Thursday, 2026/09/24: CONFERENCE SESSION FOUR
Sustainability, Integrity & Transparency in CO_2 Utilisation

EUROPEAN CARBON DIOXIDE UTILISATION SUMMIT
23RD & 24TH SEPTEMBER 2026 · ROTTERDAM

TRUE COST AND BENEFITS OF UTILIZING CO_2

- TECHNO-ECONOMIC AND LIFE CYCLE PERSPECTIVE -

Assessment requirements, methodology and results for CO2 utilization measures towards "Net Zero"

Ralph-Uwe Dietrich, Felix Habermeyer, Nathanael Heimann,
Owais Khokar, Yoga Rahmat, Julia Weyand

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AGENDA



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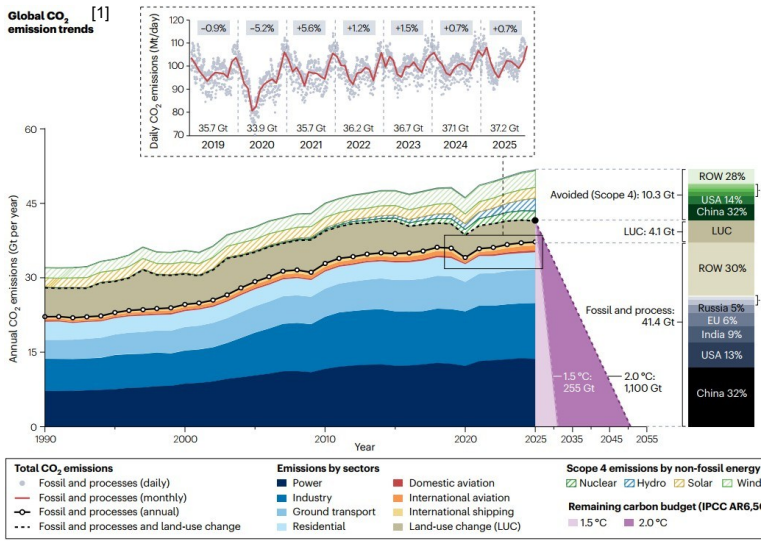
- The dimension of greenhouse gas (GHG) emission reduction
- GHG emission reduction measures
  - Hydrogen and derivates for energy import
  - Measures for heavy goods transport
  - Industry defossilization example
- Conclusion and Outlook

2

The Global Challenge
GHG emissions don't decrease



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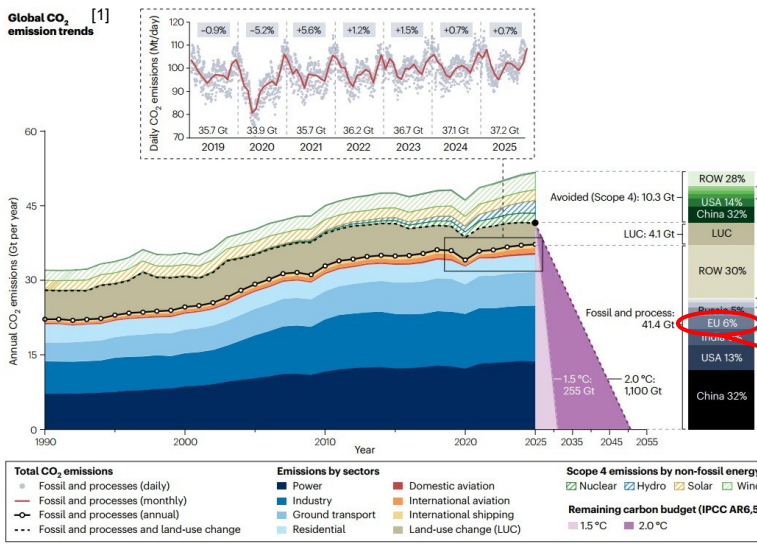
[1] Deng, Z., Zhu, B. , Davis, S., Ciais, P., & Liu, Z. (2026) Global carbon emissions and decarbonization in 2025. Nature Reviews Earth & Environment doi: 10.1038/s43017-026-00780-4.

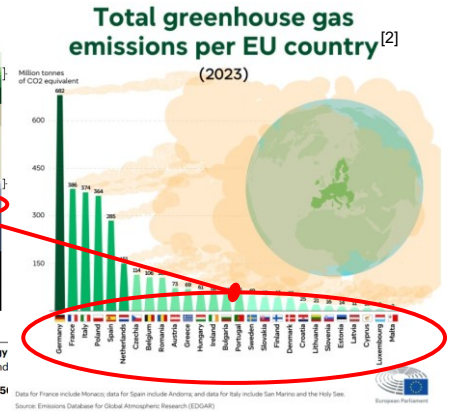
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[2] EU Parliament (2024) Greenhouse gas emissions by country and sector (infographic) https://www.europarl.europa.eu/pdfs/news/expert/2018/3/story/20180301STO98928/20180301STO98928_en.pdf

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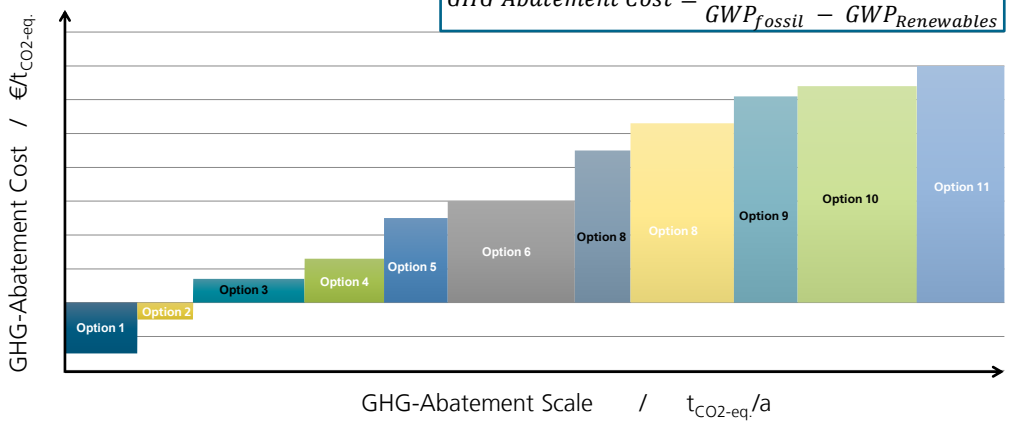
Assessment of Decarbonization options



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Merit Order of Greenhouse Gas (GHG) emission reduction measures

$$GHG\ Abatement\ Cost = \frac{Cost_{Renewables} - Cost_{fossil}}{GWP_{fossil} - GWP_{Renewables}}$$



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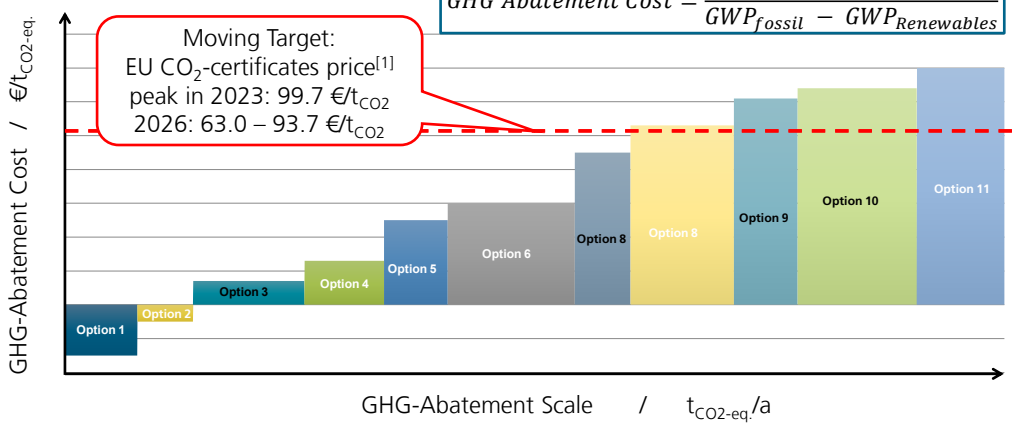
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[1] https://live.deutsche-boerse.com/rohstoff/kohlendioxid-co2-emissionsrechte?mic=ARIVA, ISIN: XC000A0C4KJ2

