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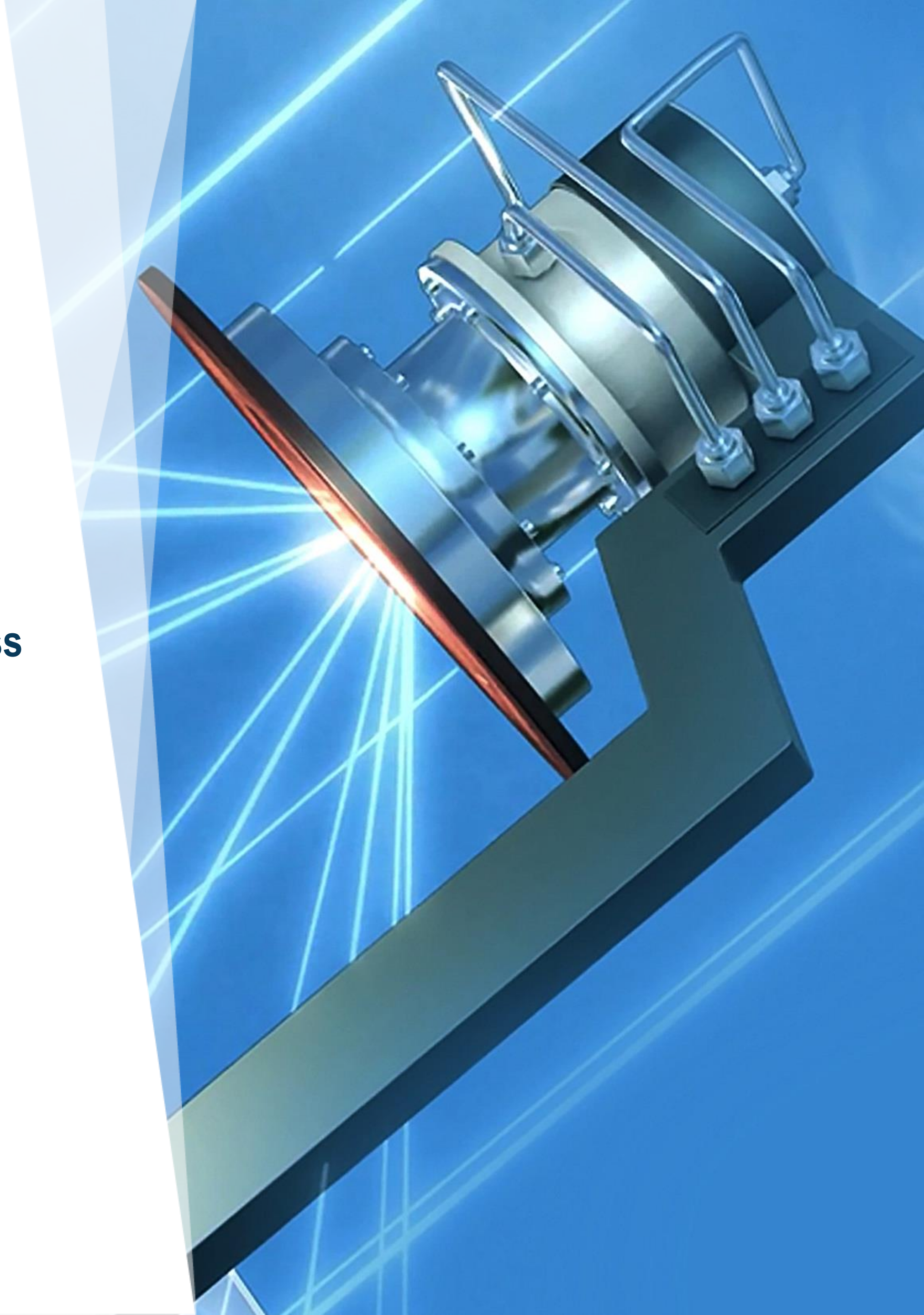
Upcoming Technologies and Challenges for Renewable Jet Fuel

A. Sizmann, V. Batteiger, C. Falter

“Maximizing SAF Benefits Beyond CO_2 Reduction”
JETSCREEN Workshop, Brussels, 26th November 2019

- Targets and challenges
- Technology options: properties, progress and potentials
- Long-term perspectives



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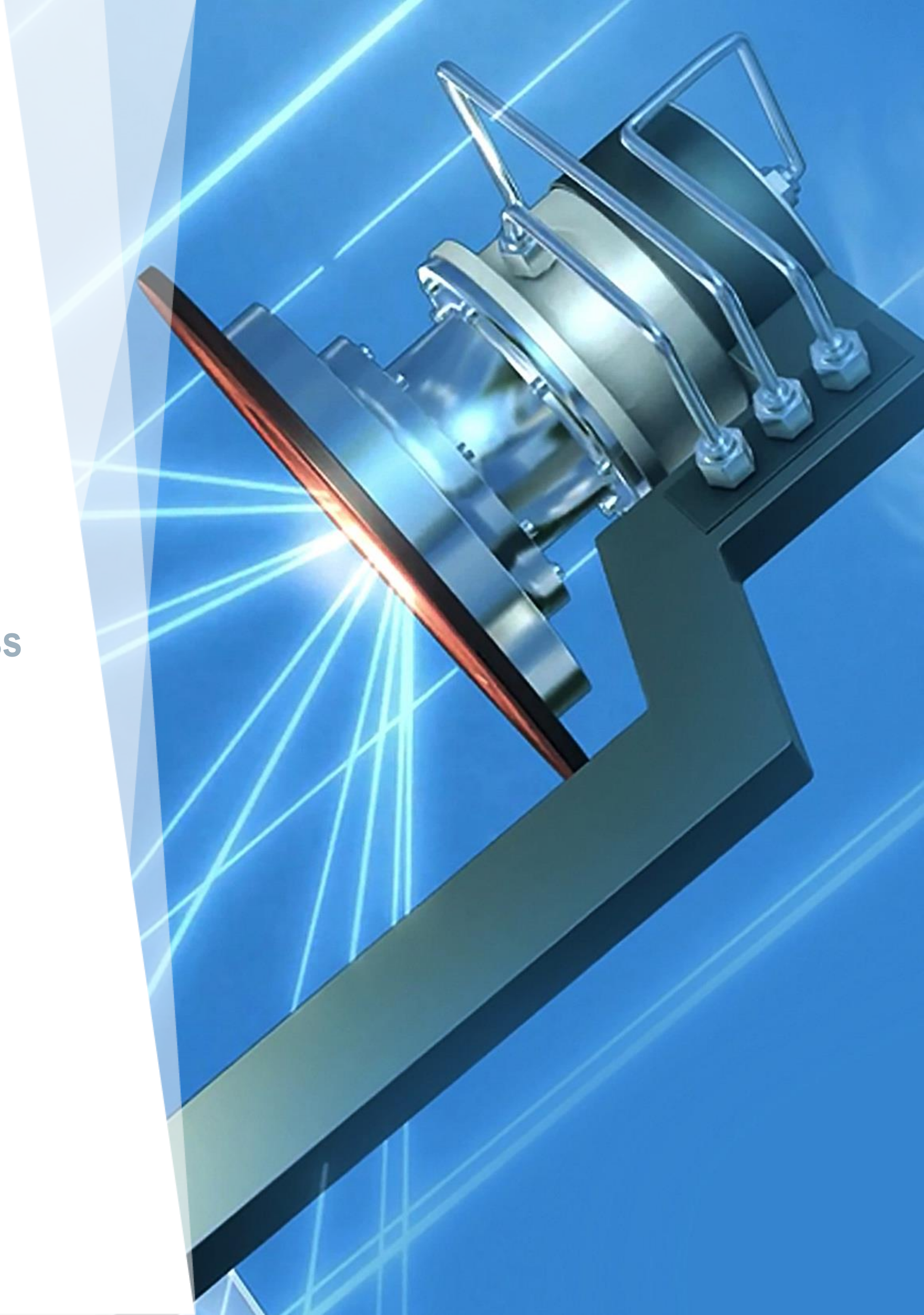
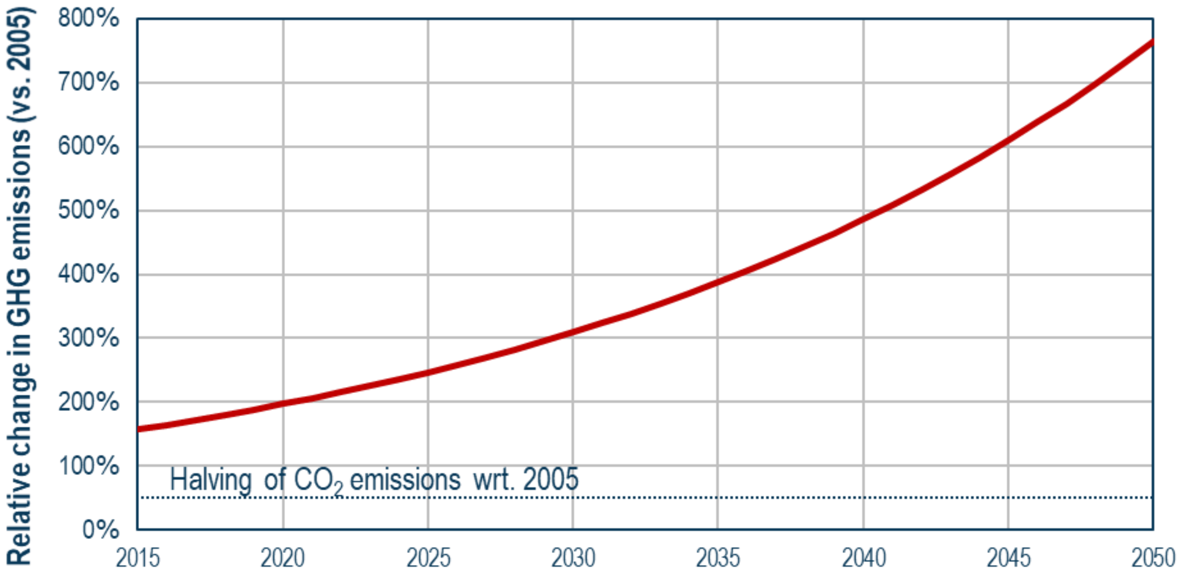


