Monday, 2024/11/11, Barcelona, Spain

CONFERENCE SESSION II
Carbon Fibres, Composites & Organic Compounds


# PATHWAYS TOWARDS NET ZERO ACCORDING TO COP28?

Decarbonization of Industry and Transport – interlinked Carbon Cycles

Ralph-Uwe Dietrich, Nathanael Heimann, Simon Maier,
Yoga Rahmat, Julia Weyand

ralph-uwe.Dietrich@dlr.de, (www.DLR.de/tt)

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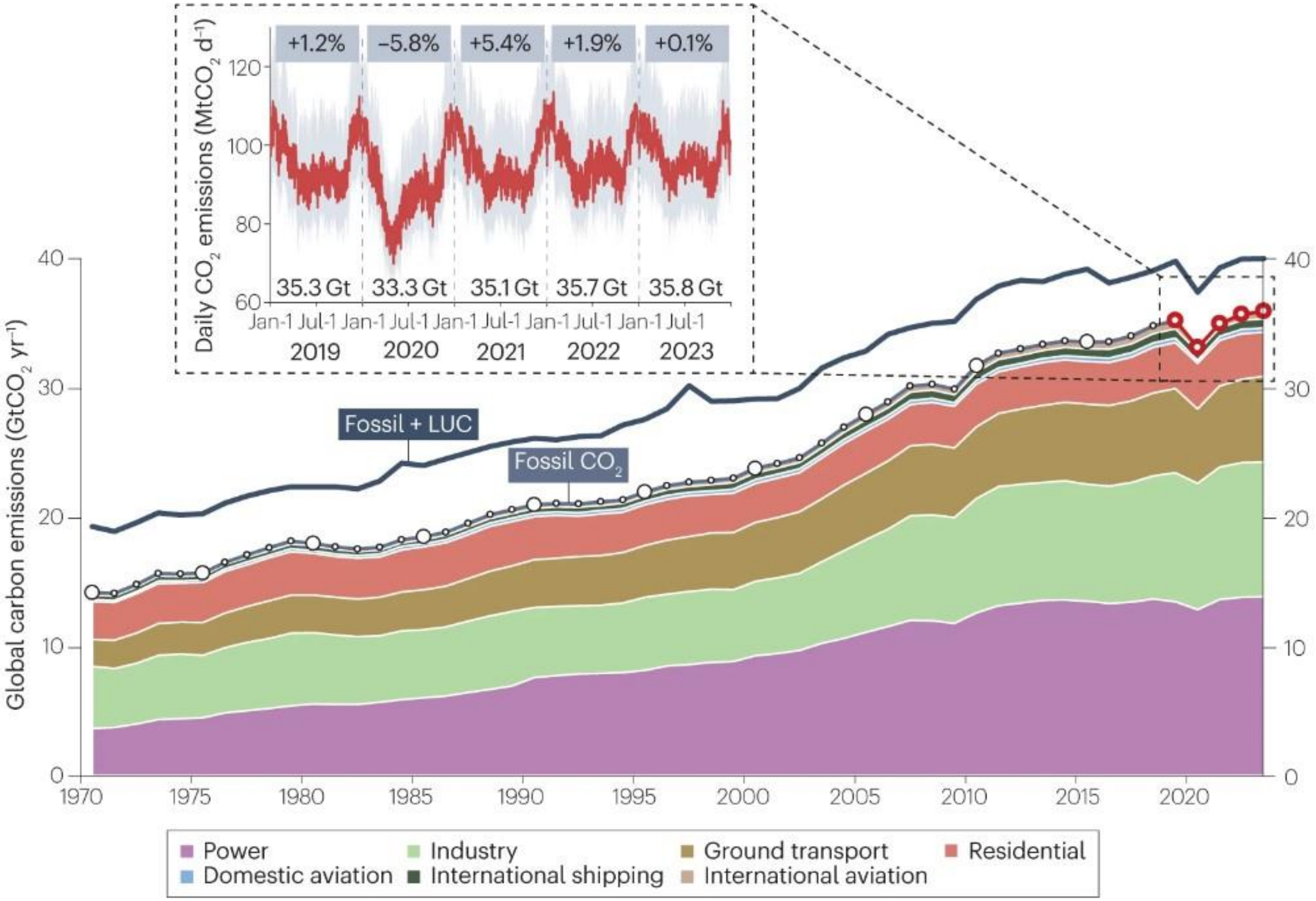
# Climate change undeniable

**Fig.1: Global $CO_2$ emissions 1970–2023** [1]




[1] https://www.nature.com/articles/s43017-024-00532-2

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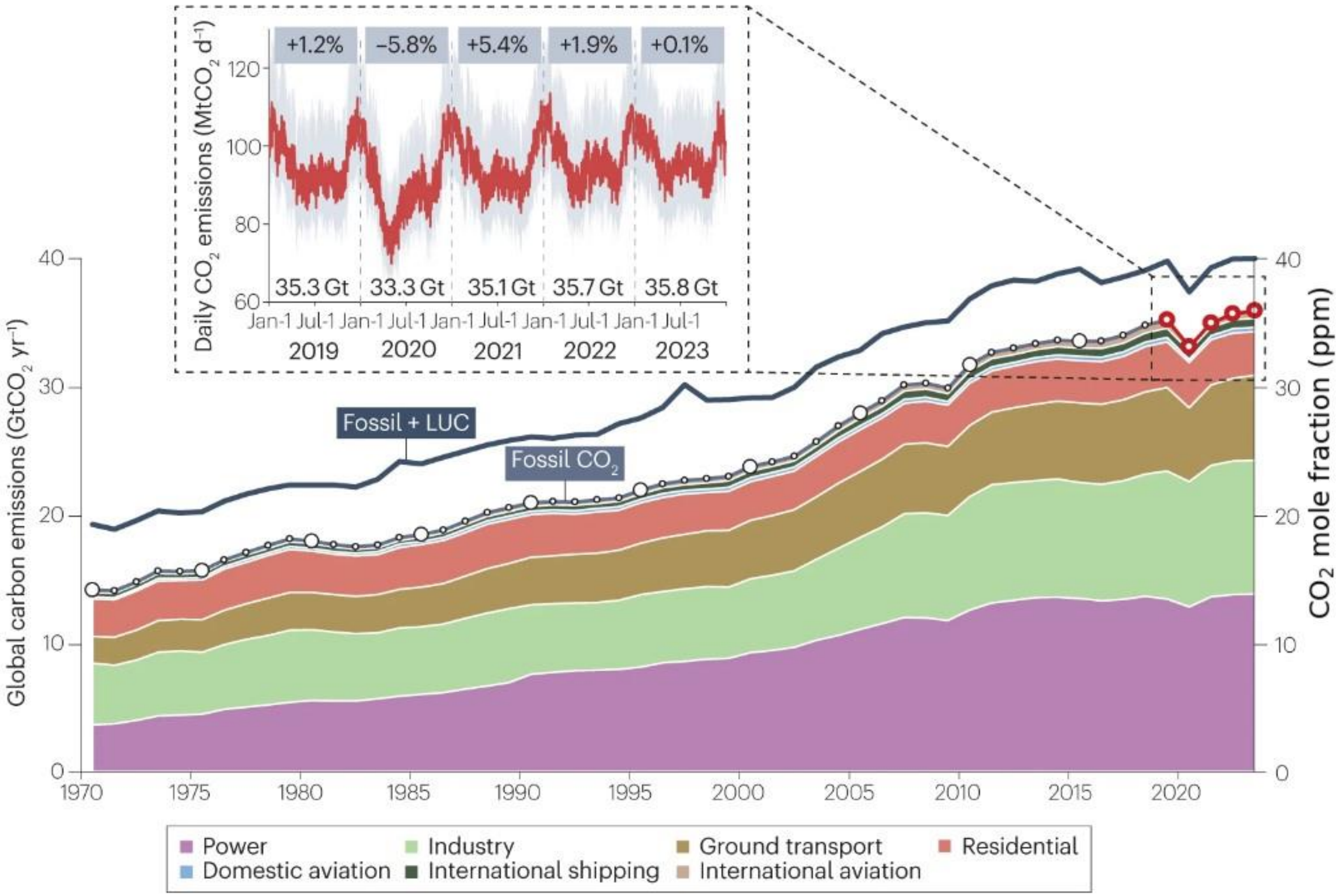


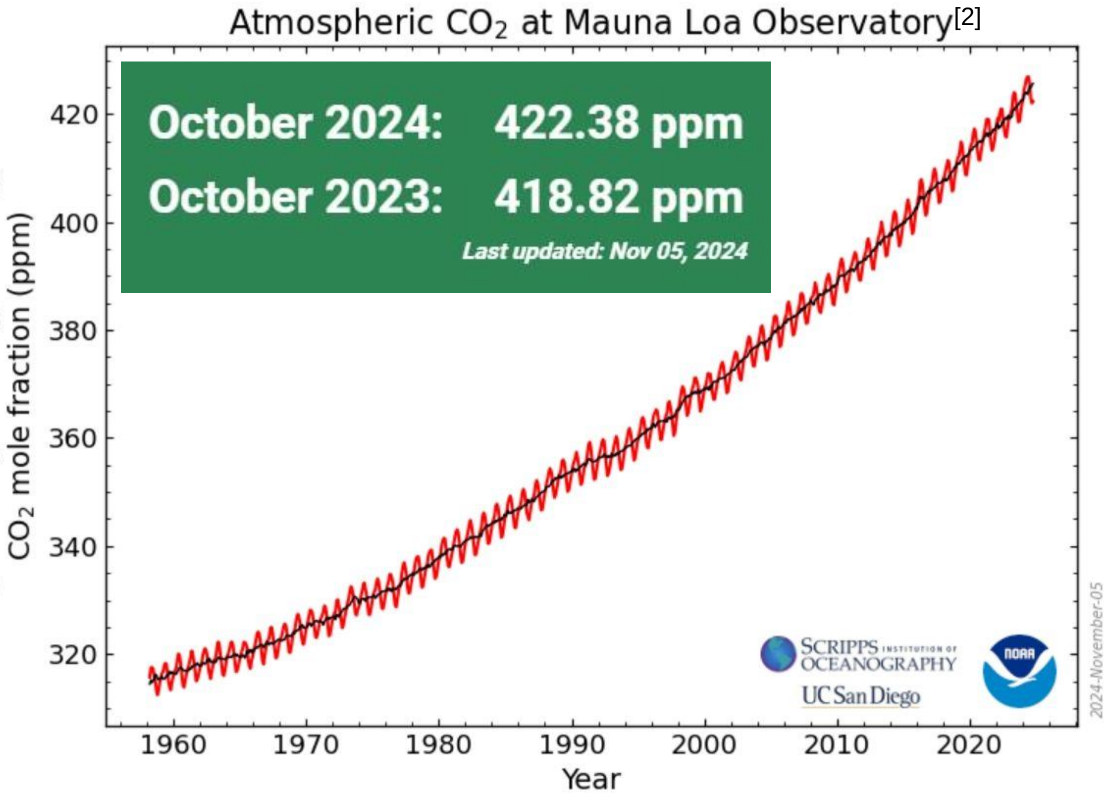


[1] https://www.nature.com/articles/s43017-024-00532-2
[2] https://scrippsco2.ucsd.edu/graphics_gallery/mauna_loa_record/mauna_loa_record.html

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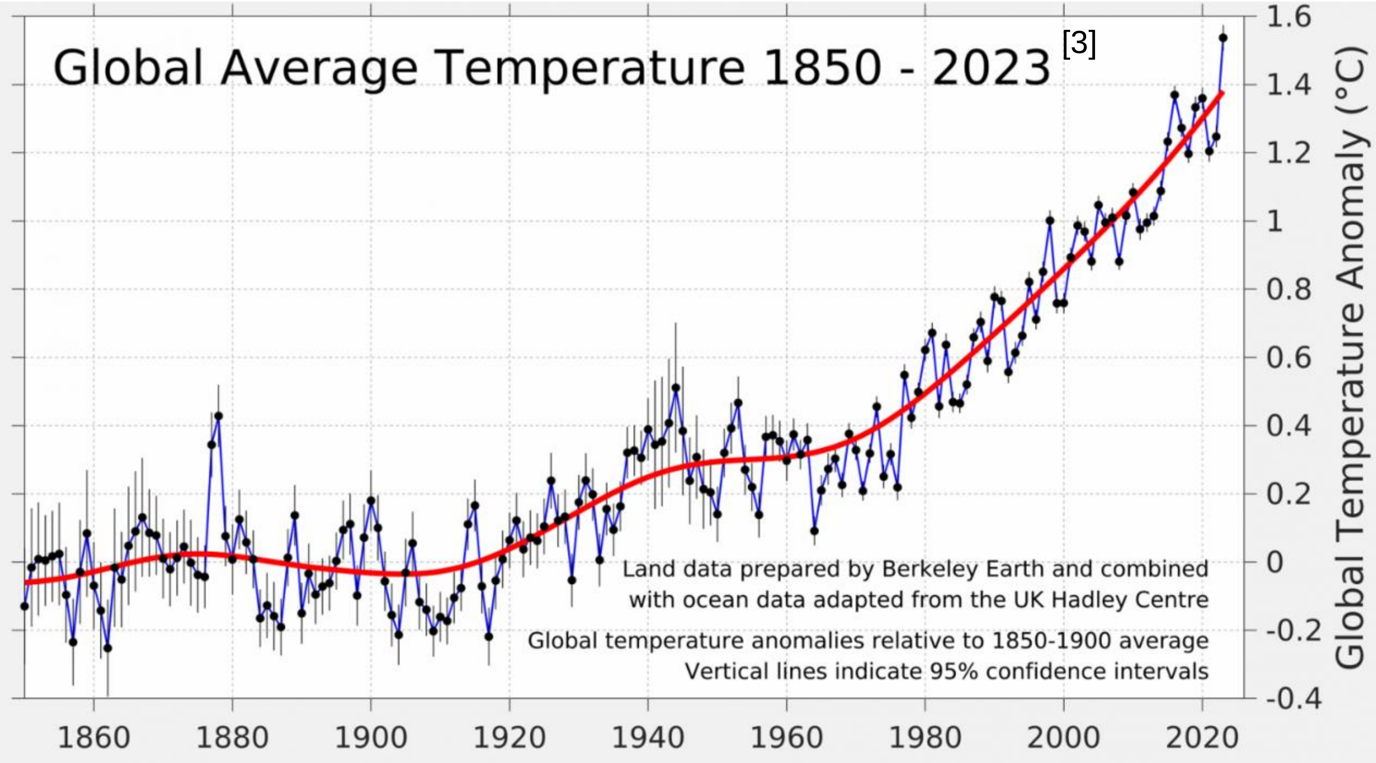
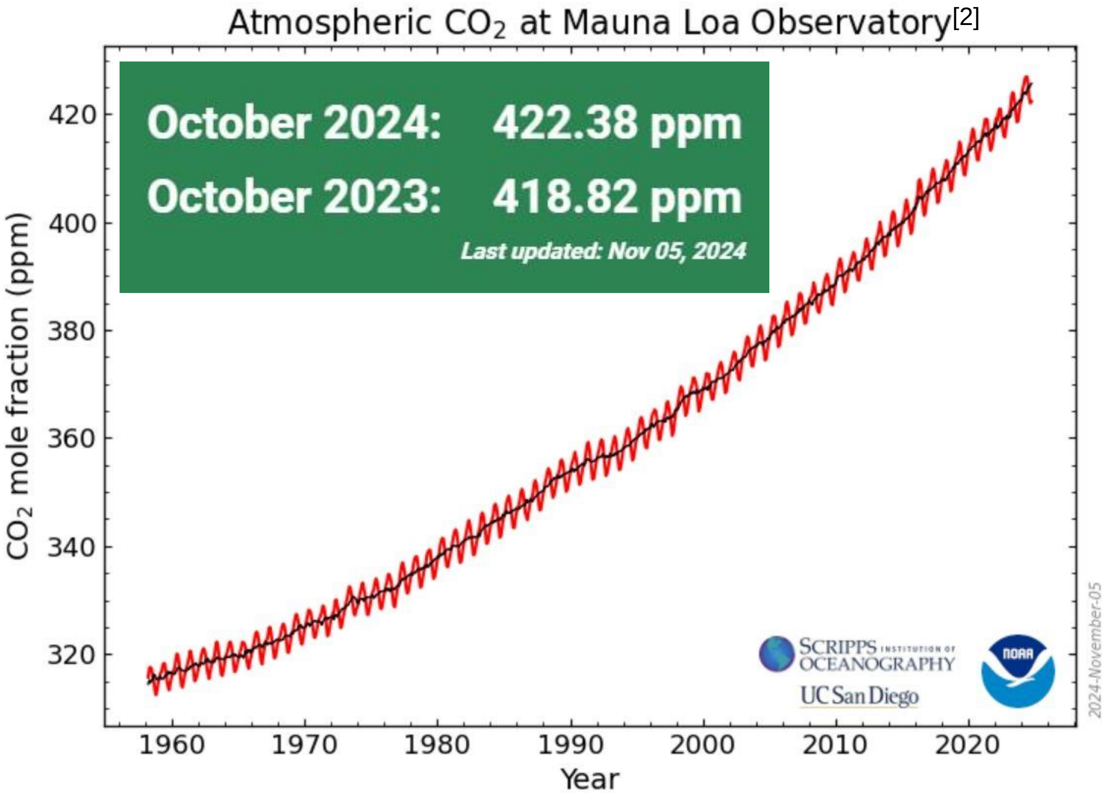
[1]




- 2024: 1.5 degree above pre-industrial average, despite Paris agreement

[1] https://www.nature.com/articles/s43017-024-00532-2
[2] https://scrippsco2.ucsd.edu/graphics_gallery/mauna_loa_record/mauna_loa_record.html
[3] https://berkeleyearth.org/global-temperature-report-for-2023/

# Decarbonization options

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Mc Kinsey order of sector decarbonization for Europe [1]

- ***Power:*** wind and solar power generation technologies decarbonize power quickest, reaching net-zero by the mid-2040s. Power demand would double as other sectors switch to electricity and green hydrogen.

