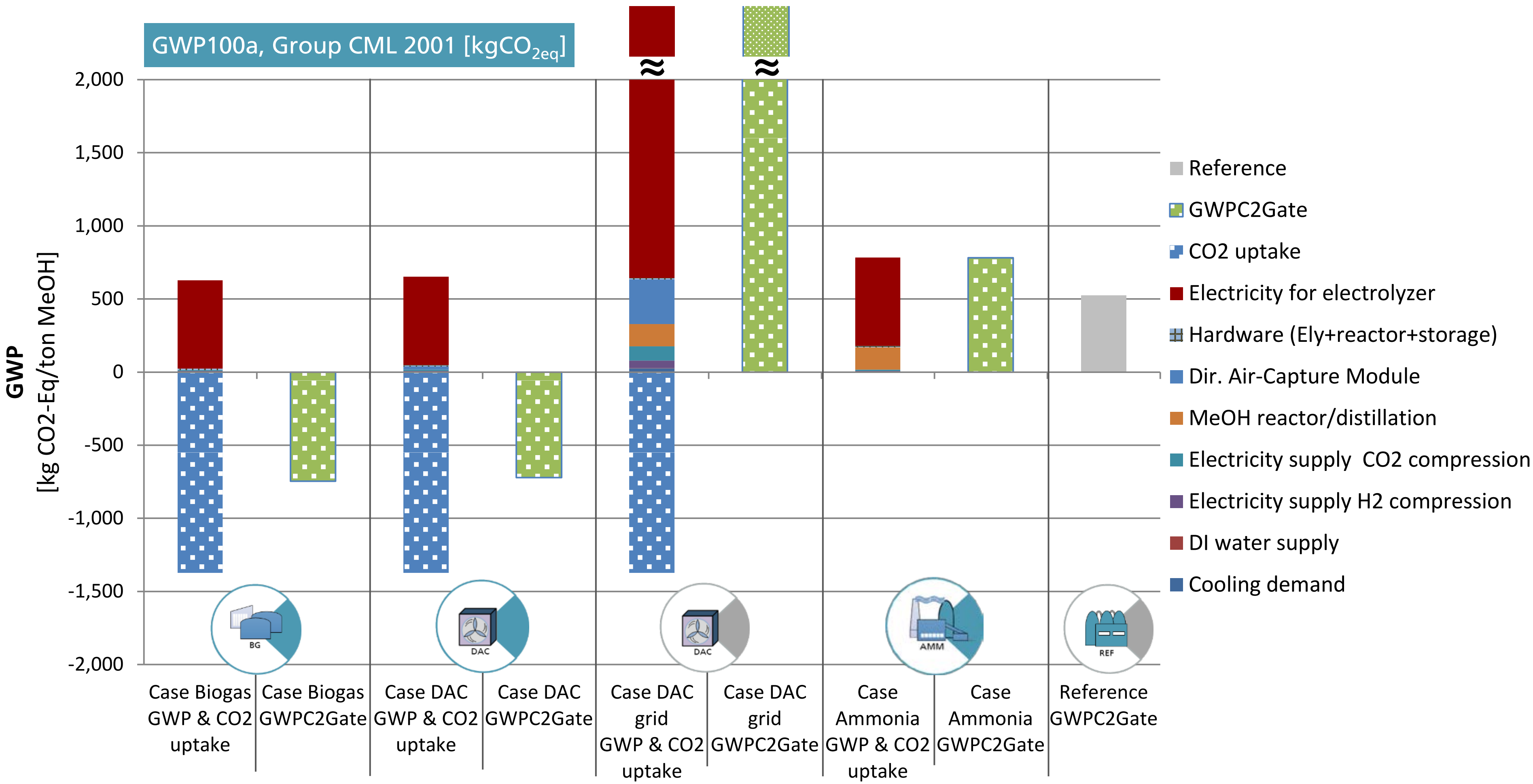
Life Cycle Impact Assessment (LCIA)

Results: Global Warming Potential



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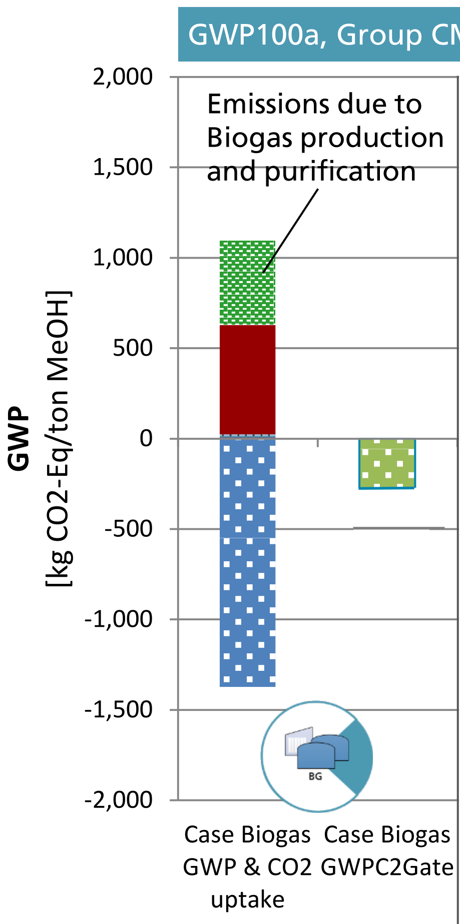
Life Cycle Impact Assessment (LCIA)

