Solar Fuel Production from Ambient Air in a Modular Solar Concentrator-Reactor System

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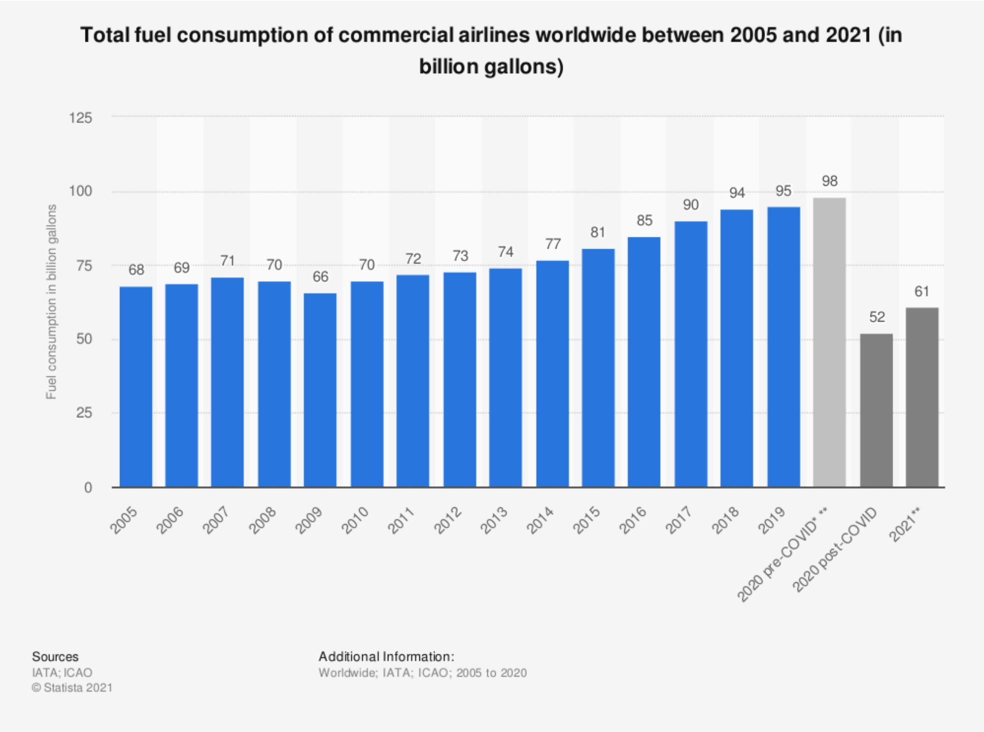
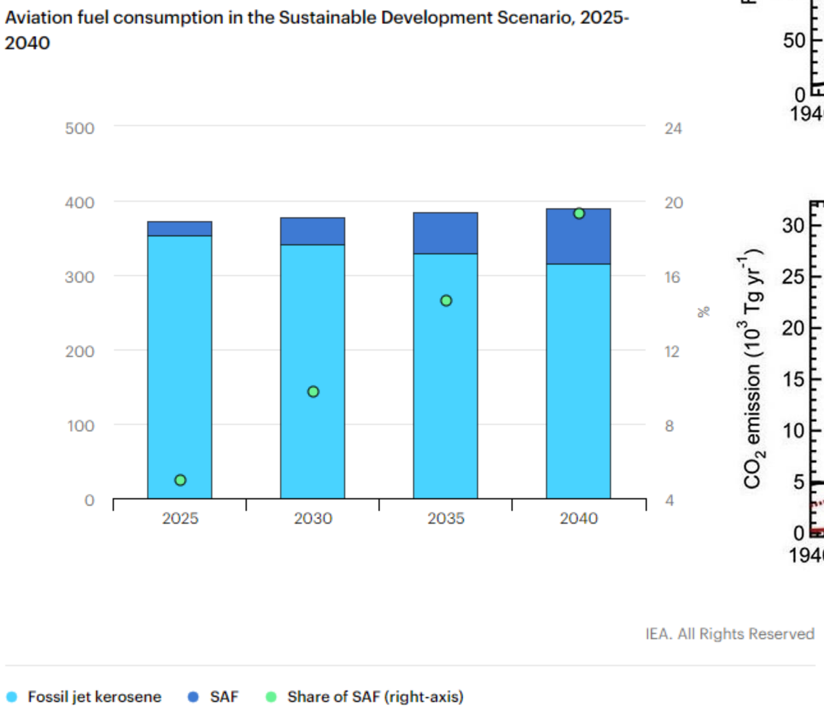
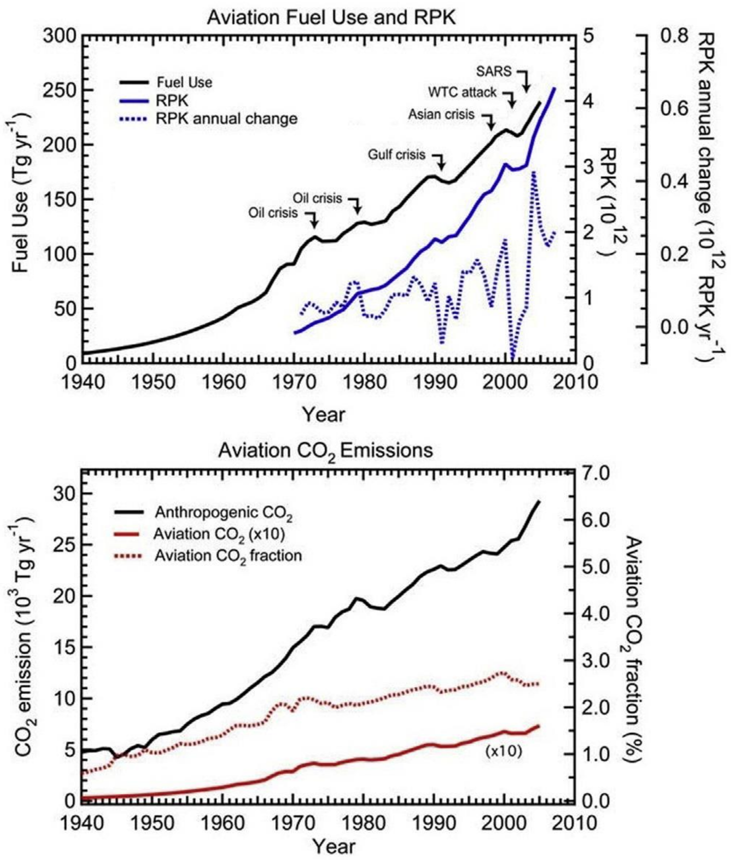
August 2021, ETH Zürich, Switzerland

Aviation fuel use and CO_2 emissions

- ~2-2.5% of total anthropogenic CO_2 emissions
- ~12% of CO_2 emissions from transport sources