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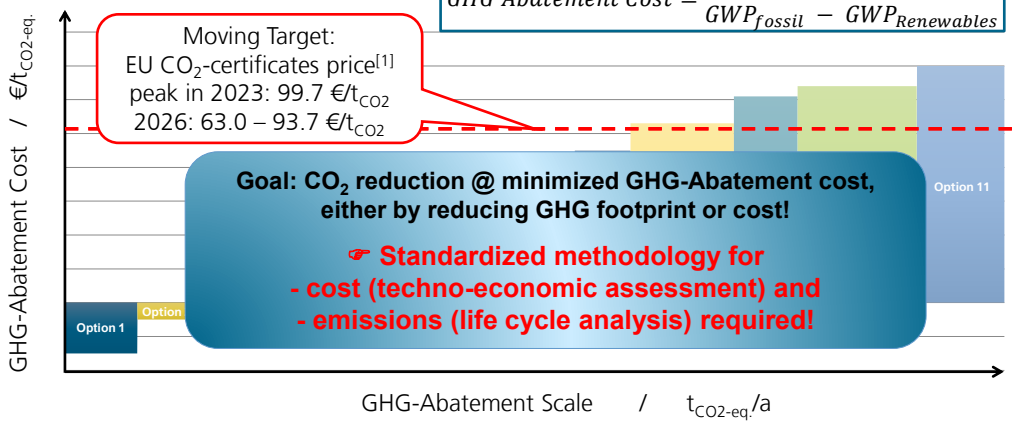
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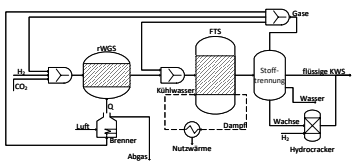
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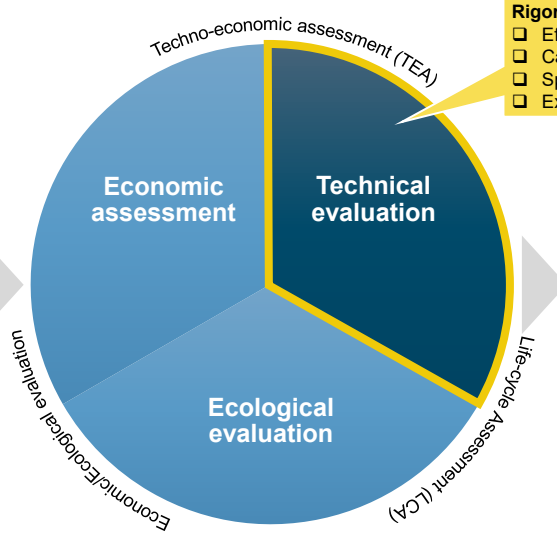
Techno-Economic and Life Cycle Assessment @ DLR

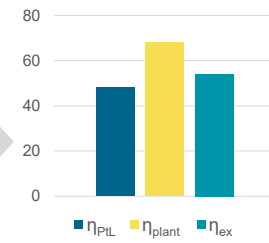


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Rigorous process simulation
- ❑ Efficiencies (X-to-Liquid, Overall)
- ❑ Carbon conversion
- ❑ Specific feedstock demand
- ❑ Exergy analysis





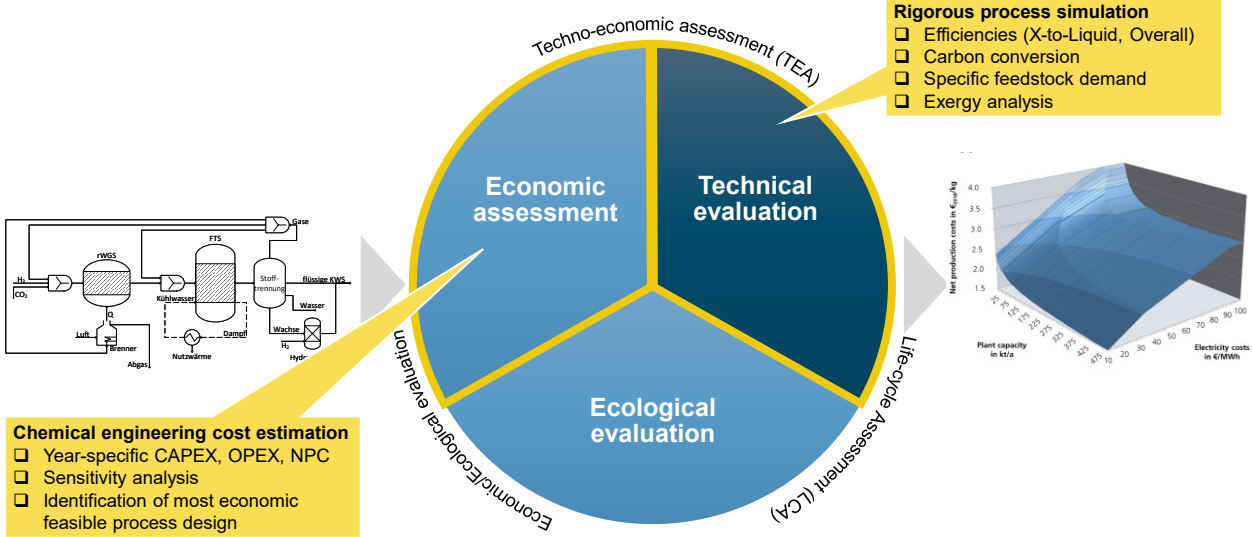


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Techno-Economic and Life Cycle Assessment @ DLR



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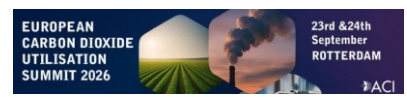


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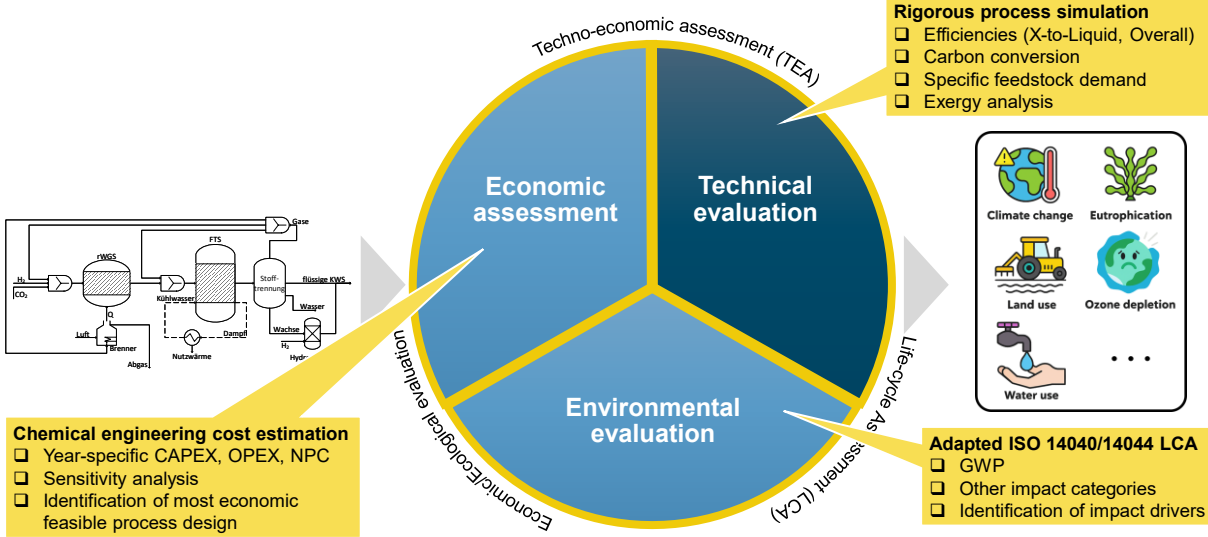
Chemical engineering cost estimation
- ❑ Year-specific CAPEX, OPEX, NPC
- ❑ Sensitivity analysis
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DLR



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

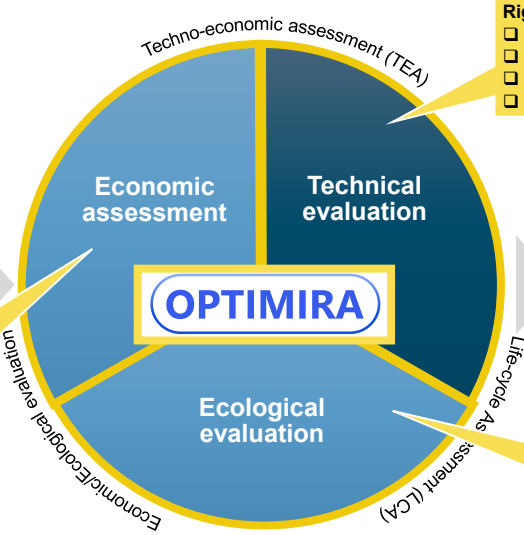
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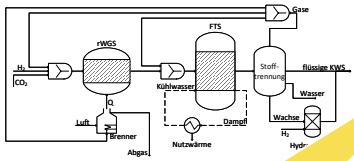
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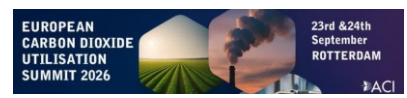
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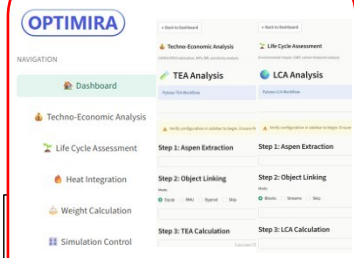
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Techno-Economic and Life Cycle Assessment @ DLR



