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CLOSED CO_2 CYCLES IN THE GLASS PRODUCTION

A techno-economic evaluation

DLR: F. Moser, S. Maier, R.-U. Dietrich
HVG: F. Drünert, B. Fleischmann

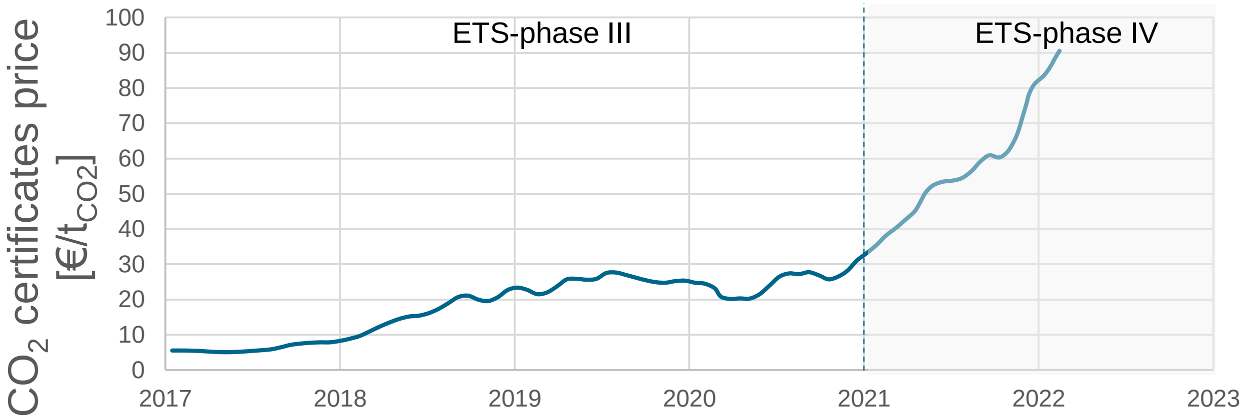
HVG-DGG
Service und Forschung für die Glasherstellung

DLR

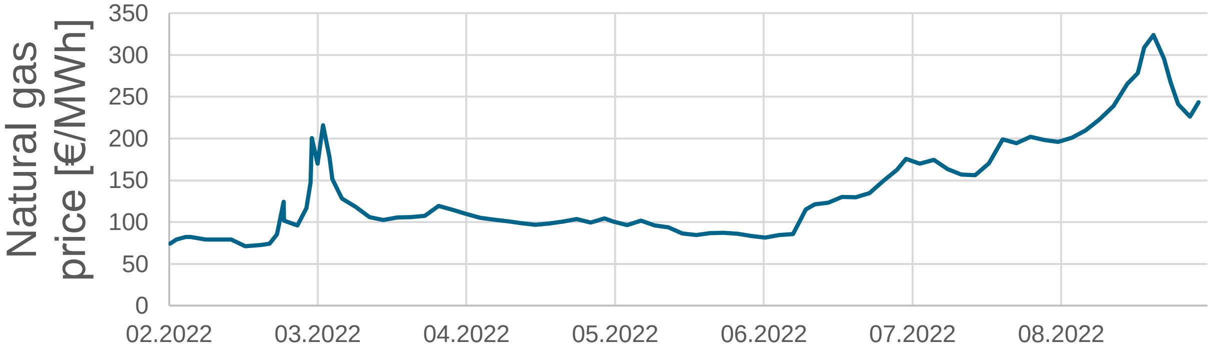
Motivation – Demand for greener glass production

- Emissions Europe in year 2020 [1]
  - 3700 million t_{CO_2eq}
- Emissions glass industry in Europe [2]
  - 22 million t_{CO2}/a
- High specific emissions
  - > 300 kg_{CO2}/t_{glass}
  - CO_2 certificates started playing a role
- Glass-furnace
  - Up ot 85% of the plants energy
- Glass furnace can be turned off …
  - Natural gas price volatility

European Union Emissions Trading Scheme [3]



Gas price Trading Hub Europe, Germany [4]



[1] Statista (2022). "Total greenhouse gas emissions in the European Union from 1990 to 2020." from https://www.statista.com/statistics/780410/total-greenhouse-gas-emissions-european-union-eu/
[2] CINEA (2022). "How LIFE is reducing emissions from glass production." from https://cinea.ec.europa.eu/news-events/news/how-life-reducing-emissions-glass-production-2022-03-16_en
[3] Kraftwerke, N. (2021). "How Does Emissions Trading Work?". from https://www.next-kraftwerke.com/knowledge/emissions-trading-scheme-ets#phase-iv-2021-to-2030
[4] Bundesnetzagentur (2022). "TTF Gaspreis." from https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Versorgungssicherheit/aktuelle_gasversorgung/grafik_gaspreis.html

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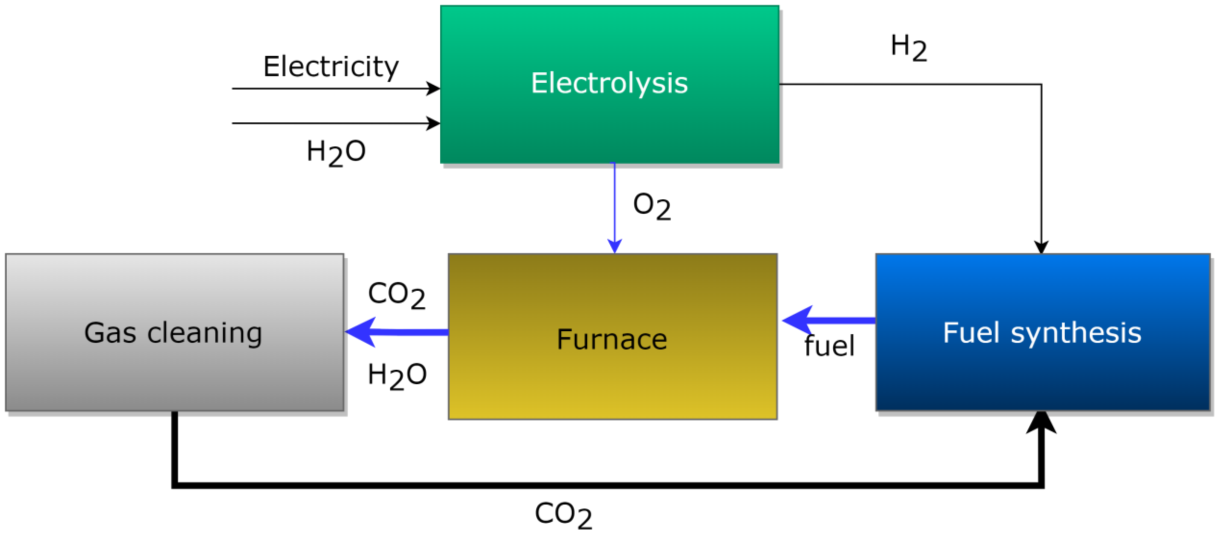

Figure – Carbon Capture and Utilization (CCU) process

[1] https://www.statista.com/statistics/780410/total-greenhouse-gas-emissions-european-union-eu/
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Motivation – Demand for greener glass production

Methane-route: Optimal process layout? Cost minimization?

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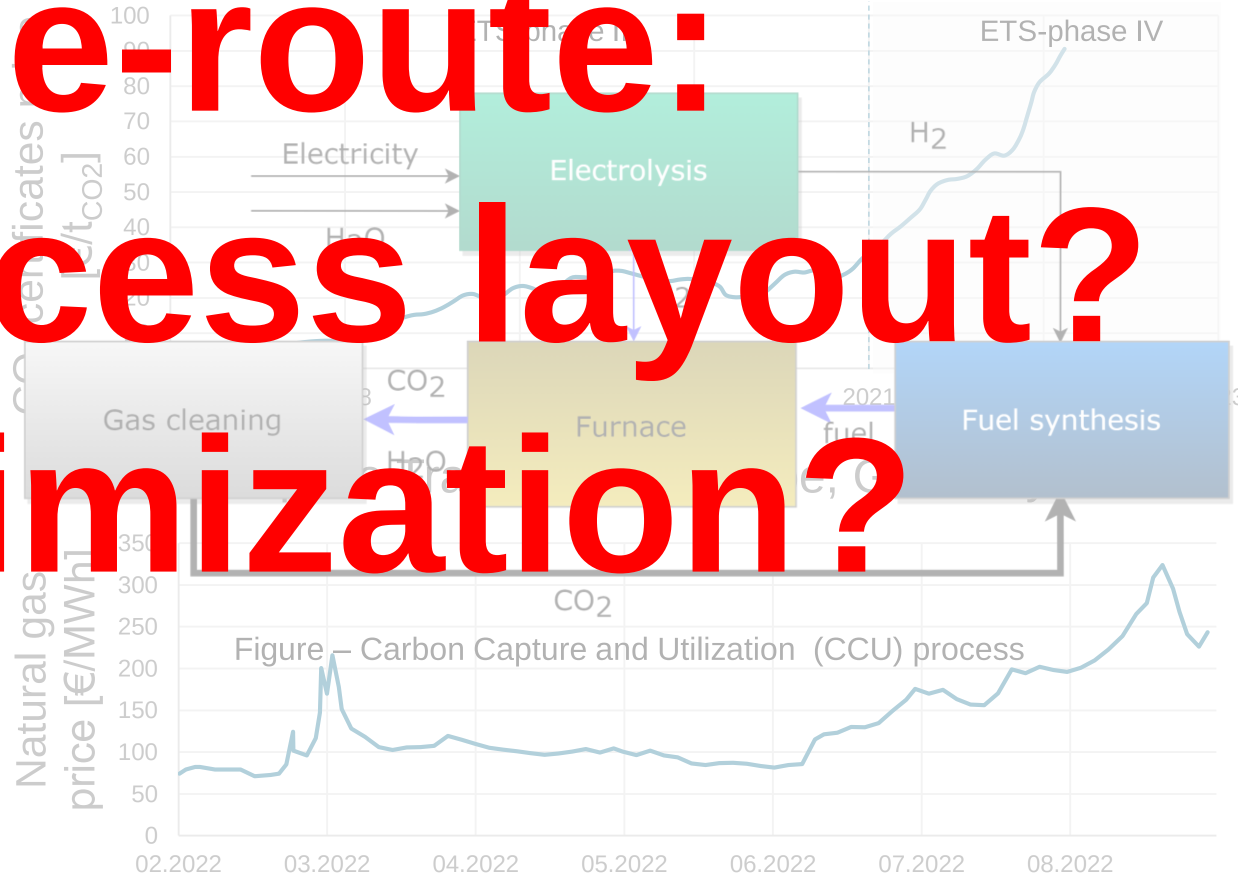