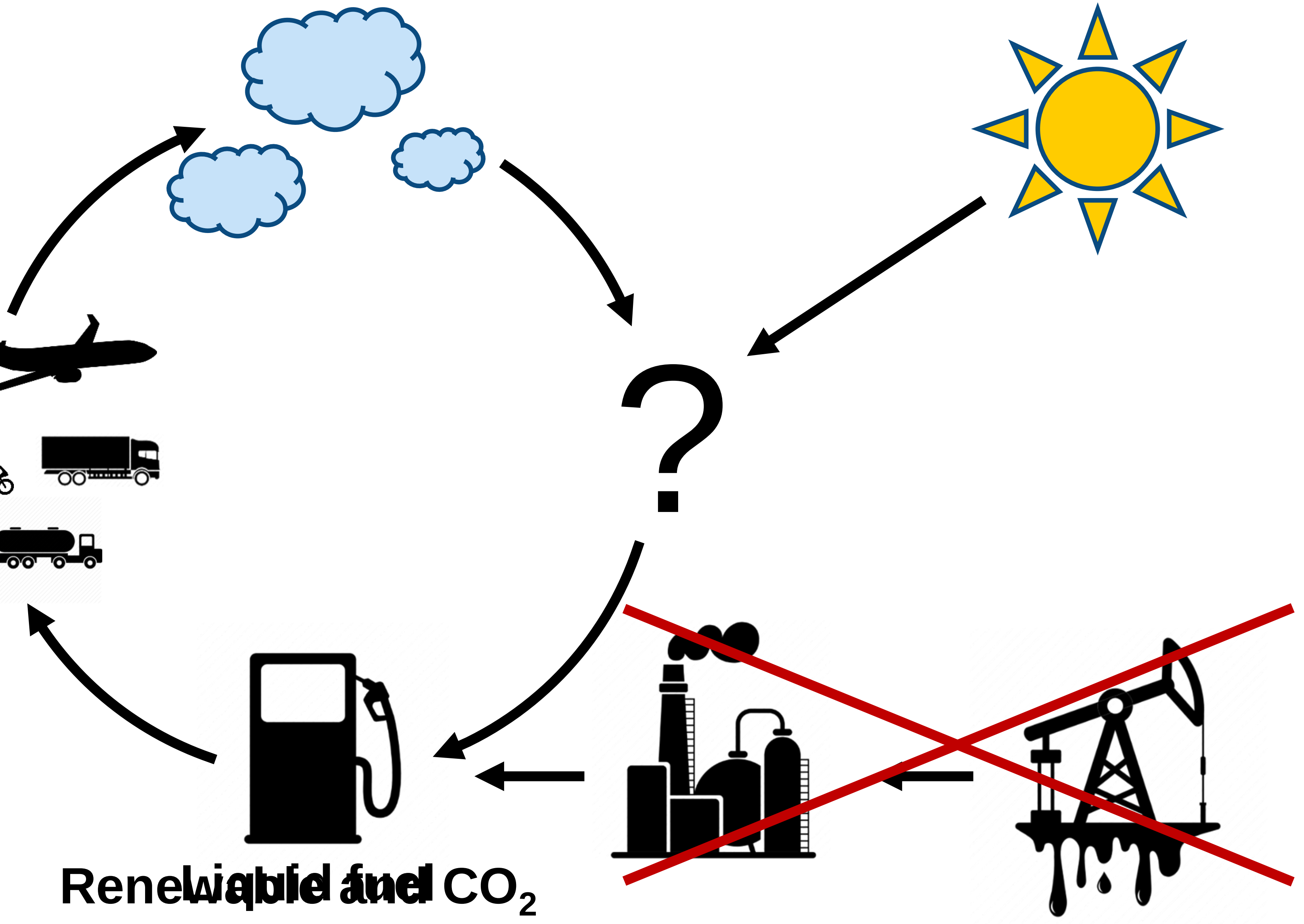




Sources:
IATA; ICAO
ATAG
IEA, *Aviation fuel consumption in the Sustainable Development Scenario, 2025-2040*, IEA, Paris
M. Grote et al. / Atmospheric Environment 95 (2014) 214-224

Fuel production

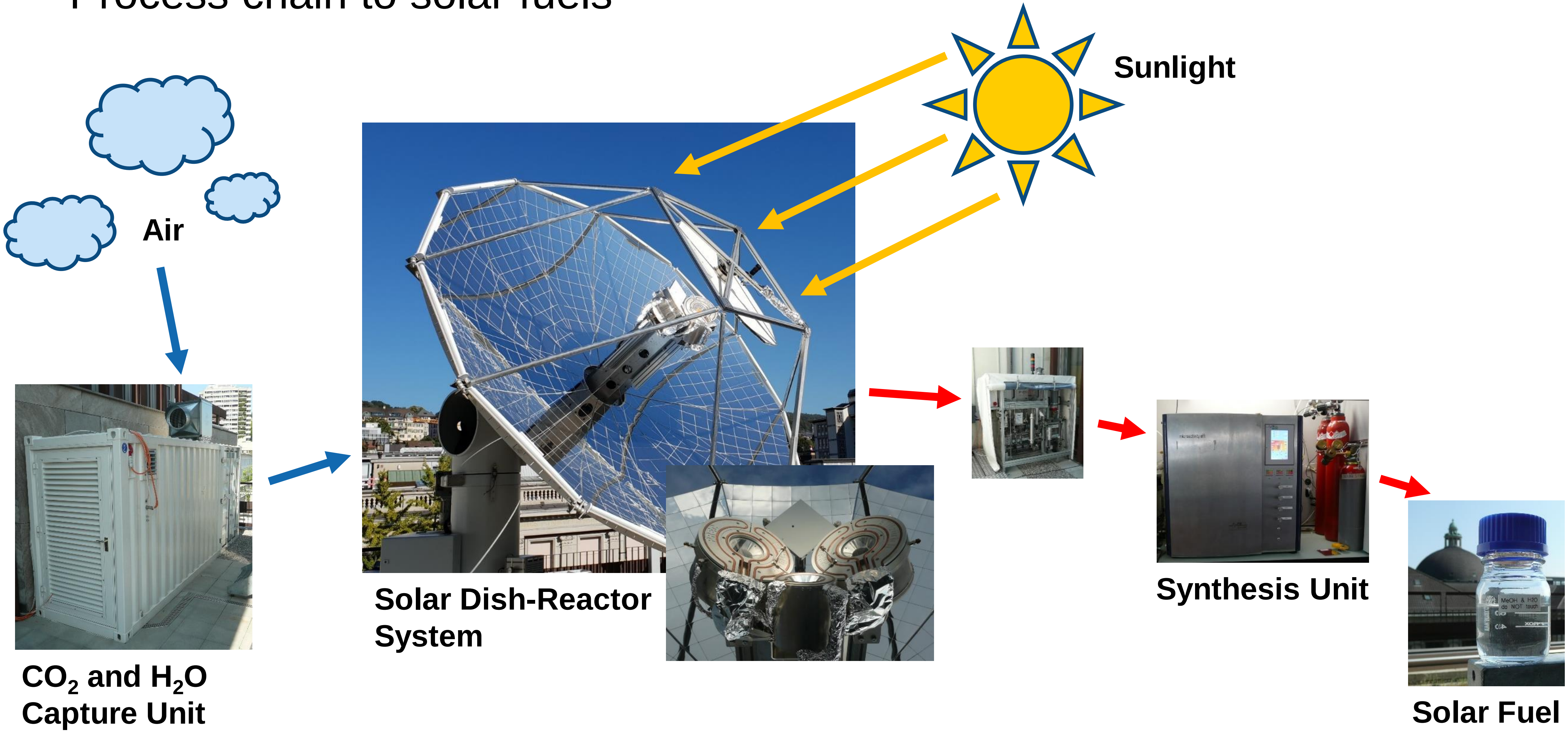
Existing Infrastructure und Technologies