Assessment example: Retrofit Coal Power Plants

[1] Mc Kinsey (2020): How the European Union could achieve net-zero emissions at net-zero cost. https://www.mckinsey.com/capabilities/sustainability/our-insights/how-the-european-union-could-achieve-net-zero-emissions-at-net-zero-cost#/

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  Assessment example: Sustainable Aviation Fuels in Europe

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- ***Industry:*** Technology required that is still under development. Even by 2050, industry would continue to generate some residual emissions from activities such as waste management and heavy manufacturing, which would have to be offset.

  Assessment example: Sustainable Glass Production

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Assessment example: Sustainable Glass Production

- ***Agriculture****:* By far the hardest sector to abate. Raising animals for food can't be reduced without significant changes in meat consumption or technological breakthroughs. Requires offsetting agriculture emissions with negative emissions in other sectors and increasing natural carbon sinks.

[1] Mc Kinsey (2020): How the European Union could achieve net-zero emissions at net-zero cost. https://www.mckinsey.com/capabilities/sustainability/our-insights/how-the-european-union-could-achieve-net-zero-emissions-at-net-zero-cost#/

# Assessment of Decarbonization options

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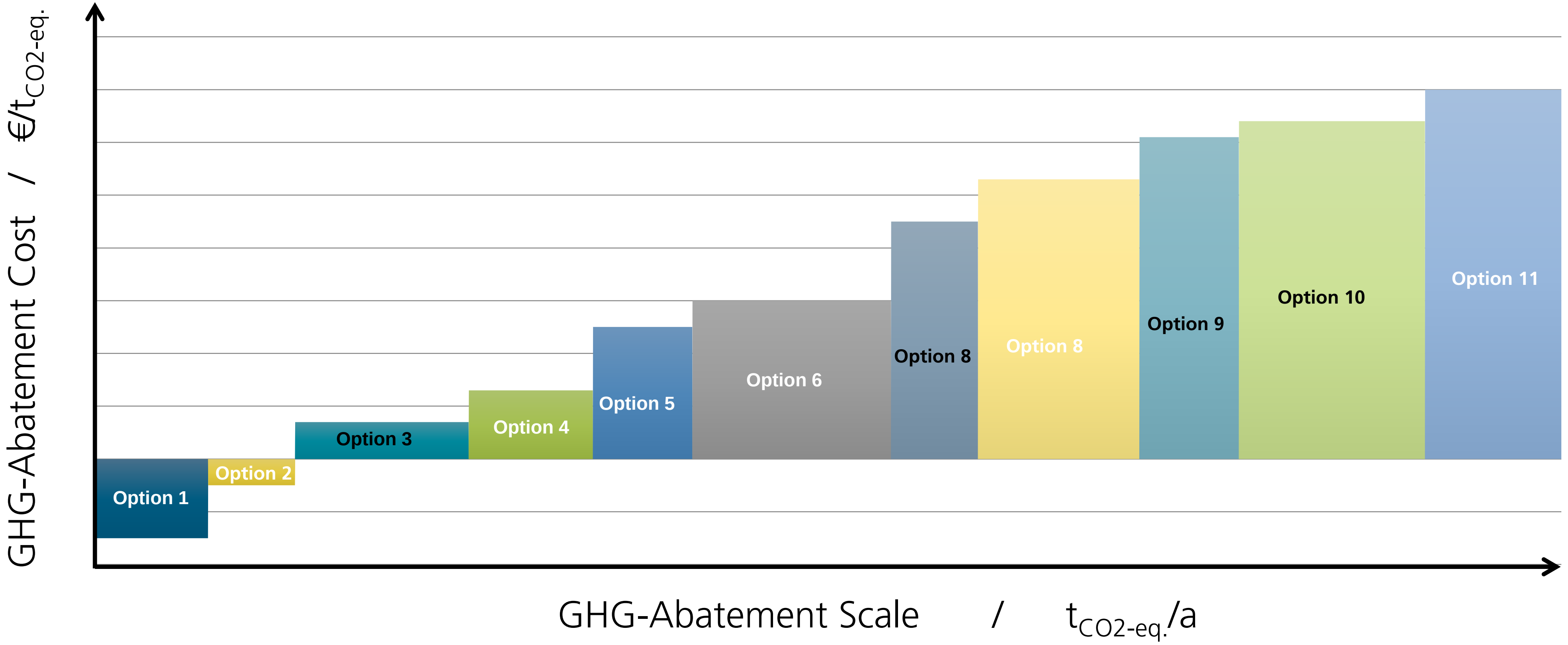
## Merit Order of Greenhouse Gas (GHG) emission reduction measures



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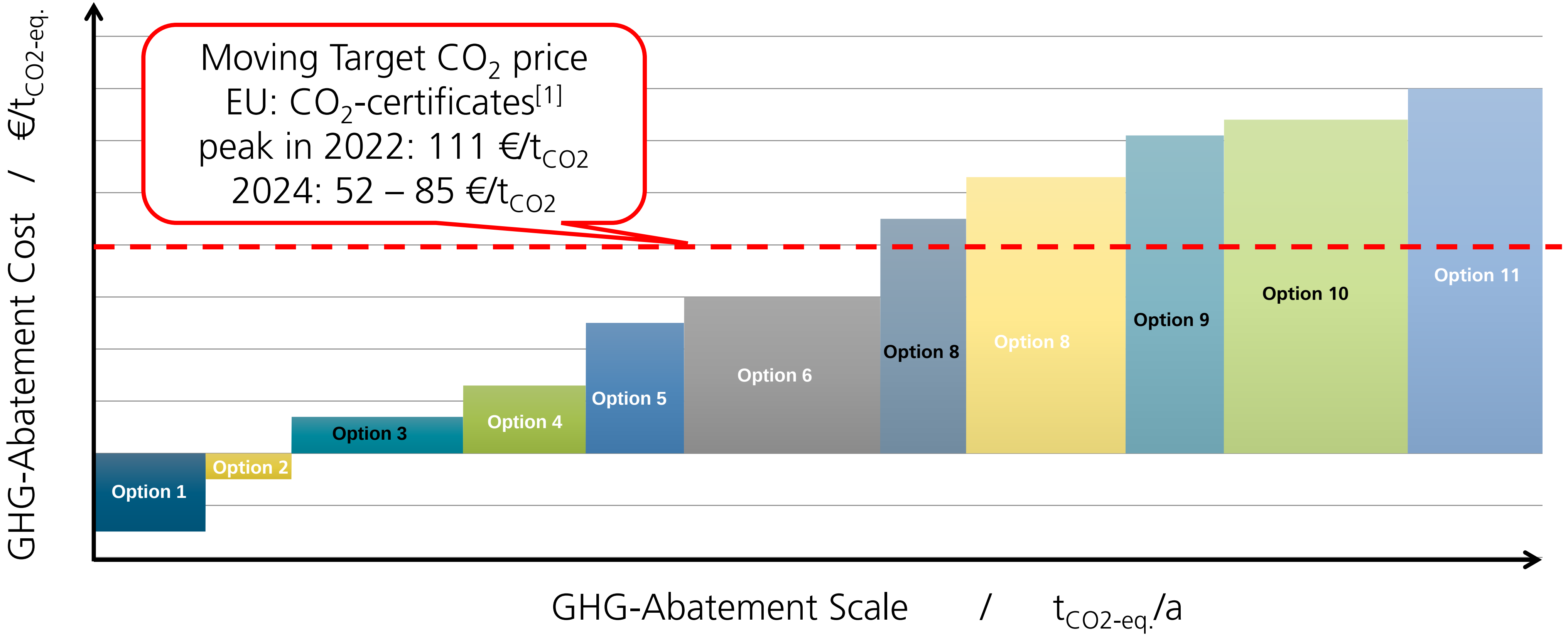


[1] https://www.boerse.de/rohstoffe/Co2-Emissionsrechtepreis/XC000A0C4KJ2

# Assessment of Decarbonization options

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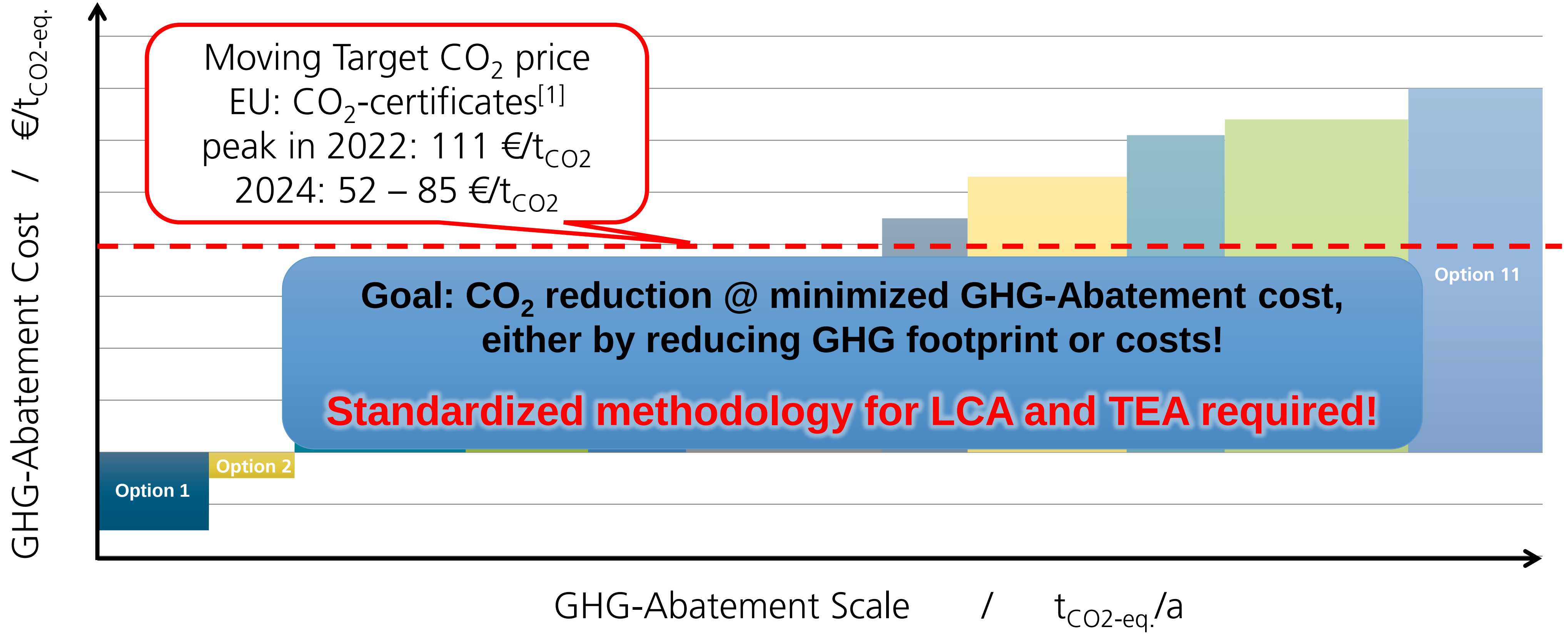


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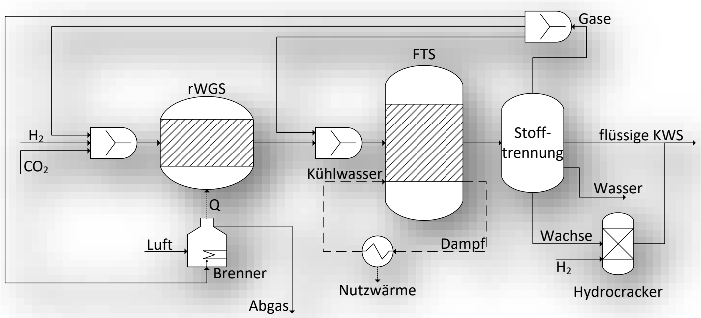
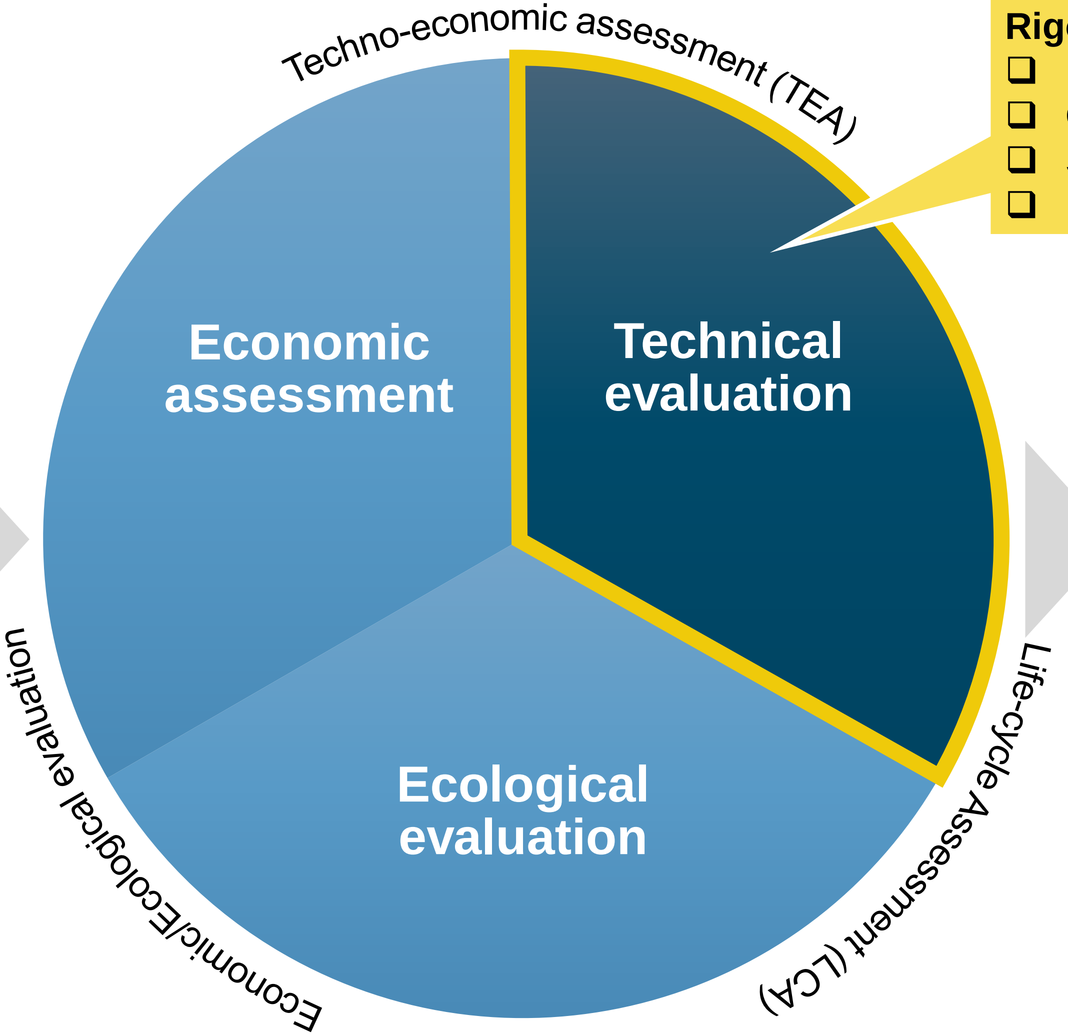
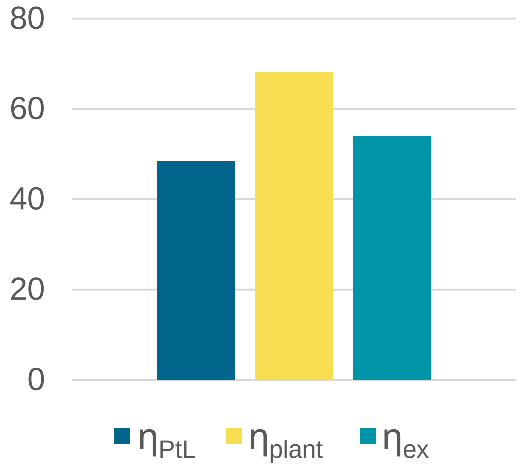
# Techno-Economic and Life Cycle Assessment @ DLR




**Rigorous process simulation**
- ❑ Efficiencies (X-to-Liquid, Overall)
- ❑ Carbon conversion
- ❑ Specific feedstock demand
- ❑ Exergy analysis