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Agenda

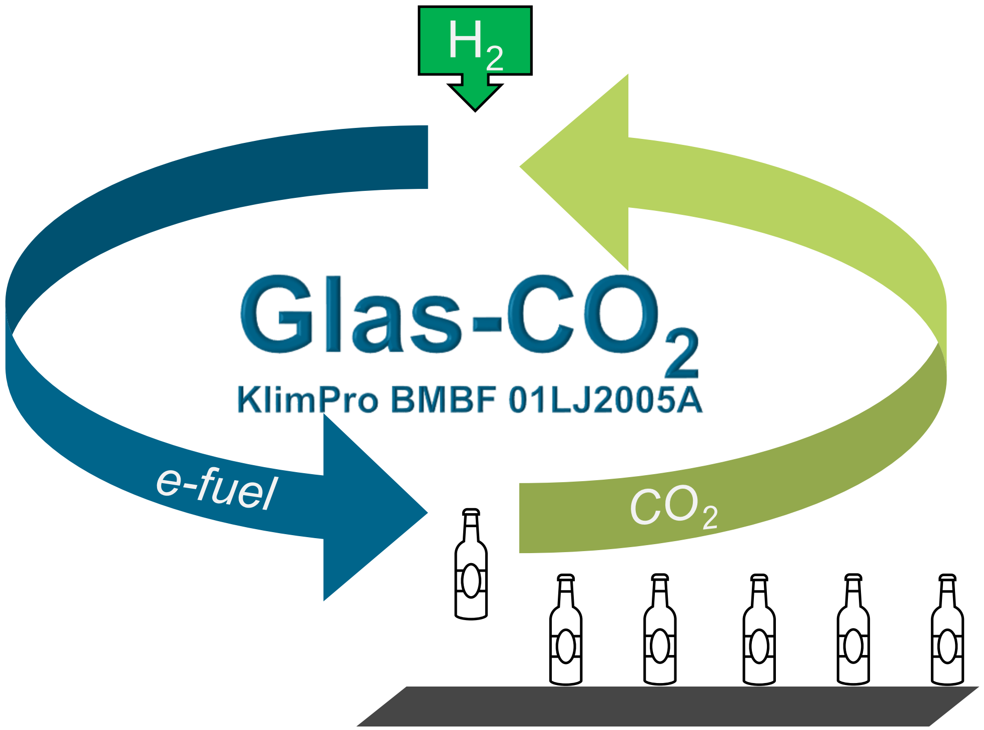
- Motivation
- Objective / Solution
- Methodology
  - Techno- economic assessment
  - Glass furnace specifications
  - Appropiate technologies
  - Economic assumptions
- Results
  - Technical assessment
  - Economic assessment
  - Sensitivity analysis
- Summary
- Outlook

Approach – Techno- economic assessment (TEA) of CCU in the glass industry

- Glass production details (HVG)
- CCU Know-How (DLR)
- Recycle of oxyfuel combustion gases
- Evaluated using the German boundary conditions
  - Day-ahead-market
- Surplus CO_2 from carbonates also converted

Glass prod. expertise: HVG-DGG [1] Service und Forschung für die Glasherstellung

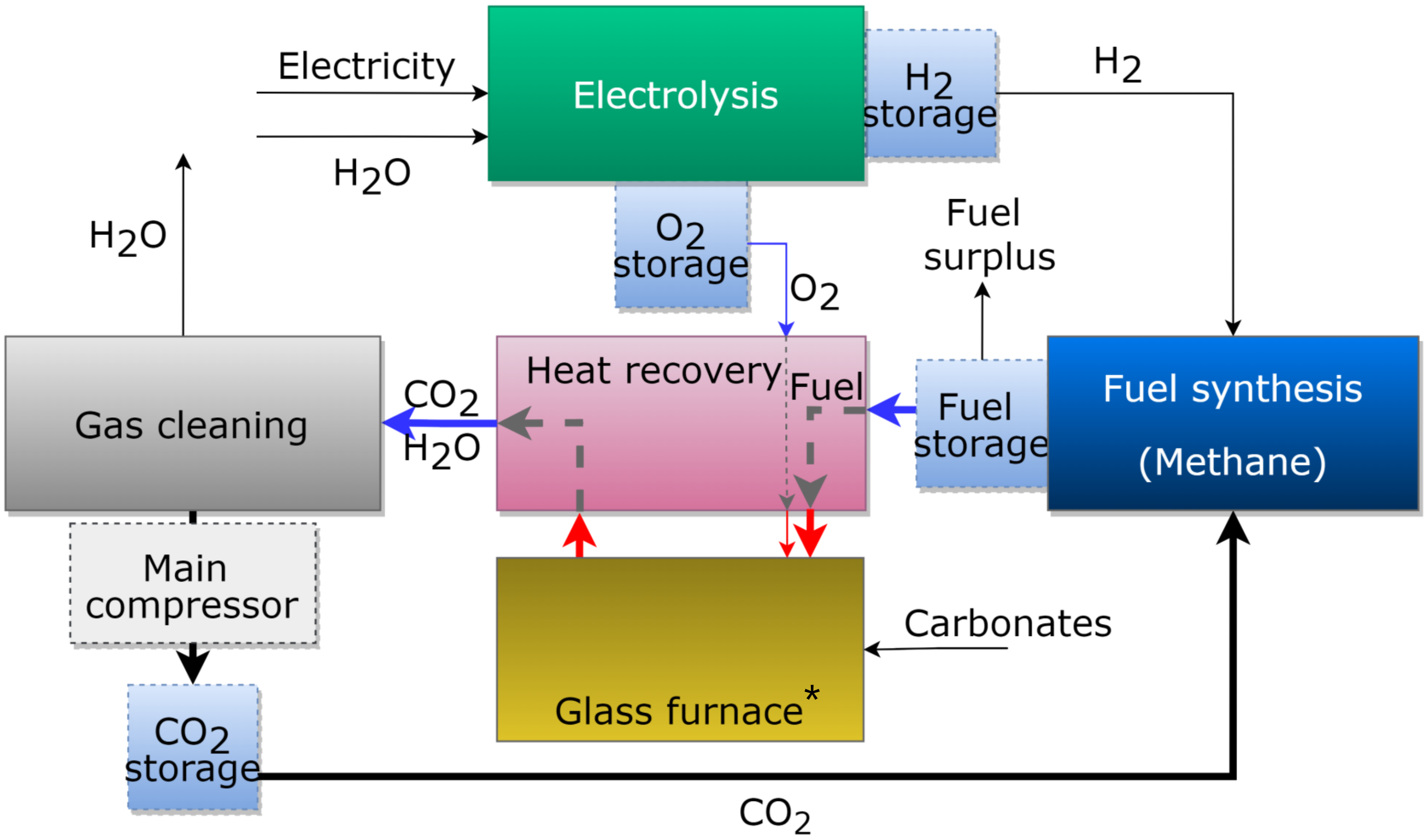
Process assessment: DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center



[1] Research associaton of the German Glass Industry (germ. Hüttentechnische Vereinigung der Deutschen Glasindustrie e. V.)

Methodology – CCU process concept for methane

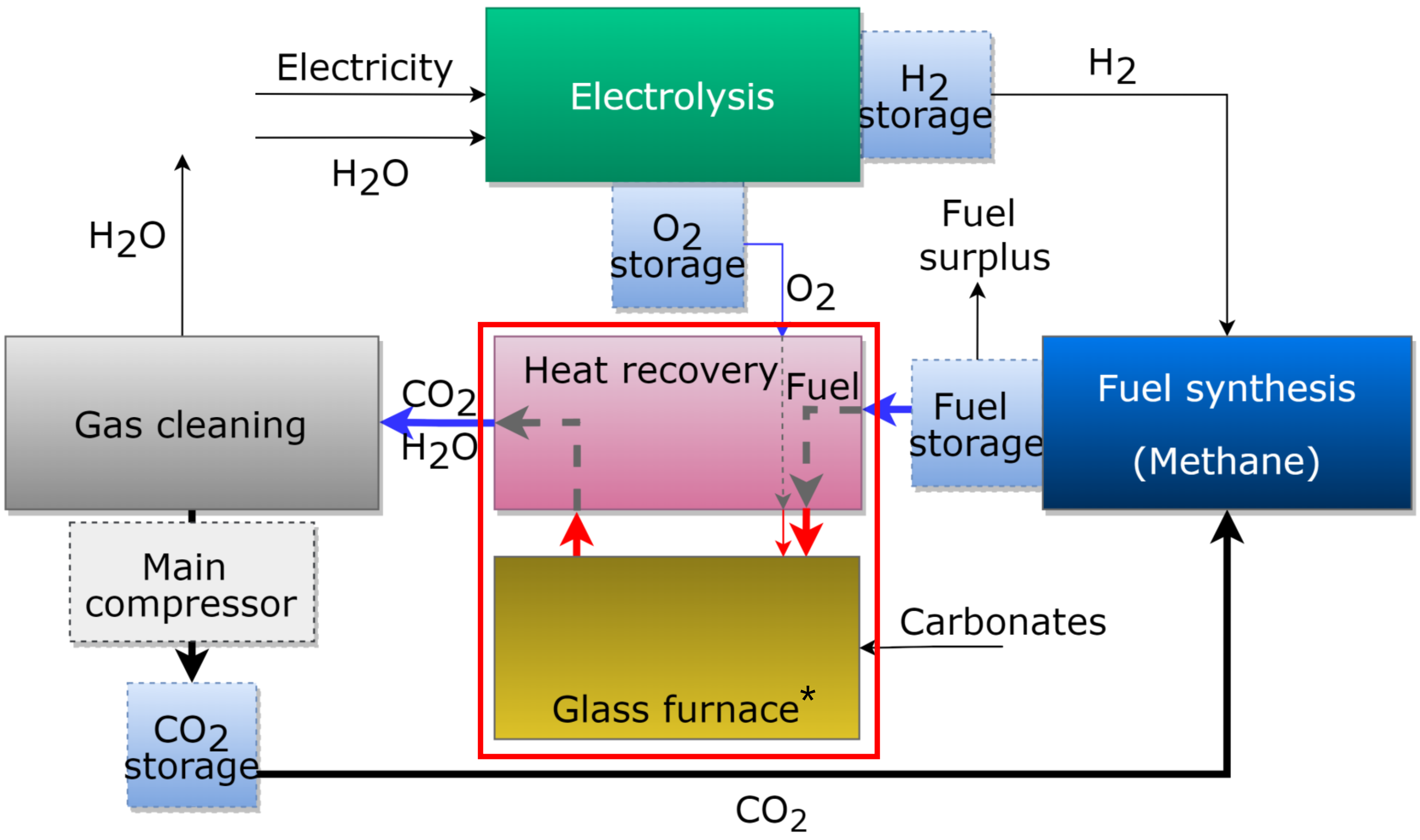
- Oxyfuel furnace
- Heat recovery



*Glass furnace is assumed as given

Methodology – CCU process concept for methane

- Oxyfuel furnace
- Heat recovery
- Gas cleaning:
  - Wet scrubber
  - Hydrogenation
  - Guard beds
- PEM-Electrolysis
- Methane synthesis
  - TREMP™-process



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Methodology - Process parameters of the glass furnace

Parameter	Value	Unit
Capacity	300	t_{glass}/day
Heat requirement [1]	4.2	MJ/kg_{glass}
Oxygen-fuel ratio (λ)	1.01	-
H_2 fuel - concentration	<10	$\%_{mol}$
Batch CO_2 in exhaust gases	15	$\%_{mol}$
Total CO_2 in exhaust gases	45	$\%_{mol}$

- Exhaust gases: CO_2, H_2O
  - Many impurities: SO_x, HCl, dust, …
- Preheating of O_2 and fuel
- Glass furnace is assumed as given

Figure - Glass furnace in operation[2]

[1] Scalet, B. M. et al. (2013). JRC Reference Report: Best available techniques (BAT) reference document for the manufacture of glass. Industrial Emissions Directive 2010/75/EU, p. 234

[2] © C-Capture (2022). "C-Capture to demonstrate carbon capture capabilities for glass manufacturing ". from https://c-capture.co.uk/c-capture-to-demonstrate-carbon-capture-capabilities-for-glass-manufacturing-with-pilkington-united-kingdom-limited/.