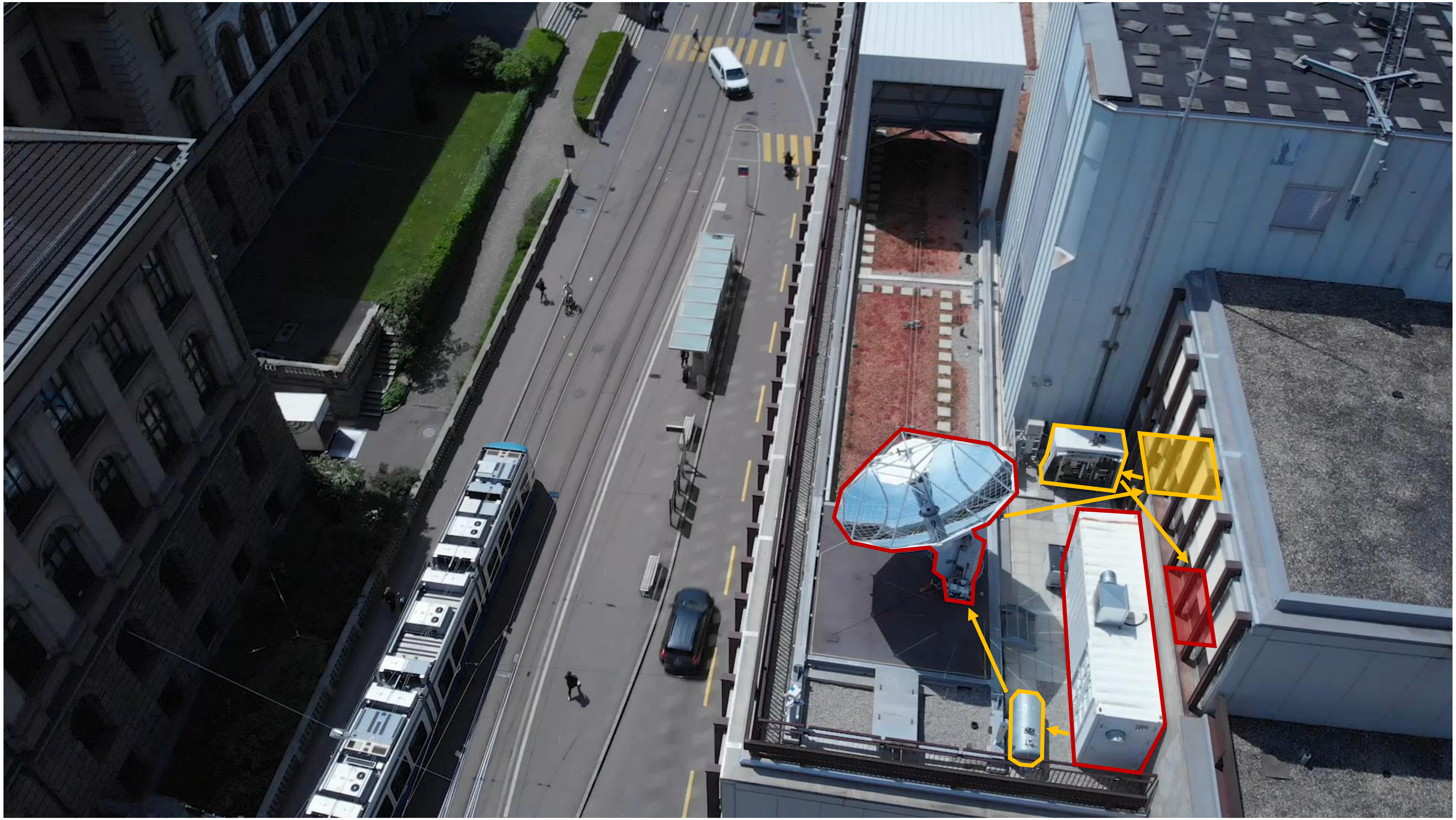
Liquid fuel

Renewable and CO_2 neutral solar fuel

Process chain to solar fuels



Location