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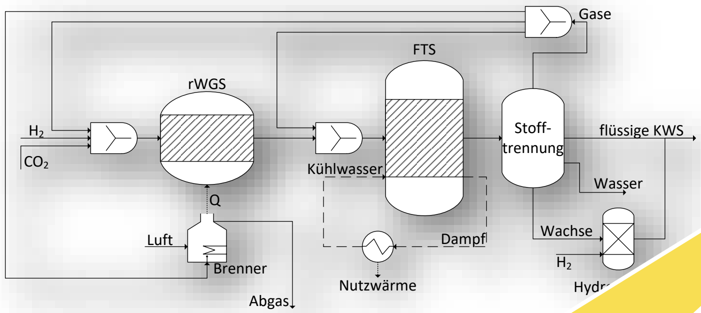
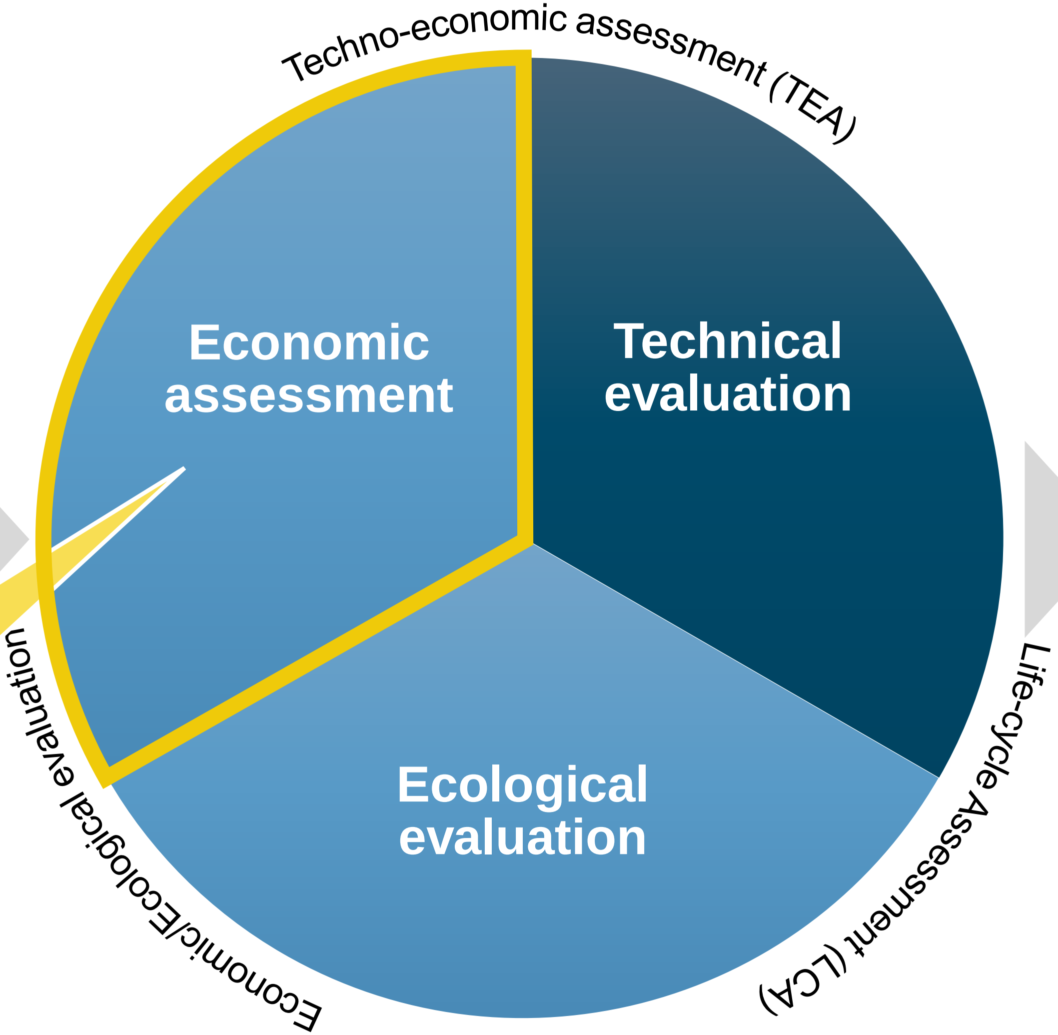
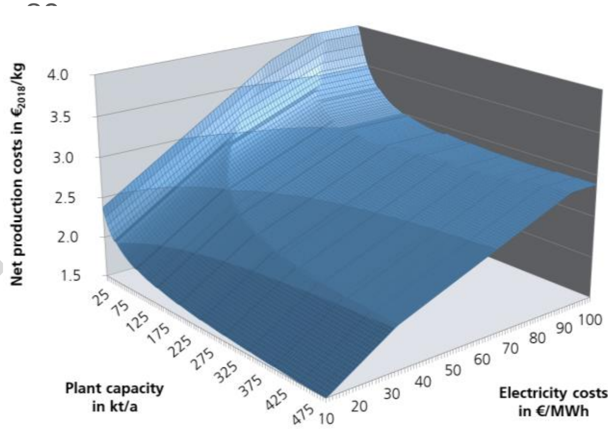



**Chemical engineering cost estimation**
- ❑ Year-specific CAPEX, OPEX, NPC
- ❑ Sensitivity analysis
- ❑ Identification of most economic feasible process design



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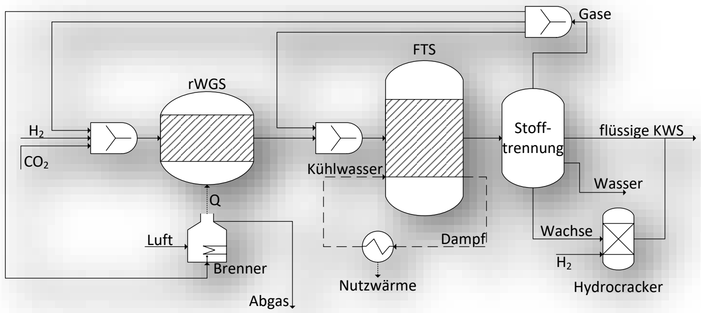


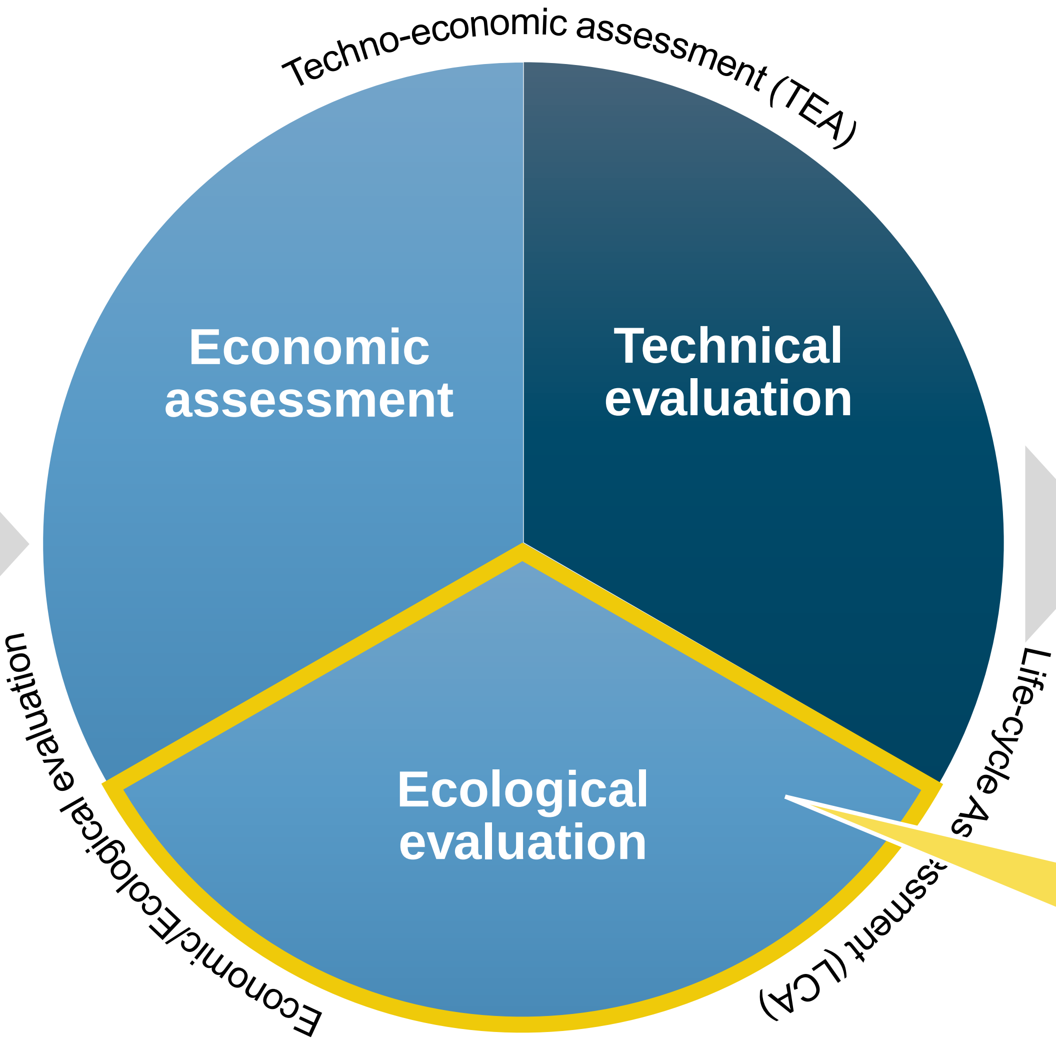


**Adapted ISO 14040/14044 LCA**
- ❑ GWP
- ❑ Other impact categories
- ❑ Identification of impact drivers

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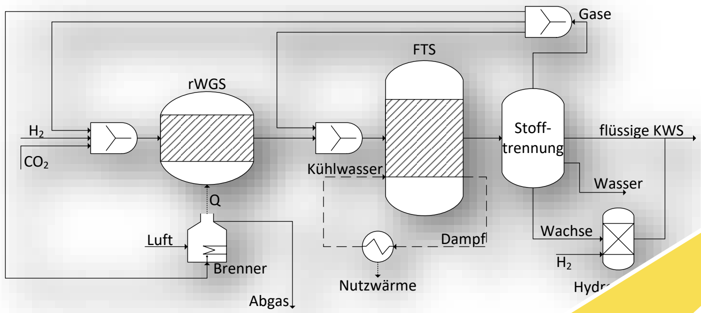


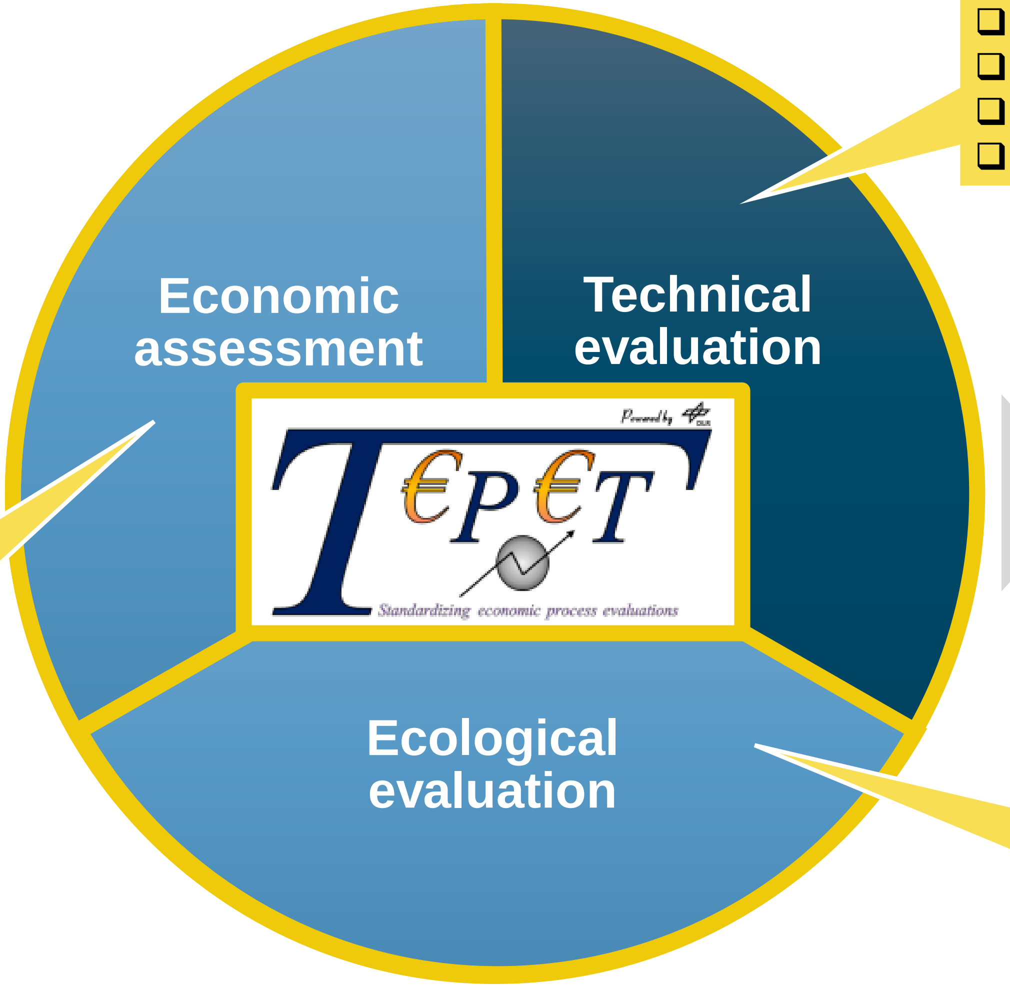


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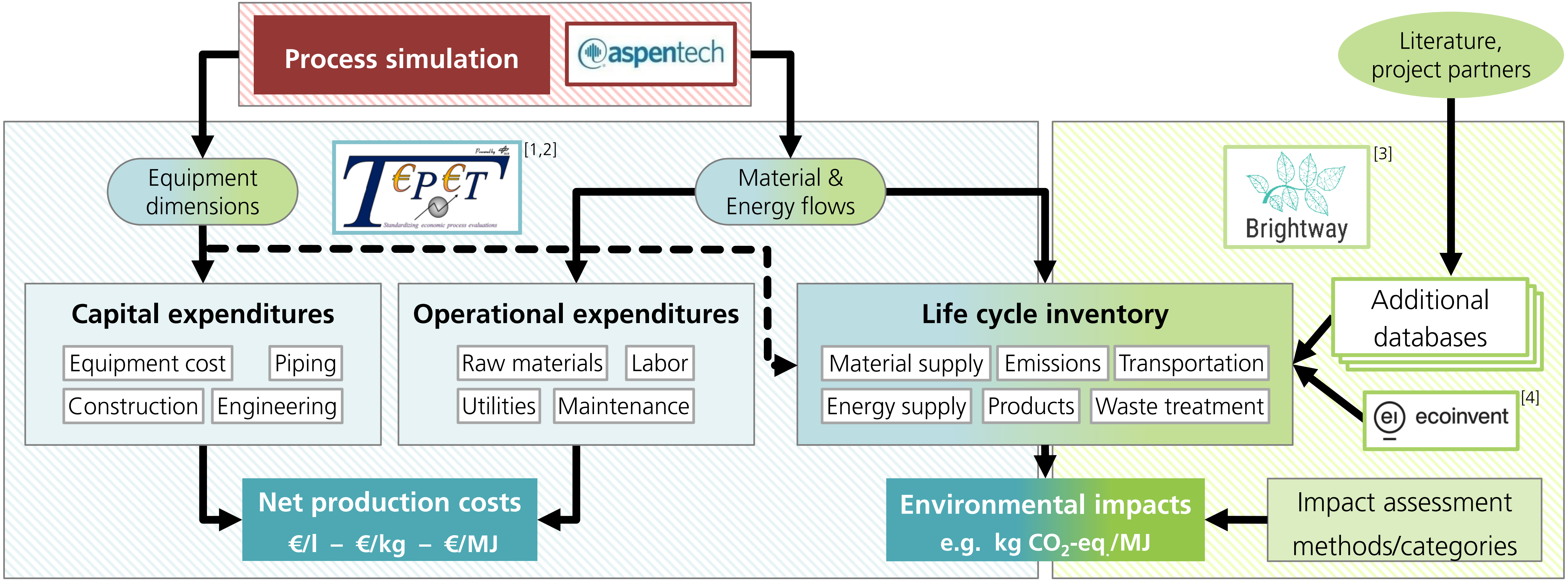
# TEPET+ – Methodology

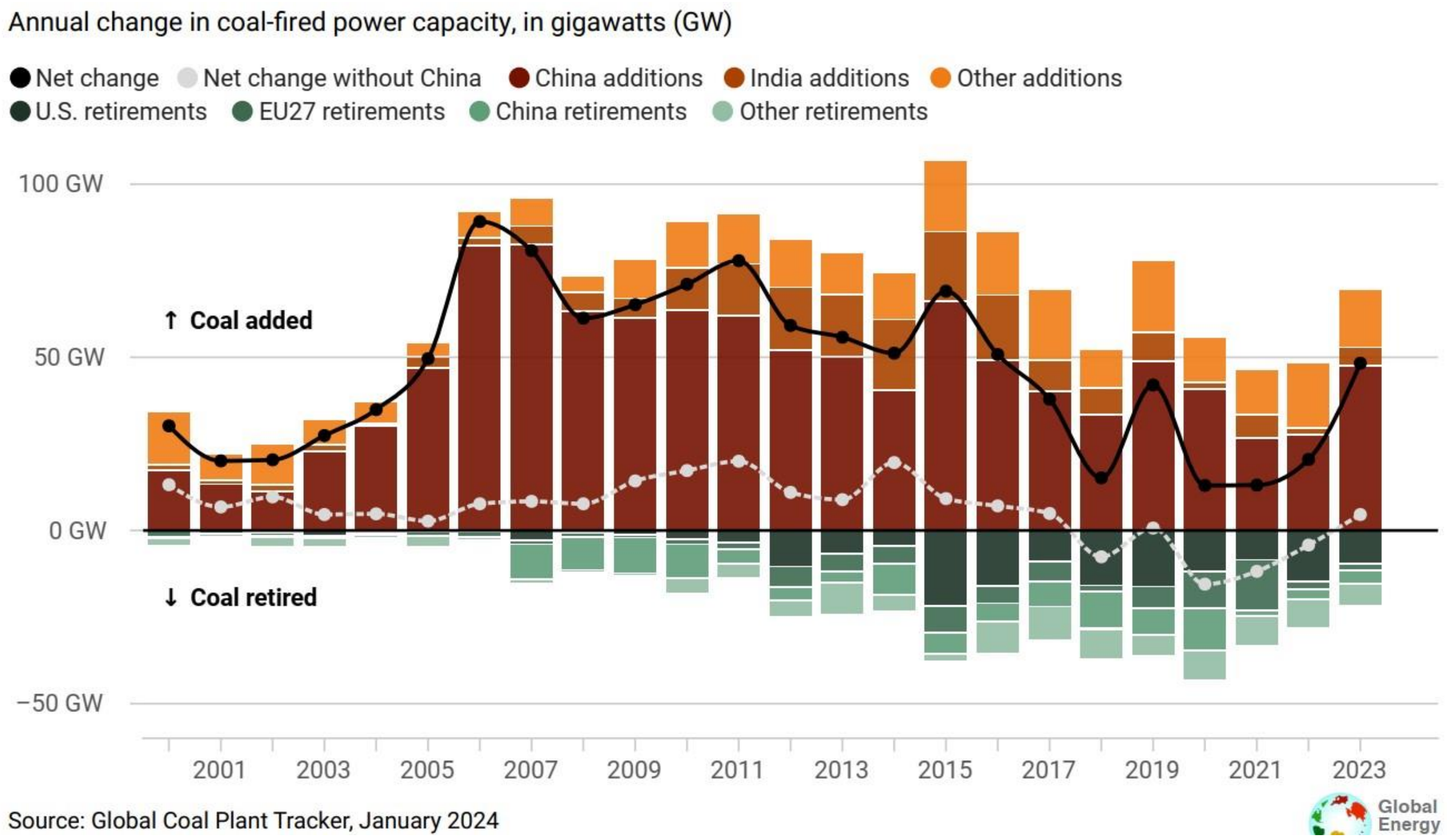



[1] Albrecht et al. (2016): https://doi.org/10.1016/j.fuel.2016.12.003
[2] Maier et al. (2021): https://doi.org/10.1016/j.enconman.2021.114651
[3] Mutel (2017): https://doi.org/10.21105/joss.00236
[4] Wernet et al. (2016): https://doi.org/10.1007/s11367-016-1087-8

# DECARBONIZATION OF POWER GENERATION

# Coal consumption: Power industry

- Global coal power capacity 2023: 2’130 GW
  - annual growth: +48.4 GW, 2/3 in China
  - Retirements at lowest level in over a decade [1]
- Emissions: 10.4 $Gt_{CO2}/a$ [2]
- Reduction to ZERO according to COP28?