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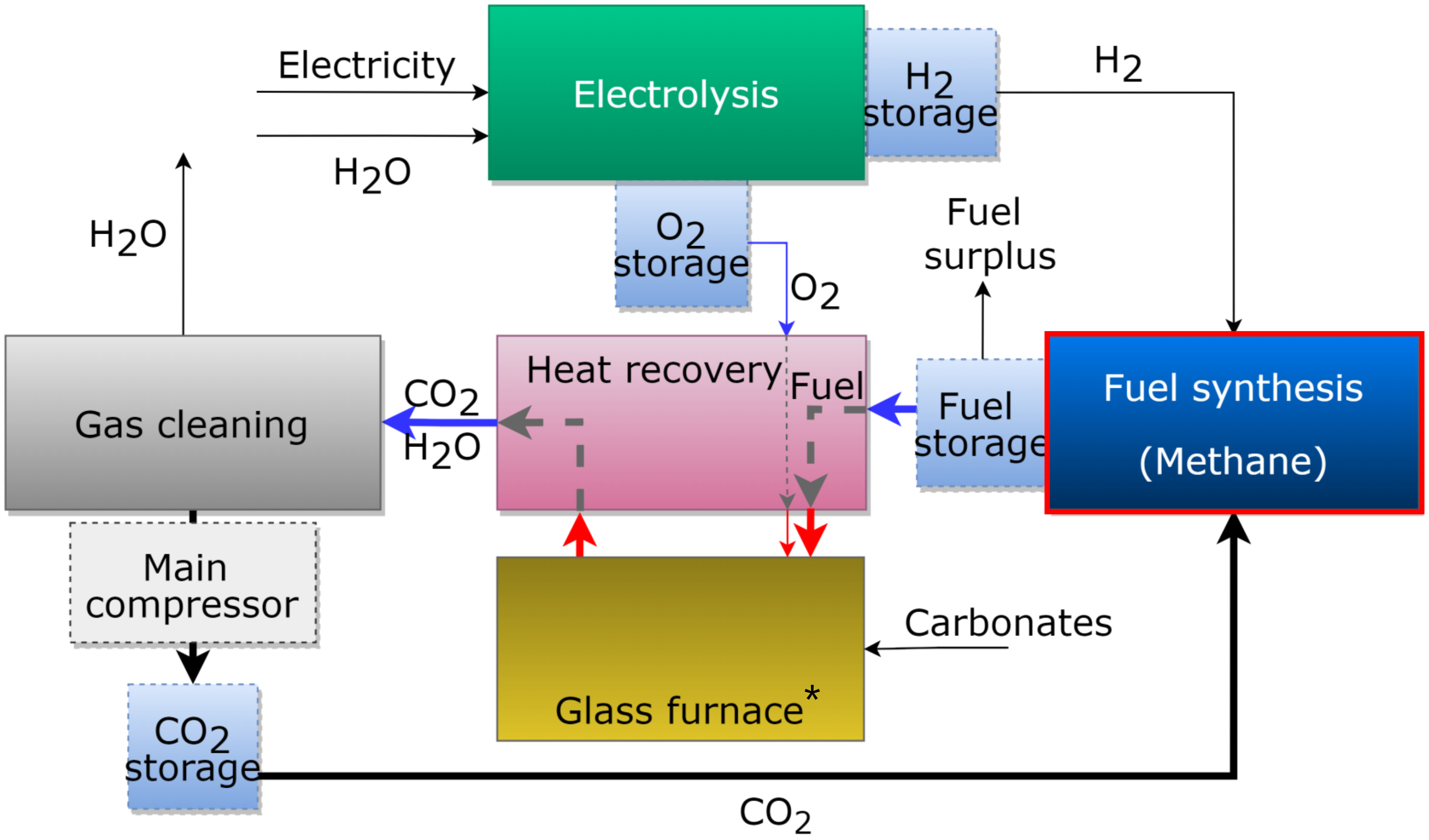

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Methodology – Methanation process

TREMP

- Temp. max catalyst 800°C [1]
  - $\uparrow T_{\max} \leftrightarrow \downarrow Irreversibilities$
- SNG composition: 95% CH_4
  - 3.3% H2
- Catalyst: Ni/Al2O3 (22% Ni)
- Operating pressure: 30 [bar]
- Kinetic model: Klose et. al [2]

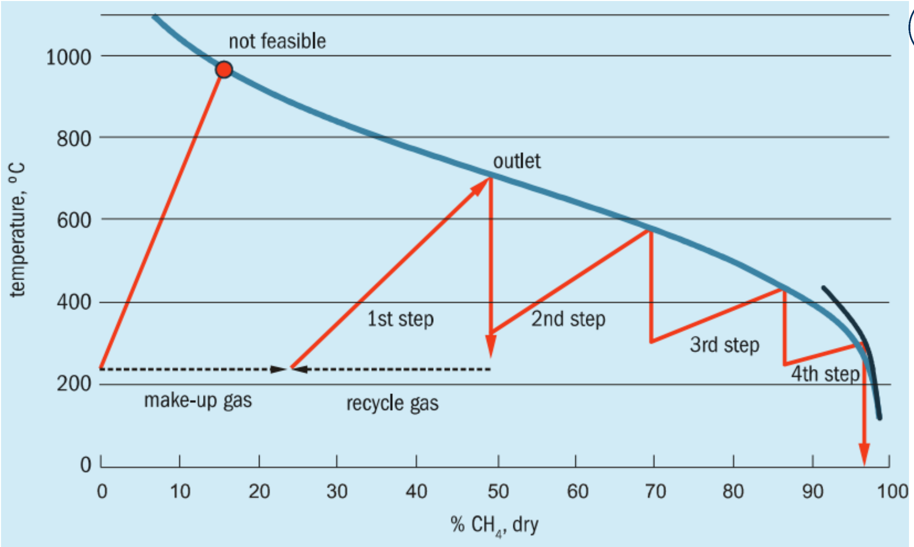

Figure – Equilibrium curve for the methanation process [1]

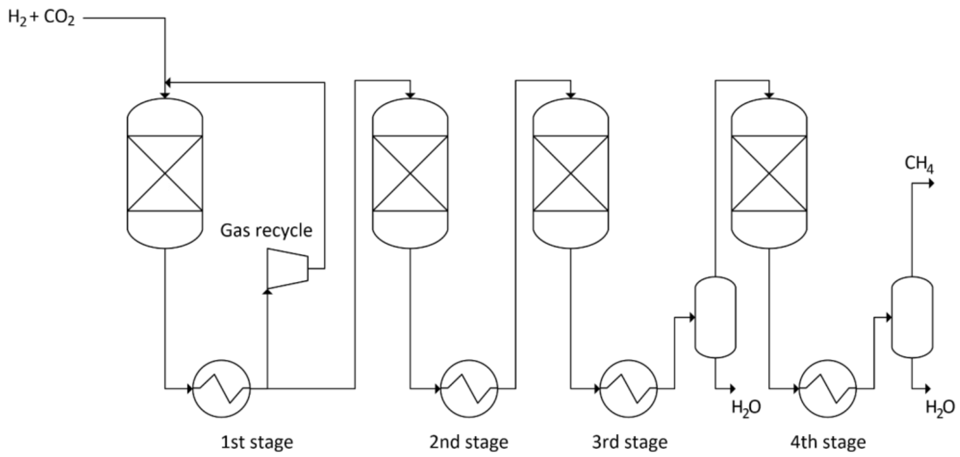

Figure - Topsøe's Recycle Energy-Efficient Methanation Process

[1] © Topsøe, H. (2011). From coal to clean energy.
[2] J. Klose, Kinetics of the methanation of carbon monoxide on an alumina-supported nickel catalyst, Journal of Catalysis, 85 (1984) 105-116.