The Aviation Target: Reduce CO_2 by 50% by 2050 (rel. to 2005)

- **Aviation target is challenging in view of anticipated growth (various scenaria)**



$$\dot{M}_{\mathrm{CO_2eq}} = \begin{bmatrix}\text{ACTIVITY}\\ \text{e.g. RPK}\end{bmatrix} \times \begin{bmatrix}\text{associated}\\ \text{CARBON}\\ \text{INTENSITY}\end{bmatrix}$$

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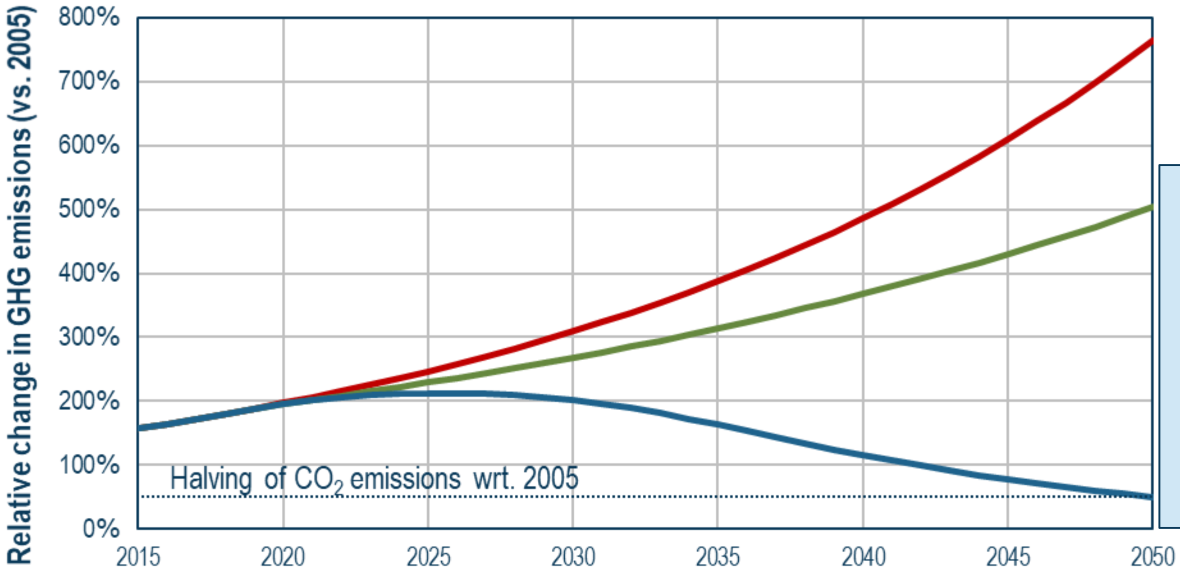
The Aviation Target: Reduce CO_2 by 50% by 2050 (rel. to 2005)

- **Future GHG emissions are a function of three main factors: (3) zero carbon energy**



100% substitution of fossil kerosene:

ATAG target requires
ca. 550 Mt/a
sustainable aviation fuel with
<10% carbon intensity
compared to conventional fuel by 2050

$$\dot{M}_{CO_2eq}(2050) = \dot{M}_{CO_2eq}(2005) \times \begin{bmatrix} \text{GROWTH} \\ \text{in} \\ \text{RPK} \end{bmatrix} \times \begin{bmatrix} \text{GAIN} \\ \text{in} \\ \text{EFFICIENCY} \end{bmatrix}^{-1} \times \left(1 - \begin{bmatrix} \text{FRACTION of 2050's} \\ \text{"ZERO-CARBON"} \\ \text{ENERGY} \end{bmatrix}\right)$$