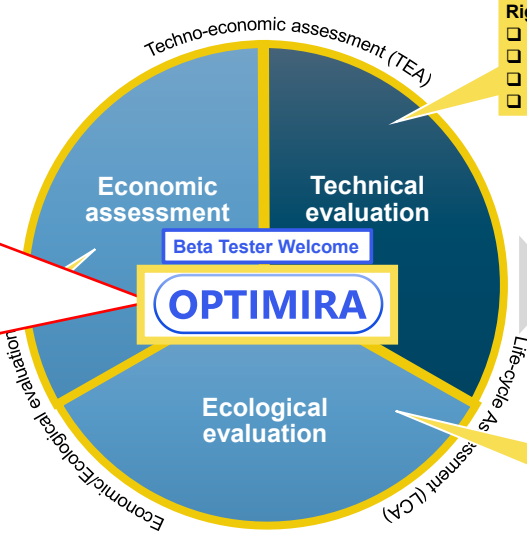
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DLR Software tool for roll-out



- Seamless Integration: Connect Aspen flowsheet via OPTIMIRA (NO upload of sensitive data).
- Automated Assessments: Execute comprehensive TEA, LCA, Heat Integration (HI), and more.
- Advanced Optimization: Transform standard process models into multidimensional analytical tools with simulation control and variation runs.

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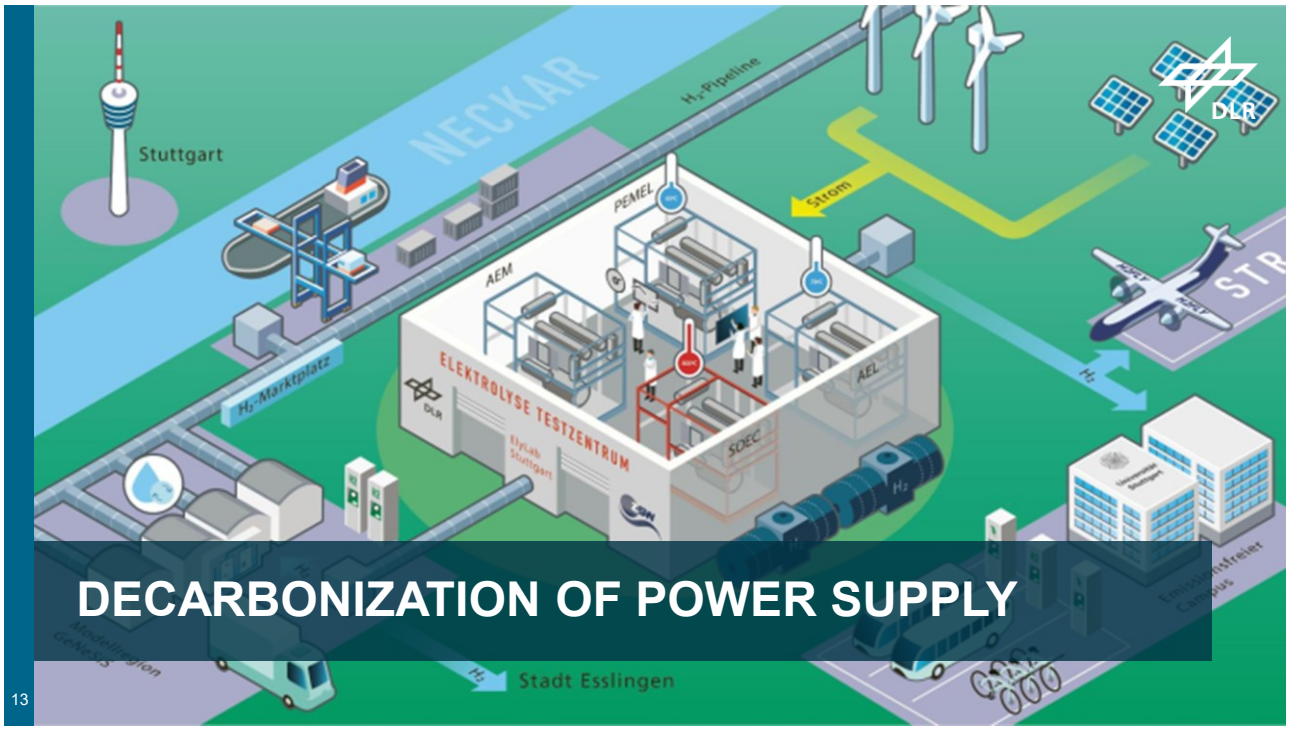


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Hydrogen – the "green power" ???
H_2 import option



DLR



- National demand for H_2 and derivatives: 95-130 TWh by 2030 [1]
- Expected import around 50 to 70% (45 to 90 TWh) [1]
- Ensuring a resilient, i.e. sustainable, stable, secure and diversified supply



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[1] BMWK (2023) National Hydrogen Strategy Update https://www.bundeswirtschaftsministerium.de/Redaktion/EN/Publikationen/Energie/national-hydrogen-strategy-update.pdf

Hydrogen – the "green power" ???
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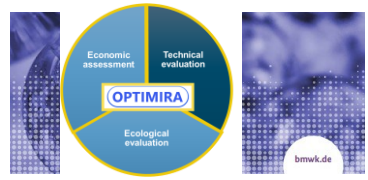


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☞How realistic?
☞Affordable?
☞Sustainable?



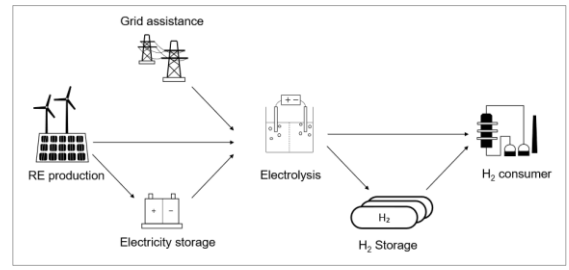
[1] BMWK (2023) National Hydrogen Strategy Update https://www.bundeswirtschaftsministerium.de/Redaktion/EN/Publikationen/Energie/national-hydrogen-strategy-update.pdf

15

Renewable H_2 from abroad
Namibia: cheap, green H_2?[1]



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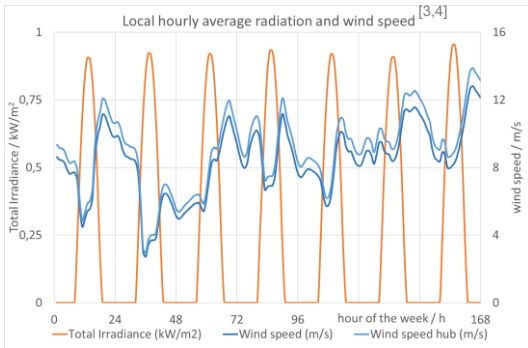
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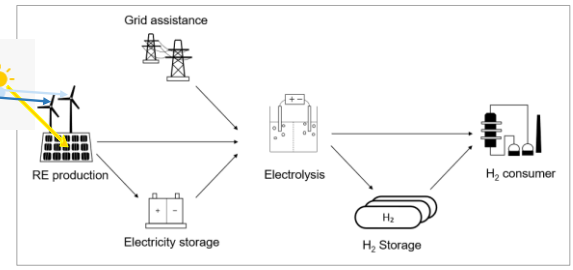
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- 1 GW H_2: Tsau Khaeb National Park, Namibia (latitude -26.8, longitude 15.3)[2]