Methodology – CCU process concept for methane

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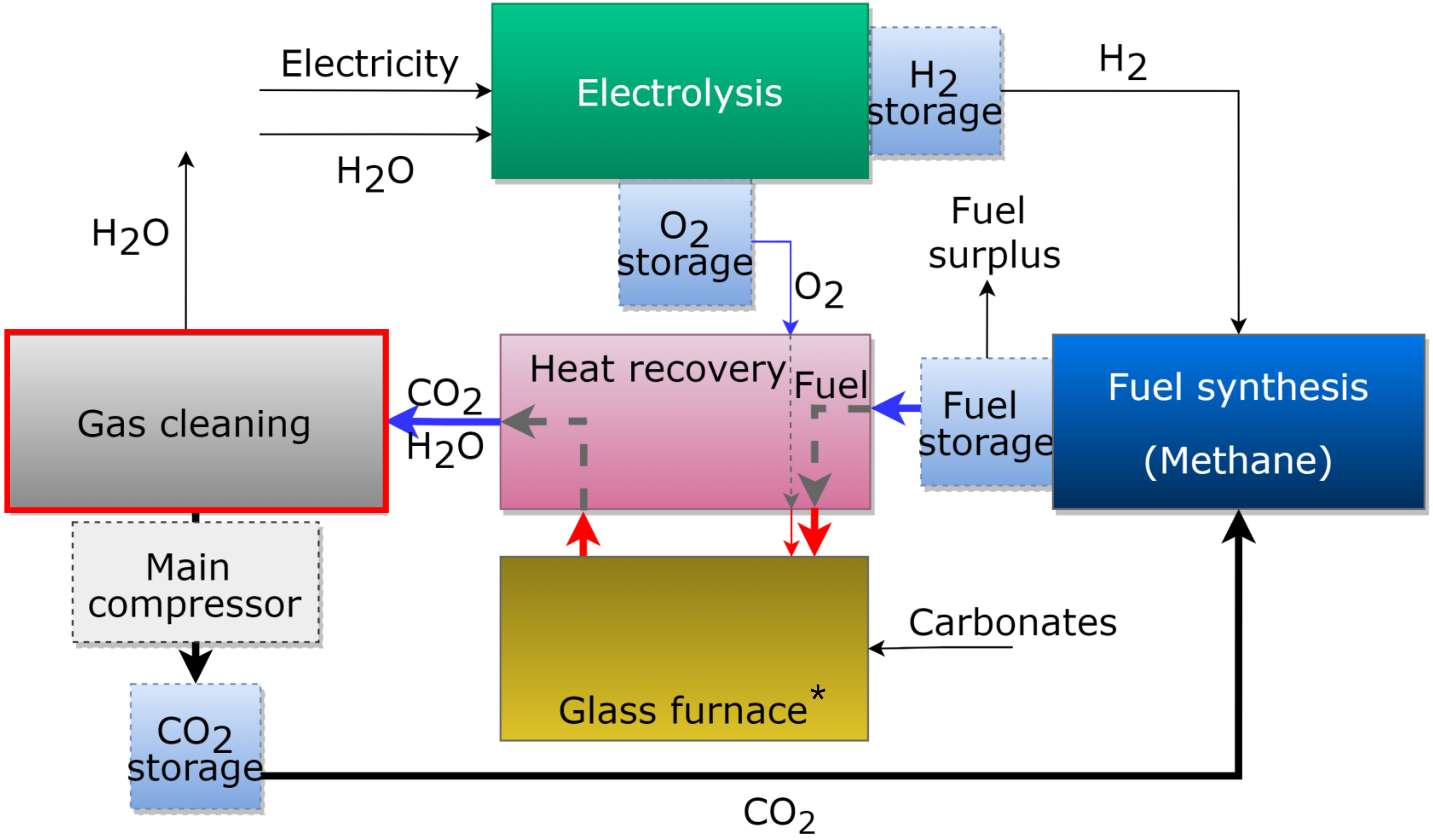

*Glass furnace is assumed as given

Methodology – Contaminants in the flue gases

Catalyst´s poisons

[1] Barbarossa, V. and G. Vanga (2011). Methanation of carbon dioxide. XXXIV Meeting of the Italian section of the Combustion Institute–Roma.
[2] Bartholomew, C. H. (1987). Mechanisms of nickel catalyst poisoning. Studies in Surface Science and Catalysis, Elsevier. 34: 81-104.

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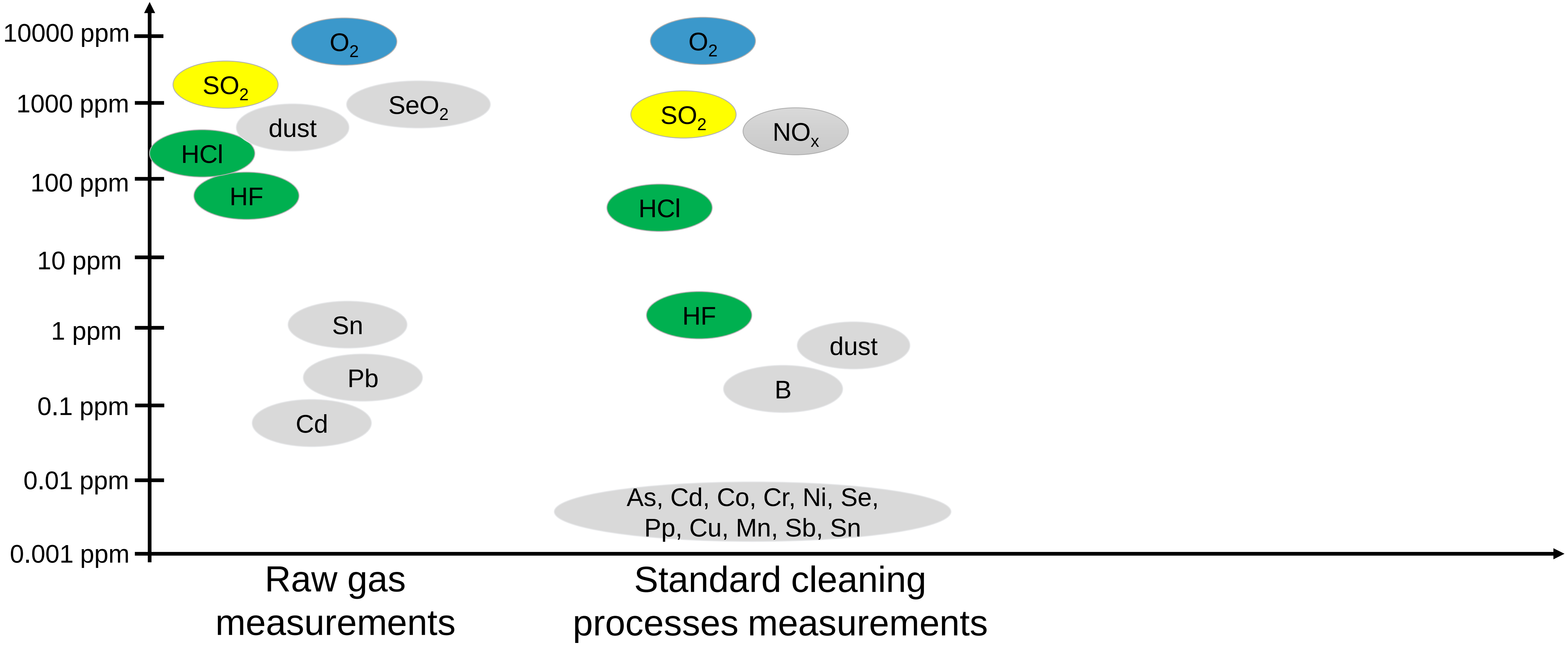

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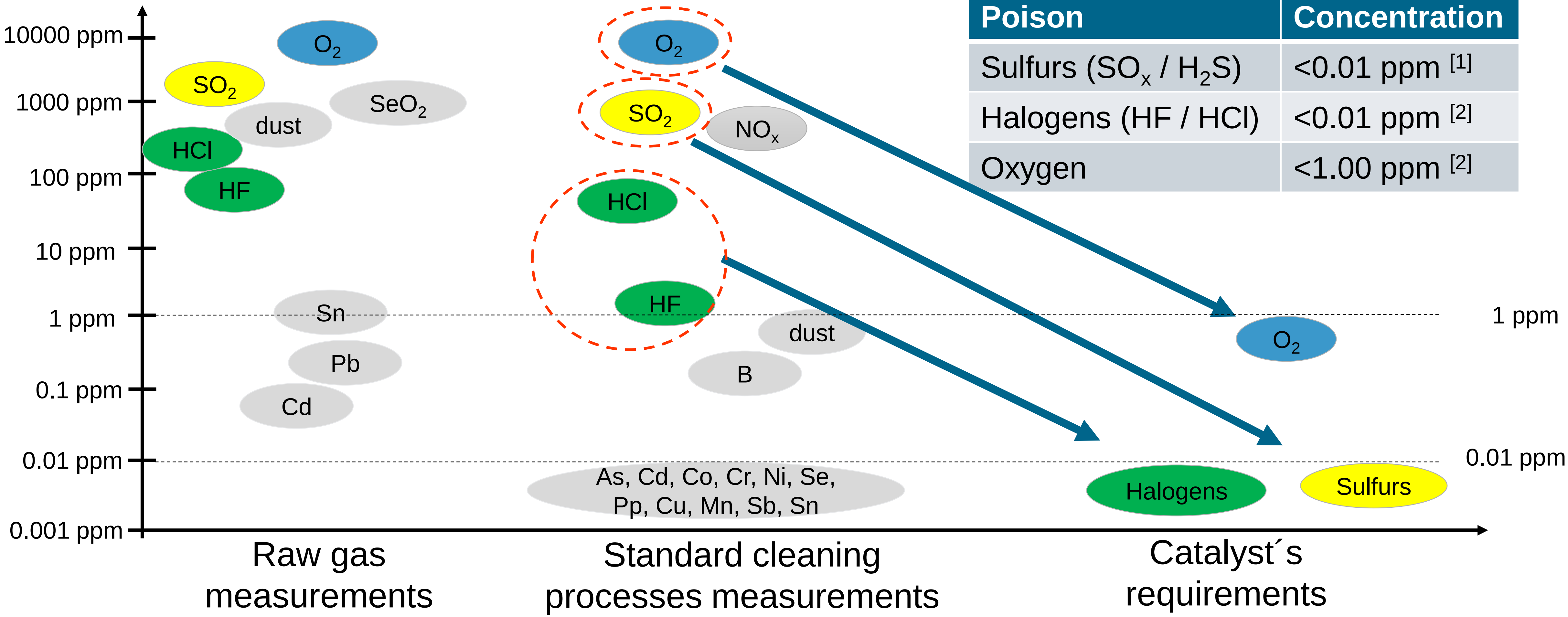

Poison	Concentration
Sulfurs (SO_x / H_2S)	<0.01 ppm [1]
Halogens (HF / HCl)	<0.01 ppm [2]
Oxygen	<1.00 ppm [2]