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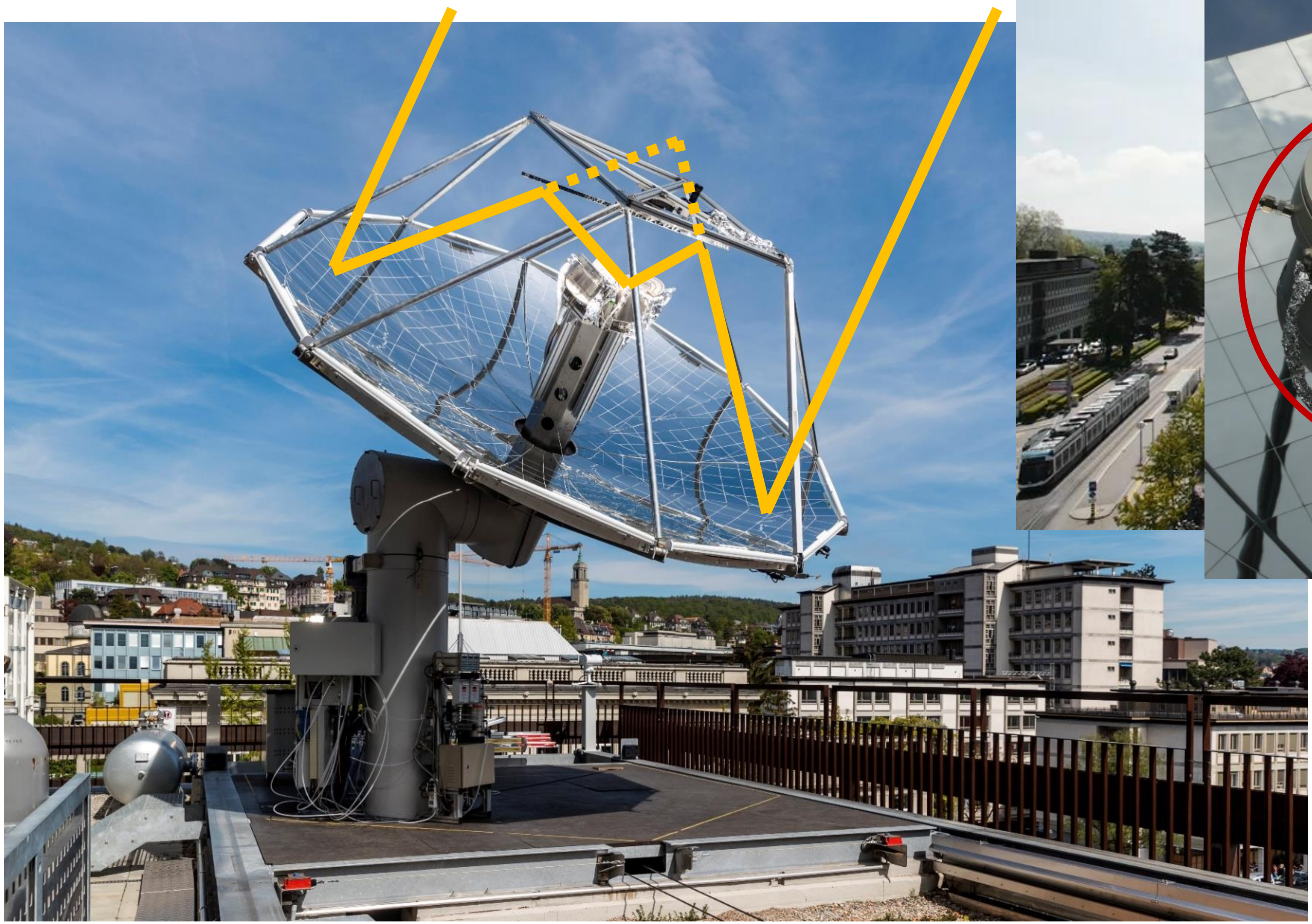
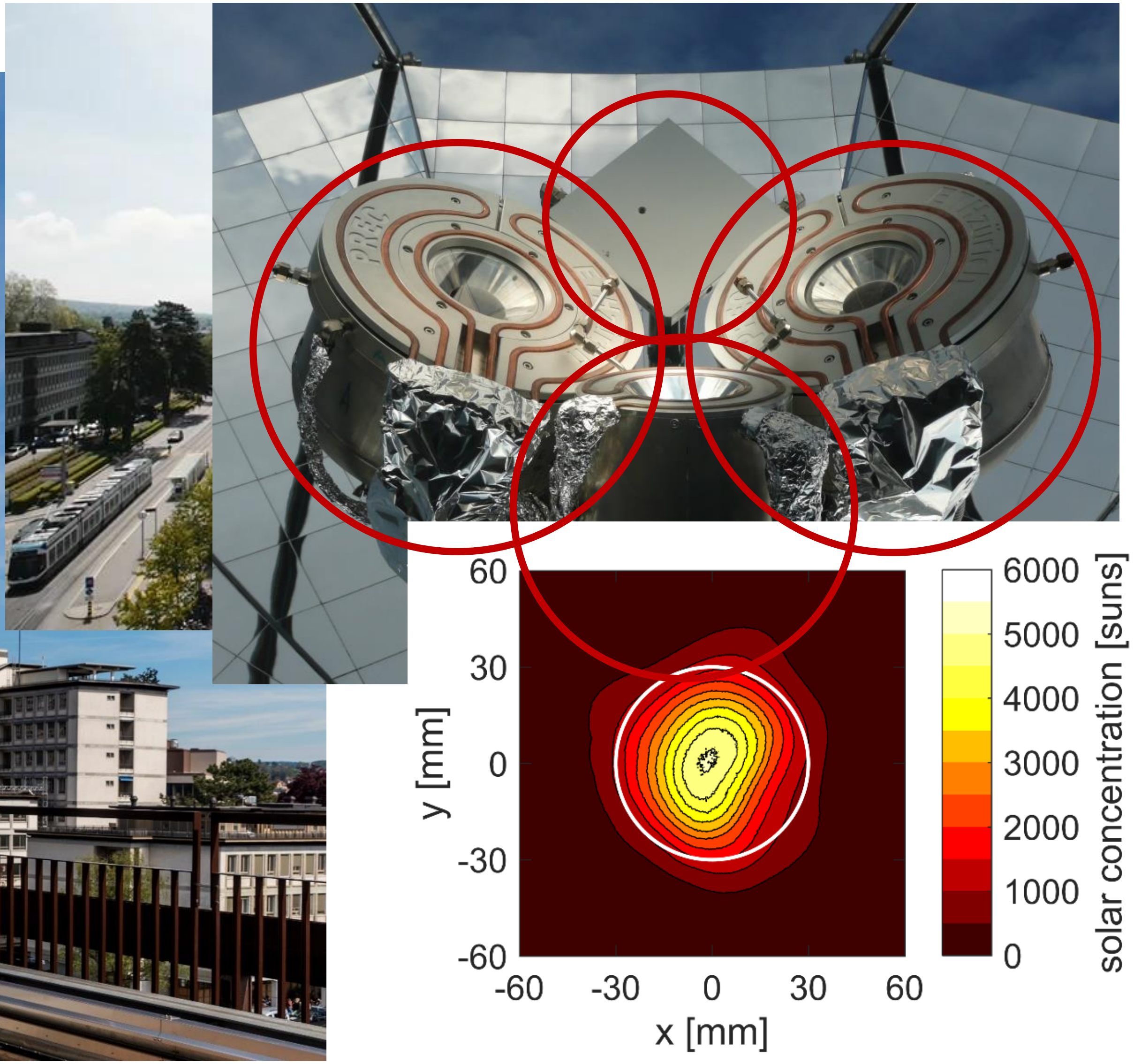
Dish-Reactor System