Results: Global Warming Potential – Focus on Case BG



Case Biogas:

- Accounting (partly via allocation) for the CO_2 emissions from biogas *production* leads to significantly increased GWP (+76%).
- As well as other impact categories:
  - Photochemical oxidation (+28%)
  - Acidifiaction (+83%)
  - Eutrophication (+376%)

→ In case of further introduction of 4th generation biofuels need for deeper ecologic analysis.

CO_2 Avoidance Cost: Present & Future
Techno-Economic Evaluation

$$CO_2\ Avoidance\ Cost = \frac{\boldsymbol{Market\ Price_{eFuel}} - Market\ Price_{f.Fuel}}{GWP_{f.Fuel,W2W} - GWP_{eFuel,W2W}}$$

- Example is based on techno-economic evaluation of green methanol production (wind/PV energy & CO_2 from biomass)

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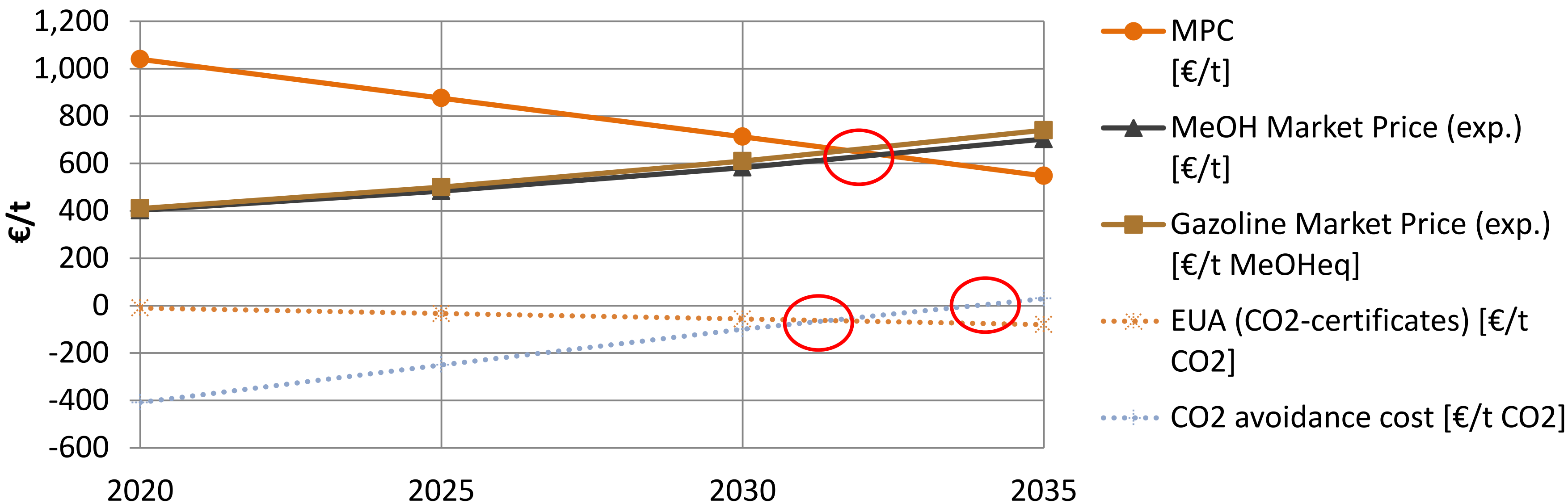
CO_2 Avoidance Cost: Present & Future
Techno-Economic Evaluation

		2020	2025	2030	2035
Electricity Price	ct/kWh	4.40	3.53	2.67	1.80
Invest Electrolyzer	€/kW	800	633	467	300
EUA (CO_2-certificates)	[€/t CO_2]	-10	-33	-57	-80
Methanol production cost	[€/t]	1,040	876	713	548
CO_2 avoidance cost	[€/t CO_2]	-409	-302	-196	-90