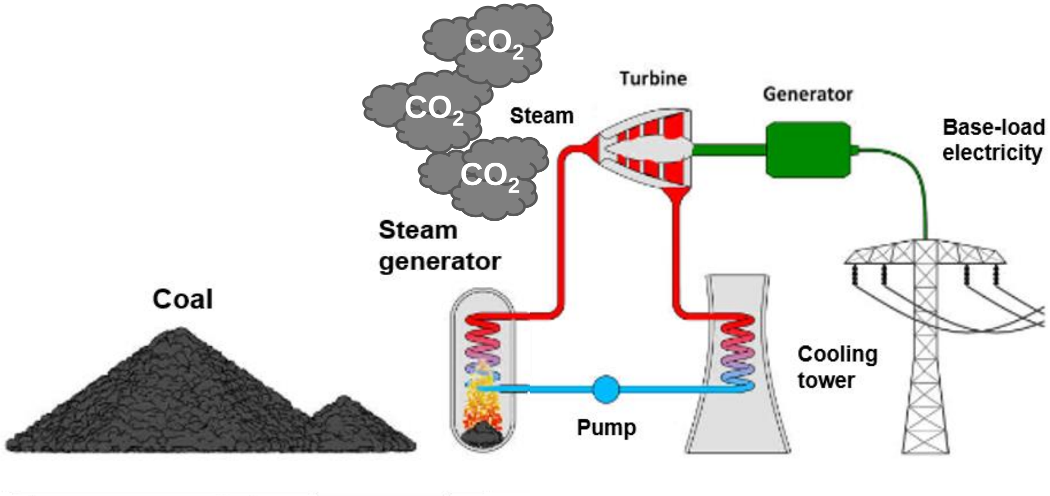



[1] IEA (2022)
[2] IEA (2022)
[

# Decarbonizing Coal Power plants
## Retrofit concept

- If no retirement, individual conversion strategy for each plant required


Locations of the coal power plants worldwide (ca. 7000 in operation)[1]



Conventional coal power plant[2]

[1] https://globalenergymonitor.org/

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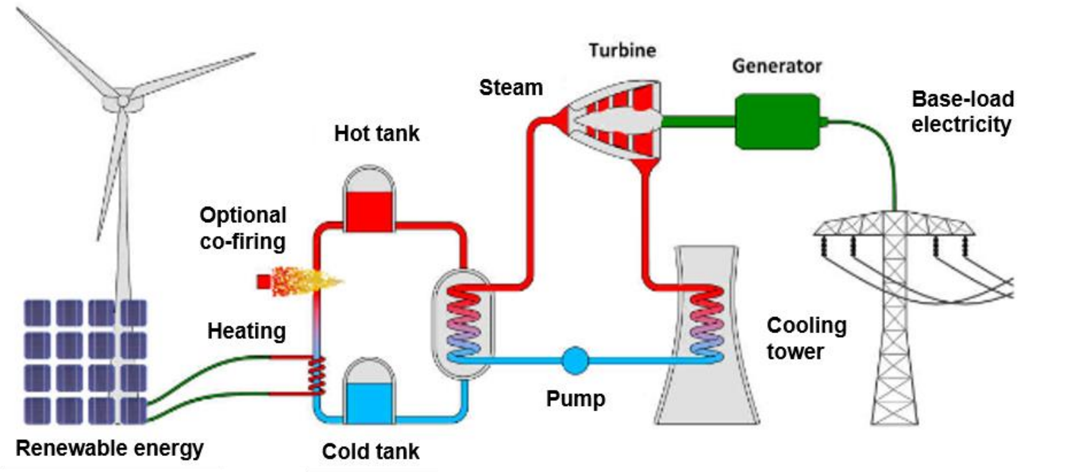


Thermal storage power plant (**TSPP**) concept coupled with Carnot-battery[2]

- Thermal storage electrically heated with fluctuating renewable electricity

[1] https://globalenergymonitor.org/
[2] Iñigo Labairu et al. (2024) Wärmespeicherkraftwerke zur Dekarbonisierung, Jahrestreffen DECHEMA Fachsektion Energie, Chemie und Klima.

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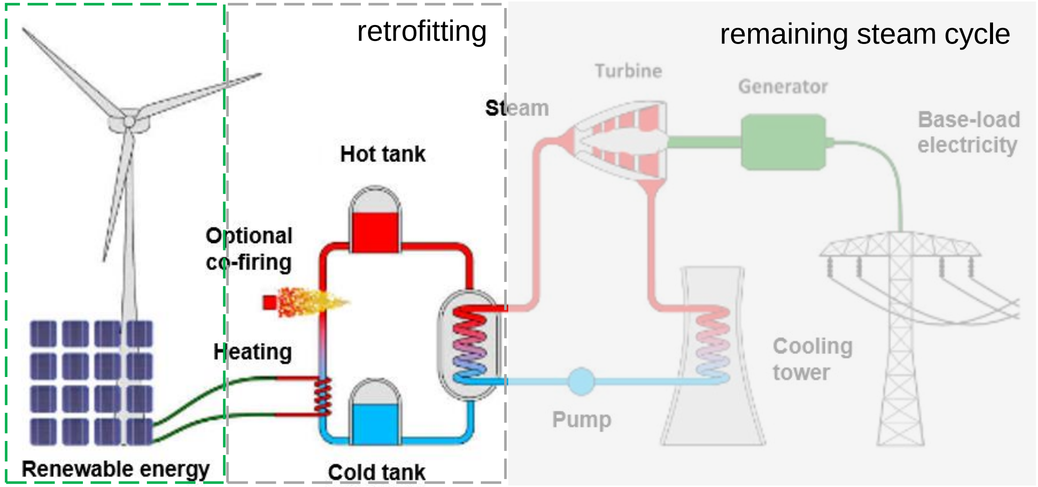


Thermal storage power plant (**TSPP**) concept coupled with Carnot-battery[2]

- Thermal storage electrically heated with fluctuating renewable electricity
- Adapted to each capacity, turbine type, steam temperature, pressure, …

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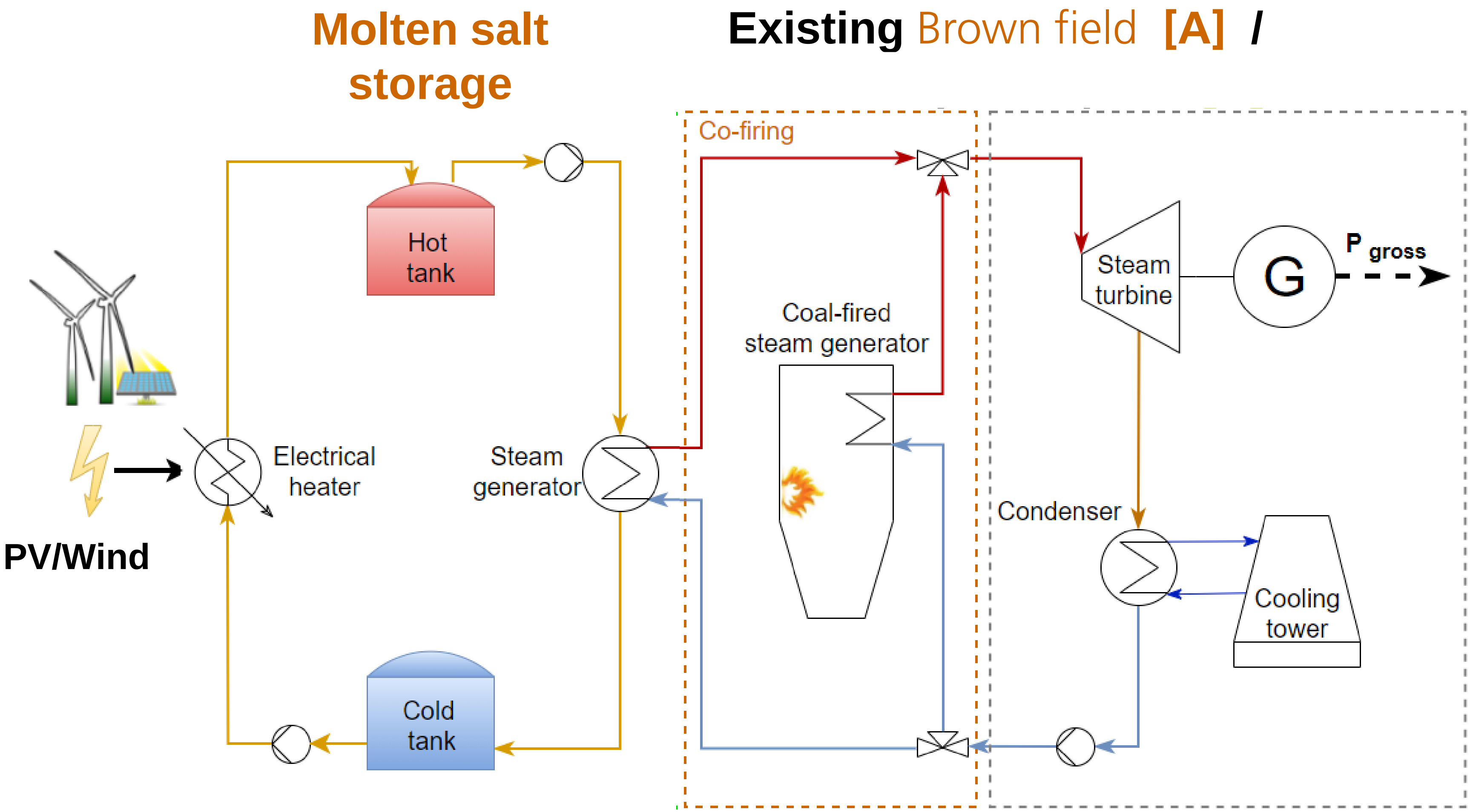
[2] Iñigo Labairu et al. (2024) Wärmespeicherkraftwerke zur Dekarbonisierung, Jahrestreffen DECHEMA Fachsektion Energie, Chemie und Klima.

# Thermal storage power plant (TSPP)

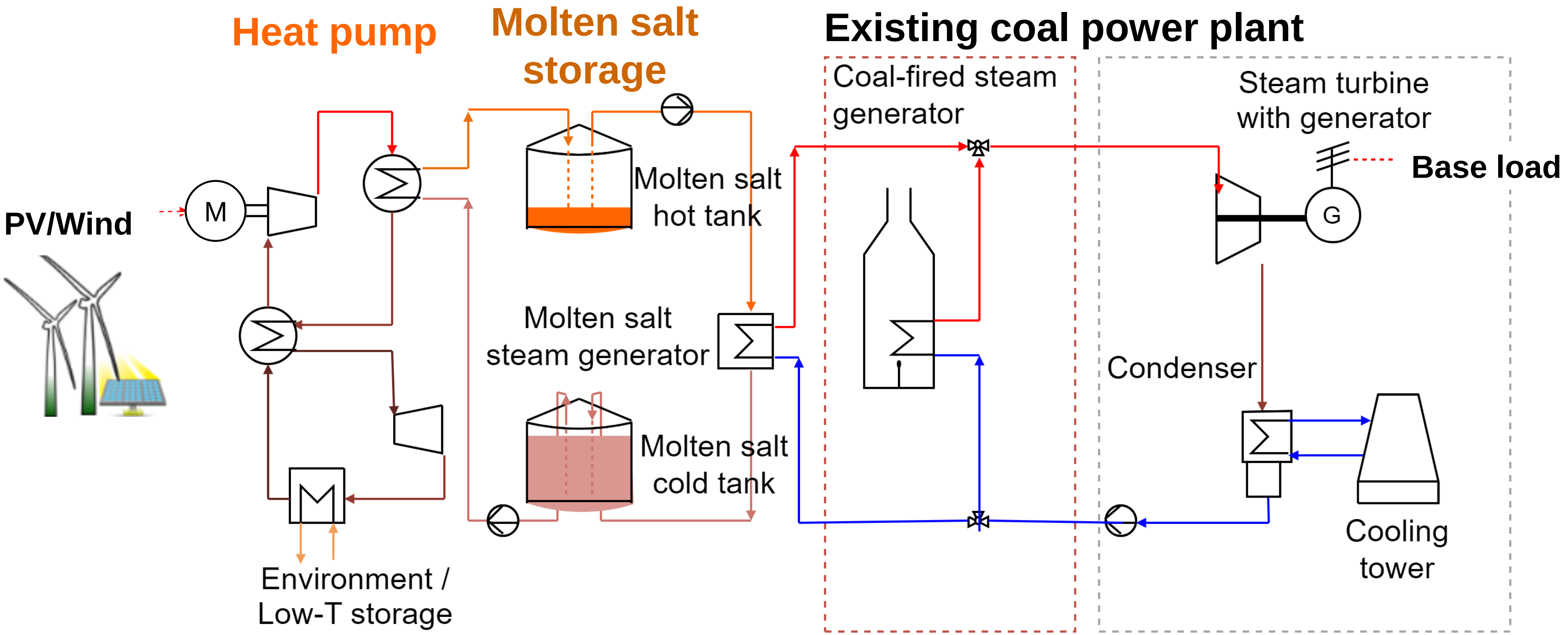
## [A E-heater coupled with power block




[B] Green field includes new steam cycle (state-of-the-art)