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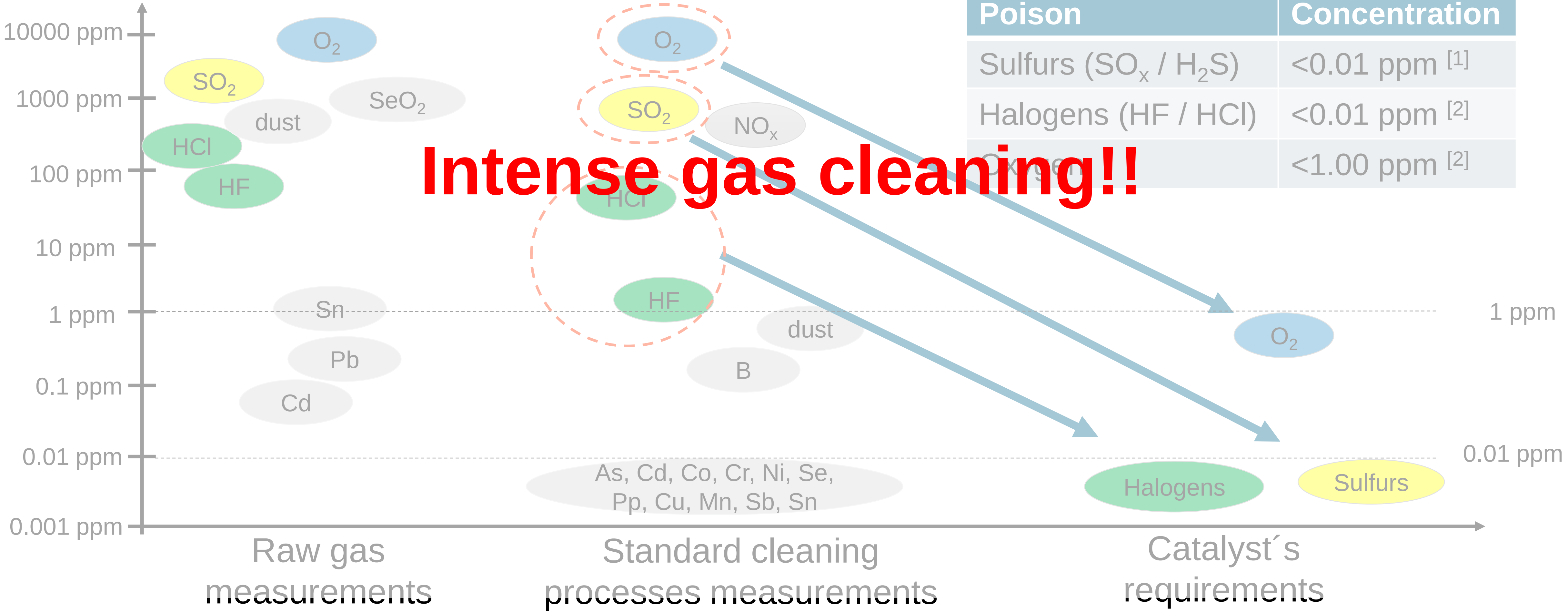

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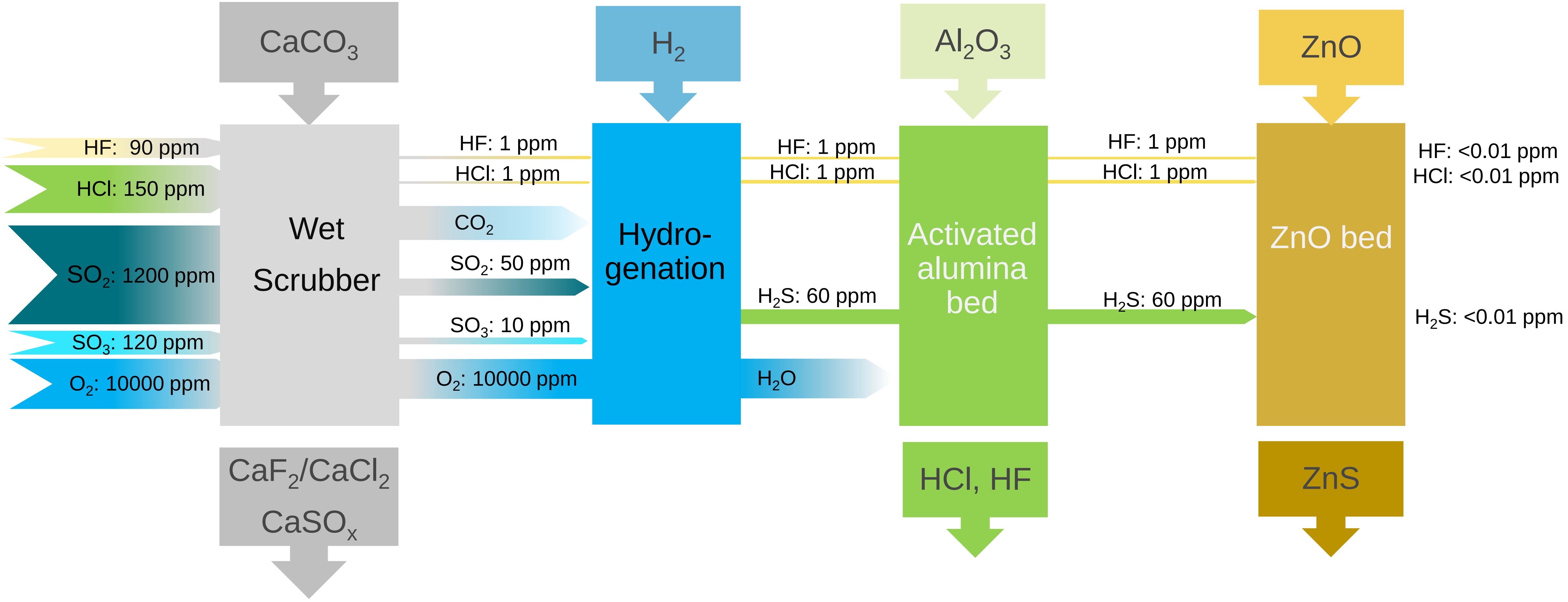
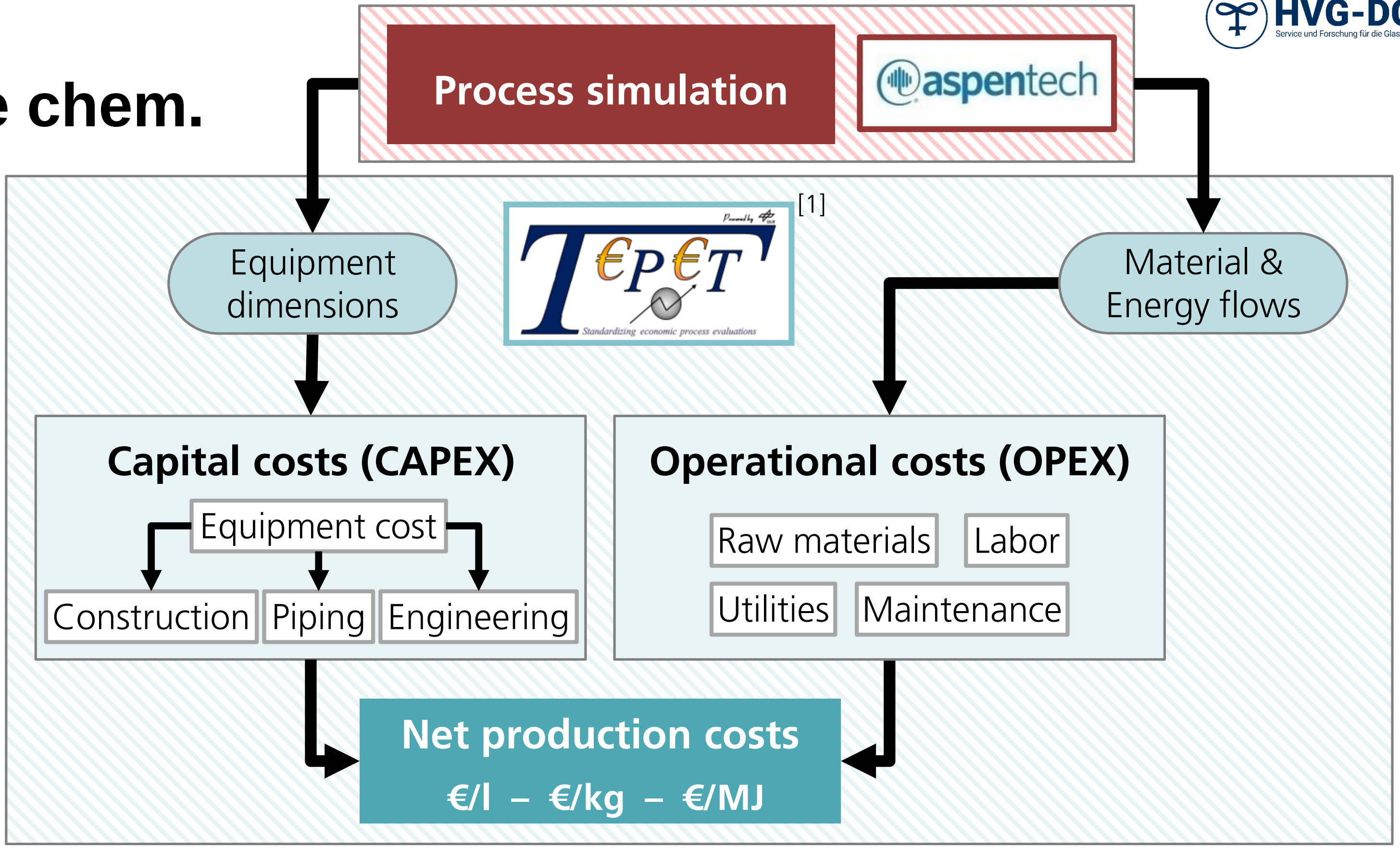
Methodology – Gas cleaning

Gas Cleaning



Methodology – Techno-economic assessment (TEA)

- Adapted from **best-practice chem. eng. methodology**
- Meets AACE class 3-4, Accuracy: **+/- 30 %**
- **Year specific** using annual CEPCI Index
- Automated interface for **seamless integration, heating networks, …**
- Easy sensitivity studies for **each** parameter
- Learning curves, economy of scale, …



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

Methodology – Base case condition

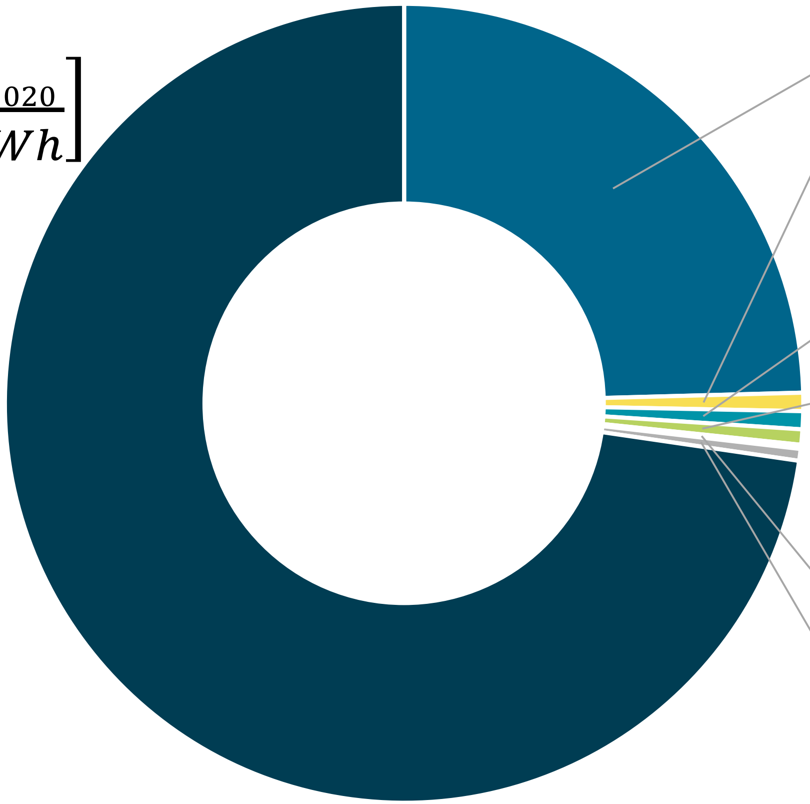
Evaluation input	
Plant capacity	300 t_{glass}/day
Synthetic fuel	Methane
Base year	2020
Interest rate	7%
Glass furnace operation	24/7/365
Methanation plant full load hours	8000 h/a
Plant lifetime	30 a
Green electricity price	42.31 €/MWh