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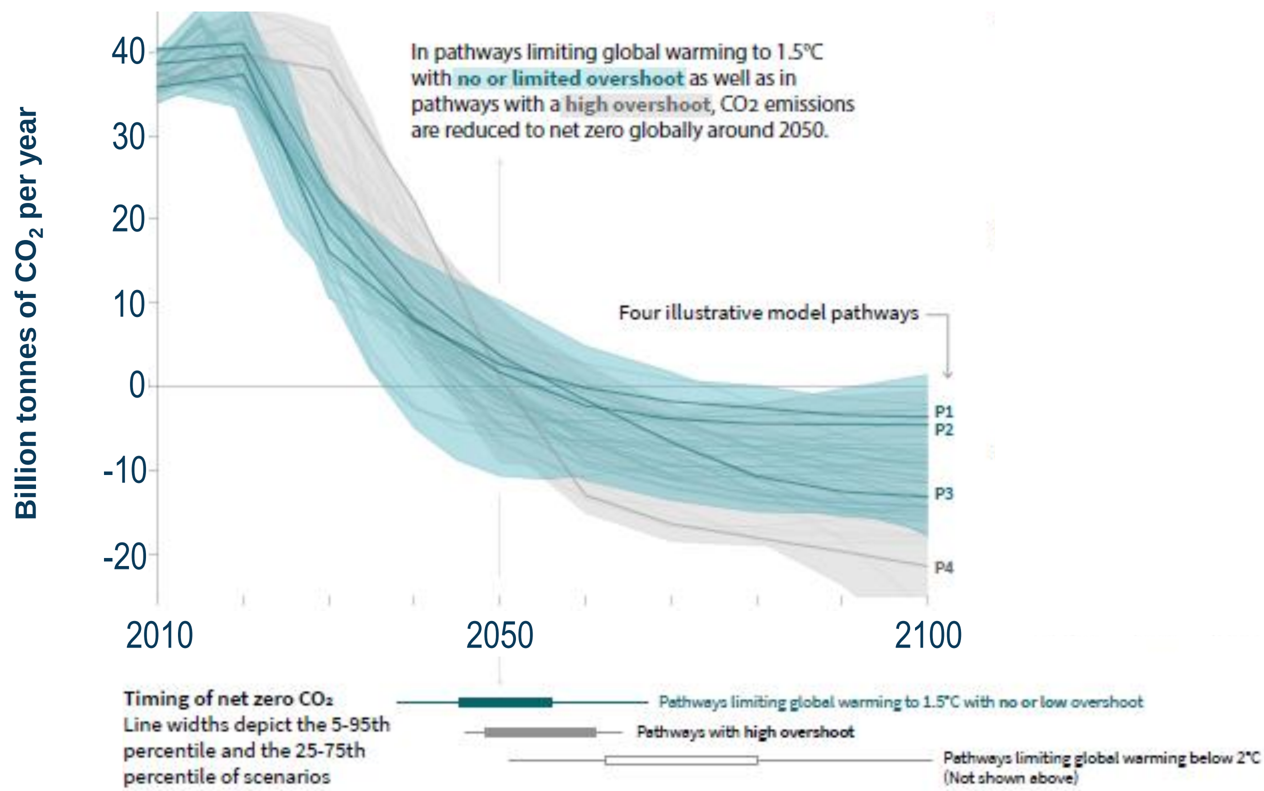
The 1.5 °C Target: „Negative“ CO_2 Emissions after 2050

Global Warming of 1.5 °C (IPCC special report, 2018)

Global total net CO_2 emissions: De-carbonize all sectors, remove CO_2 from atmosphere



see https://www.ipcc.ch/sr15/

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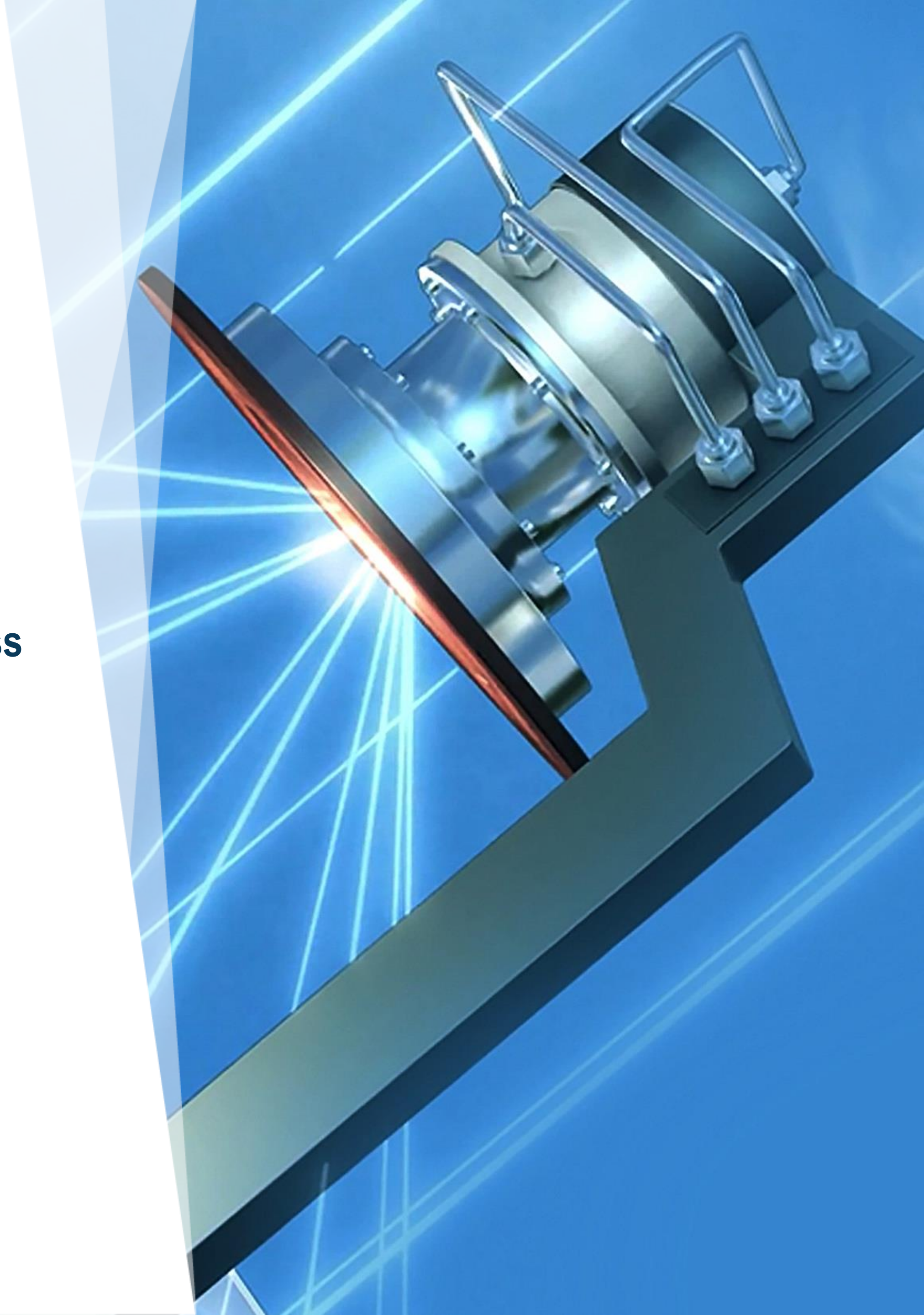