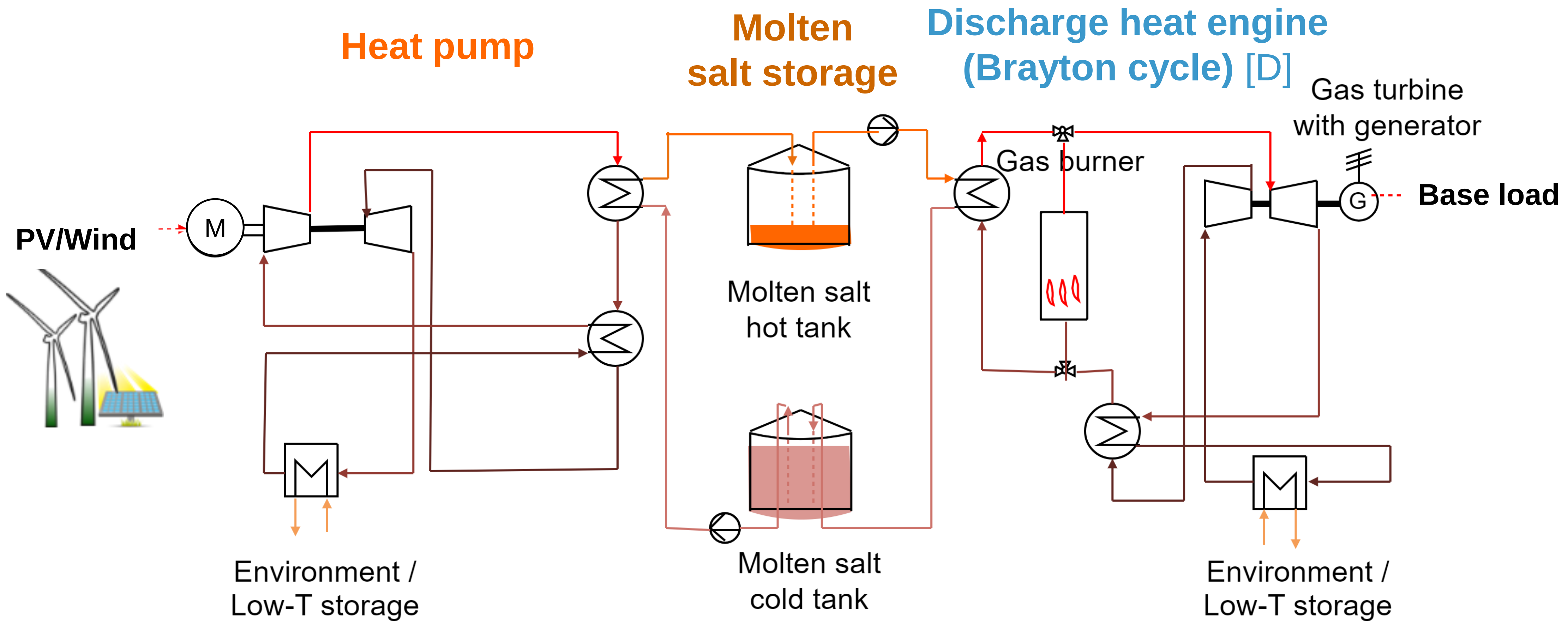
Source: DLR-project Global Coal Atlas

# Thermal storage power plant (TSPP)
## [C] High temperature heat pump (HT-HP)



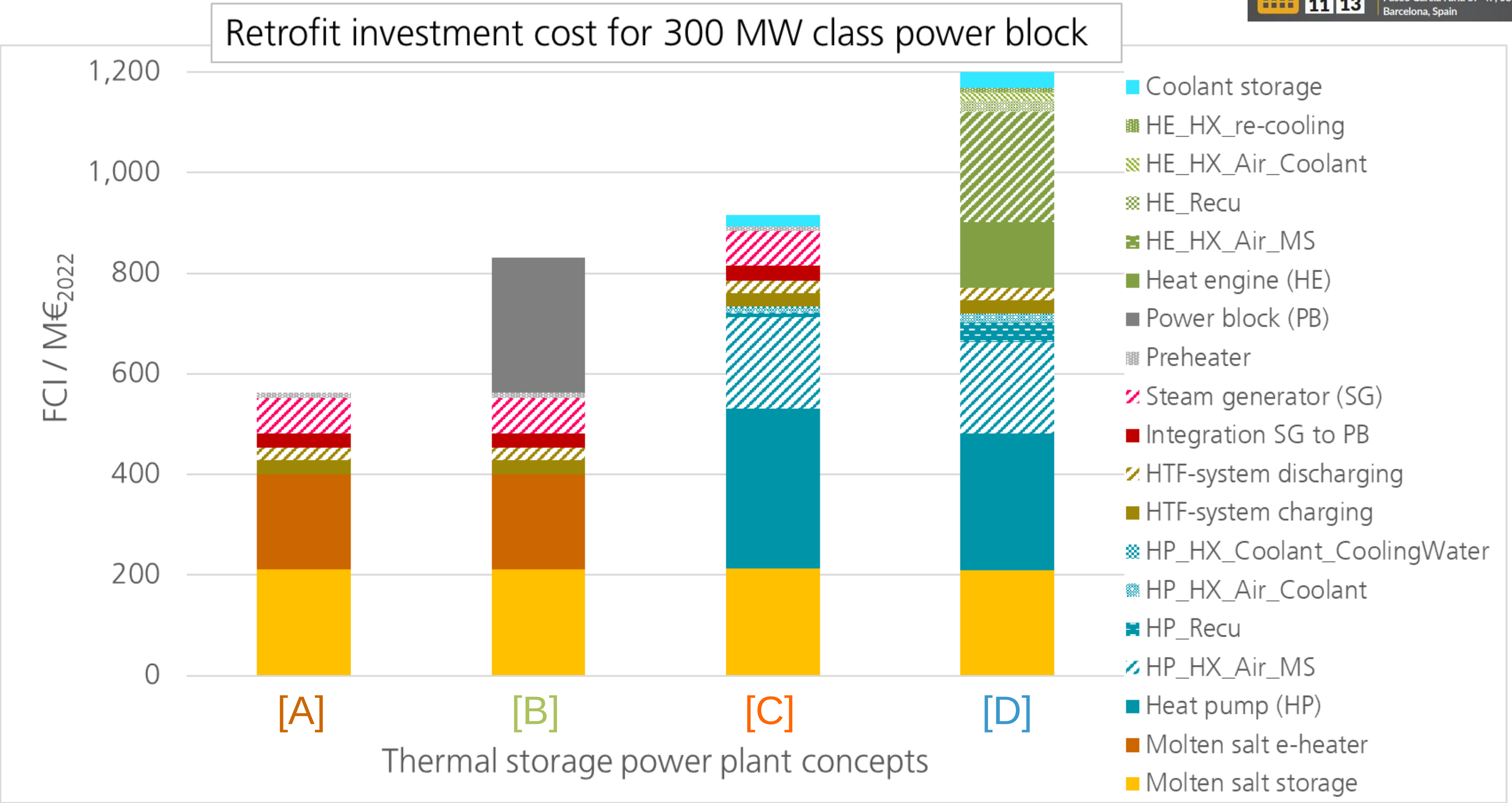

Source: DLR-project Global Coal Atlas

# Thermal storage power plant (TSPP)
## [D] HT-HP coupled with Brayton cycle




Source: DLR-project Global Coal Atlas

# Example Coal Power plant
## Thermal storage power plant (TSPP)

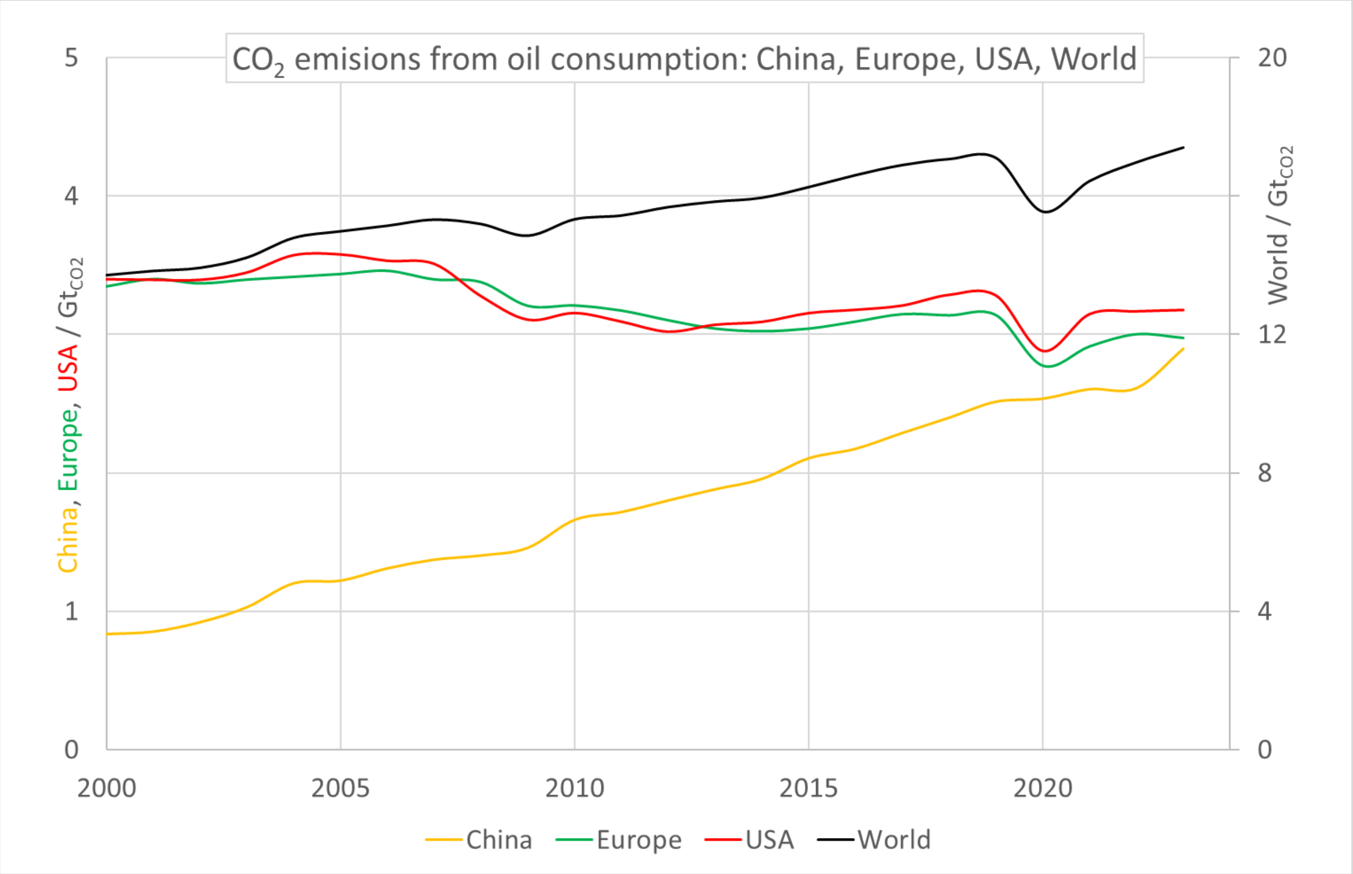



- Retrofit / new built cost: 400 – 900 M€ / 800 – 1.200 M€ for 300 MW block
- $CO_2$ abatement cost: 150 – 200 €/$t_{CO2}$

# DECARBONIZATION OF TRANSPORT

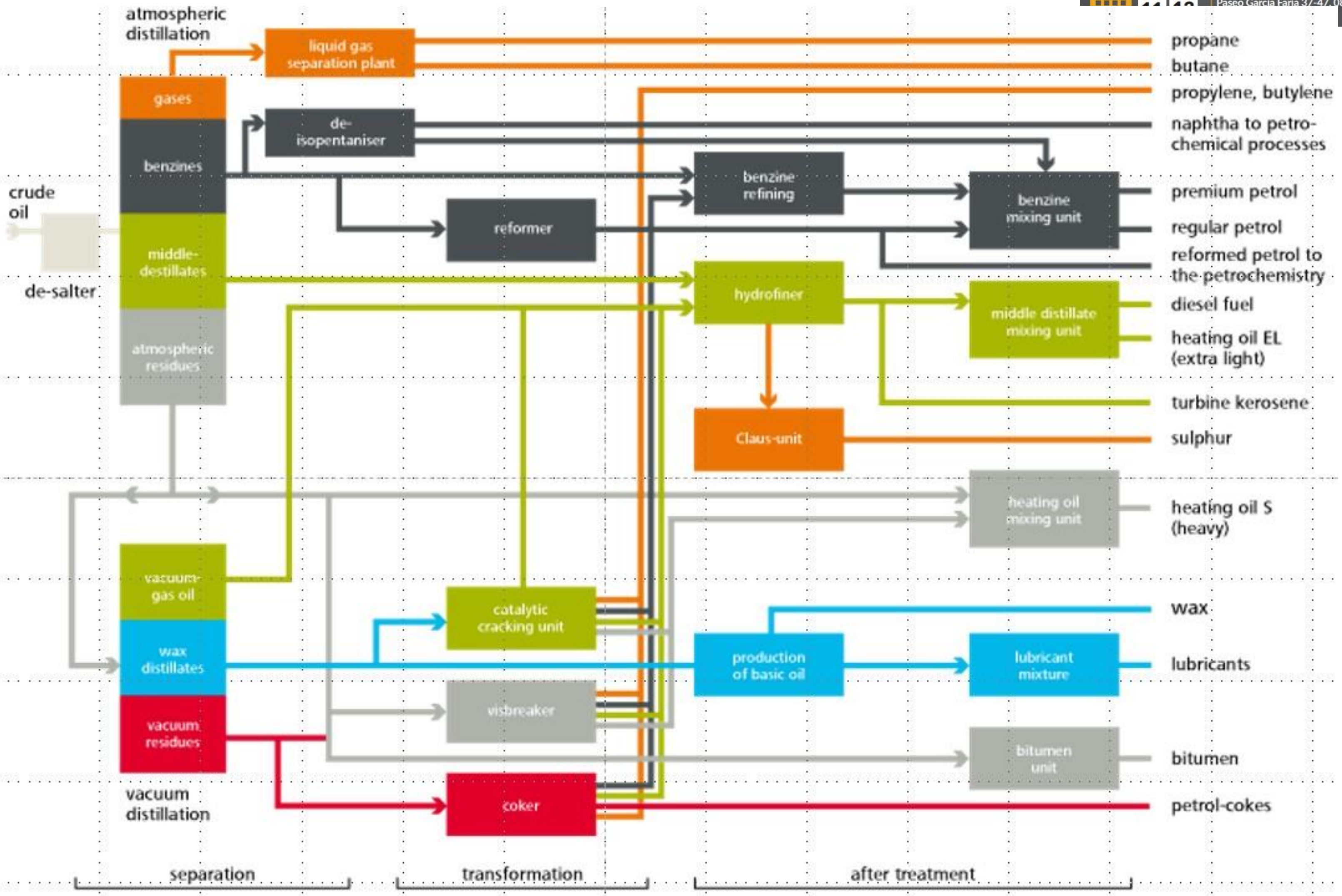
# Oil consumption: Refineries

- Global oil consumption 2023: 54.6 GWh [1]
  - annual growth: +1.34 GWh, 2/3 in China
  - Steady increase of consumption, no sign of mitigation
- Emissions: 17.4 $Gt_{CO2}$/a
- Reduction to ZERO according to COP28?




[1] Oil consumption in TWh from: https://ourworldindata.org/grapher/oil-consumption-by-country, 1 TWh crude oil = 0.319 Mt $CO_2$

# Decarbonization of refineries
## Transition towards sustainability



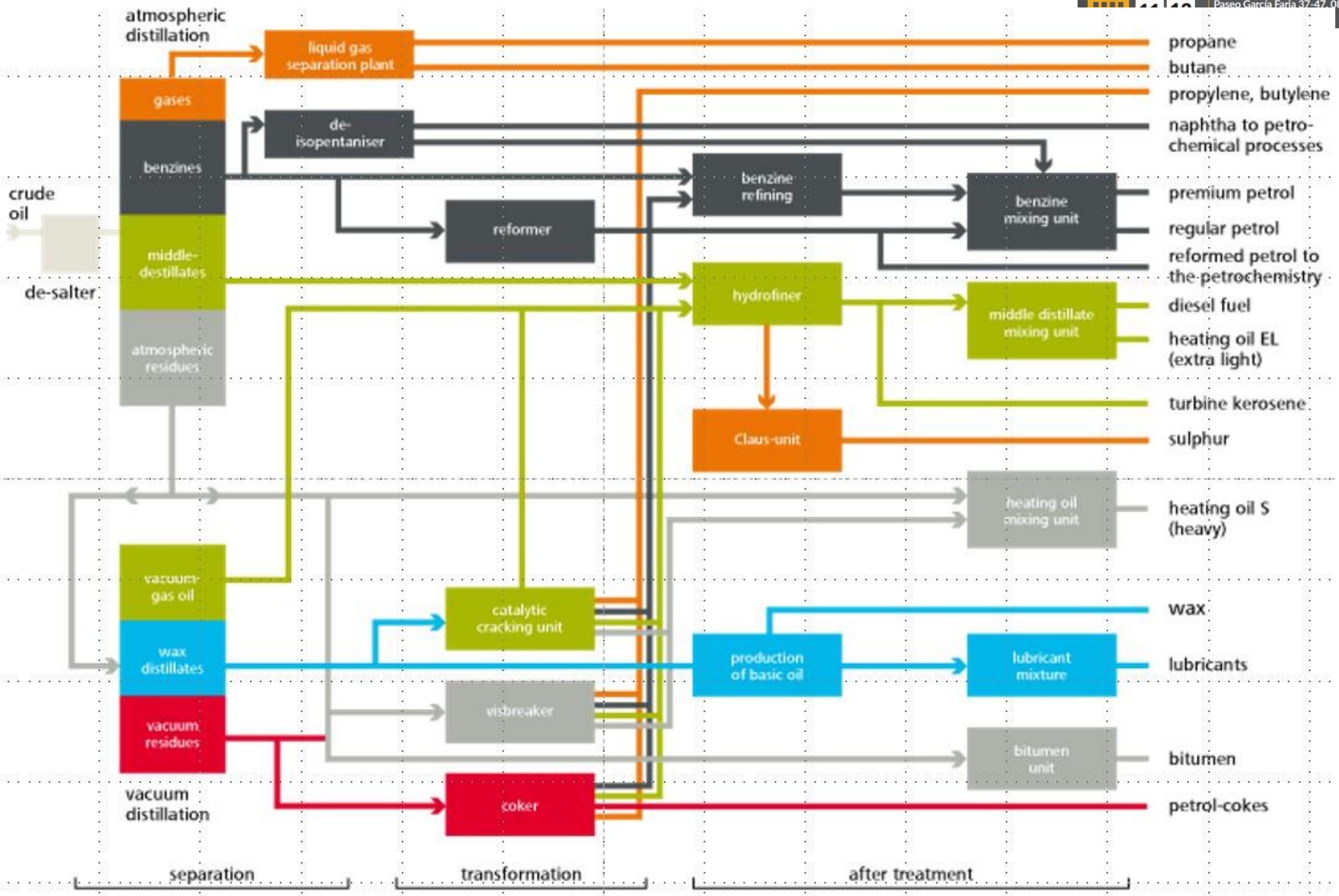

Source: MiRO "Vom Tanker zur Tankstelle" http://miro-ka.de/german/contact/P_PP.pps

# Decarbonization of refineries
## Transition towards sustainability

New feedstocks

- Sustainable Carbon
  - Biomass
  - Direct Air Capture
  - (Industrial $CO_2$)