✓Backup supply through gas grid
✓Costs of the modification of the plant only (i.e. glass furnace costs are excluded)

Methodology – Economic assumptions

Electricity price

- Electricity price [1]: 42.31 $\left[\frac{€_{2020}}{MWh}\right]$
- Day-Ahead Market
- Certificates of origin



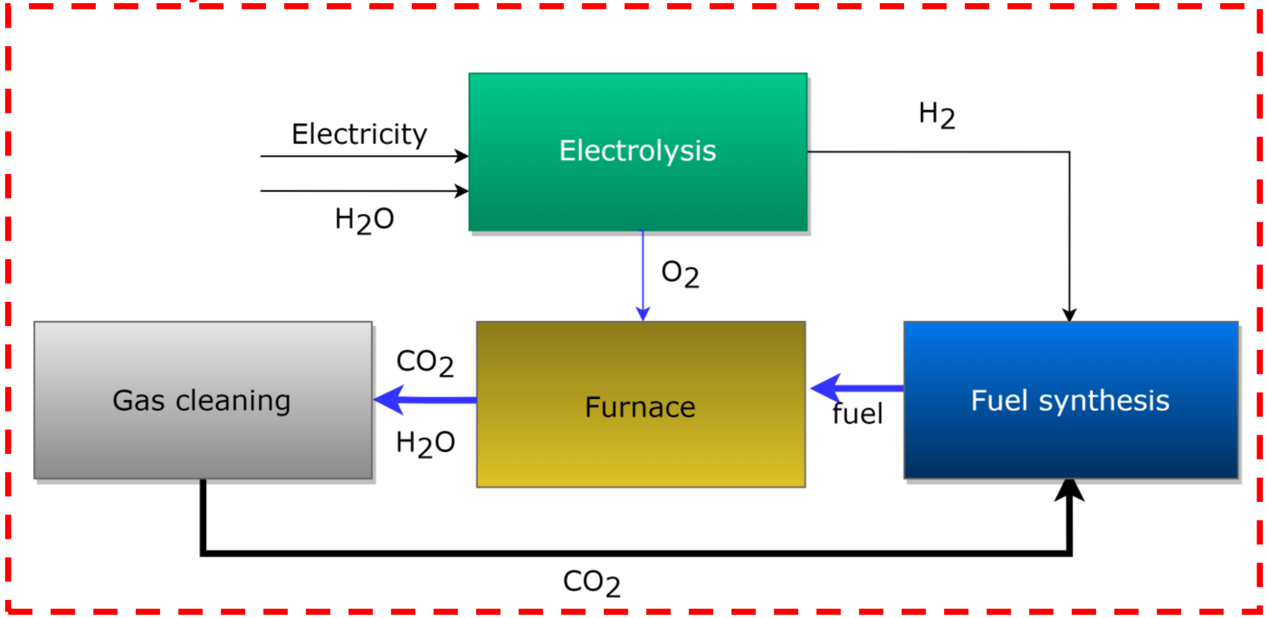
[1] Bundesnetzagentur (2022). Marktdaten.
[2] E. Spot, Marktintegration erneuerbarer Energien – Mission erfüllt?, in, 2020.

Results – Technical assessment

Efficiencies

- $\eta_{PtF} = \frac{\dot{m}_{Fuel,Total} \cdot LHV}{\dot{P}_{el,PEMEL} + \dot{P}_{el.,others} - \dot{P}_{el.,SC}}$ =45%

Boundary:



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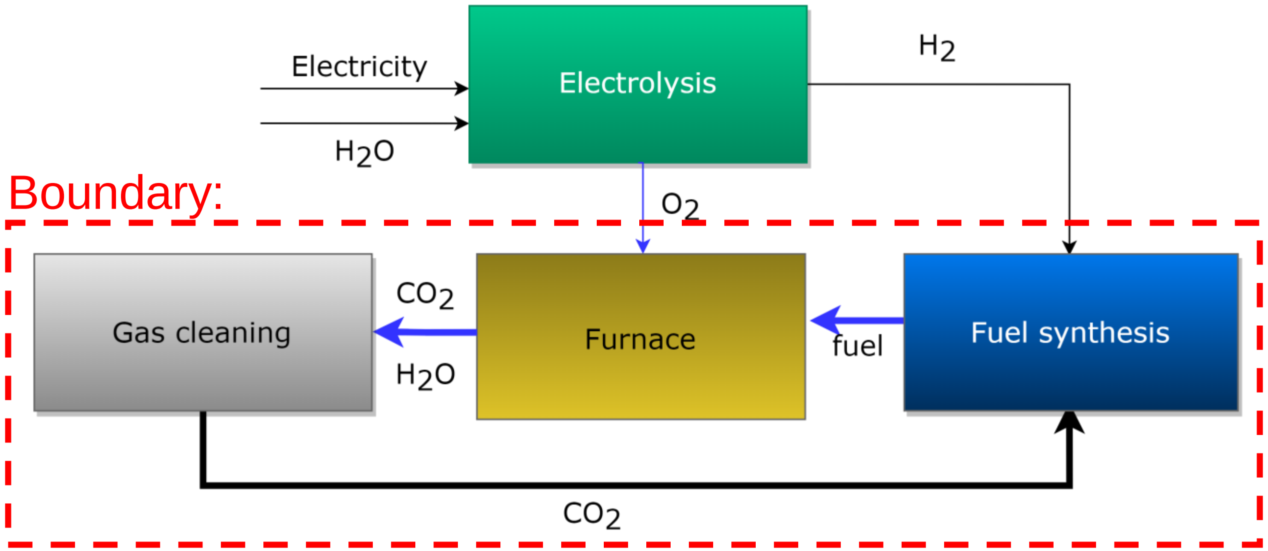
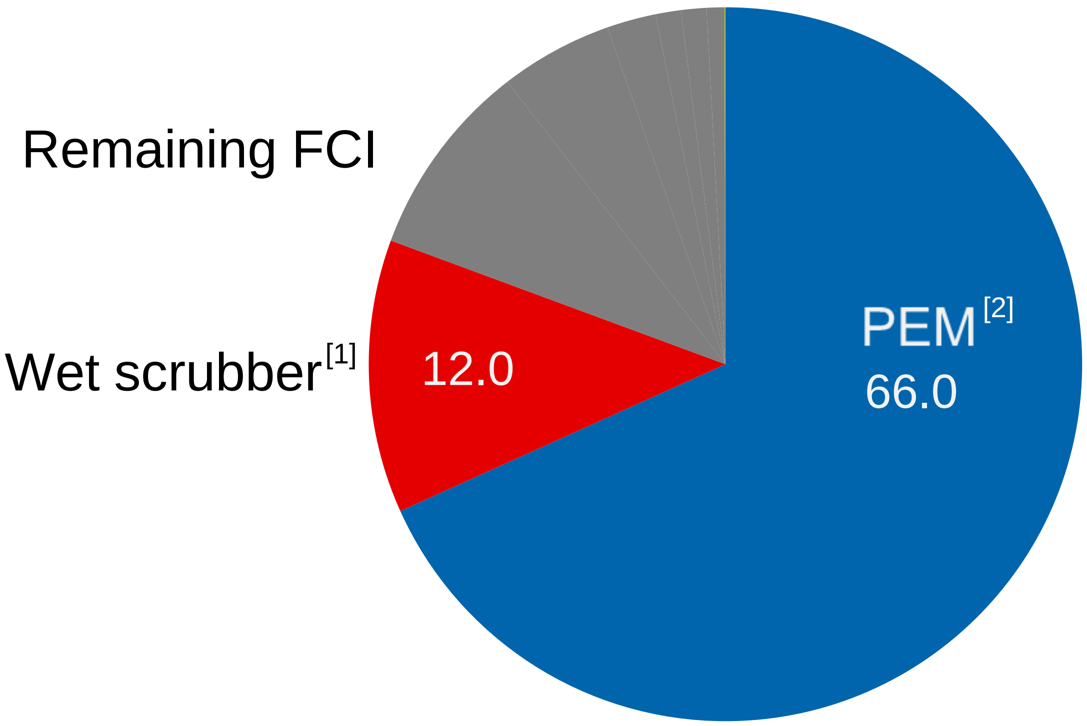
- $\eta_{H_2tF} = \frac{\dot{m}_{Fuel} \cdot LHV_{Fuel}}{\dot{m}_{H_2} \cdot LHV_{H_2}} = 90\%$

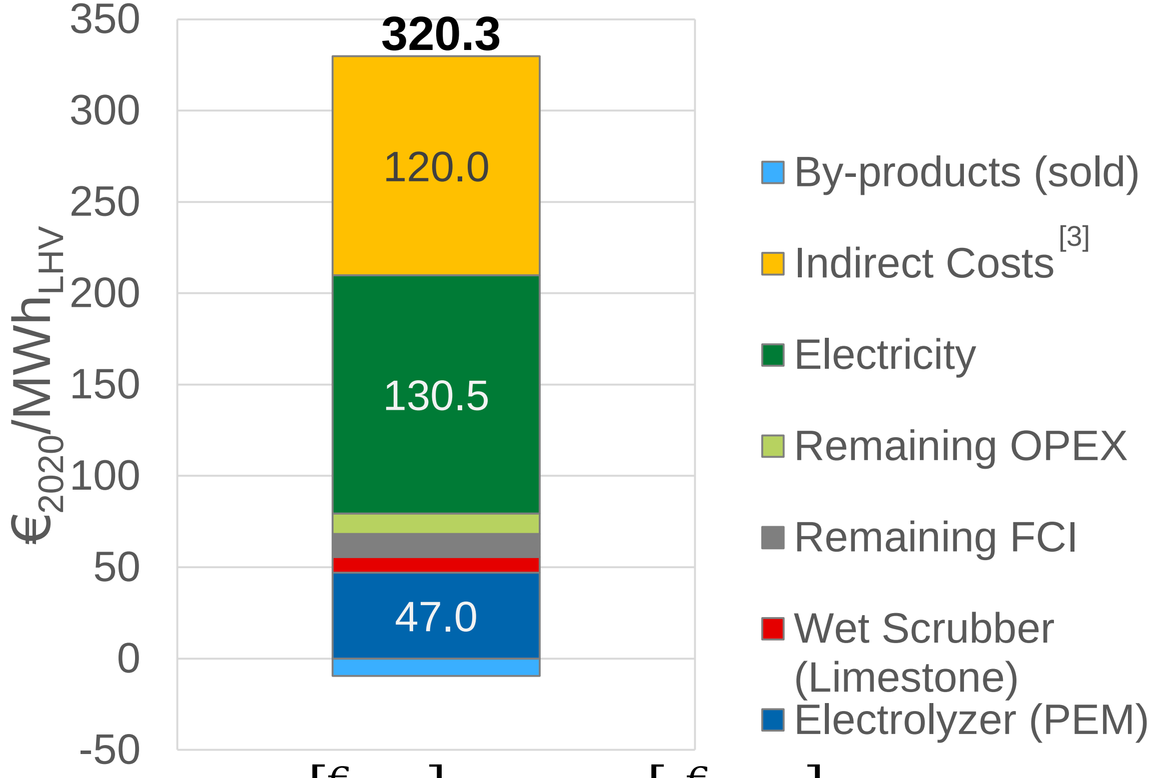


Results – Economic assessment

Fixed Capital Investment costs
(96.6 Mio. €)