Feedstock-flexible Conversion: HyFlexFuel

FEEDSTOCK | **PROCESS** | **PRODUCT**

Water, heat, pressure

Hydrothermal liquefaction

Biocrude

Catalytic upgrading

Hydrocarbon fuels

Process water

Anaerobic digestion

Hydrothermal gasifictaion

Nutrient recovery

Fertilizer $(NH_4)Mg[PO_4]$

Treated water

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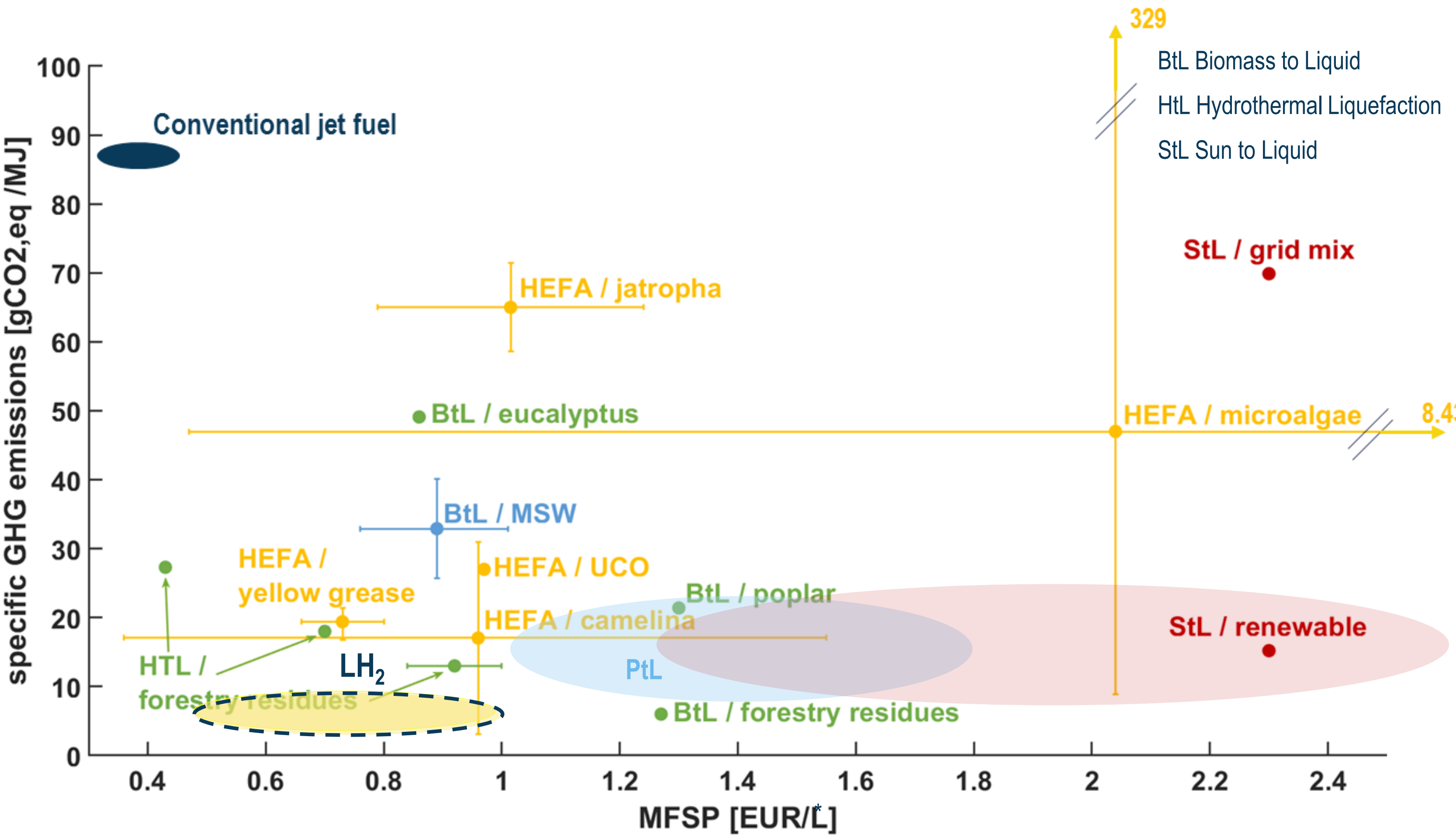
Drop-in Fuels from Renewable Sources

Minimum fuel selling price and specific GHG emissions



[* per L kerosene-eq]

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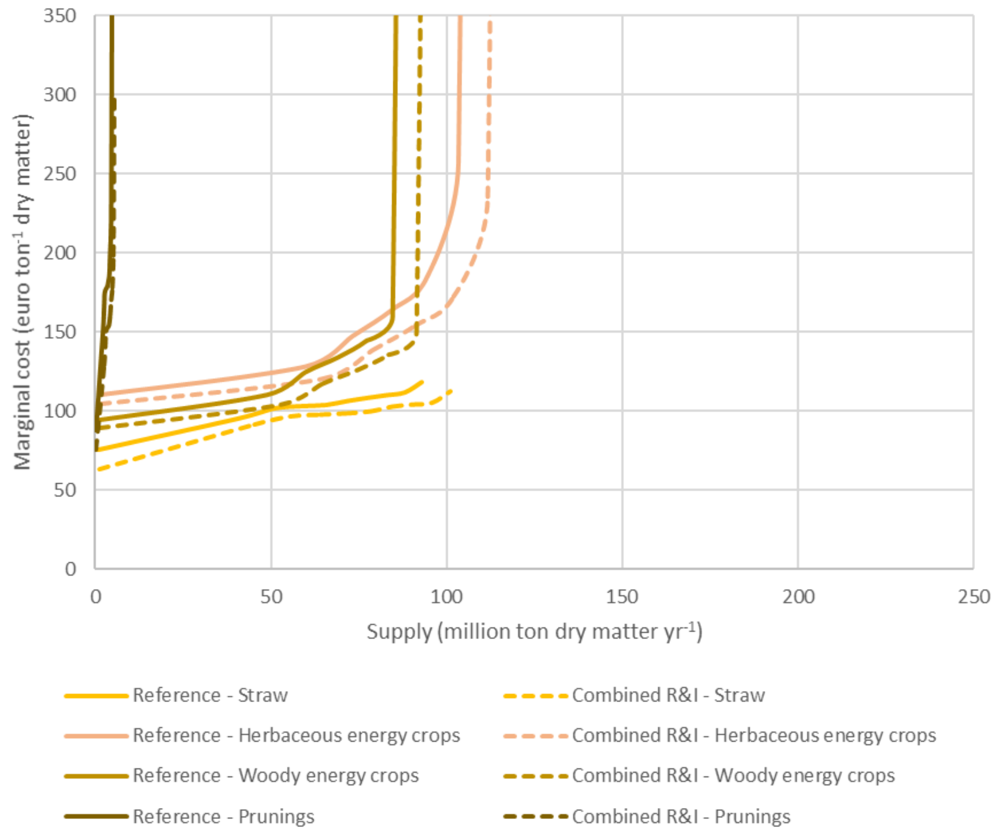
Geographical Potential of Agricultural Biomass

Cost-supply curves of agricultural biomass

- for the Reference and the Combined R&I scenarios in 2050 for agriculture

⇒ Characteristic „hard limit“ in sustainable supply,

⇒ However, actual marginal cost of biofuel may give biomass a competitive advantage over StL and PtL.