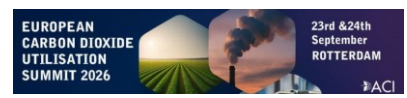




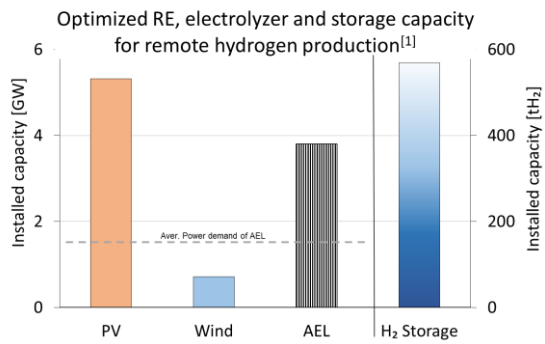
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[2] Dietrich et. al (2025). Hydrogen Non-Conventional Storage Options. In: Encyclopedia of Electrochemical Power Sources, doi: 10.1016/B978-0-323-96022-9.00183-3
[3] Pfenninger, S. and Staffell, I. (2016). Long-term patterns of European PV output. Energy 114, pp. 1251-1265. doi: 10.1016/j.energy.2016.08.060
[4] Staffell, I. and Pfenninger, S. (2016). Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output. Energy 114, pp. 1224-1239. doi:10.1016/j.energy.2016.08.068

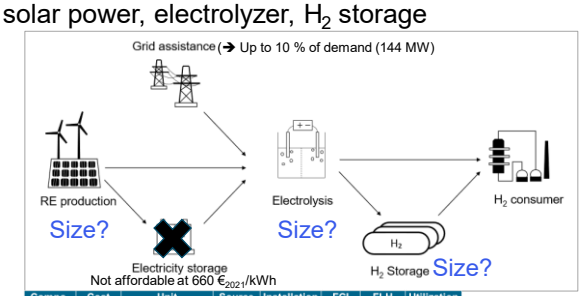
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Renewable H_2 from abroad
Sizing renewable stabile H_2?[1]



- 1 GW H_2: Tsau Khaeb National Park, Namibia (latitude -26.8, longitude 15.3)
  - Locally cost optimized design of wind and solar power, electrolyzer, H_2 storage





Compo-nent	Cost Data	Unit	Source	Installation	FCI [10⁹ €]	FLH [h/a]	Utilization [%]
PV farm	492*	$€_{2021}kW_{Peak}^{-1}$	[16]	23.21 km²	2.32	2,342	74.5
Wind turbine	1'573*	$€_{2021}kW_{Peak}^{-1}$	[20]	283 á 2.5 MW_{el}	1.13	5,638	83.2
AEL	160*	$€_{2021}kW^{-1}$	[16]	3.80 GW_{el}	0.98	3,327	37.8
H_2 tank	700	$ kg_{H2}^{-1}	[21]	569 t	0.70		30.5**
Grid Energy	150	$€_{2021}MWh^{-1}$	Assump-tion			800	9.1

*Perspective data for 2030 according to source
**Average filling level

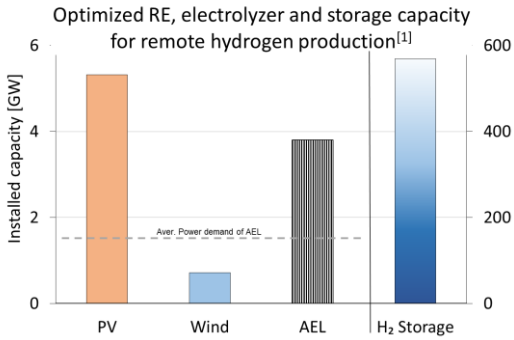
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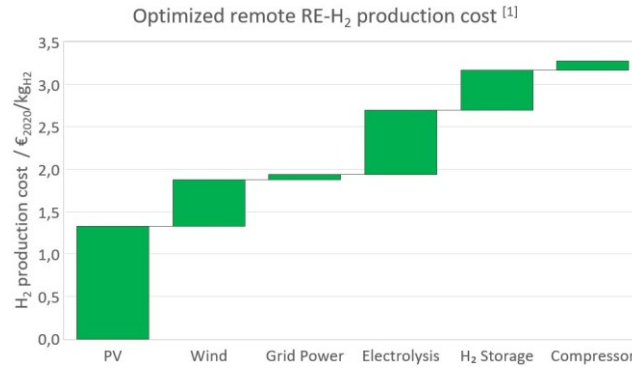
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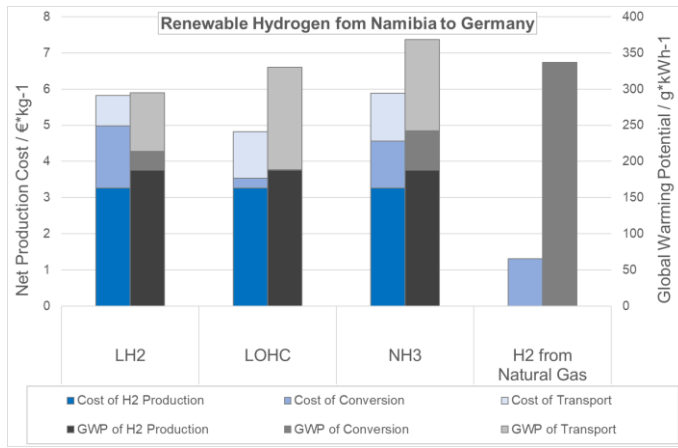


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Renewable H_2 arrival in Germany
+Conversion/Transp./Reconversion[1]



- Namibian Hydrogen won't be competitive soon, if exported to Germany

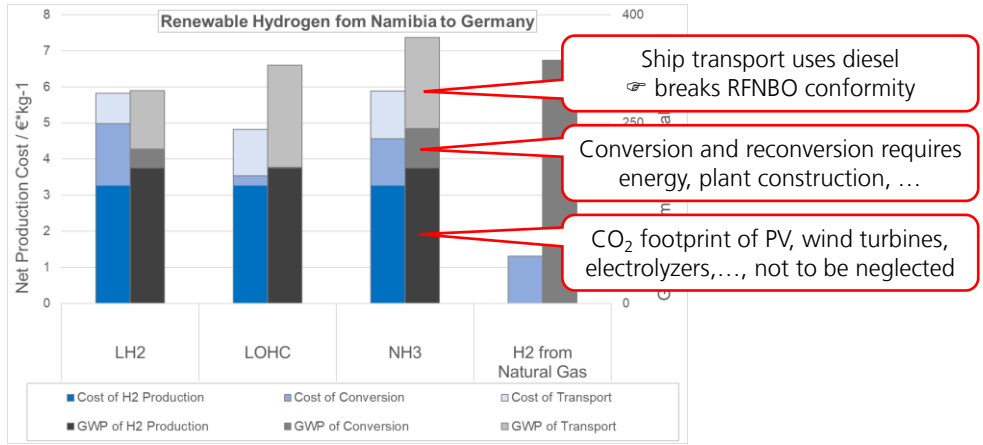


[1] Thess et. al (2025) Namibischer Wasserstoff: Champagner oder Mineralwasser für das deutsche Energiesystem? Energiewirtschaftliche Tagesfragen (11), Seiten 14-18.

Renewable H_2 arrival in Germany +Conversion/Transp./Reconversion[1]