- Sustainable Hydrogen
  - Biomass
  - RE electrolysis

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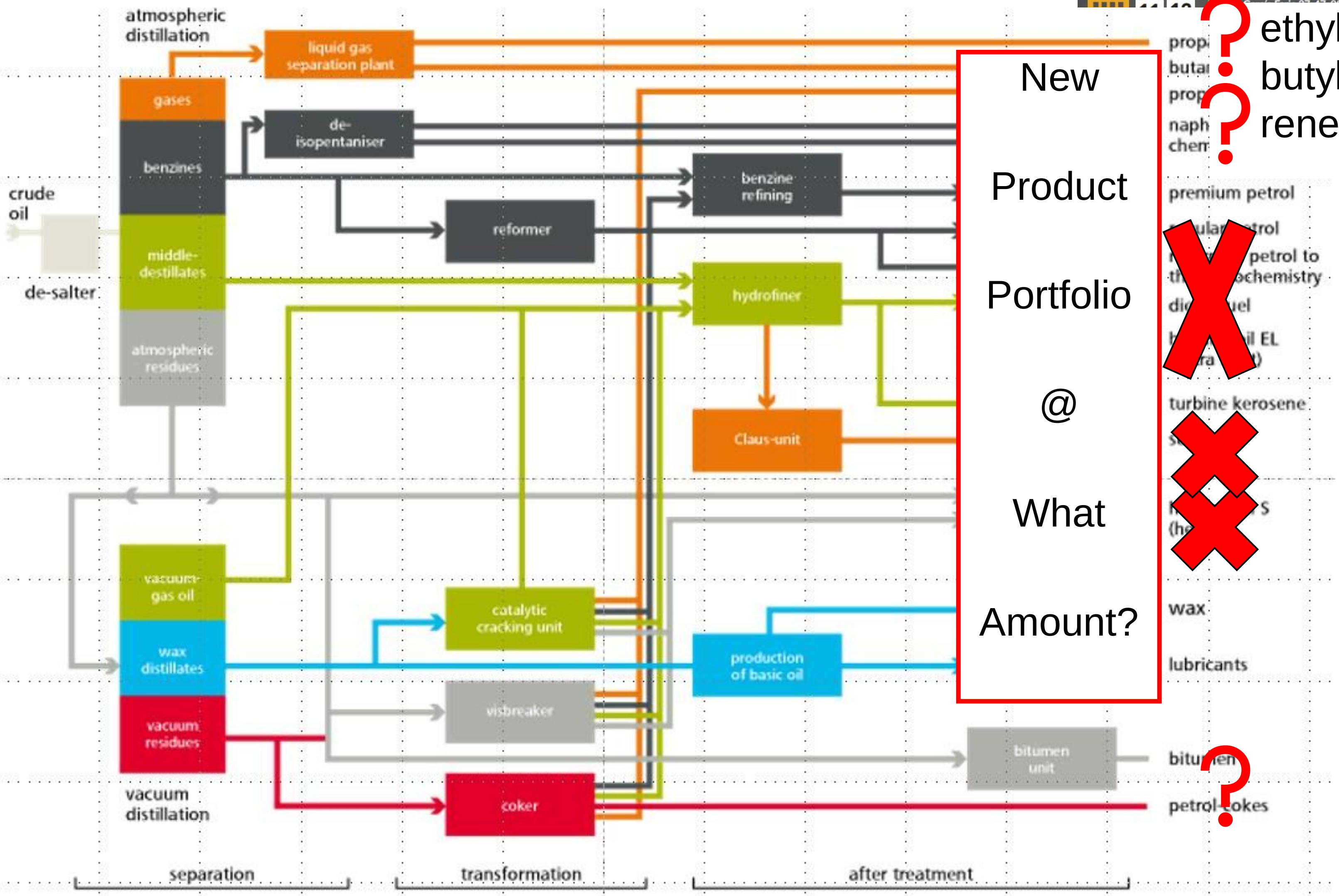


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New Product Portfolio @ What Amount?

ethylene, propylene, butylene from renewables?

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New feedstocks

- Sustainable Carbon
  - Biomass
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  - (Industrial $CO_2$)
- Sustainable Hydrogen
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  - RE electrolysis

New processes

- Biomass processing
- Methanation
- Methanol
- Fischer-Tropsch
- Mixed Alcohol
- …?

New Product Portfolio @ What Amount?

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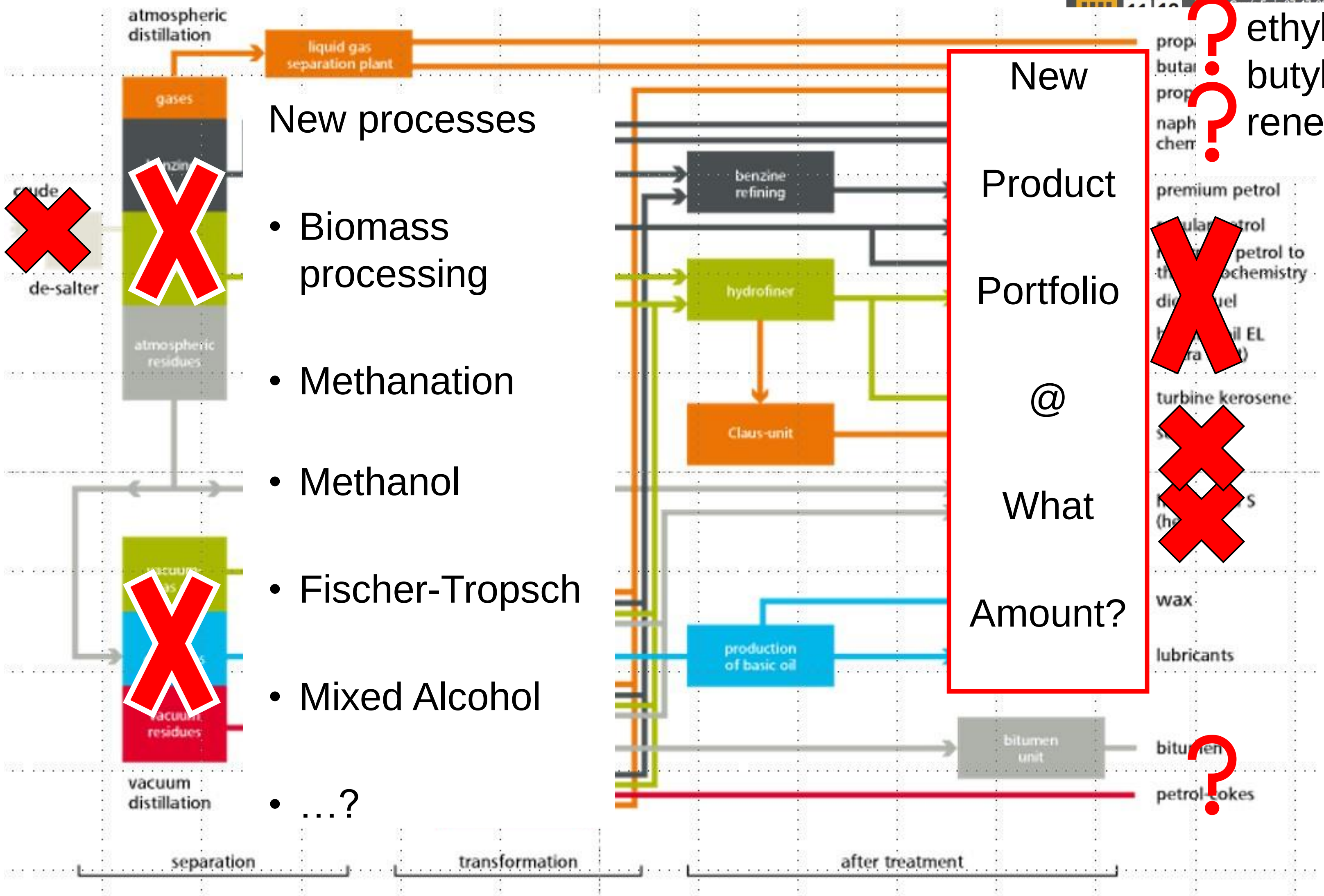
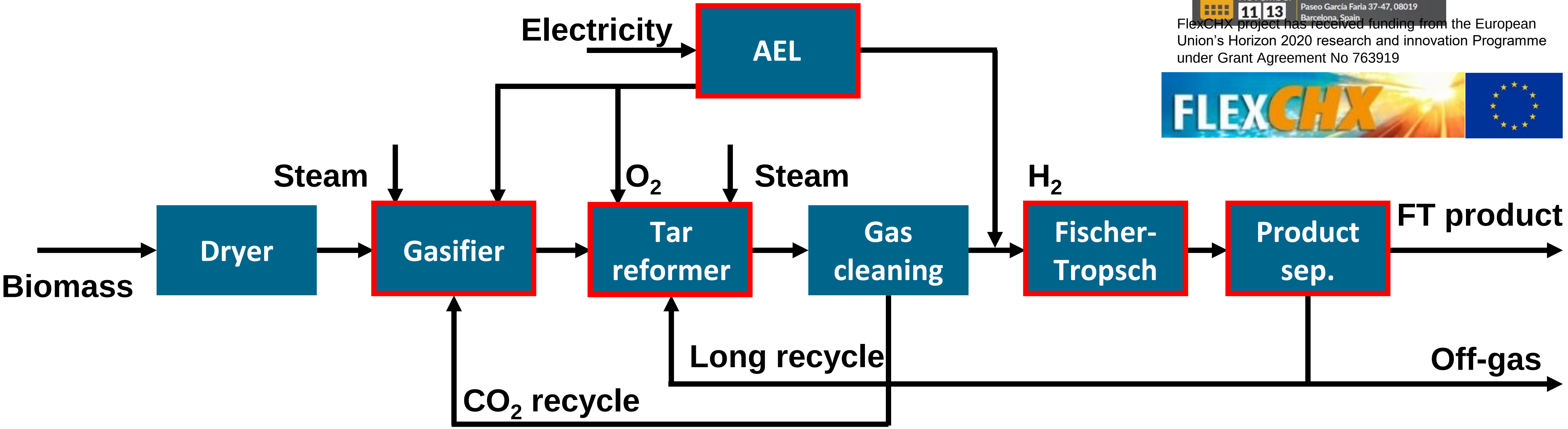



Source: MiRO "Vom Tanker zur Tankstelle" http://miro-ka.de/german/contact/P_PP.pps

# Example aviation
## Sustainable Aviation Fuels (SAF)

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



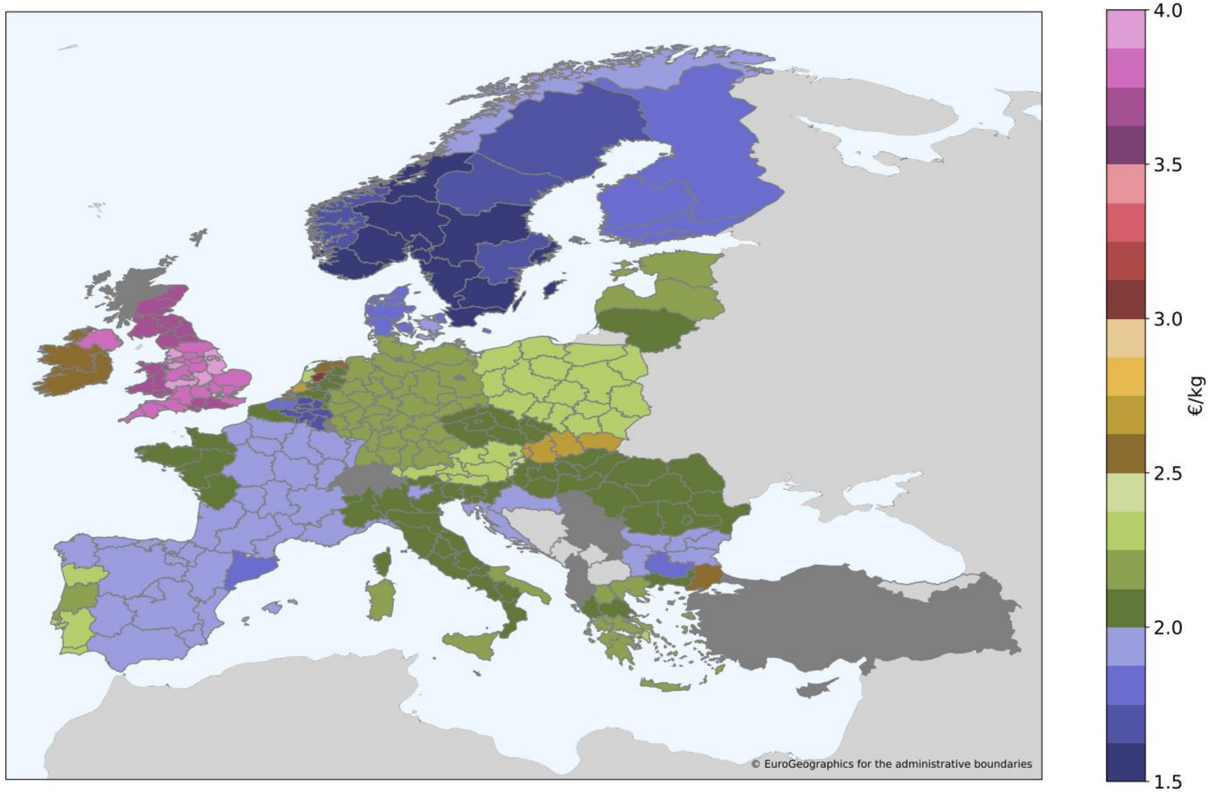

**Process details:**

- Plant size: 50, 200 and 400 $MW_{th}$
- Experimentally validated gasifier and reformer model (literature/project data)[1,2]
- AEL electrolyzer – most mature electrolysis technology [3]
- Fischer-Tropsch: Slurry bubble column reactor [4]
- Fischer-Tropsch product $C_{5+}$ to be converted in to SAF in central refinery

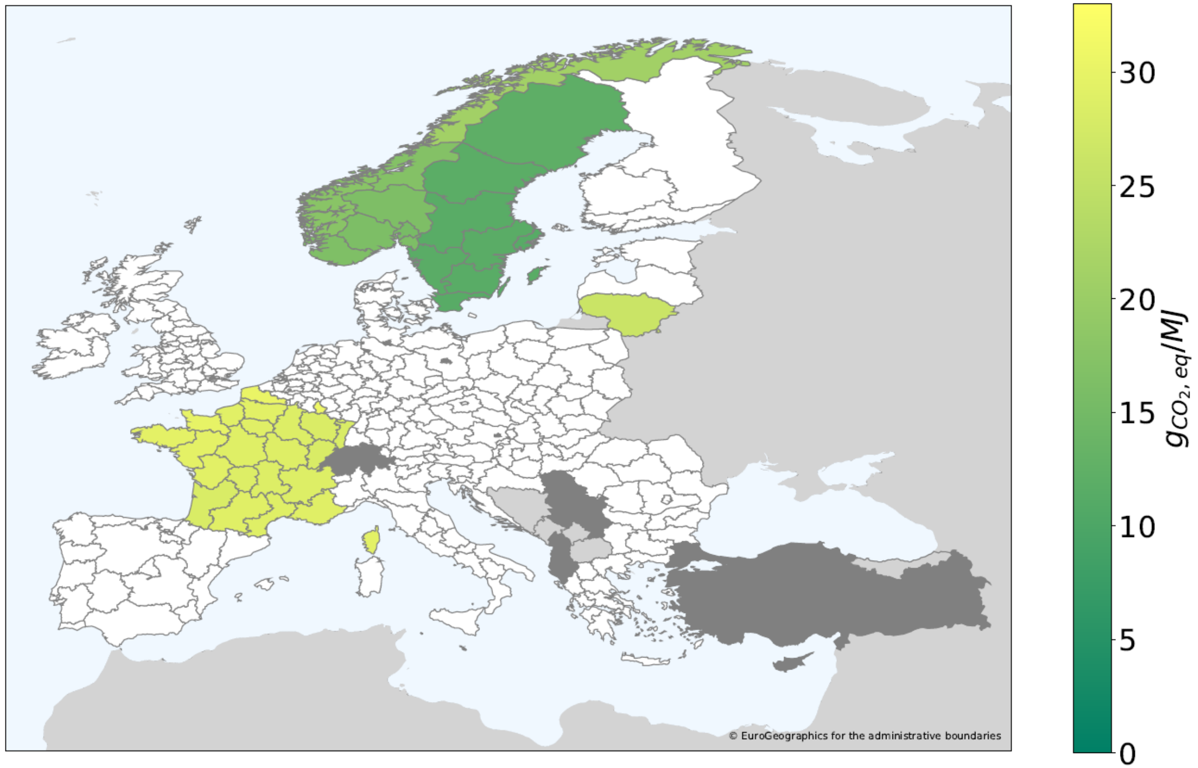
[1] Hannula, I. (2016). Hydrogen enhancement potential of synthetic biofuels manufacture in the European context: A techno-economic assessment. *Energy*, *104*, 199-212.
[2] Kurkela, E., Kurkela, M., & Hiltunen, I. (2021). Pilot-scale development of pressurized fixed-bed gasification for synthesis gas production from biomass residues. *Biomass Conversion and Biorefinery*, 1-22.
[3] Buttler, A., & Spliethoff, H. (2018). Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids: A review. *Renewable and Sustainable Energy Reviews*, *82*, 2440-2454.
[4] Todic, B., Bhatelia, T., Froment, G. F., Ma, W., Jacobs, G., Davis, B. H., & Bukur, D. B. (2013). Kinetic model of Fischer–Tropsch synthesis in a slurry reactor on Co–Re/Al2O3 catalyst. *Industrial & Engineering Chemistry Research*, *52*(2), 669-679.