Research and innovation perspective of the mid-and long-term potential for advanced biofuels in Europe, EC 2018
DOI 10.2777/37969

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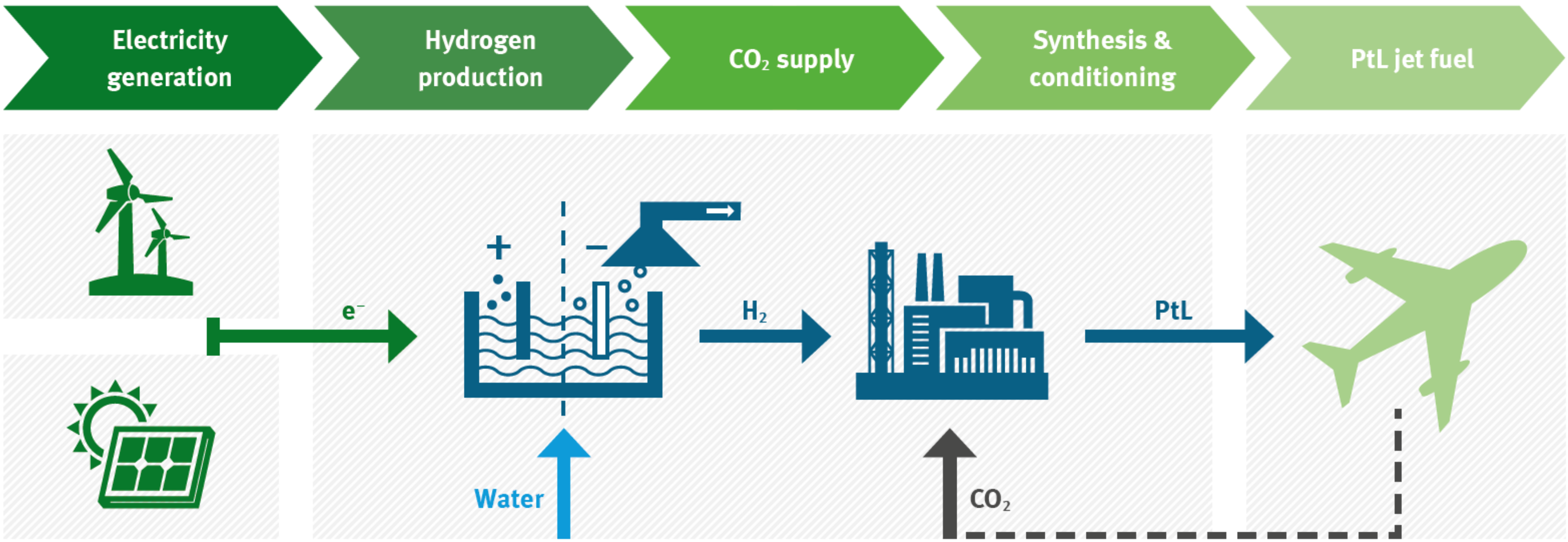
Background Study: Power-to-Liquid (PtL) for Aviation

- **The pathway produces hydrogen as an intermediate energy carrier**



Source: Power-to-Liquids: Potentials and Perspectives for the Future Supply of Renewable Aviation Fuel, Umweltbundesamt, 2016, http://bit.ly/2cowOyf

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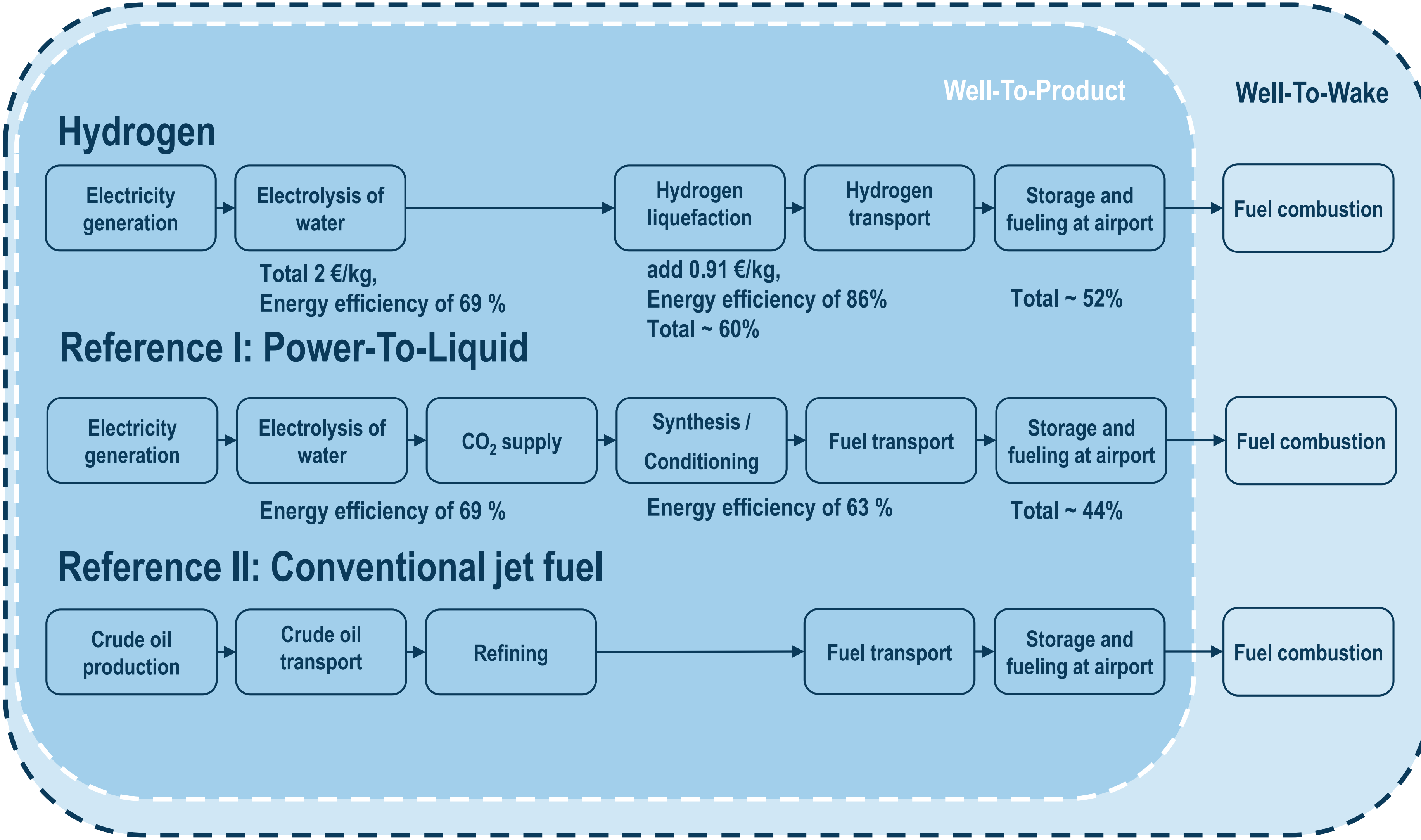
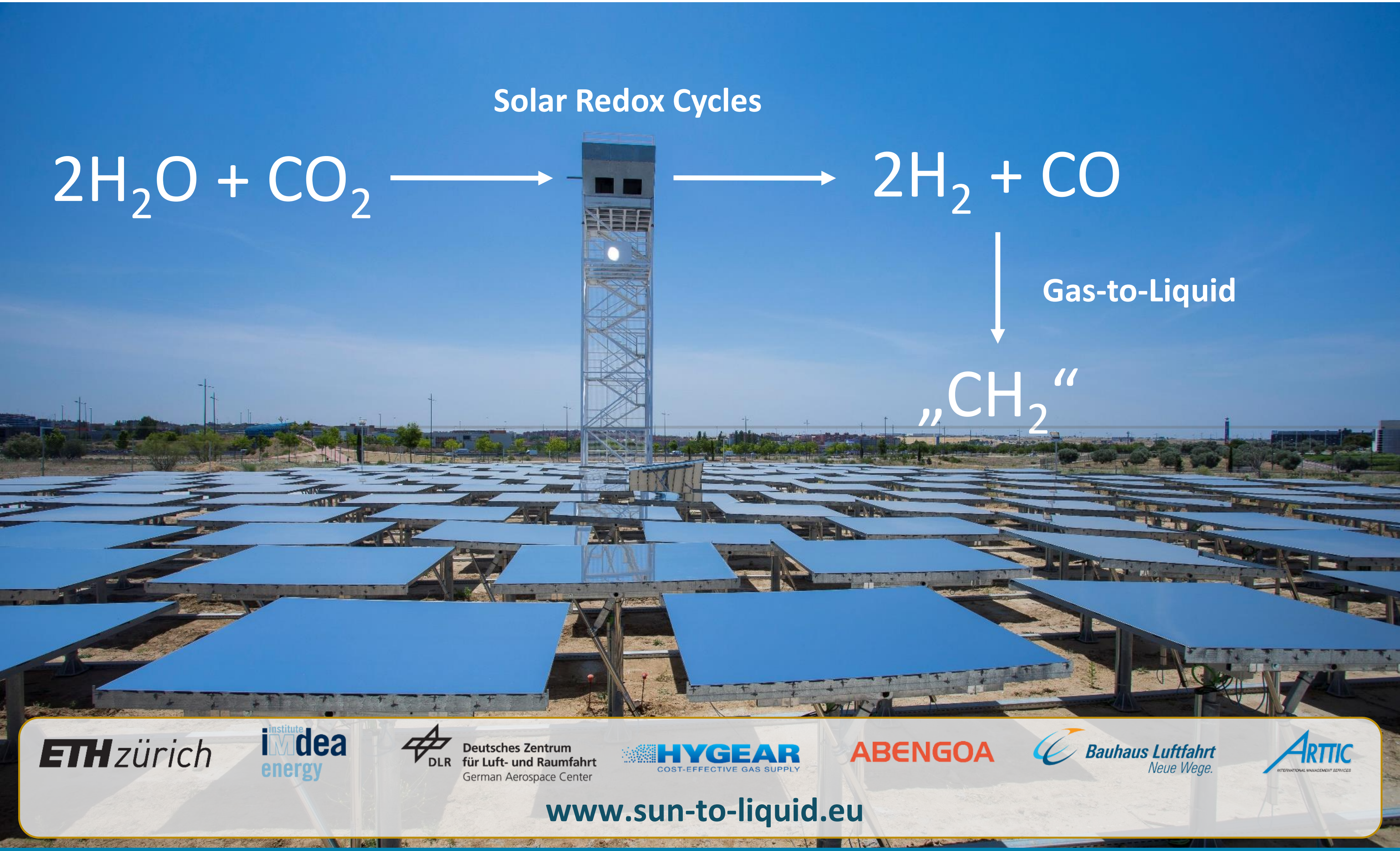
Hydrogen: One-step Production Process