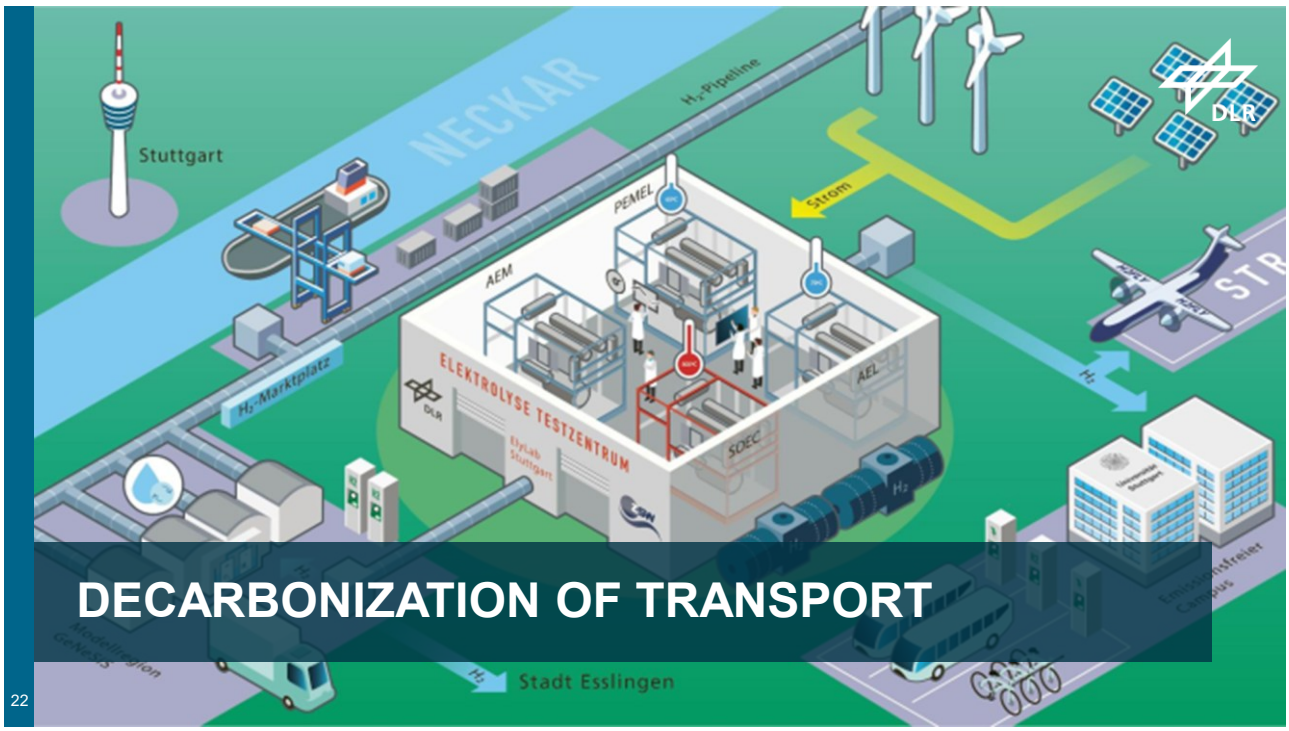


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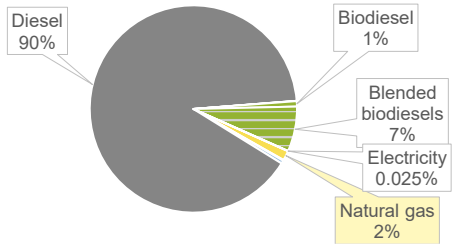
DECARBONIZATION OF TRANSPORT

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Heavy goods transport in Europe
= Hard-to-abate sector



- Vital for economy
  - Truck milage: 1.9 10^6 t-km a^{-1} (2024)[1]
- Fuel: fossil-based, crude oil import
  - 2,257 PJ a^{-1} (2023)[2] ☞ 170 Mt_{CO2}/a
- Fuel distribution @ European trucks [2]



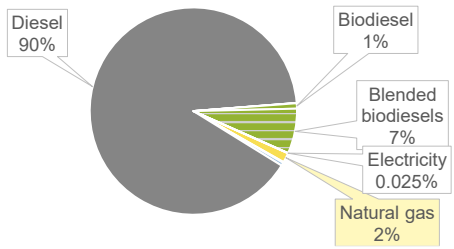
[1] https://ec.europa.eu/eurostat/databrowser/view/road_go_tq_tott/default/table?lang=en
[2] https://ec.europa.eu/eurostat/databrowser/product/page/nrg_d_traq
[3] ICCT (2026) EUROPEAN HEAVY-DUTY VEHICLE MARKET DEVELOPMENT QUARTERLY (JANUARY–MARCH 2026), https://theicct.org/publication/eu-hdv-market-development-quarterly-january-march-2026-jun26/

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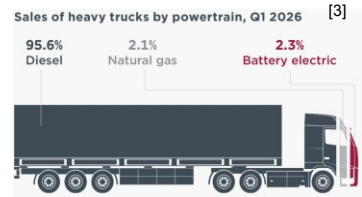


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Future Trend:
Tank-to-Wheel Emission Reduction

- Electrification?



[3]

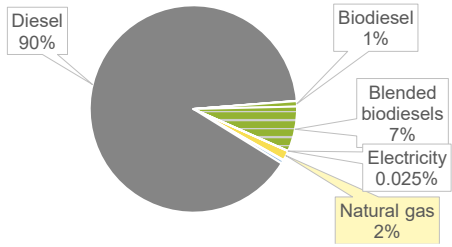
[1] https://ec.europa.eu/eurostat/databrowser/view/road_go_tq_tott/default/table?lang=en
[2] https://ec.europa.eu/eurostat/databrowser/product/page/nrg_d_traq
[3] ICCT (2026) EUROPEAN HEAVY-DUTY VEHICLE MARKET DEVELOPMENT QUARTERLY (JANUARY–MARCH 2026), https://theicct.org/publication/eu-hdv-market-development-quarterly-january-march-2026-jun26/

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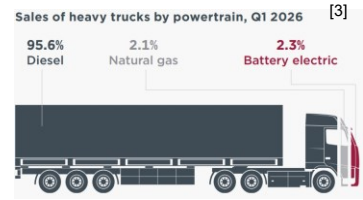


- Vital for economy
  - Truck milage: 1.9 10^6 t-km a^{-1} (2024)[1]
- Fuel: fossil-based, crude oil import
  - 2,257 PJ a^{-1} (2023)[2] ☞ 170 Mt_{CO2}/a
- Fuel distribution @ European trucks [2]

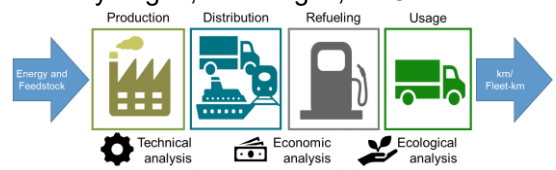


Future Trend:
Tank-to-Wheel Emission Reduction

- Electrification?



- Hydrogen, natural gas, HVO? ☞ WtW



[1] https://ec.europa.eu/eurostat/databrowser/view/road_go_tq_tott/default/table?lang=en
[2] https://ec.europa.eu/eurostat/databrowser/product/page/nrg_d_traq
[3] ICCT (2026) EUROPEAN HEAVY-DUTY VEHICLE MARKET DEVELOPMENT QUARTERLY (JANUARY–MARCH 2026), https://theicct.org/publication/eu-hdv-market-development-quarterly-january-march-2026-jun26/

25

Heavy Goods Vehicle (HGV) traffic
Fuel cost and carbon footprint



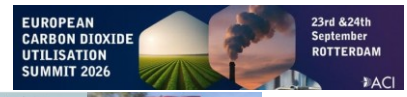


- Goal: TEA&LCA of renewable LH2, FT-Diesel and Bio-LNG use in trucks
- WtW: fuel cost (M€**2024**/a) and GWP ($kt_{CO2\text{-}eq.}$/a), predictive for **2030** [1]
- Question: Will renewable LH_2-FC trucks become competitive in Europe?

26

[1] Heimann et. Al (2026) Standardized cost and environmental impacts assessment of renewable heavy-duty transport

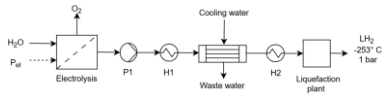
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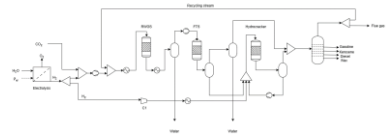
DLR



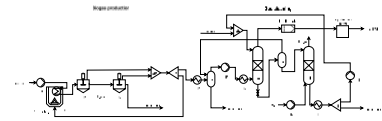
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Hydrogen production, liquefaction



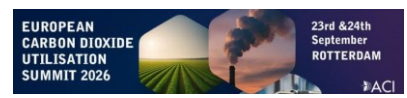
Hydrogen production, Fischer-Tropsch synthesis, product separation



Biomass fermentation, methane separation, liquefaction

[1] Heimann et. Al (2026) Standardized cost and environmental impacts assessment of renewable heavy-duty transport

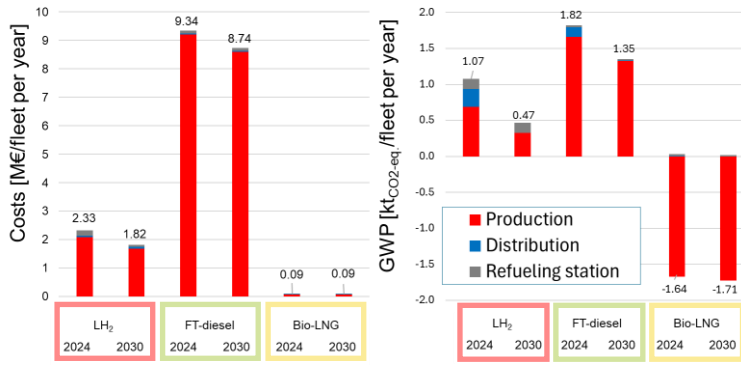
Heavy Goods Vehicle (HGV) traffic
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DLR