PtM: LCA and CO2 Avoidance Cost
Bottom Lines

- PtM can have lower GWP than fossil methanol production.
- Source of electrical energy is crucial for overall eco-performance.
- Other evaluated impact categories (AP, POCP) are in the same range of improvement with EP performing worse than fossil reference.
- Way for solving multi-functionality has big influence on results (procedures should be stated/published)
- With the prospected improvements in central system components an economic competition can be reachable…
- …but only to a parallel introduction of an efficient carbon taxation system
- And (in the EU) a recognition of CCU as CO_2-sink

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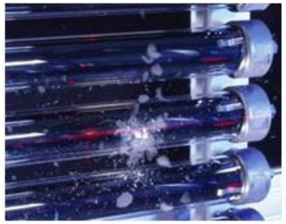
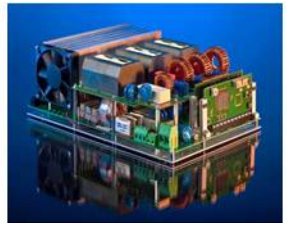
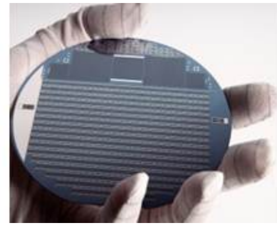
Thank you for your attention!

Any Questions?

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Product System Studied
Assumptions & Limitations

- Methanol reference plant: steam reforming based on natural gas*.
- CO_2 capturing technology is assumed to be fully dynamic, nearby located, no material demand for construction (yet).
- H_2 storage without losses.
- Distillation unit heat demand is internally covered by MeOH synthesis.

*ecoinvent 3.3 process: methanol production [GLO]

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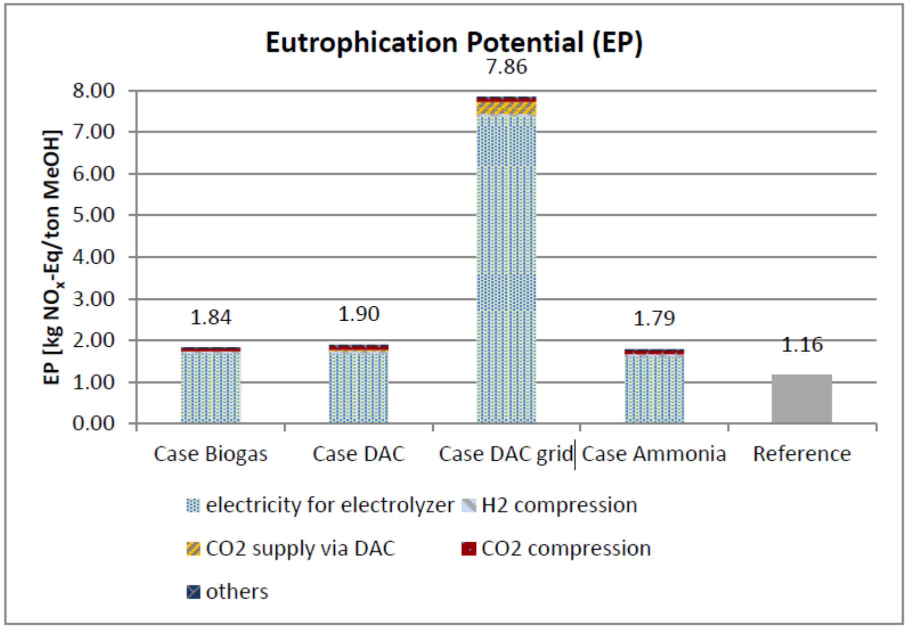
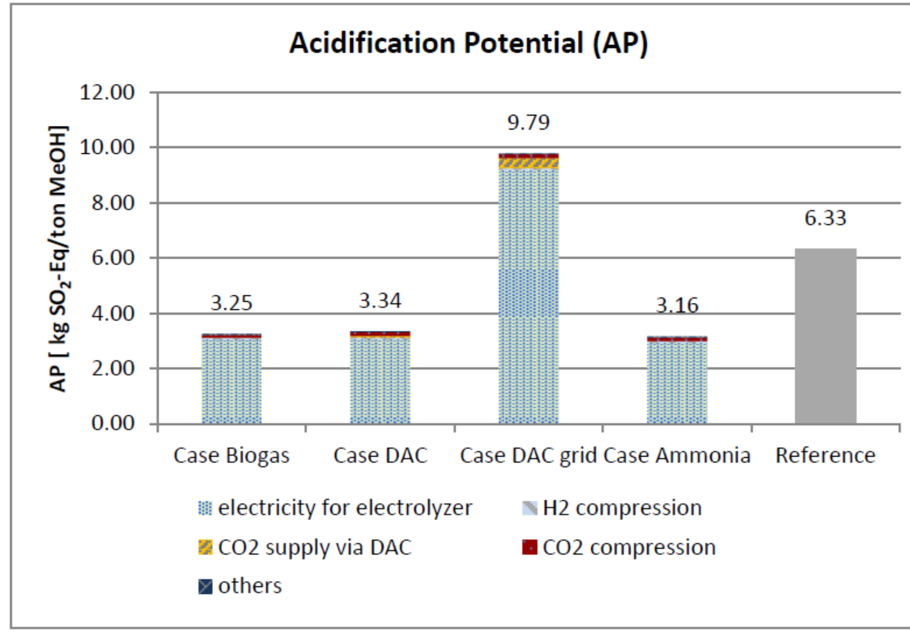
Product System Studied
Oher Impact Categories