SUN-to-LIQUID Approach to Solar Fuel

SUN to LIQUID
Fuels from concentrated sunlight



www.sun-to-liquid.eu

Key Technology: Ceria-based Redox Cycles

SUN to LIQUID
Fuels from concentrated sunlight

- State-of-art in laboratory: $\eta_{solar\text{-}to\text{-}CO}$ = 5.25% for thermochemical CO_2 splitting

Endothermic reduction:

$$(\sim 1500°C):\ CeO_2 \rightarrow CeO_{2\text{-}\delta} + \frac{\delta}{2} O_2$$

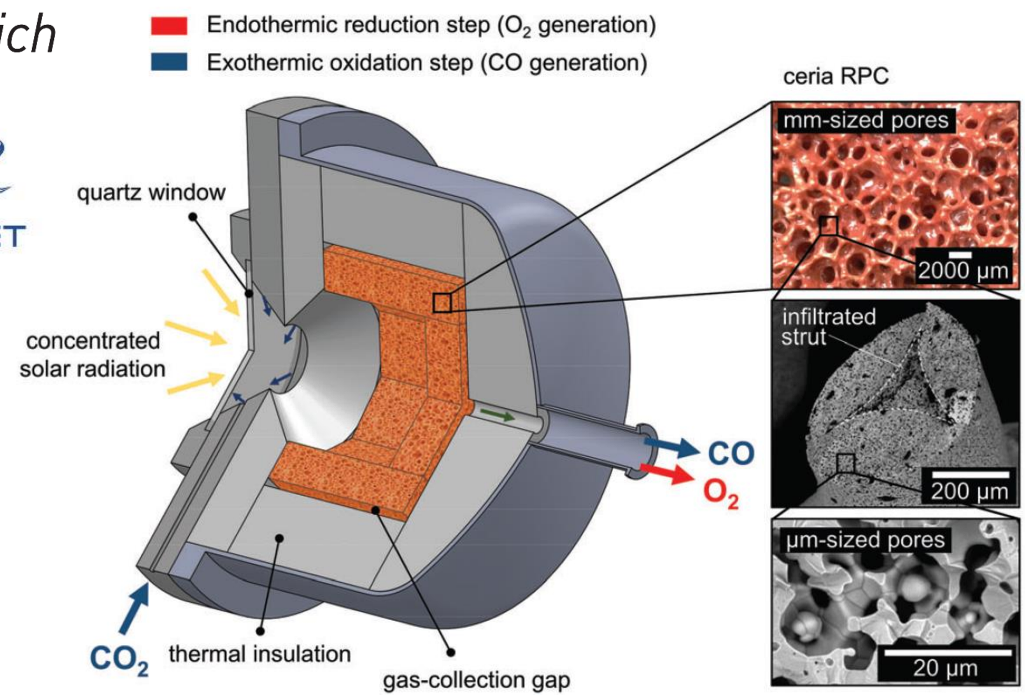
Exothermic oxidation:

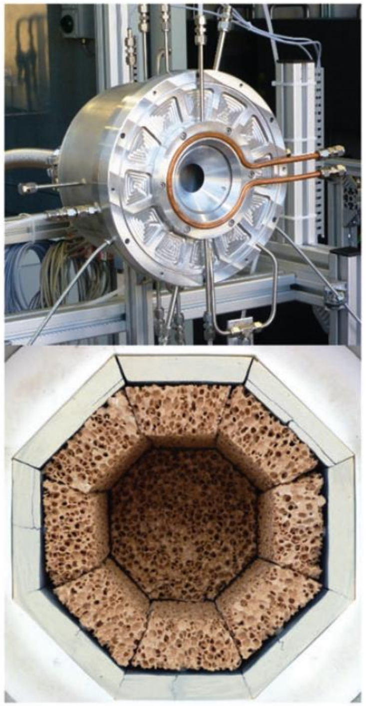
$$(\sim 1000°C):\ CeO_{2\text{-}\delta} + \delta H_2O \rightarrow CeO_2 + \delta H_2$$

$$(\sim 1000°C):\ CeO_{2\text{-}\delta} + \delta CO_2 \rightarrow CeO_2 + \delta CO$$

ETH zürich

SOLAR-JET





Source: Marxer et al, *Solar thermochemical splitting of CO_2 into separate streams of CO and O_2 with high selectivity, stability, conversion, and efficiency*, Energy Environ. Sci., 2017,10, 1142-1149; see also: http://www.solar-jet.aero/page/media-centre/scientific-publications.php