DAIMLER TRUCK

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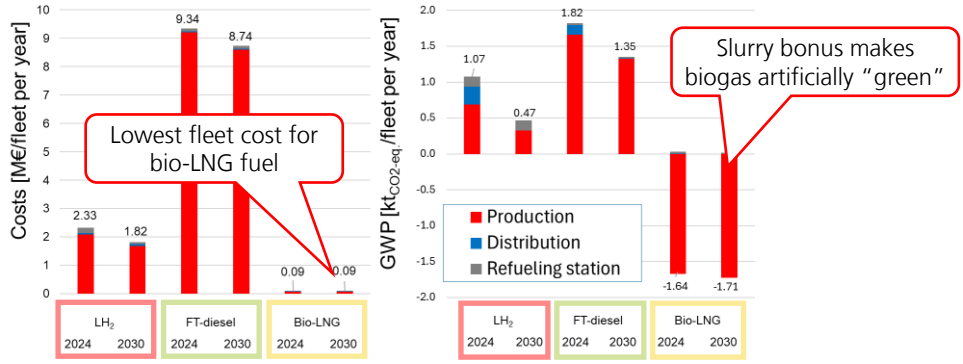
Heavy Goods Vehicle (HGV) traffic
Fuel cost and carbon footprint



DLR

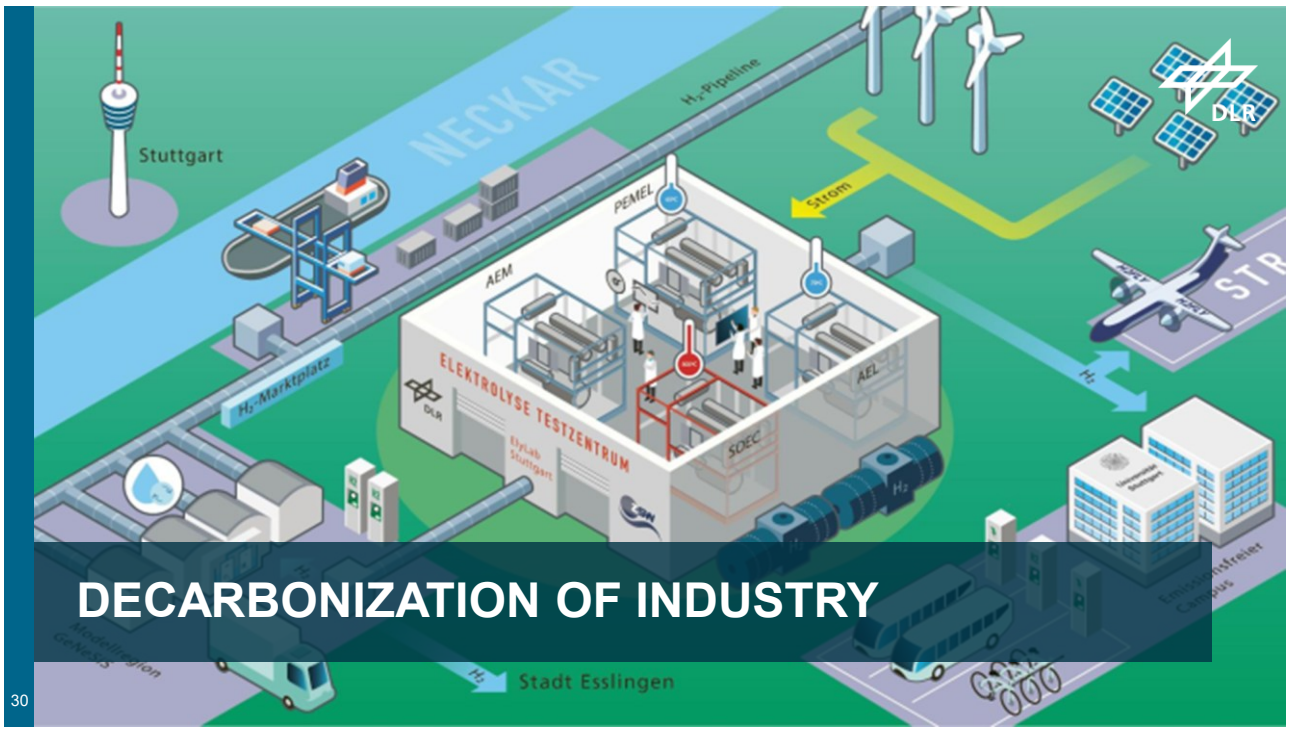
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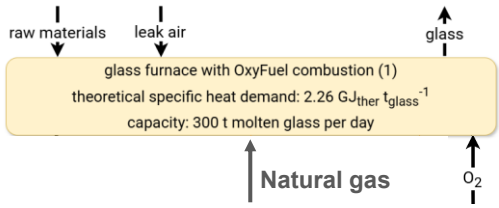


30

Decarbonization of basic industry
CCU: Container glass production[1]



DLR



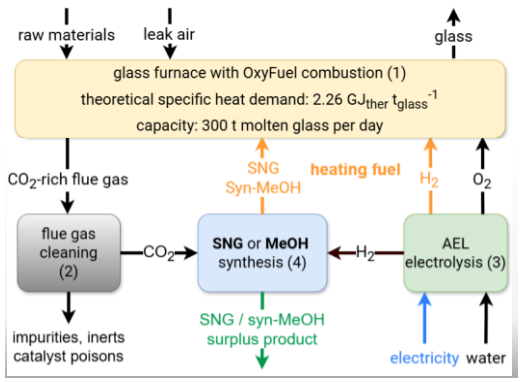
[1] Rahmat et al. (2027) Advancing the defossilization of the glass industry based on the integration of synthetic fuels production. *Fuel, 428, 140180*. https://doi.org/10.1016/j.fuel.2026.140180

• DLR.de • Slide 32 • Dietrich et. al • Assessment requirements, methodology and results for CO2 utilisation measures towards "Net Zero" • 24. September 2026, Rotterdam

Decarbonization of basic industry
CCU: Container glass production[1]



DLR

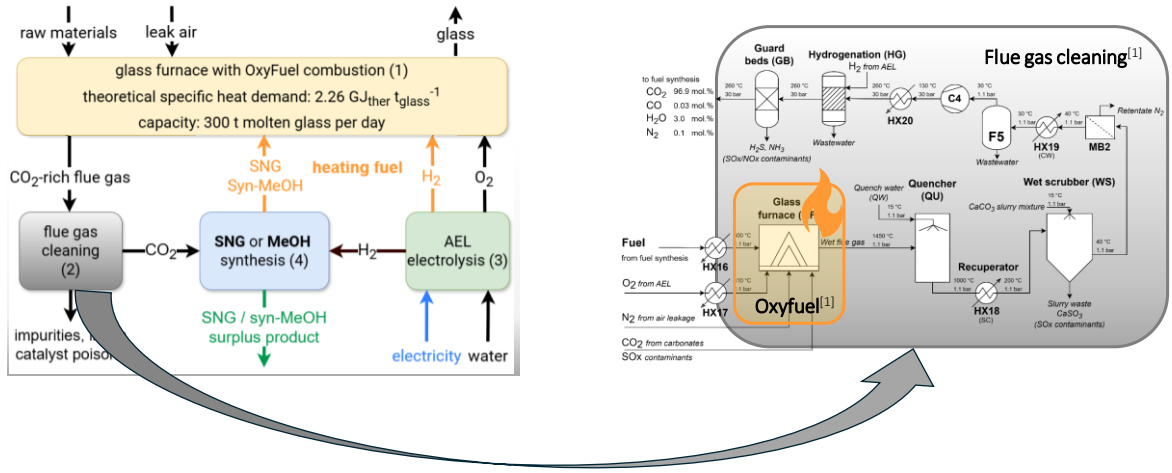


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DLR



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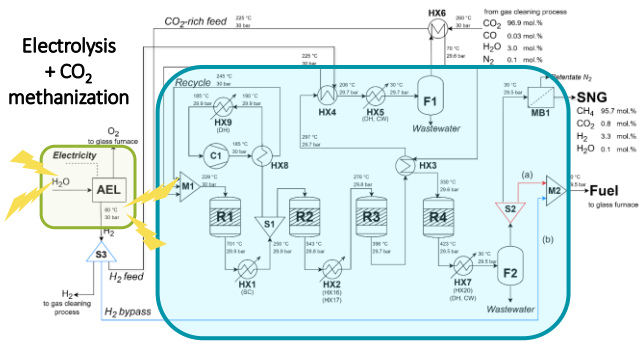
33

Decarbonization of basic industry
CCU: Container glass production[1]



DLR

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



SNG synthesis, adapting advanced TREMP™-process [1]