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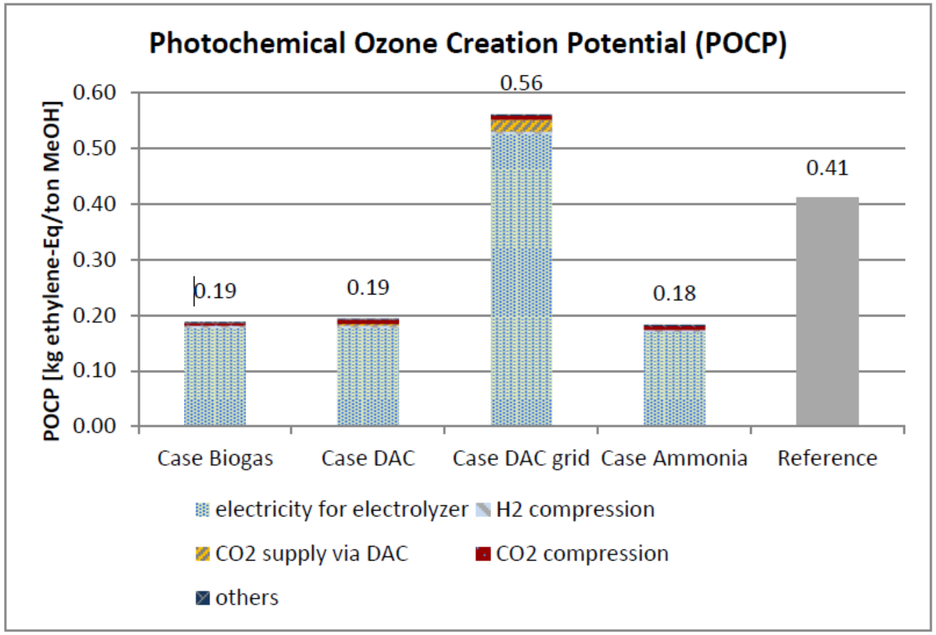

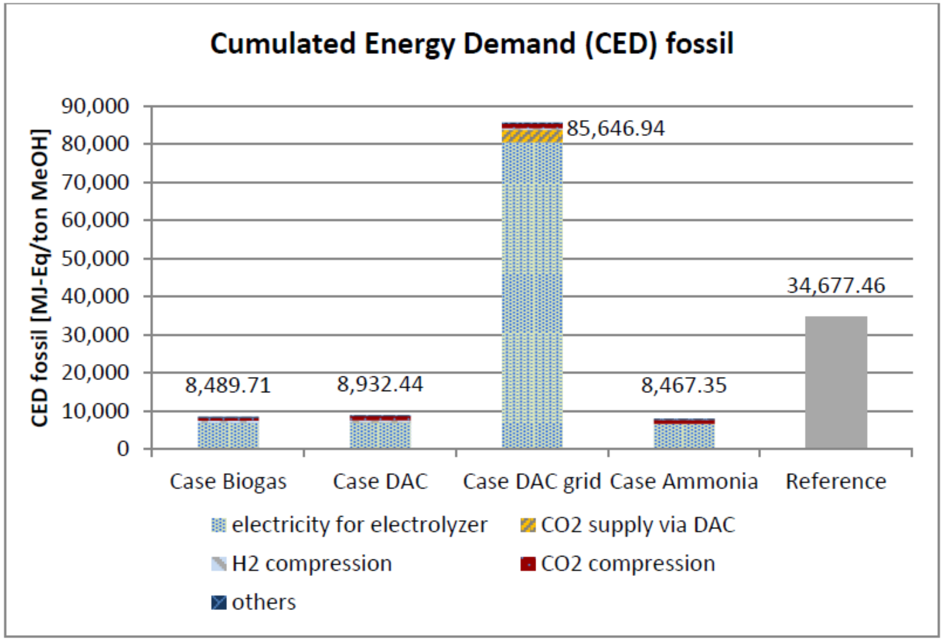

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