# Grid connected PBtL:
## Northern Europe preferred

### Net production cost [$€_{2020}/kg_{C5+}$]:




### Fuel GWP 2020 [$g_{CO2,eq}/MJ$]:




| Net Production cost | Greenhouse Gas Abatement |
|---|---|
| + Abundant cheap woody biomass and low carbon electricity in Scandinavia | – High carbon footprint of power production in most European countries |

# DECARBONIZATION OF INDUSTRY

# Natural gas consumption

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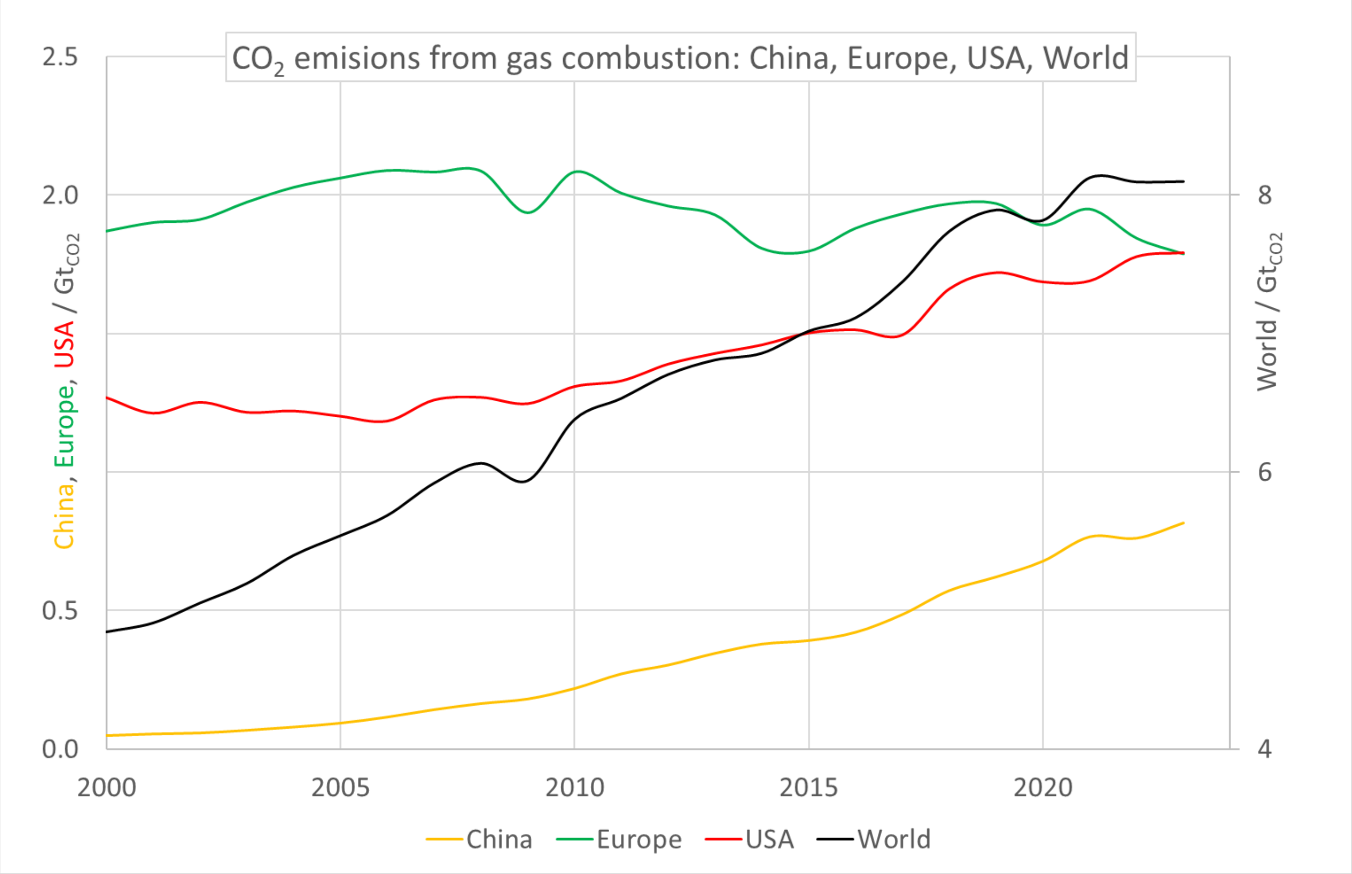
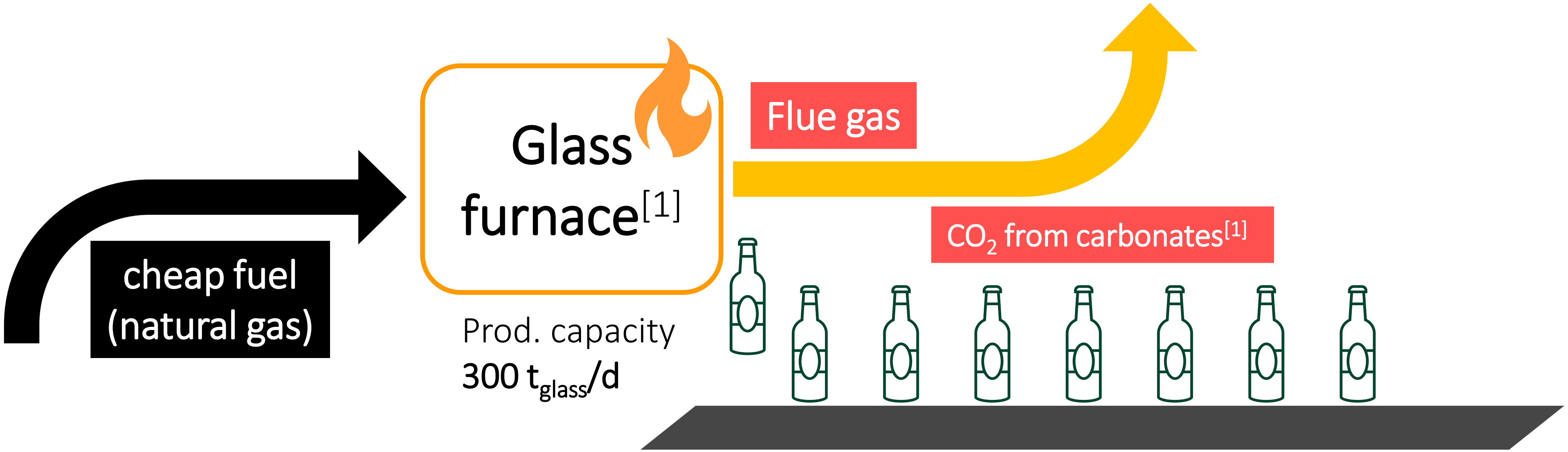
- Global gas consumption 2023: 40.1 GWh [1]
  - annual growth: +0.5 GWh, gradual rebalancing after 2022 gas price shock [2]
  - "expected to see solid growth in 2024" [3], no sign of mitigation
- Emissions: 8.1 $Gt_{CO2}$/a (additional along supply chain)
- Reduction to ZERO according to COP28?




[1] Gas consumption in TWh from https://ourworldindata.org/grapher/gas-consumption-by-country, 1 TWh natural gas = 0.319 Mt $CO_2$
[2] IEA (2022) https://www.iea.org/reports/gas-market-report-q1-2024
[3] Keisuke Sadamori, IEA Director of Energy Markets and Security, https://www.iea.org/news/global-gas-demand-set-for-stronger-growth-in-2024-despite-heightened-geopolitical-uncertainty,

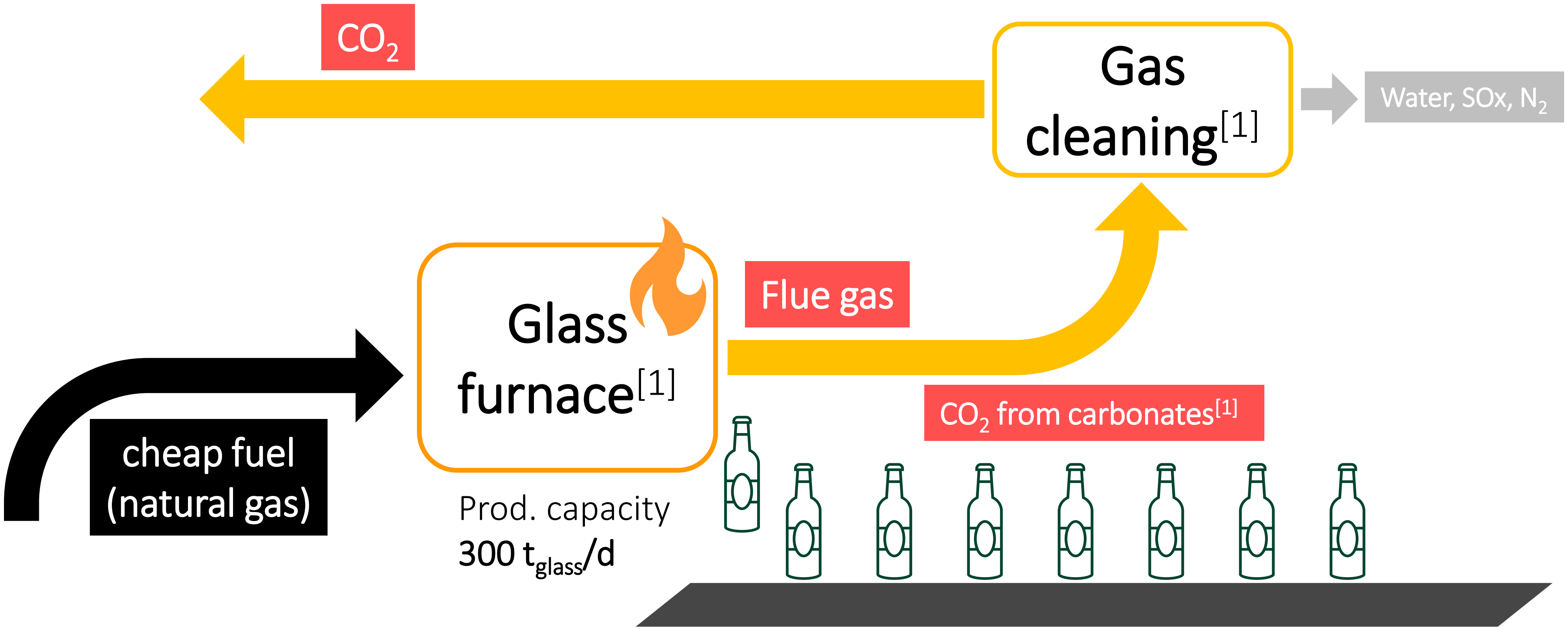
# Example glass furnace
## Standard oxyfuel glass production [1]




[1] Drünert et al. (2023) Techno-economic assessment of carbon capture and utilization concepts for a CO2 emission-free glass production, https://ustv-dgg-2023.sciencesconf.org/44970

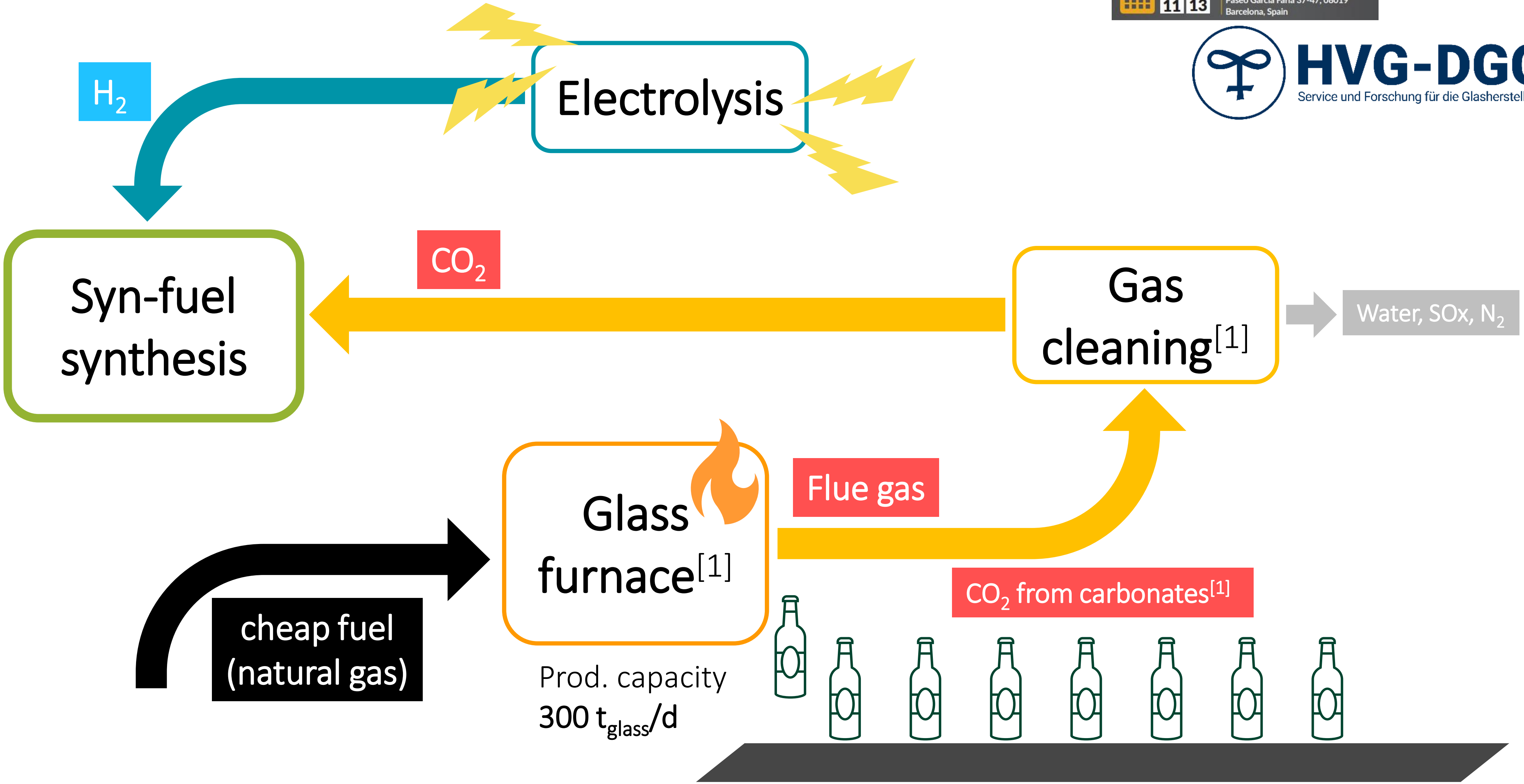
# Example glass furnace

## $CO_2$ capture of glass production [1]




[1] Drünert et al. (2023) Techno-economic assessment of carbon capture and utilization concepts for a CO2 emission-free glass production, https://ustv-dgg-2023.sciencesconf.org/44970

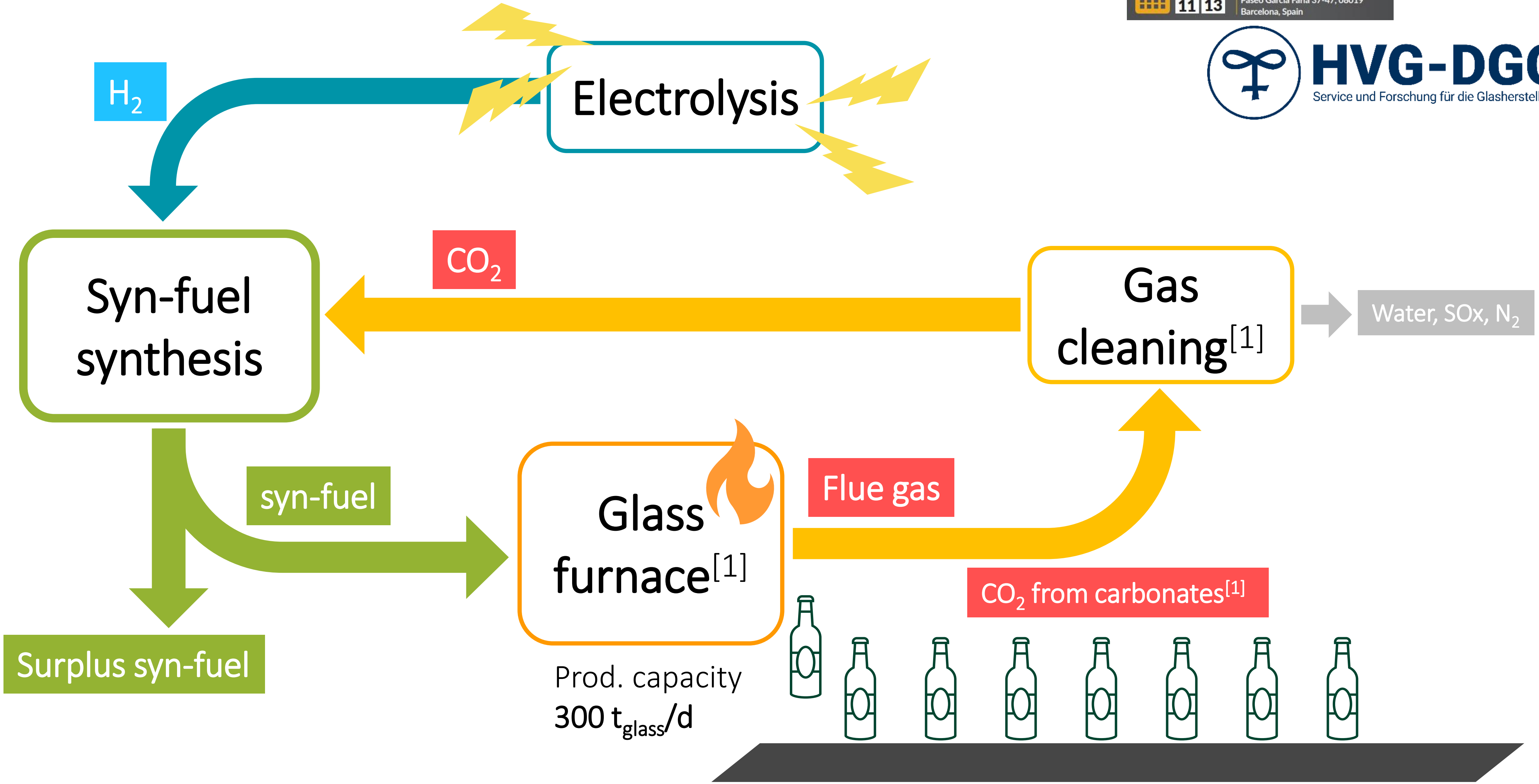
# Example glass furnace
## CCU for glass production [1]




[1] Drünert et al. (2023) Techno-economic assessment of carbon capture and utilization concepts for a CO2 emission-free glass production, https://ustv-dgg-2023.sciencesconf.org/44970