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34

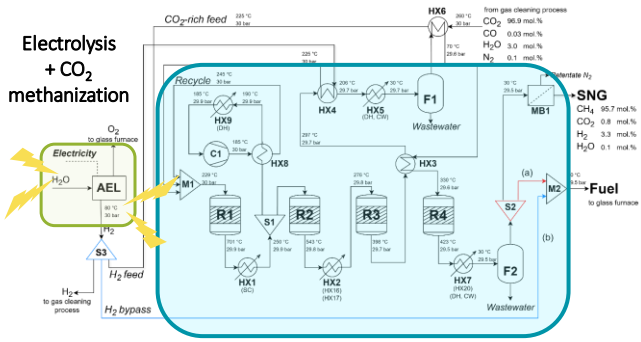
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CCU: Container glass production[1]



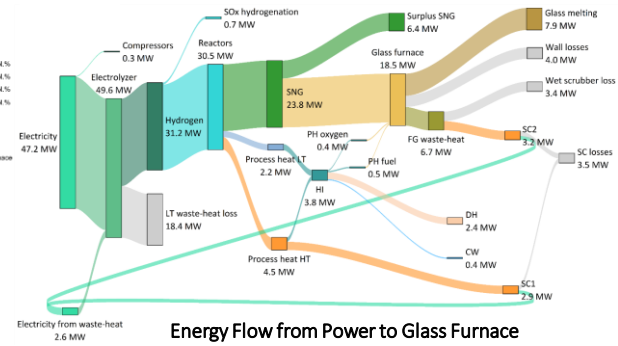
DLR

SNG from oxyfuel offgas CCU: DE, 2022, 300 t/d container glass

Electrolysis
+ CO_2
methanization



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Energy Flow from Power to Glass Furnace

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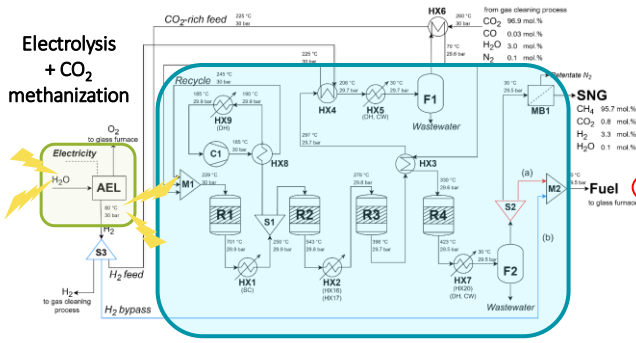
Decarbonization of basic industry
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DLR

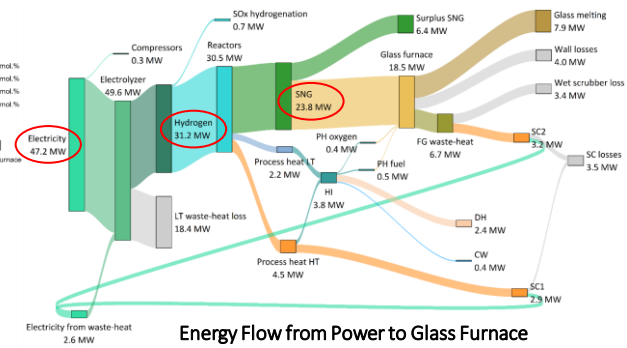
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η_{PtF} = 45.3 % | η_{HtF} = 82.9 %



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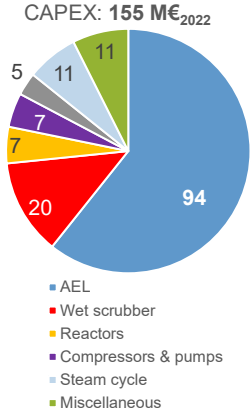
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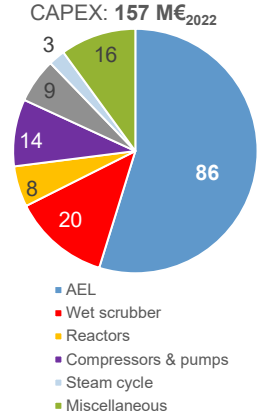
SNG

CAPEX: **155 M€$_{2022}$**



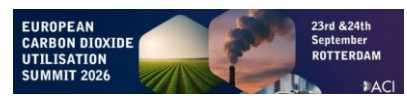
Syn-MeOH

CAPEX: **157 M€$_{2022}$**



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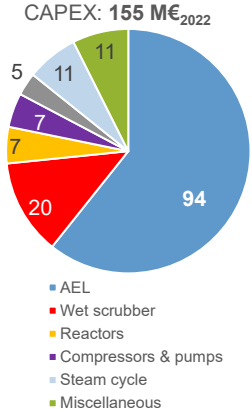


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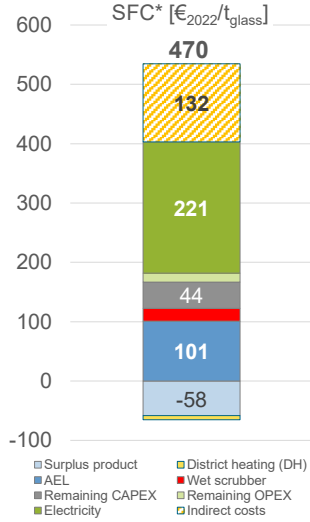
*SFC: Specific Fuel Cost

SNG

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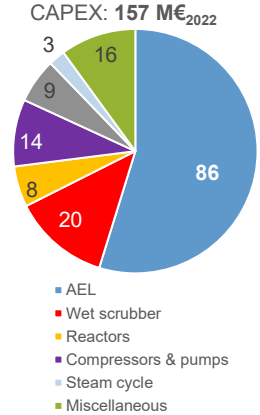


SFC* [€$_{2022}$/t$_{glass}$]