Breakdown of NPC

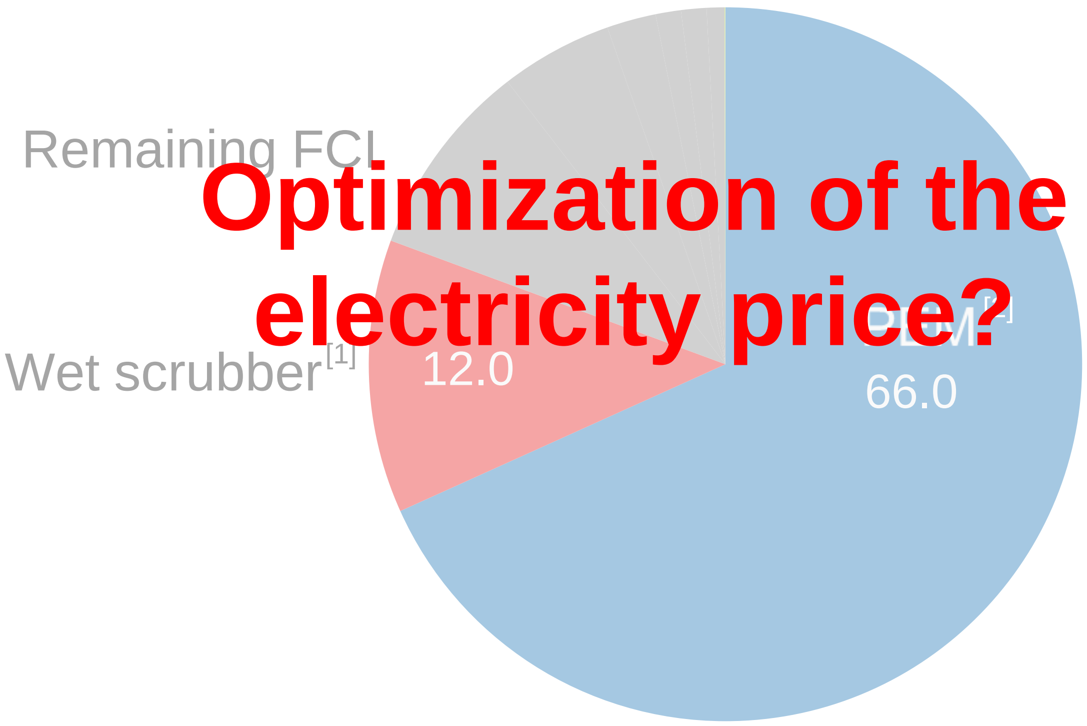


NPC: $320\left[\frac{€_{2020}}{MWh}\right] \leftrightarrow 0.40\left[\frac{€_{2020}}{kg_{Glass}}\right]$

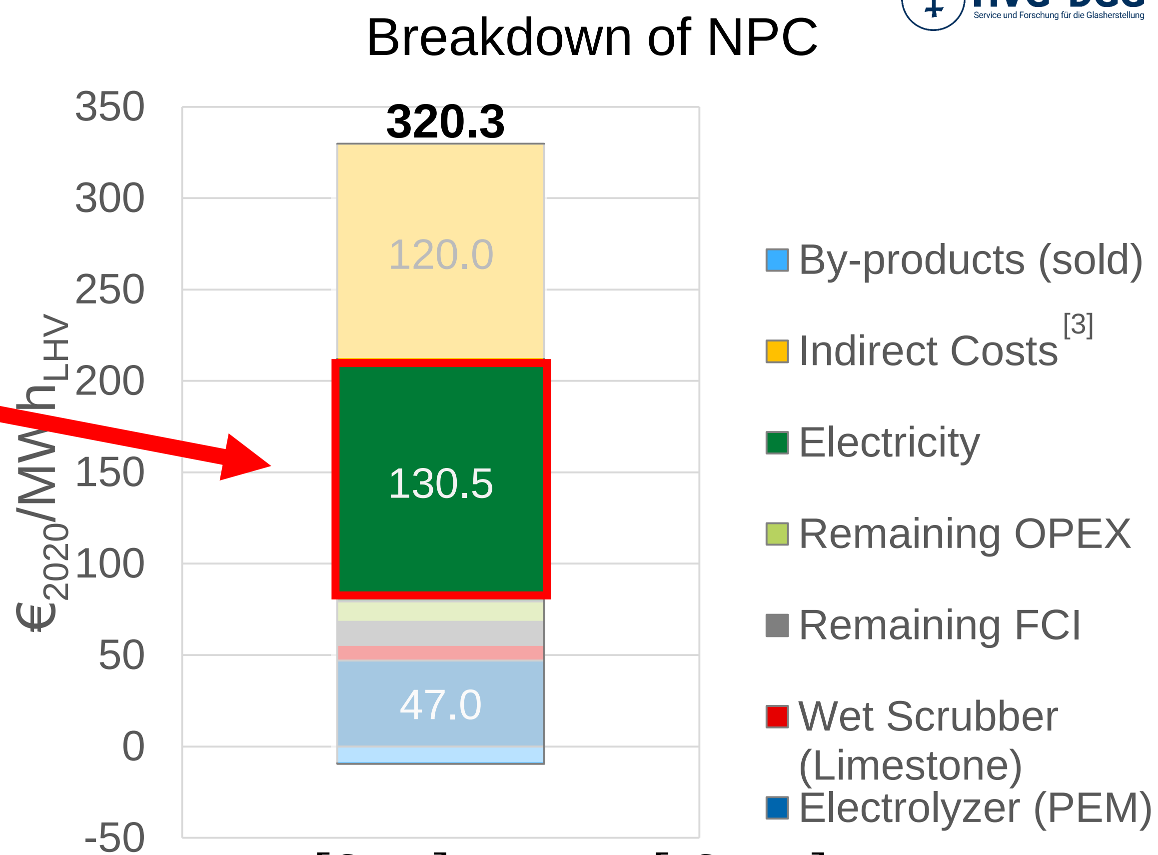
TTF-European gas price (25.08.20)[4] $\rightarrow 8.9\left[\frac{€_{2020}}{MWh}\right]$

[1] J. L. Sorrels (Chapter 1 Wet and Dry Scrubbers for Acid Gas Control)
[2] Deutsches Zentrum für Luft- und Raumfahrt (DLR) (Studie über die Planung einer Demonstrationsanlage zur Wasserstoff-Kraftstoffgewinnung durch Elektrolyse mit Zwischenspeicherung in Salzkavernen unter Druck)
[3] M. Peters, K. Timmerhaus and R. West, Plant design and economics for chemical engineers, New York, United States: McGraw-Hill, 2004, ISBN 007-124044-6
[4] Tradingeconomics (2022). "EU Natural Gas." from https://tradingeconomics.com/commodity/eu-natural-gas.

Results – Economic assessment



Optimization of the electricity price?



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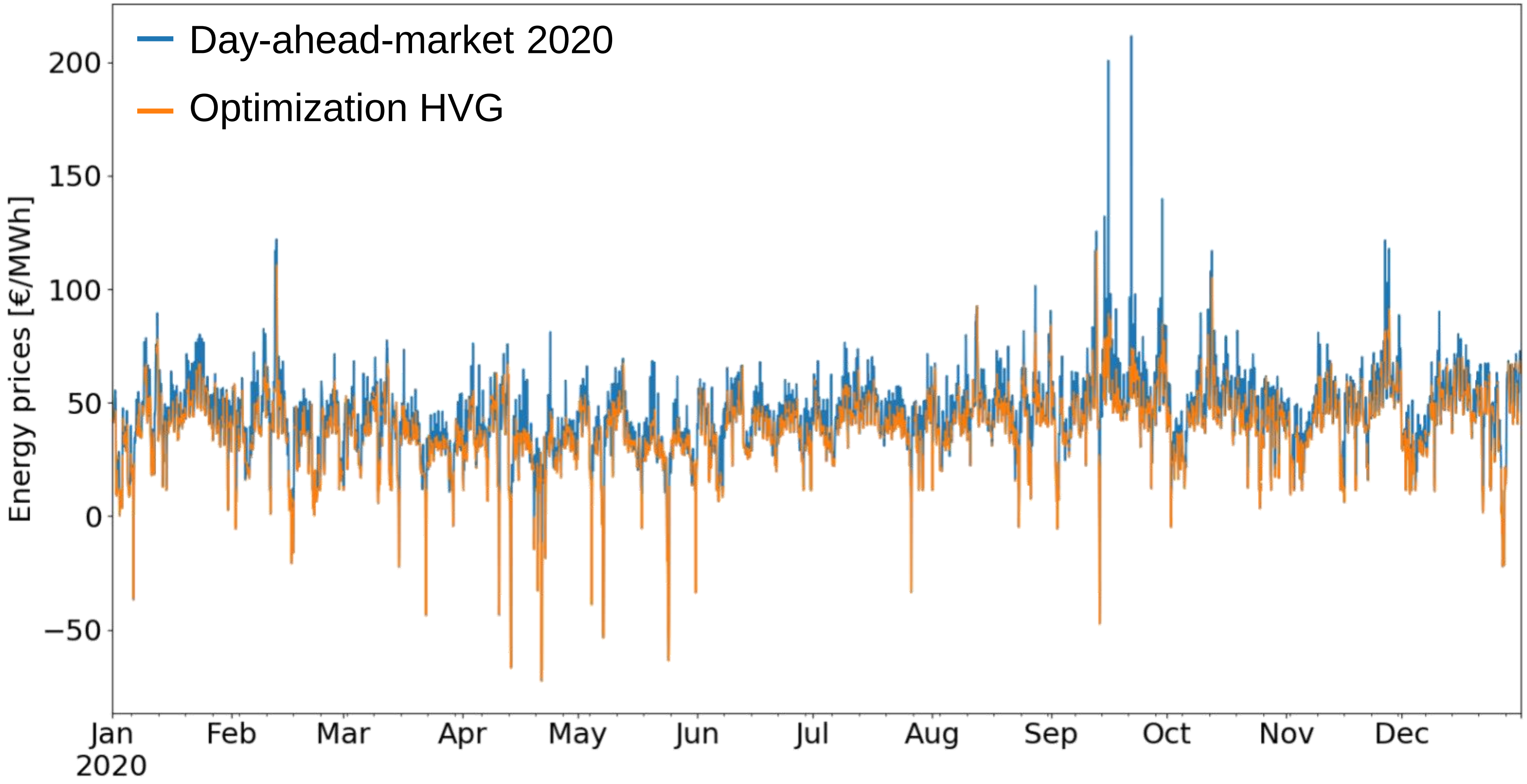
Results – Electricity price, sensitivity analysis