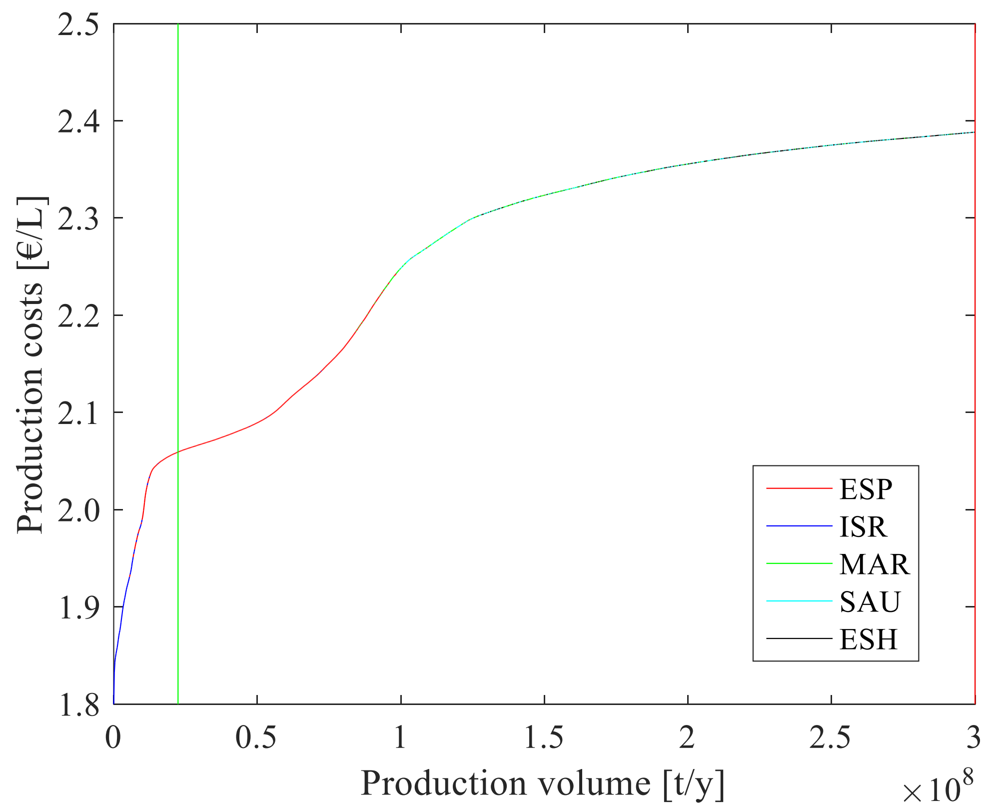
Geographical Potential of Solar Fuels

Cost-supply curves for the MENA region

- MENA demand: green line
- World demand: red line

⇒ World demand can easily be covered in the MENA region (graph cut off at world demand)

⇒ Even single countries can produce enough fuels to cover the world demand



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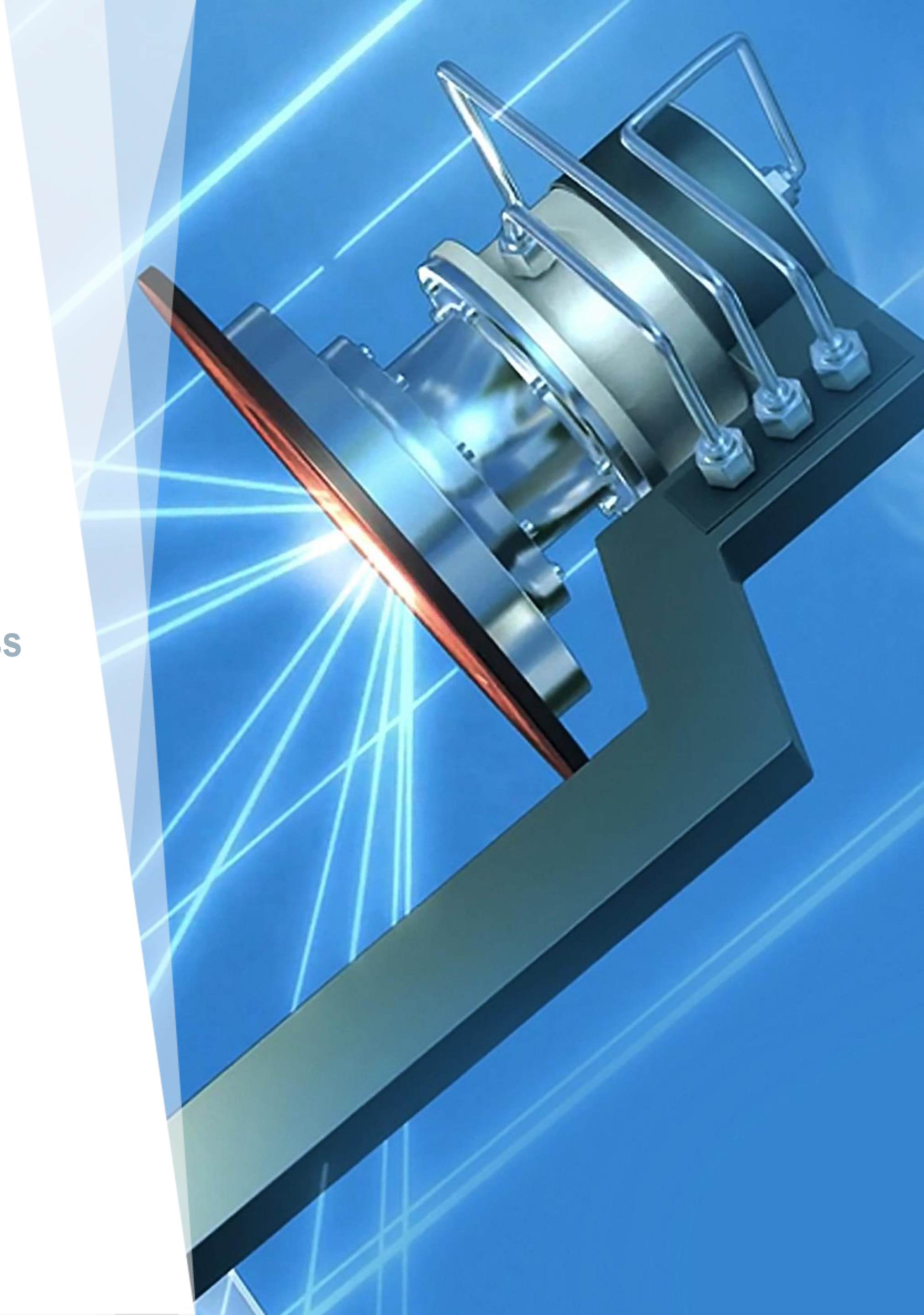
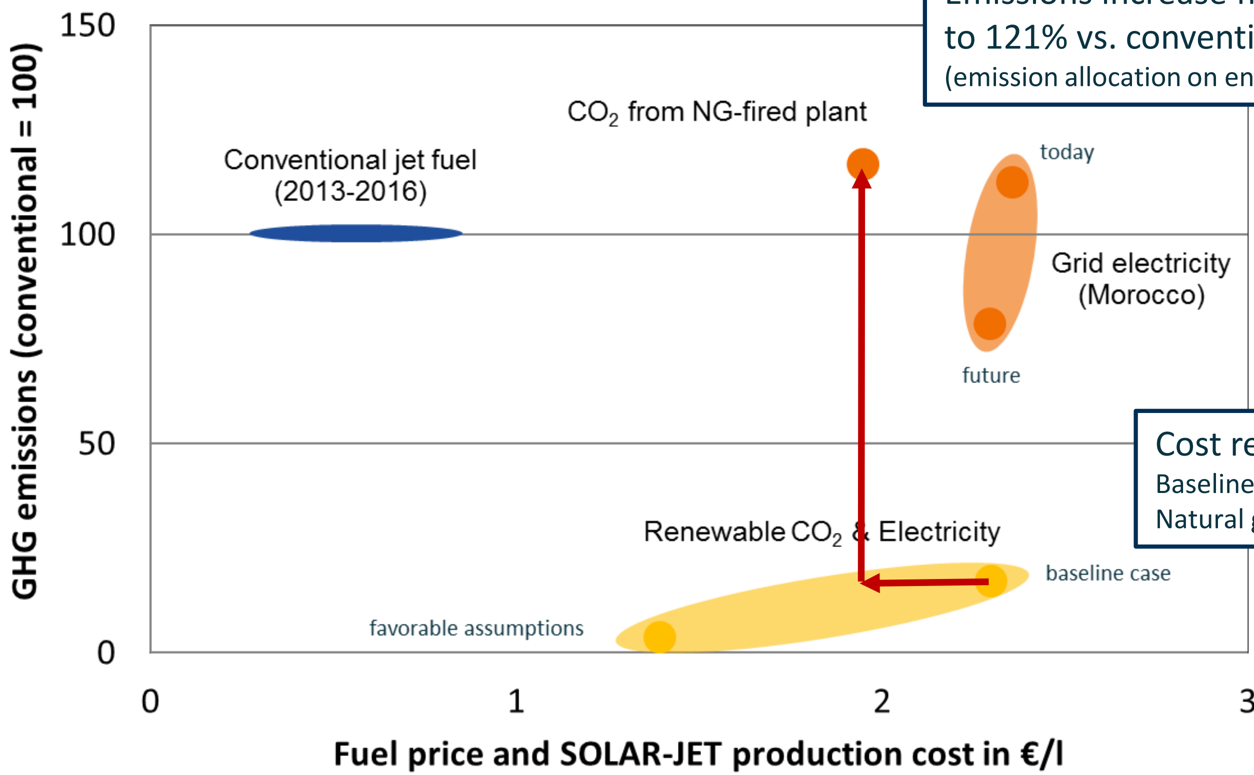