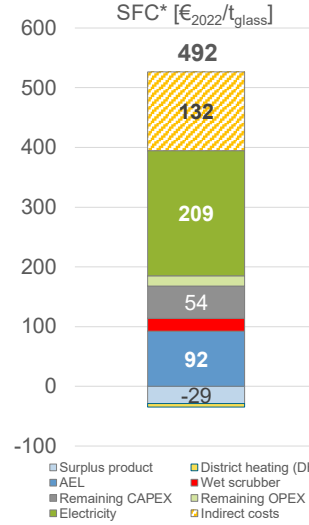


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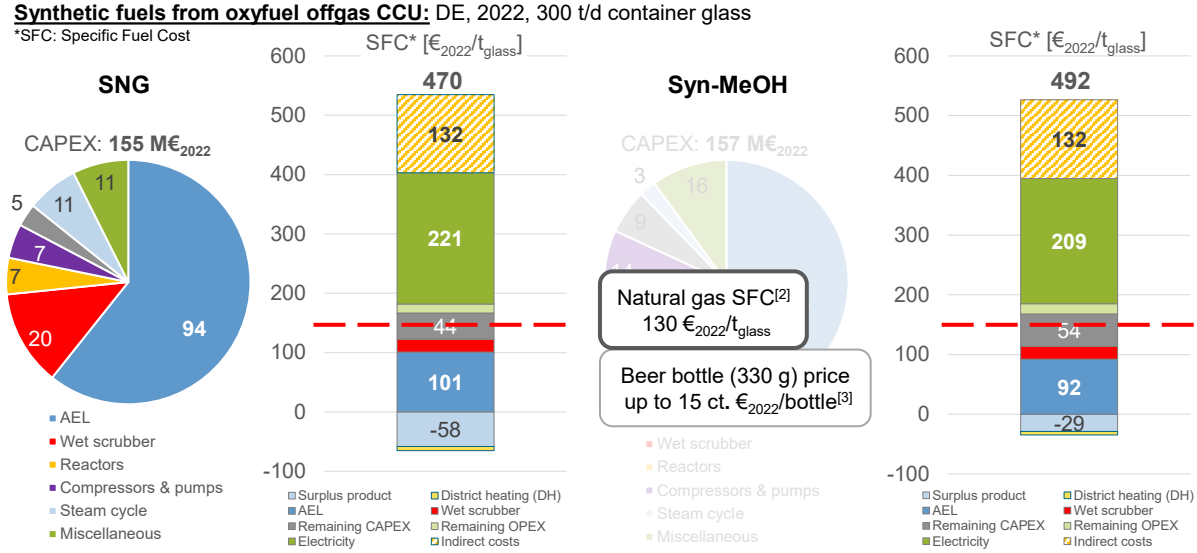
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Decarbonization of basic industry
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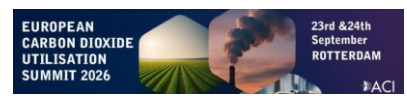
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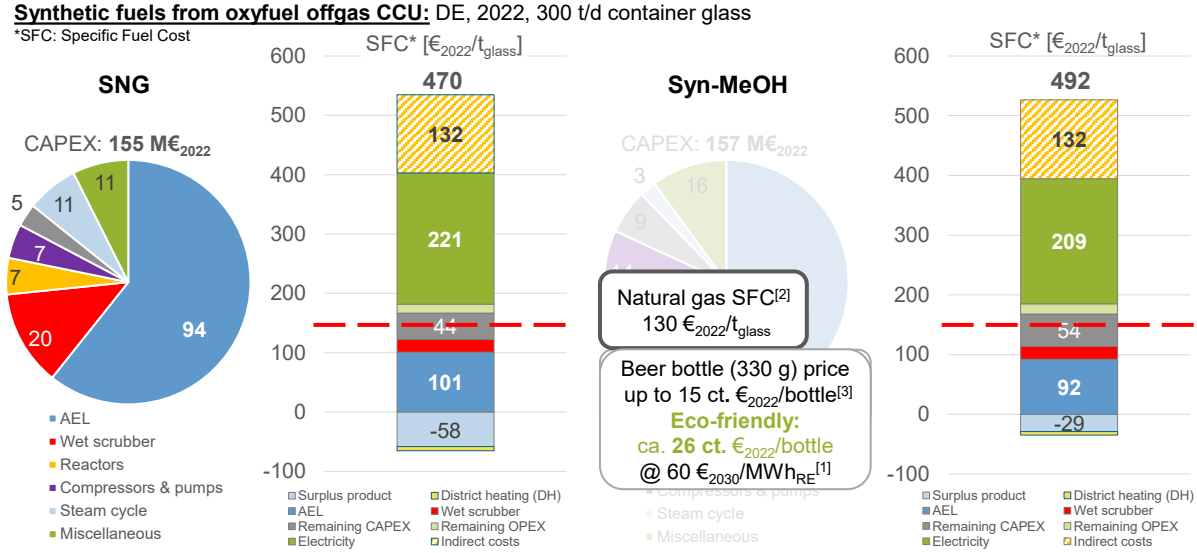
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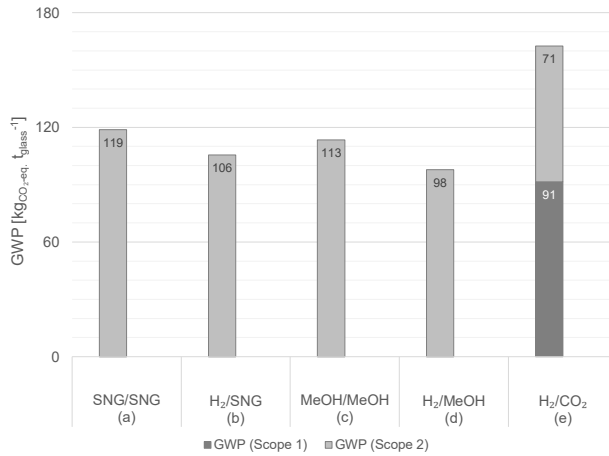


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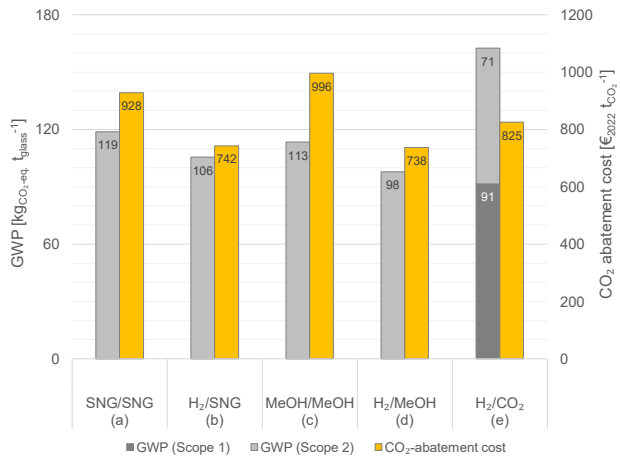


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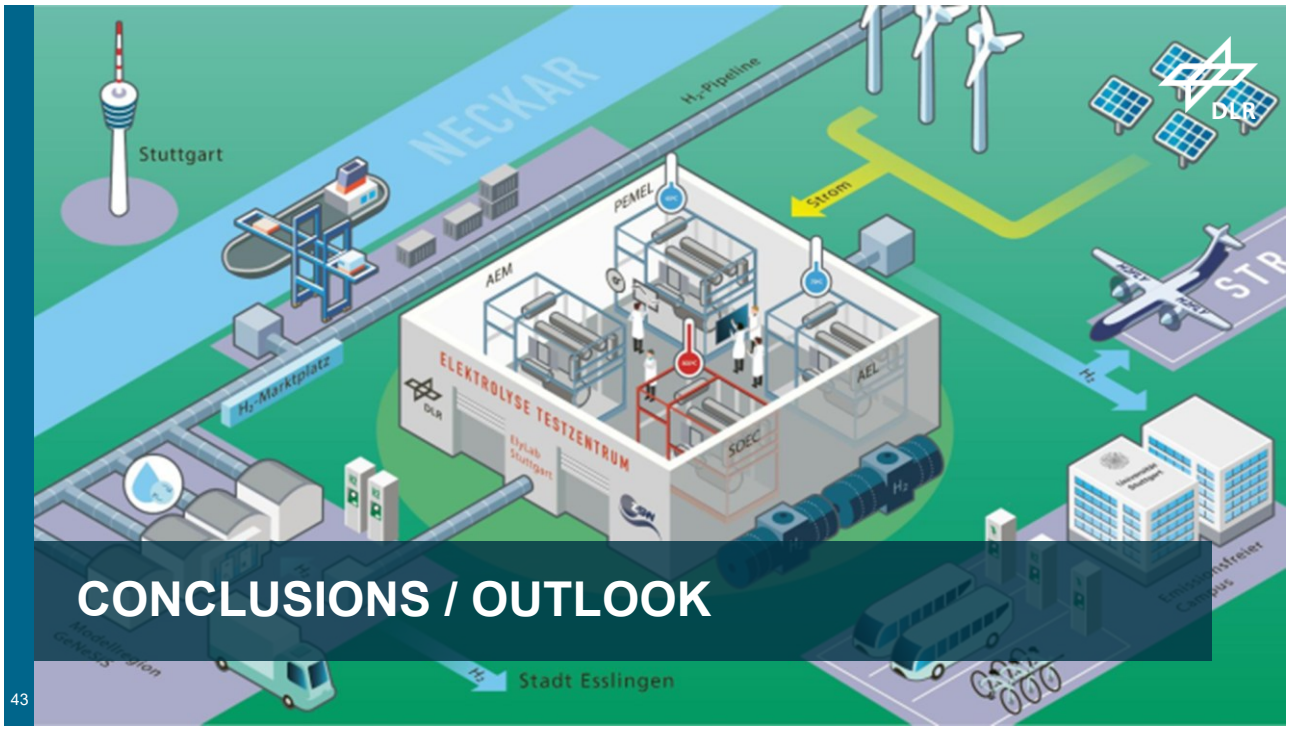
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CONCLUSIONS / OUTLOOK

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Summary



DLR

- Climate change mitigation is urgent on a global scale
  - GHG emission reduction required from 37.2 Gt/a in 2025 to ZERO in 2050

44

Summary



DLR

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- Developed countries need to provide technical solutions, international regulations need to ensure its commercial viability
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  - Choosing preferred technologies and locations
  - R&D demand and optimization potential
  - Purposeful regulation ☞ update RED III, RFNBO, etc.

Summary



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  - Purposeful regulation ☞ update RED III, RFNBO, etc.
- DLR standardized methodology is applicable for any decarbonization measure locally/globally

TRY ☞ OPTIMIRA

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Partner search towards Decarbonization



DLR

Looking for research / development / demonstration / deployment 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 heatpump/electrolyzer applications that optimally fits 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

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Partner List & Team



DLR

- Join our partner list
  - direct orders welcome

AIRBUS

BASF
We create chemistry

DAIMLER TRUCK

EnBW

LEAG

TotalEnergies

☞ DLR's Techno-economic assessment (TEA) team



- Experienced team of engineers and scientists
- 10+ years of methodology and tool development
- 15 national and international research projects
  ☞ DLR is well-known as facilitator, coordinator, partner
- 30 scientific papers and 6 industrial consultancies

Thursday, 2026/09/24: CONFERENCE SESSION FOUR
Sustainability, Integrity & Transparency in CO_2 Utilisation



THANK YOU FOR YOUR KIND ATTENTION!

QUESTIONS?

Assessment requirements, methodology and results for CO2 utilization measures towards "Net Zero"

Ralph-Uwe Dietrich, Felix Habermeyer, Nathanael Heimann, Owais Khokar, Yoga Rahmat, Julia Weyand

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

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