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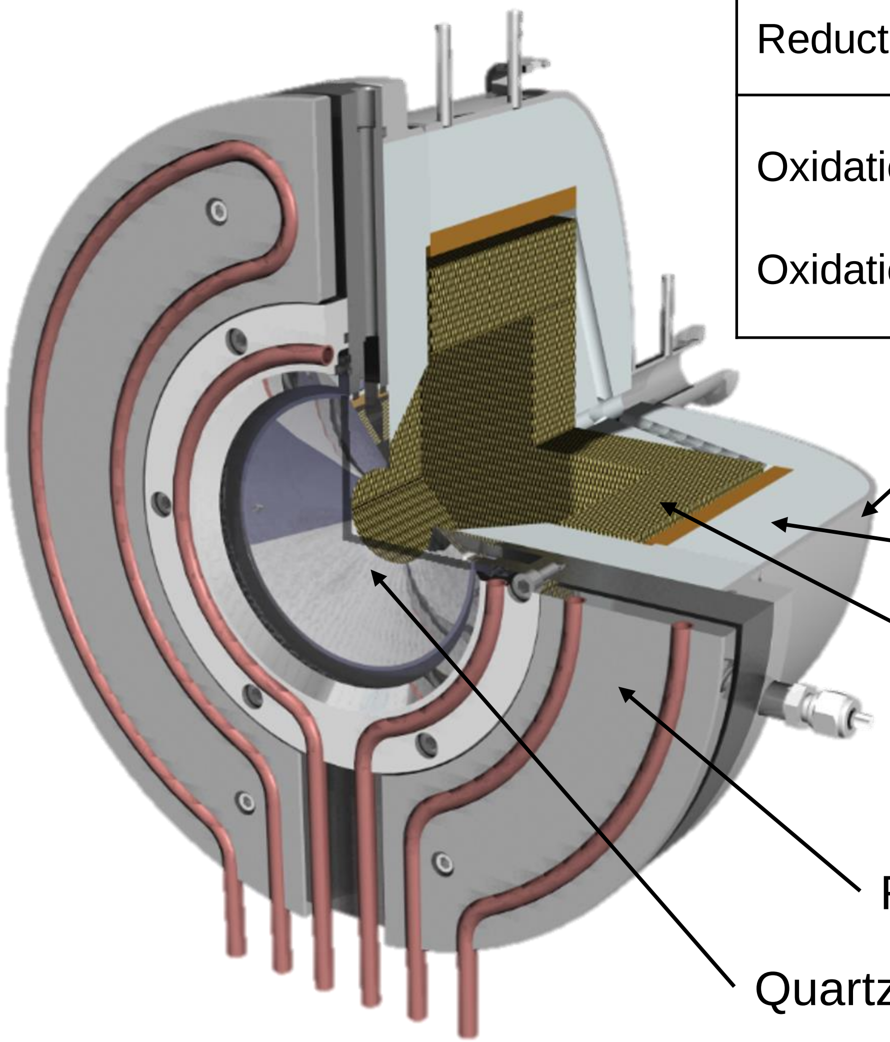
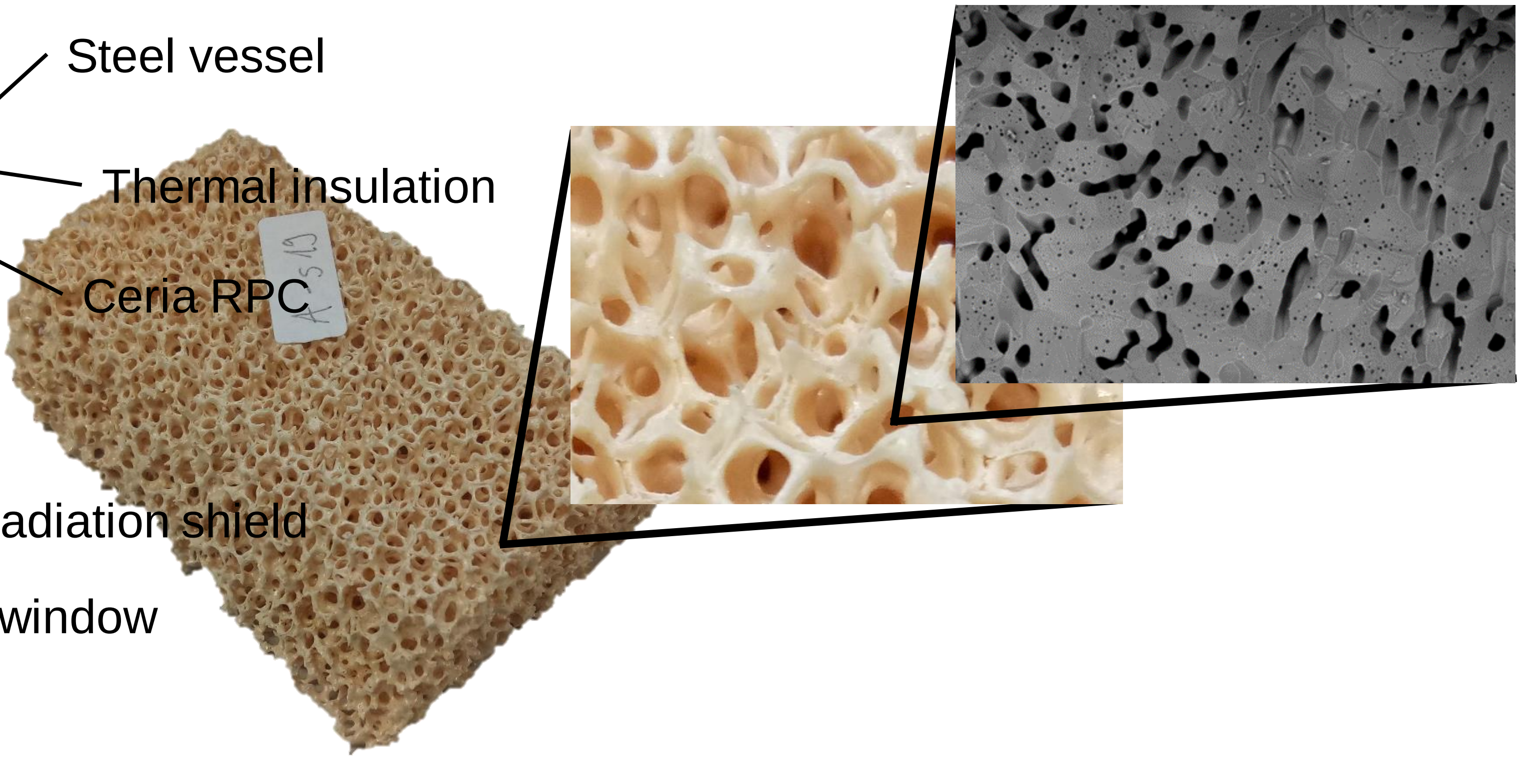
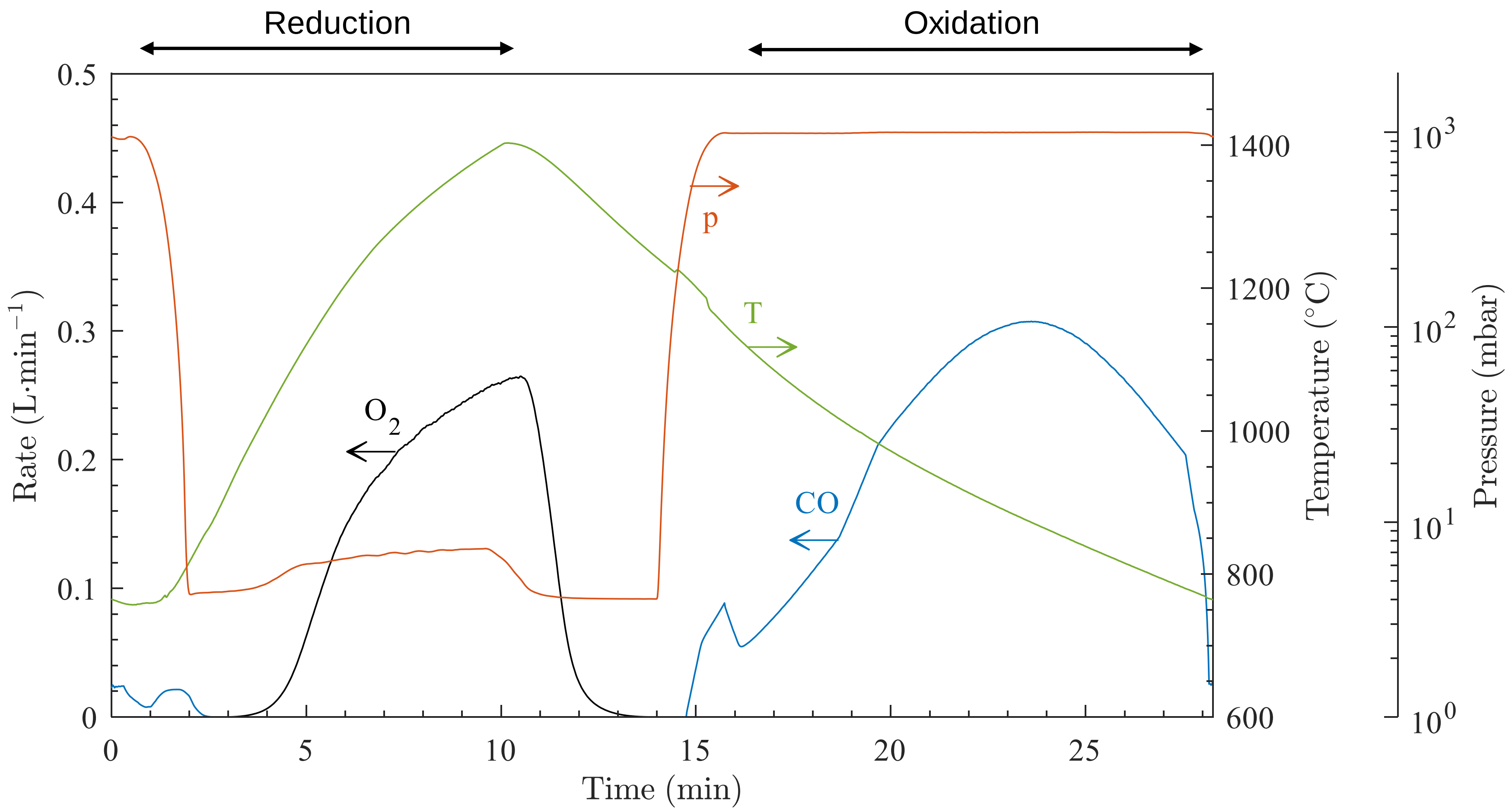
Solar Reactors