Utilization of storage



Results – Electricity price, sensitivity analysis

DLR

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Algorithm

- Storage capacity variation (hours)
- Electrolyzer overdimensioning
  - Faster charging speed for storage

Less operation time per day (electrolyzer only)

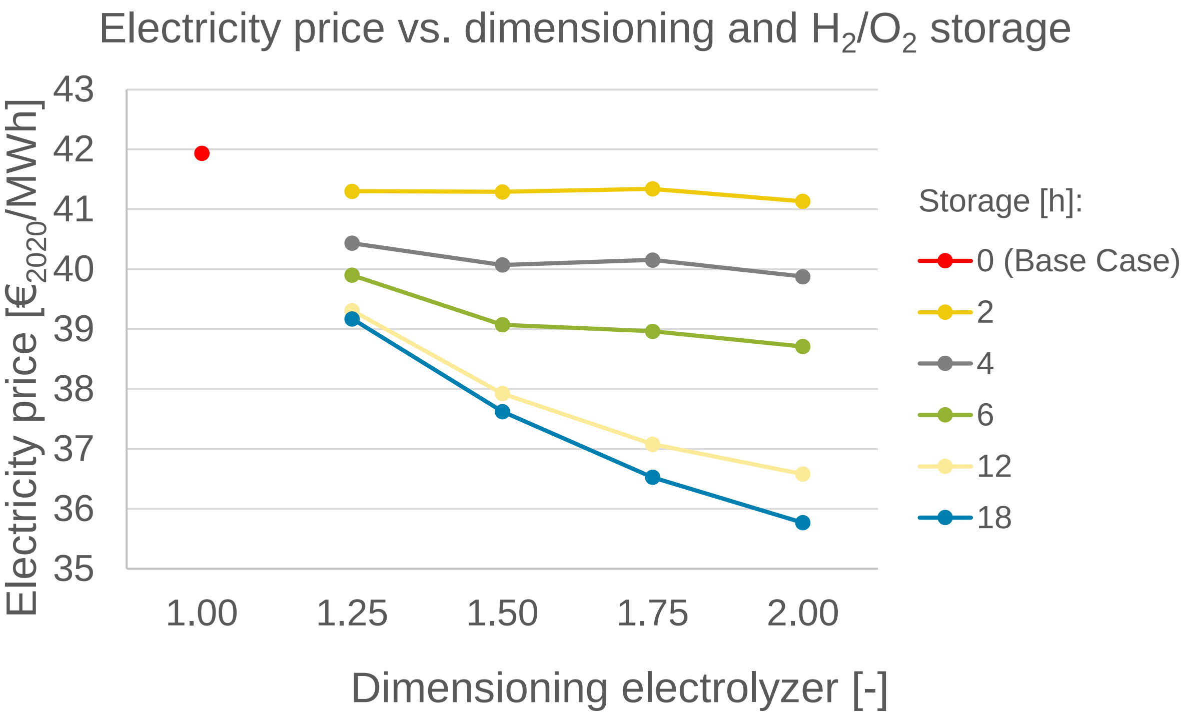
Optimization of electricity purchase in day-ahead-market

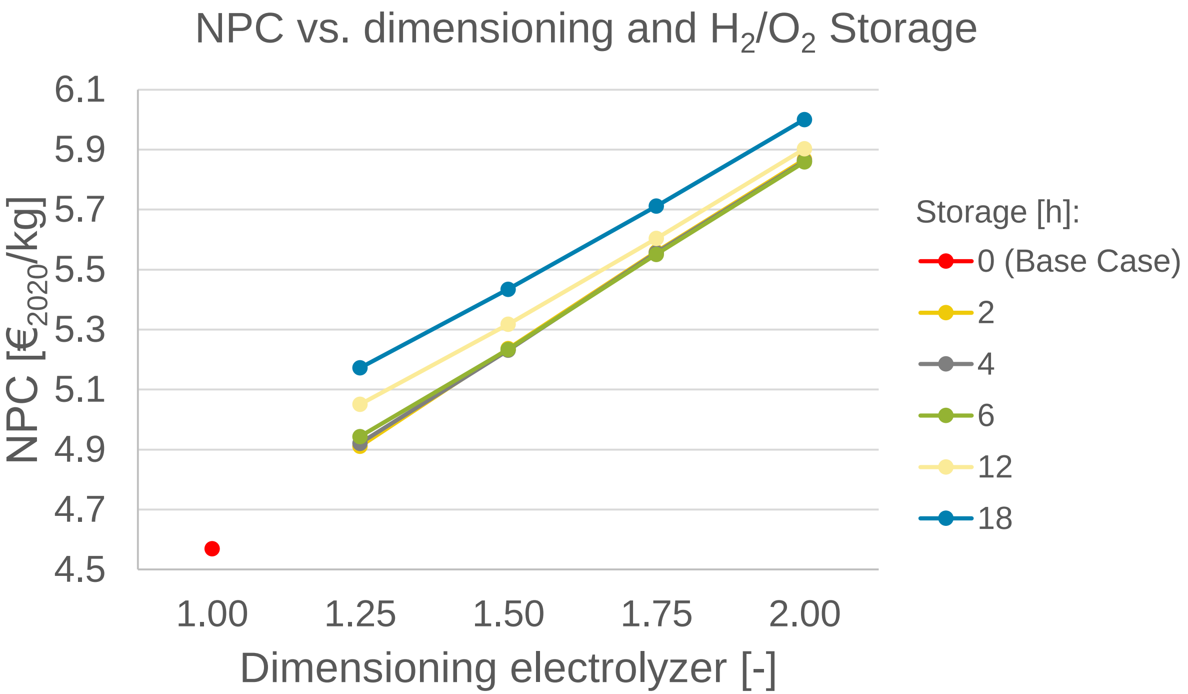
↑↑ CAPEX

↓↓ OPEX

NPC?

Results – Sensitivity analysis





- Storage increase leads to a higher NPC
- Fluctuations are not big enough in the year 2020

Summary

- Process design for methane synthesis developed and assessed
  - Realistic conditions were implemented (HVG)
- CCU could be implemented in the glass industry
  - NPC: 320 $€_{2020}/MWh_{LHV} \leftrightarrow$ 0.40 $€_{2020}/kg_{glass}$
    - Electricity: 40%
    - PEM: 15%

… pilot plant validation?

- Electricity price algorithm developed and implemented
  - Storage is not economically viable in 2020

… but what would happened with higher fluctuations?

Outlook

Figure - Methanol synthesis plant [1]

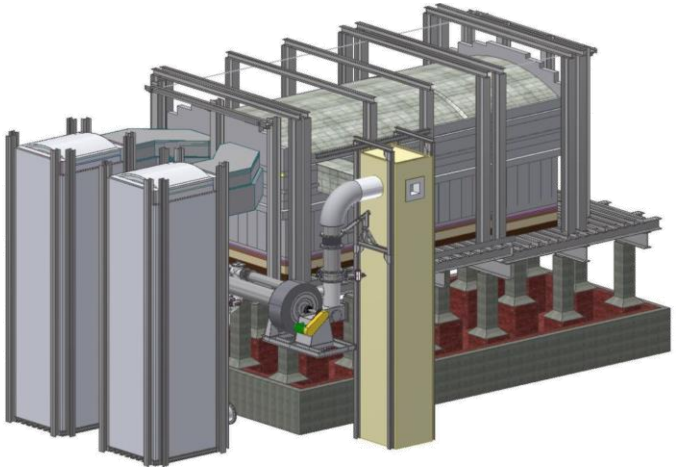


Figure - Linde‘s OPTIMELT Thermochemical Regenerator System [2]

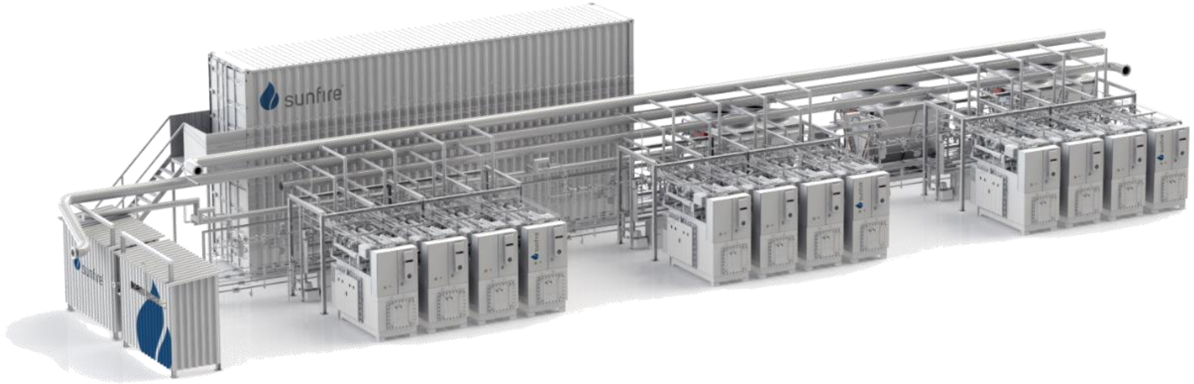


Figure – Concept of a solid oxide electrolysis cell [3]

[1] © Energy, G. (2022). "Advanced Methanol Amsterdam." from https://www.gidara-energy.com/advanced-methanol-amsterdam
[2] © Sundaram, S. K. (Ed.). (2018). 78th Conference on Glass Problems. John Wiley & Sons.
[3] © by ND2.0 SunFire (2022). "Renewables Everywhere - Electrolysis at its best." from https://www.sunfire.de/assets/images/7/Sunfire_SOEC_Elektrolyseure-75796dd7.png

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