# Example glass furnace

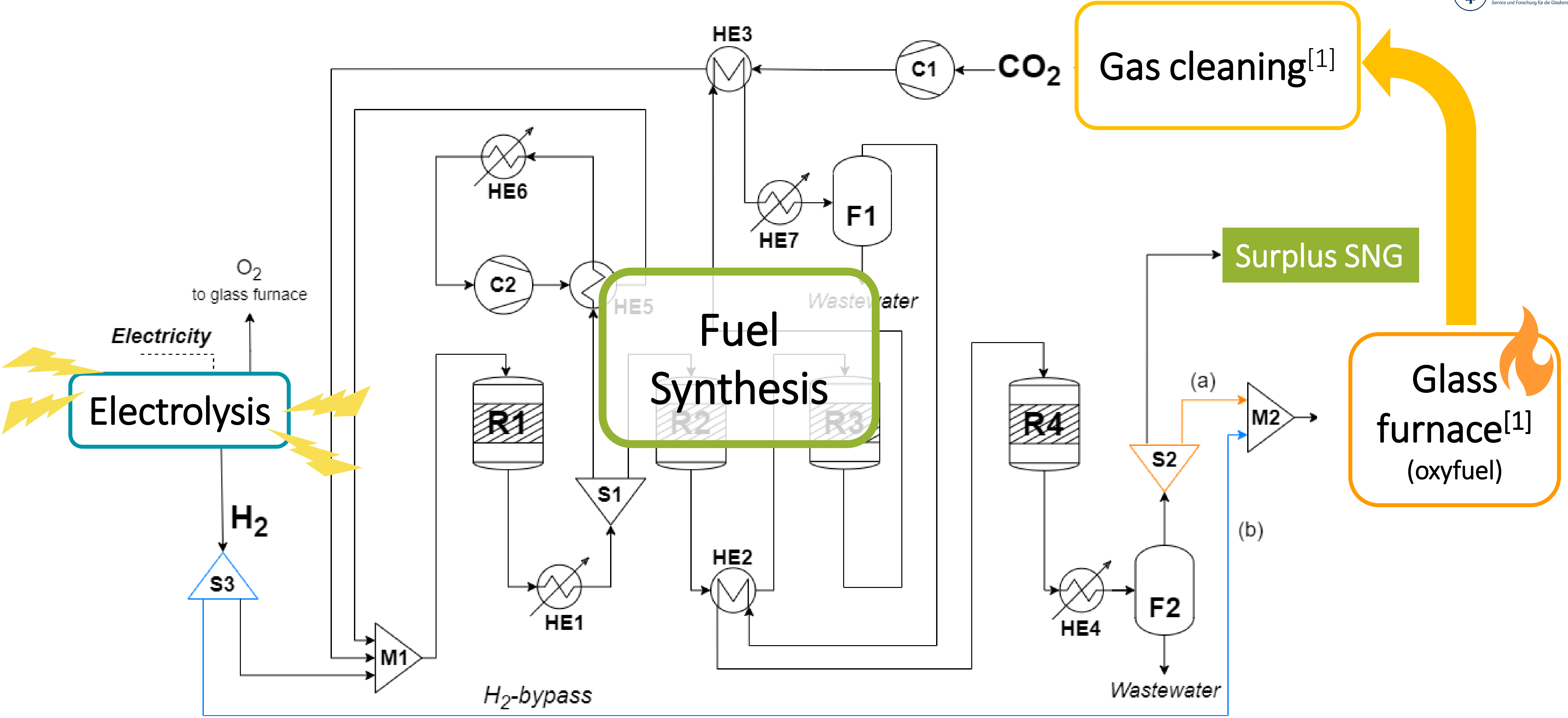
## $CO_2$-free glass production [1]




[1] Drünert et al. (2023) Techno-economic assessment of carbon capture and utilization concepts for a CO2 emission-free glass production, https://ustv-dgg-2023.sciencesconf.org/44970

# CCU process description

## Process flow diagram: SNG

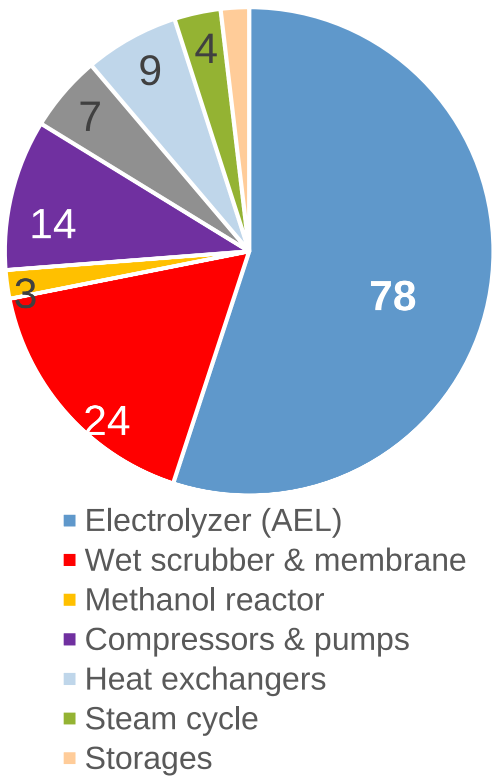


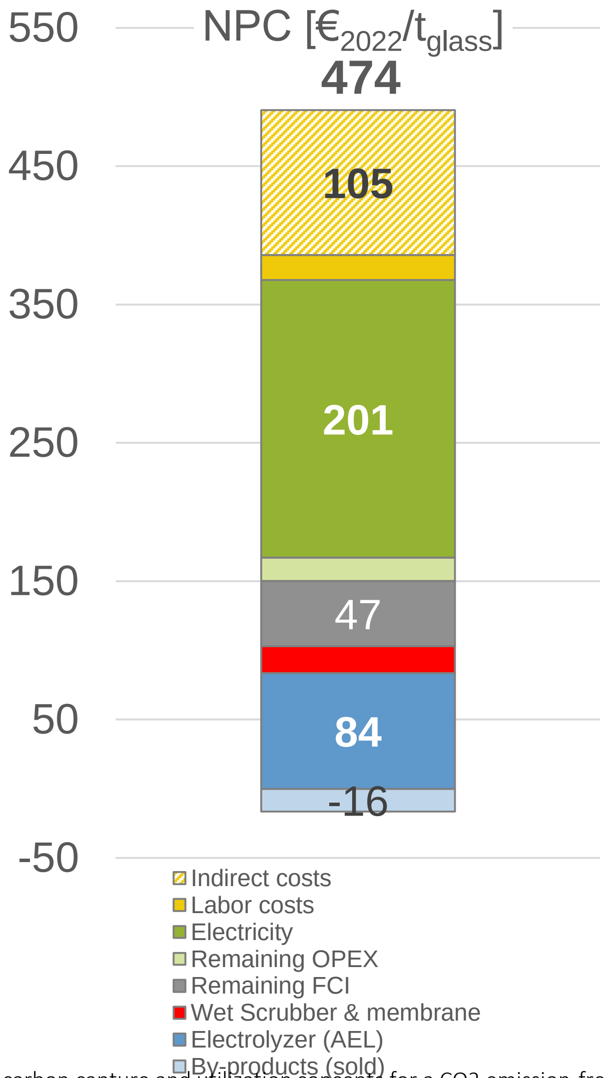

[1] Drünert et al. (2023) Techno-economic assessment of carbon capture and utilization concepts for a CO2 emission-free glass production.

# Decarbonization of basic industry
## Example: $CO_2$-free glass production [1]

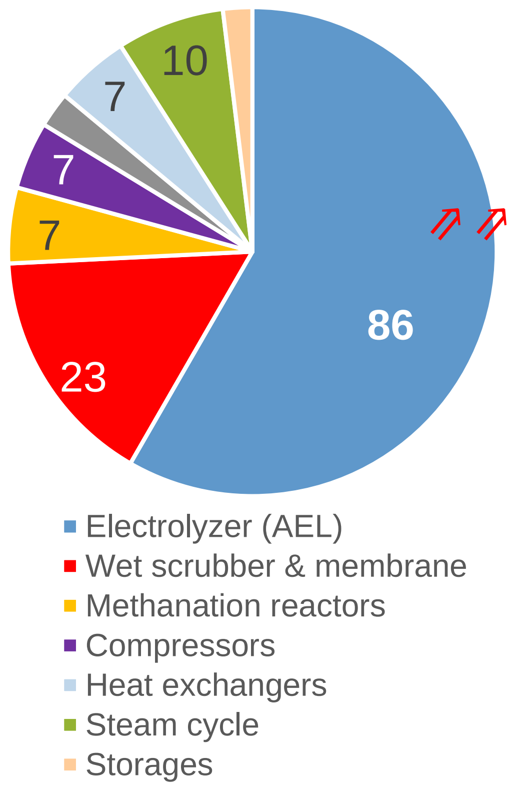
**Synthetic fuels from oxyfuel offgas CCU:** DE, 2022, 300 t/d container glass

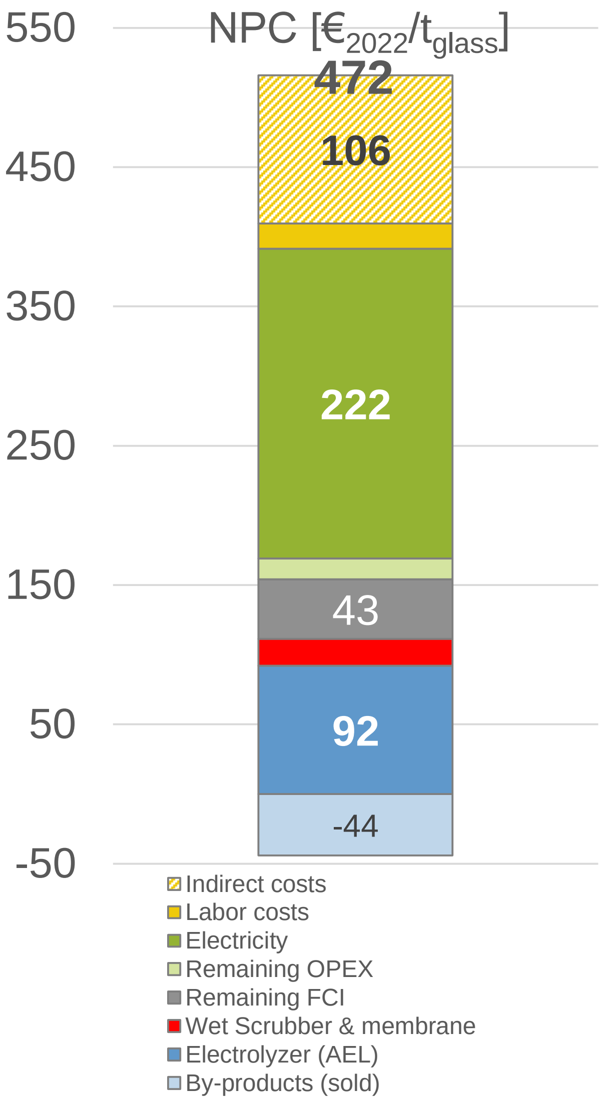
### Syn-MeOH




### SNG




[1] Drünert et al. (2023) Techno-economic assessment of carbon capture and utilization concepts for a CO2 emission-free glass production, https://ustv-dgg-2023.sciencesconf.org/44970

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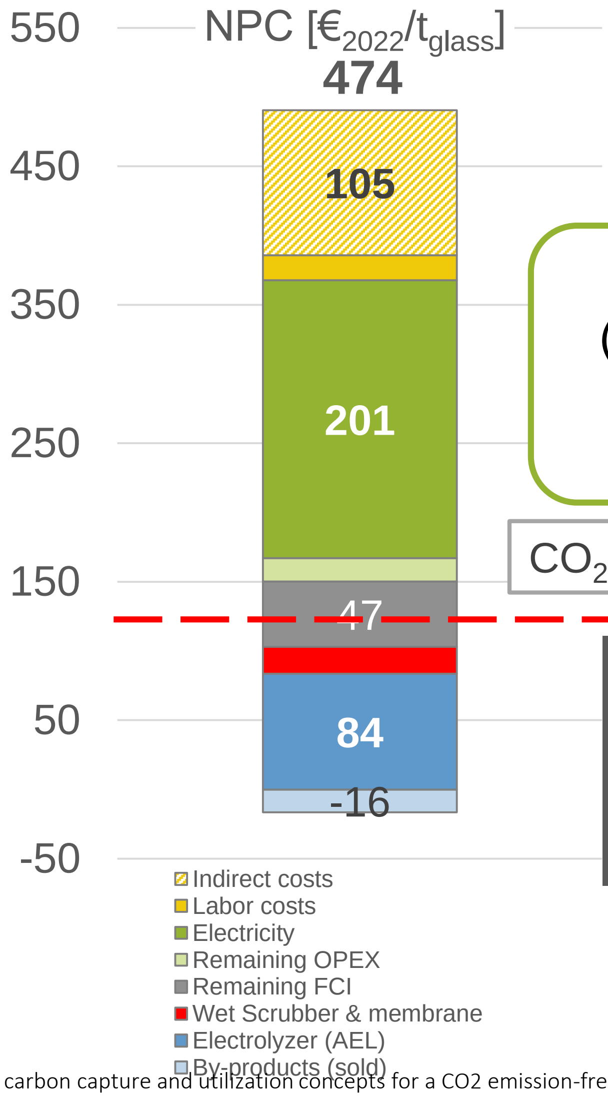
# Decarbonization of basic industry
## Example: $CO_2$-free glass production [1]

**<u>Synthetic fuels from oxyfuel offgas CCU:</u>** DE, 2022, 300 t/d container glass

**Syn-MeOH**

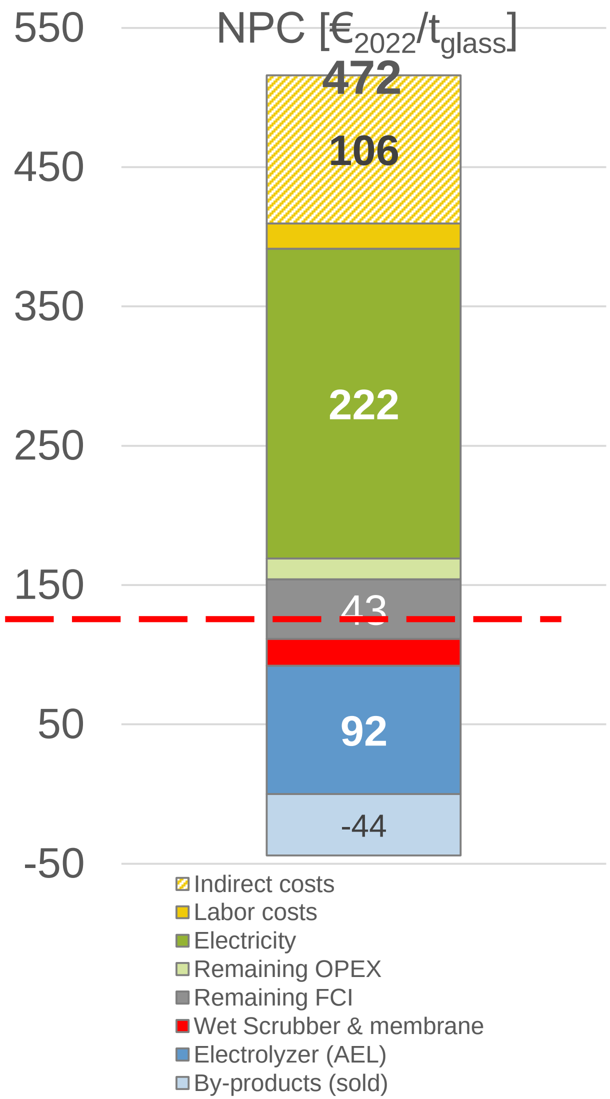



**SNG**

Conventional beer bottle:
(330 g) ≈15 ct. $€_{2022}$/bottle
**Eco-friendly** beer bottle
ca. **26 ct.** $€_{2022}$/bottle ⇗ ⇗

$CO_2$-abatement costs: **643 $€_{2022}/t_{CO2}$**

**130 $€_{2022}/t_{glass}$**
**Natural gas**
**Avg. market price**




[1] Drünert et al. (2023) Techno-economic assessment of carbon capture and utilization concepts for a CO2 emission-free glass production, https://ustv-dgg-2023.sciencesconf.org/44970

# CONCLUSIONS / OUTLOOK

# Outlook

- Climate change mitigation is urgent on a global scale
  - GHG emission reduction required from 35.8 Gt/a to ZERO
- Developed countries need to provide technical solutions, international regulations need to ensure its commercial viability
  - Europe and others can be demonstrators, large emitters have to adapt
- Techno-economical and ecological assessment can provide transparent, technology-agnostic guidance
  - Choosing preferred technologies and locations
  - R&D demand and optimization potential
  - Purposeful regulation
- DLR standardized methodology is globally applicable ➔

# Partner search towards Decarbonization

## Looking for research partner

- Fuel consumer on the way to sustainable transport
  - Explore new fuels and its impact on your environmental footprint and costs
- Energy / fuel / chemicals supplier with pressure to become sustainable
  - Explore the integration of renewables into your production scheme
  - Find electrolyzer applications that fit into your production scheme
- Technology supplier for fuels and chemicals
  - Explore new process routes that include renewable feedstocks
- Technology developer for sustainable products
  - Search for the economic and ecological optimal production
  - Quantify opportunities for improvement, localize bottlenecks
  - Predict new processes market rollout

Monday, 2024/11/11, Barcelona, Spain

CONFERENCE SESSION II
Carbon Fibres, Composites & Organic Compounds


# THANK YOU FOR YOUR ATTENTION! QUESTIONS?

**Decarbonization of Industry and Transport – interlinked Carbon Cycles**

Ralph-Uwe Dietrich, Nathanael Heimann, Simon Maier,
Yoga Rahmat, Julia Weyand

ralph-uwe.Dietrich@dlr.de, (www.DLR.de/tt)

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