Reduction: $\Delta H \approx$ 475 kJ per ½ mole O_2	$\frac{1}{\Delta\delta} \mathrm{CeO}_{2-\delta_{ox}} \rightarrow \frac{1}{\Delta\delta} \mathrm{CeO}_{2-\delta_{red}} + \frac{1}{2} \mathrm{O}_2$
Oxidation with CO_2: $\Delta H \approx$ -192 kJ/mol CO_2	$\frac{1}{\Delta\delta} \mathrm{CeO}_{2-\delta_{red}} + \mathrm{CO}_2 \rightarrow \frac{1}{\Delta\delta} \mathrm{CeO}_{2-\delta_{ox}} + \mathrm{CO}$
Oxidation with H_2O: $\Delta H \approx$ - 234 kJ/mol H_2	$\frac{1}{\Delta\delta} \mathrm{CeO}_{2-\delta_{red}} + \mathrm{H_2O} \rightarrow \frac{1}{\Delta\delta} \mathrm{CeO}_{2-\delta_{ox}} + \mathrm{H}_2$





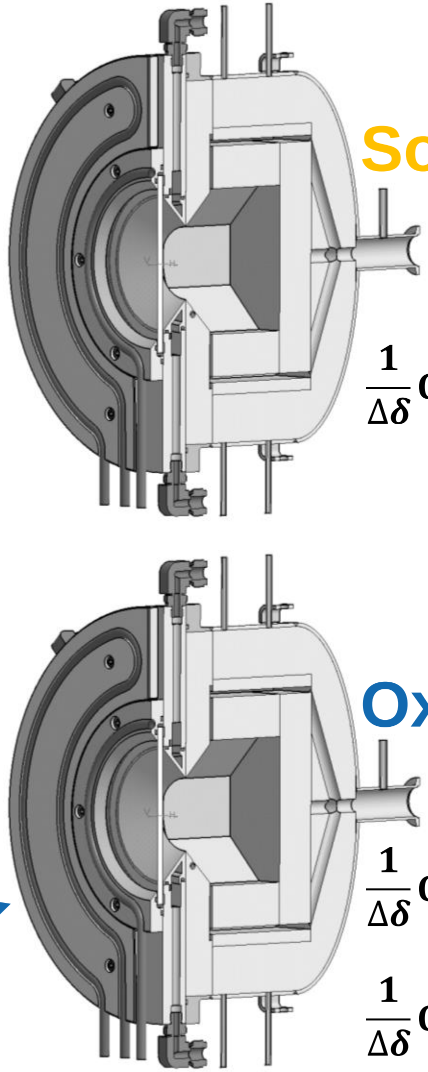
Exemplary Cycle CO_2 splitting



Conditions	Reduction	Oxidation
	On-sun	Off-sun
Gas flow	1 l/min Ar	7 l/min CO_2
Pressure	4 mbar	1 bar

Parallel Operation of two Reactors

Concentrated Solar Irradiation



Solar Reduction

$$\frac{1}{\Delta\delta}\mathrm{CeO}_{2-\delta_{\mathrm{ox}}} \rightarrow \frac{1}{\Delta\delta}\mathrm{CeO}_{2-\delta_{\mathrm{red}}} + \frac{1}{2}\mathrm{O}_2$$

O_2

CO / H_2

Oxidation

$$\frac{1}{\Delta\delta}\mathrm{CeO}_{2-\delta_{red}} + \mathrm{CO}_2 \rightarrow \frac{1}{\Delta\delta}\mathrm{CeO}_{2-\delta_{ox}} + \mathrm{CO}$$

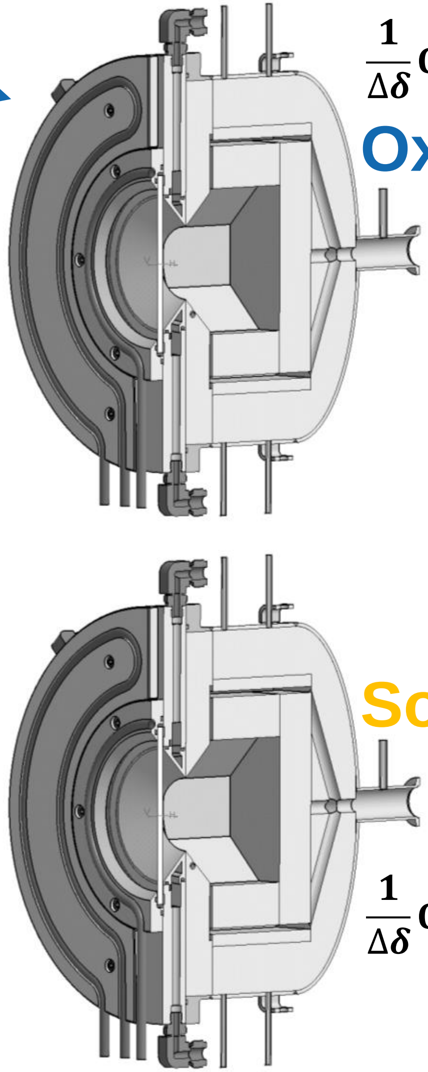
$$\frac{1}{\Delta\delta}\mathrm{CeO}_{2-\delta_{\mathrm{red}}} + H_2\mathrm{O} \rightarrow \frac{1}{\Delta\delta}\mathrm{CeO}_{2-\delta_{\mathrm{ox}}} + \mathrm{H}_2$$

CO_2 / H_2O

Parallel Operation of two Reactors

$$\frac{1}{\Delta\delta}\mathrm{CeO}_{\,2-\delta_{red}} + \mathrm{CO_2} \rightarrow \frac{1}{\Delta\delta}\mathrm{CeO}_{\,2-\delta_{ox}} + \mathrm{CO}$$

$$\frac{1}{\Delta\delta}\mathrm{CeO}_{\,2-\delta_{red}} + H_2\mathrm{O} \rightarrow \frac{1}{\Delta\delta}\mathrm{CeO}_{\,2-\delta_{ox}} + \mathrm{H_2}$$