Cost and Life-cycle Impact of CO_2 Source

- Consideration of further carbon emissions along production chain can result in higher life-cycle emission compared to conventional fuel



Emissions increase from 20% to 121% vs. conventional jet fuel (emission allocation on energy basis)

Cost reduction by 32 ct/L
Baseline, air capture: 100 €/t_{CO2}
Natural gas plant: 40 €/t_{CO2}

Source: C. Falter, V. Batteiger, A. Sizmann; *Climate Impact and Economic Feasibility of Solar Thermochemical Jet Fuel Production*, Environ. Sci. Technol., 2016, 50 (1)

Industrial CO_2 sources

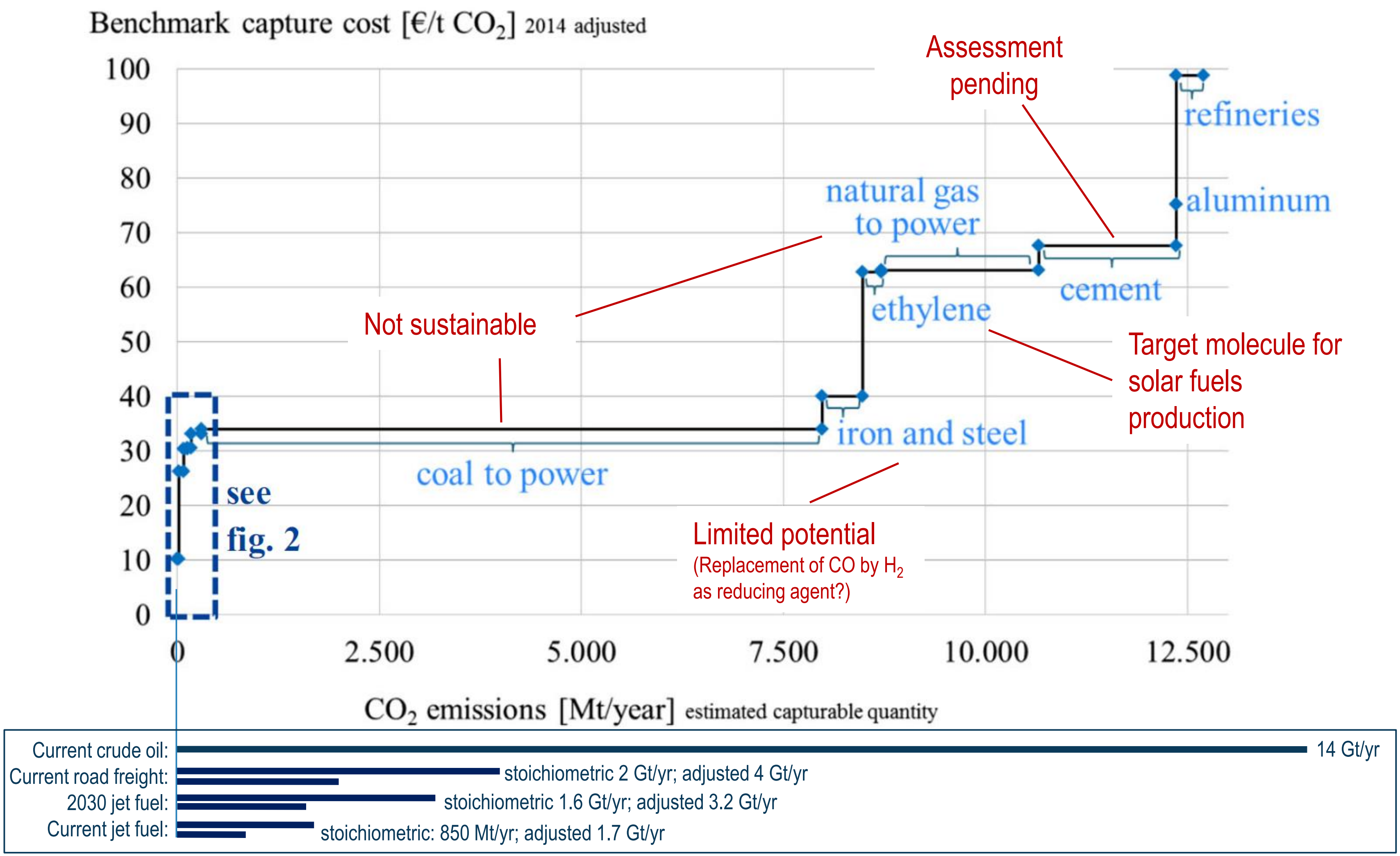


Diagram Source: Figure 3 in: H. Naims, *Economics of carbon dioxide capture and utilization—a supply and demand perspective*, Environ Sci Pollut Res (2016) 23: 22226.
Overlapping statements (in red) and estimates of CO_2 demands (below diagram) added by V. Batteiger (BHL)

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Conclusion

Targets and challenges

- Growth of aviation RPKs need to be overcompensated by efficiency gains and introduction of „zero-carbon“ energy
- Ramp-up, volume and net zero carbon fuel quality are challenging: By 2050 around 550 Mt/a of sustainable aviation fuel are required for 100% substitution of fossil kerosene.

Technology options: properties, progress and potentials

- HTL: Technical scalability of biofuel production is supported by feedstock flexibility
- PtL, StL: Long-term sustainable scalable production potentials for the future fuel demand is alternatively guaranteed through direct conversion of water and CO_2 on non-arable land.

Long-term perspectives

- Atmospheric CO_2 is a virtually unlimited resource for fuel production.
- Direct air capture of CO_2, low cost of carbon and of capital are key to long-term sustainable growth of aviation with synthetic PtL or StL hydrocarbon fuels

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Thank you for your attention!

HyFlexFuel

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SOLAR-JET

SUN to LIQUID
Fuels from concentrated sunlight

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