Oxidation

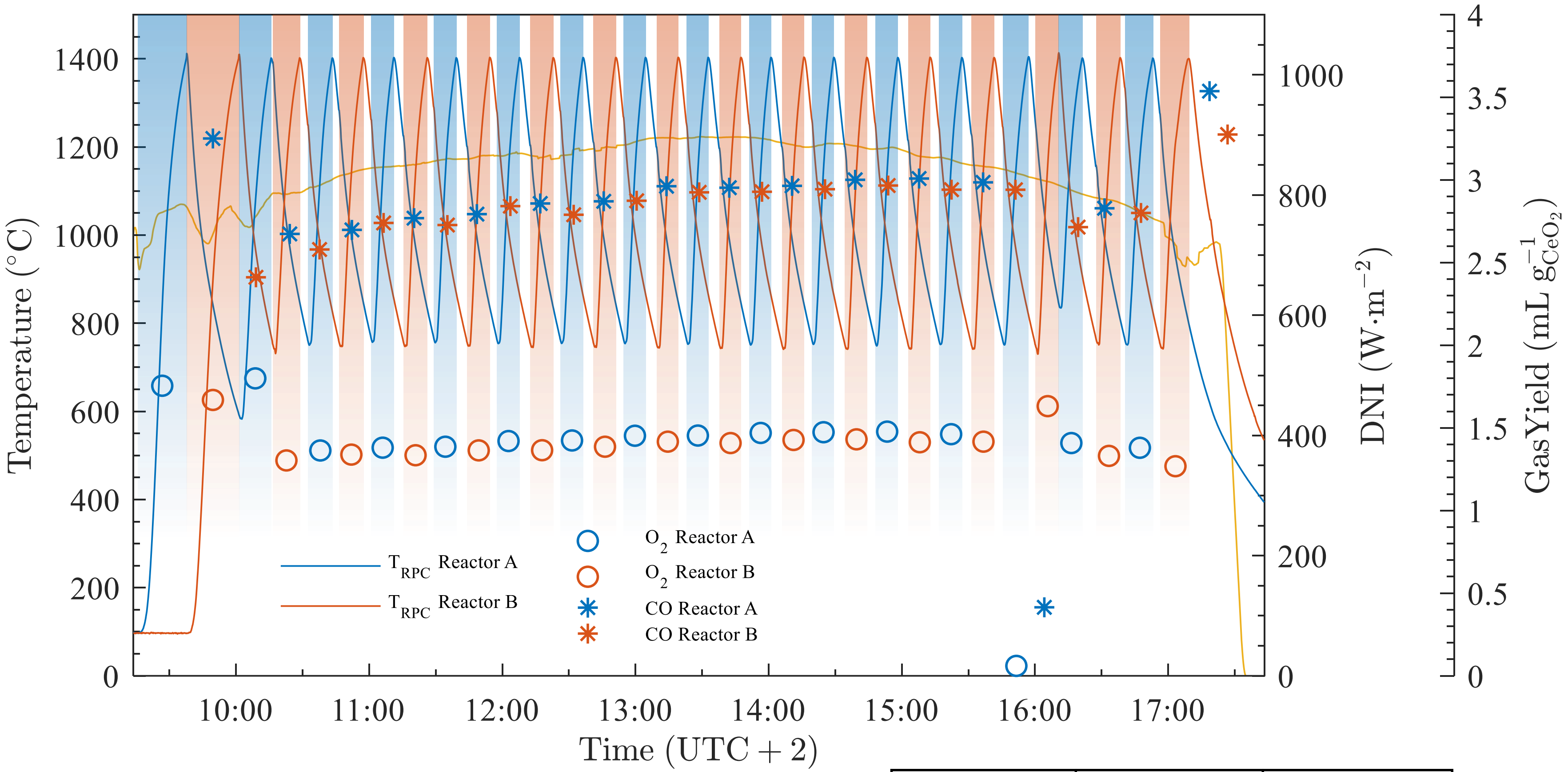
Solar Reduction

$$\frac{1}{\Delta\delta}\mathrm{CeO}_{\,2-\delta_{ox}} \rightarrow \frac{1}{\Delta\delta}\mathrm{CeO}_{\,2-\delta_{red}} + \frac{1}{2}\mathrm{O_2}$$

O_2

CO / H_2

Exemplary Day CO_2 splitting



Conditions	Reduction	Oxidation
	On-sun	Off-sun
Gas flow	1 l/min Ar	7 l/min CO_2
Pressure	4 mbar	1 bar
Mass loading	Reactor A: 3752 g Reactor B: 3760 g	

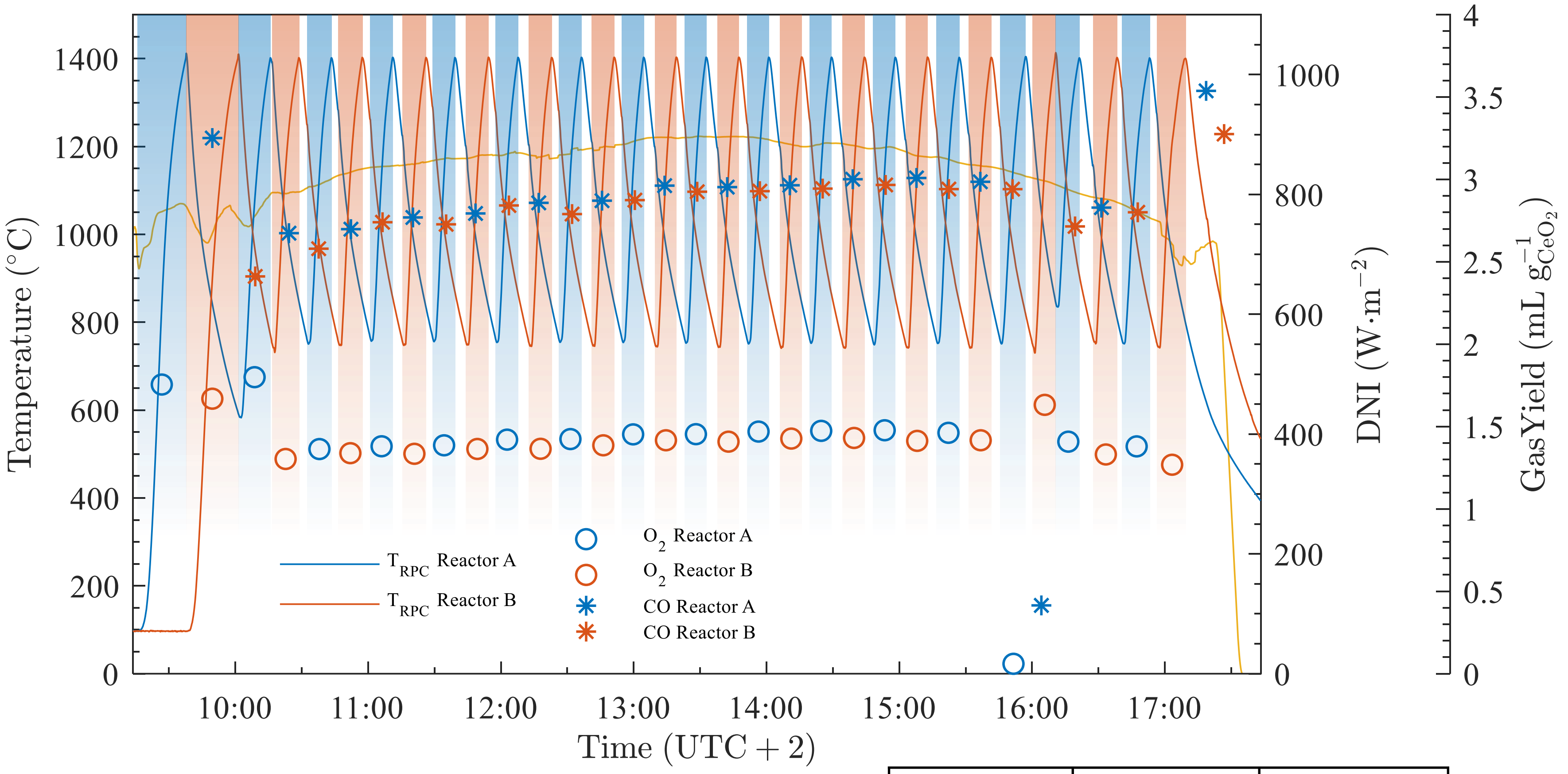
- Power input up to 5.9 kW
- Mean solar flux concentration 2360 suns

- Avg. peak O_2 evolution 0.29 ml g^{-1}_{CeO2} min^{-1}
- Avg. total O_2 evolution 1.44 ml g^{-1}_{CeO2}
- Avg. peak CO production 0.31 ml g^{-1}_{CeO2} min^{-1}
- Avg. total CO production 2.89 ml g^{-1}_{CeO2}

- 32 consecutive cycles:
  - 338 L CO
  - 168 L O_2
  - CO/O_2 ratio 2.01

- $\eta_{solar-to-fuel} = \frac{Q_{fuel}}{Q_{solar}+Q_{inert}+Q_{pump}} = 3.8\%$

Exemplary Day CO_2 splitting



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- $\eta_{solar-to-fuel} = \dfrac{Q_{fuel}}{Q_{solar}+Q_{inert}+Q_{pump}} = 3.8\%$

Increase $\eta_{solar-to-fuel}$:

- Optimize operation parameters/setup
- Optimise porous ceramic structure (all participating)
- Heat recovery (T-swing)

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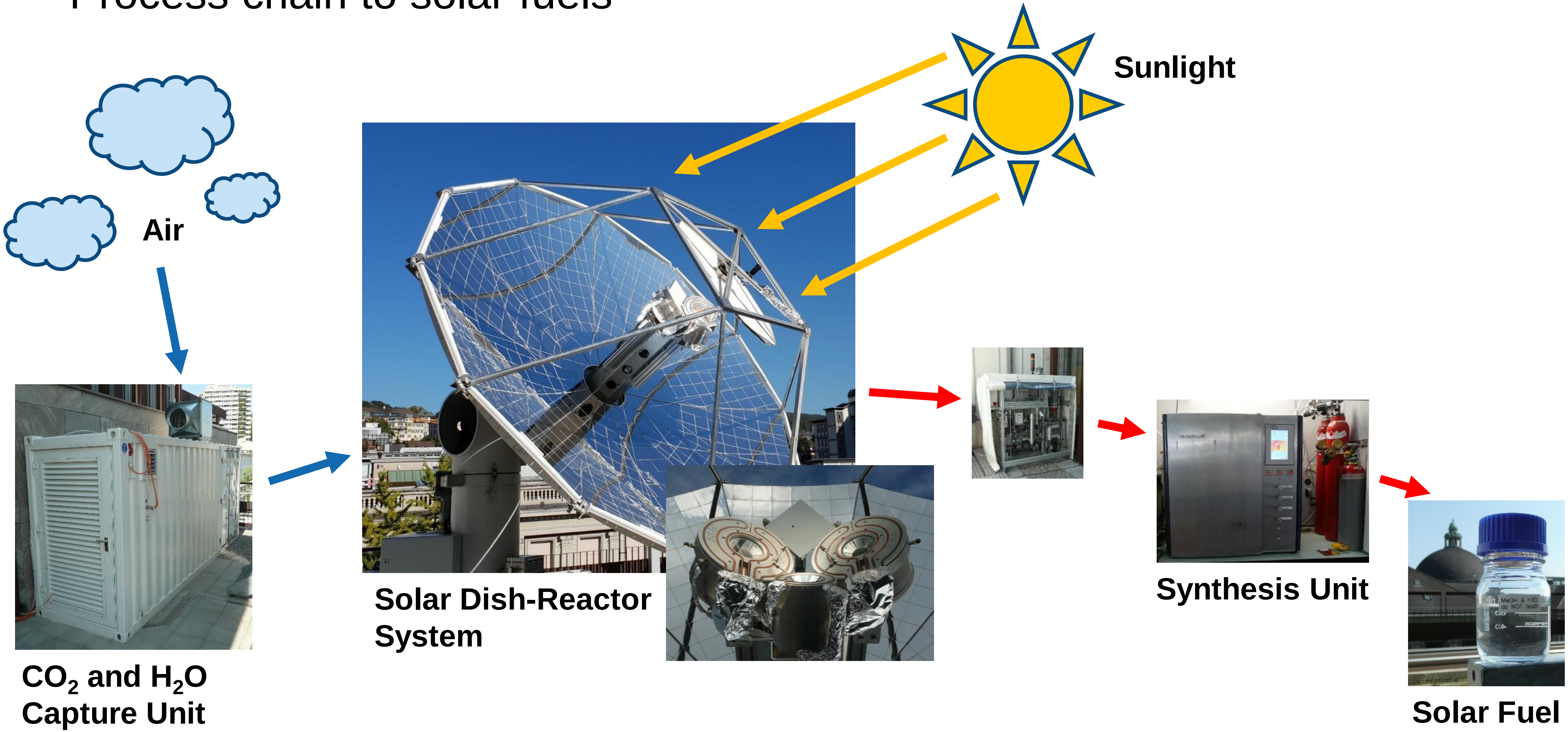
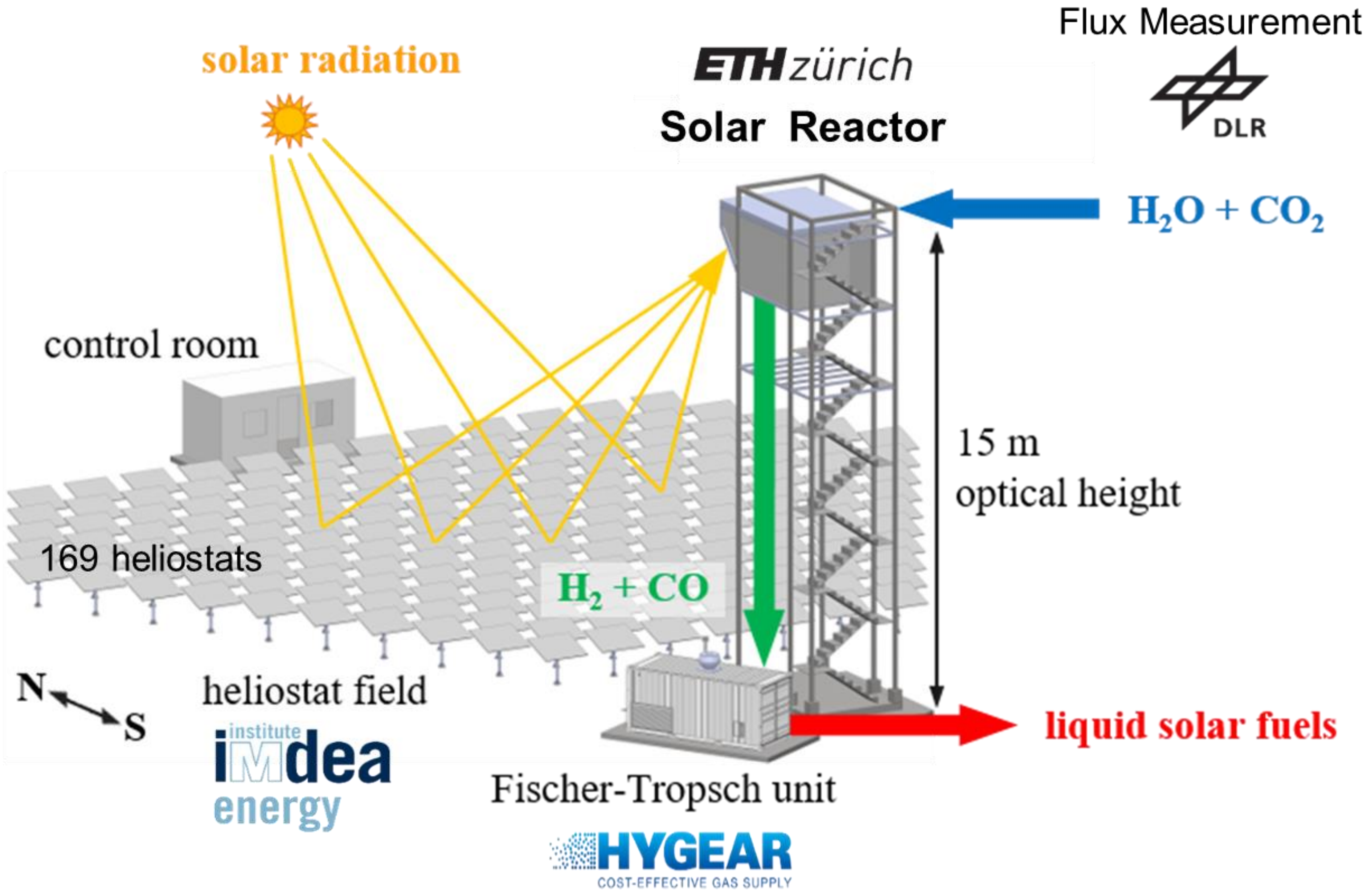
Process chain to solar fuels



Upscaling - Sun-to-liquid Project (Móstoles, Spain)



Generation 2
50 kW Pilot-scale
RPC

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Thank you very much for your attention

This project is being funded by the Swiss Federal Office of Energy (Grant No. SI/501213-01), the Swiss National Science Foundation (Grant No. 206021_170735), and the European Research Council under the European Union’s ERC Advanced Grant (SUNFUELS – Grant No. 320541).

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