Solar fuel production via thermochemical cycles: Process and receiver-reactor technology

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Motivation

- **Renewable fuels** offering near zero Greenhouse Gas (GHG) emissions **are key in achieving sustainable long-haul transportation**, particularly in aviation.
- **Synthetic kerosene** produced through solar pathways **represents a clean alternative to fossil fuels** and **is fully compatible with** the **existing infrastructure**.
- Solar kerosene **reduces GHG-emissions by** more than **80% at** prices of **1.72-1.97 €/L** (Fig. 3) [1]. These higher fuel prices are only expected to increase airfares by 10-15% [2].

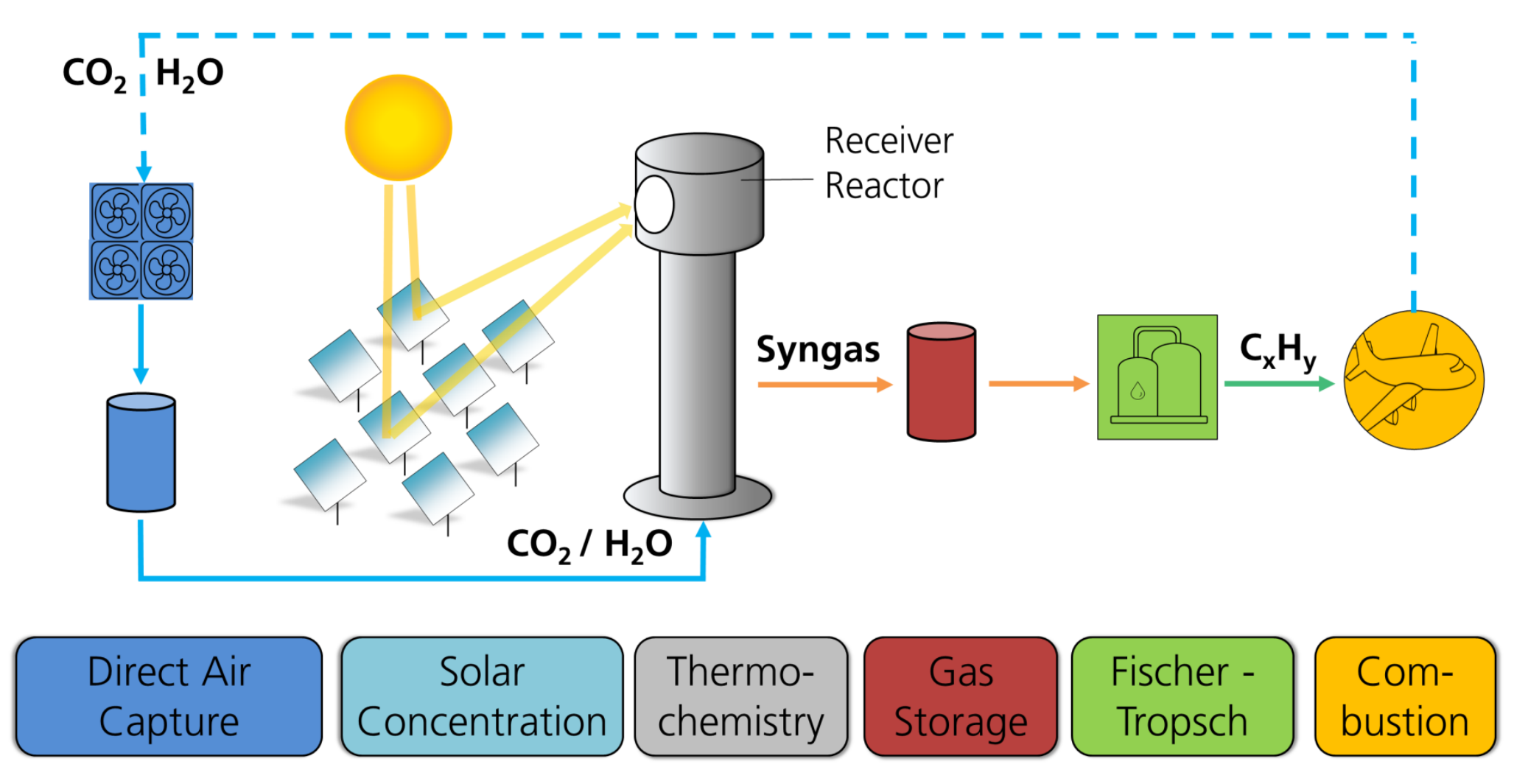

Fig. 1: Schematic of solar thermochemical kerosene production

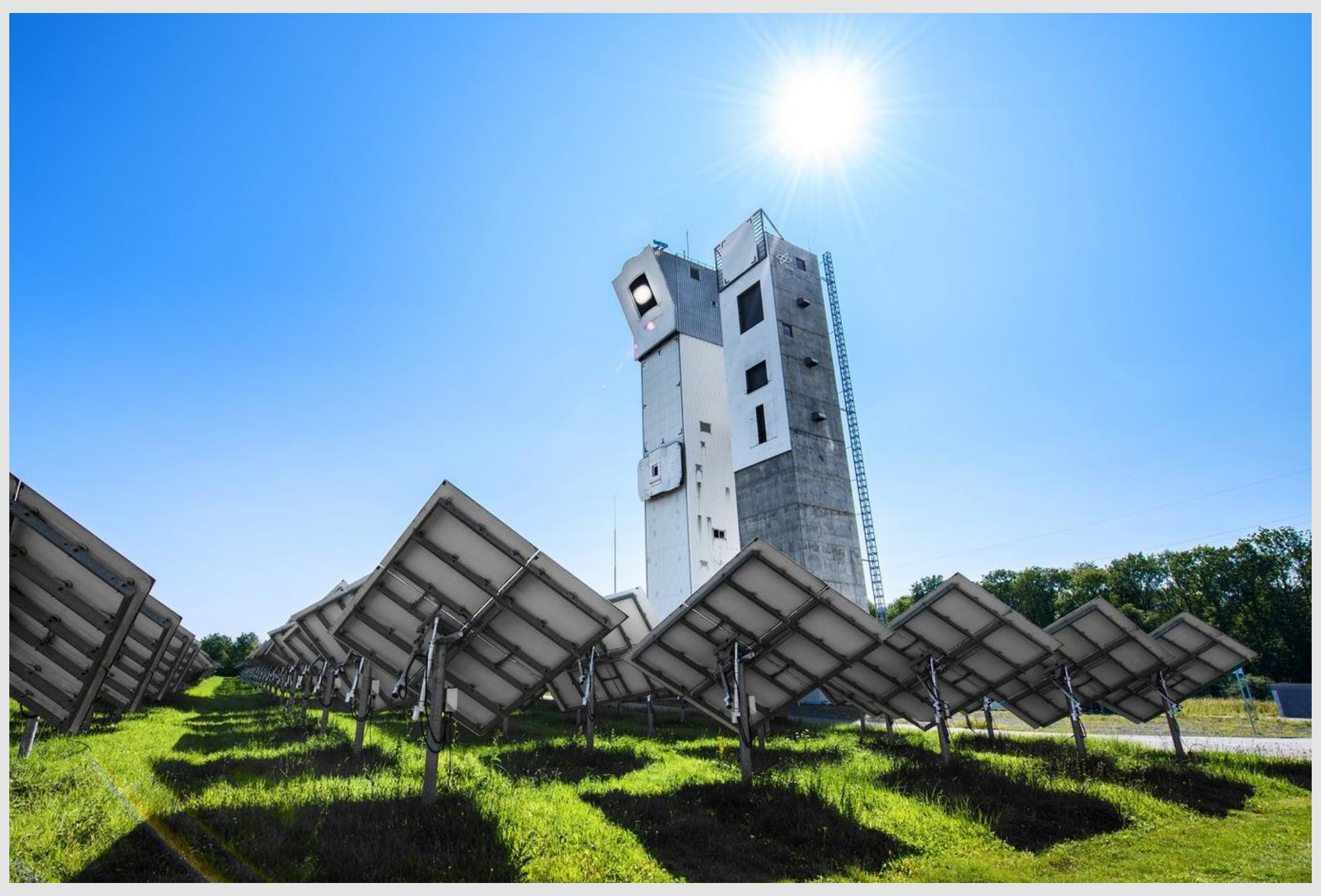

Fig. 2: Solar tower in Jülich, DLR ©

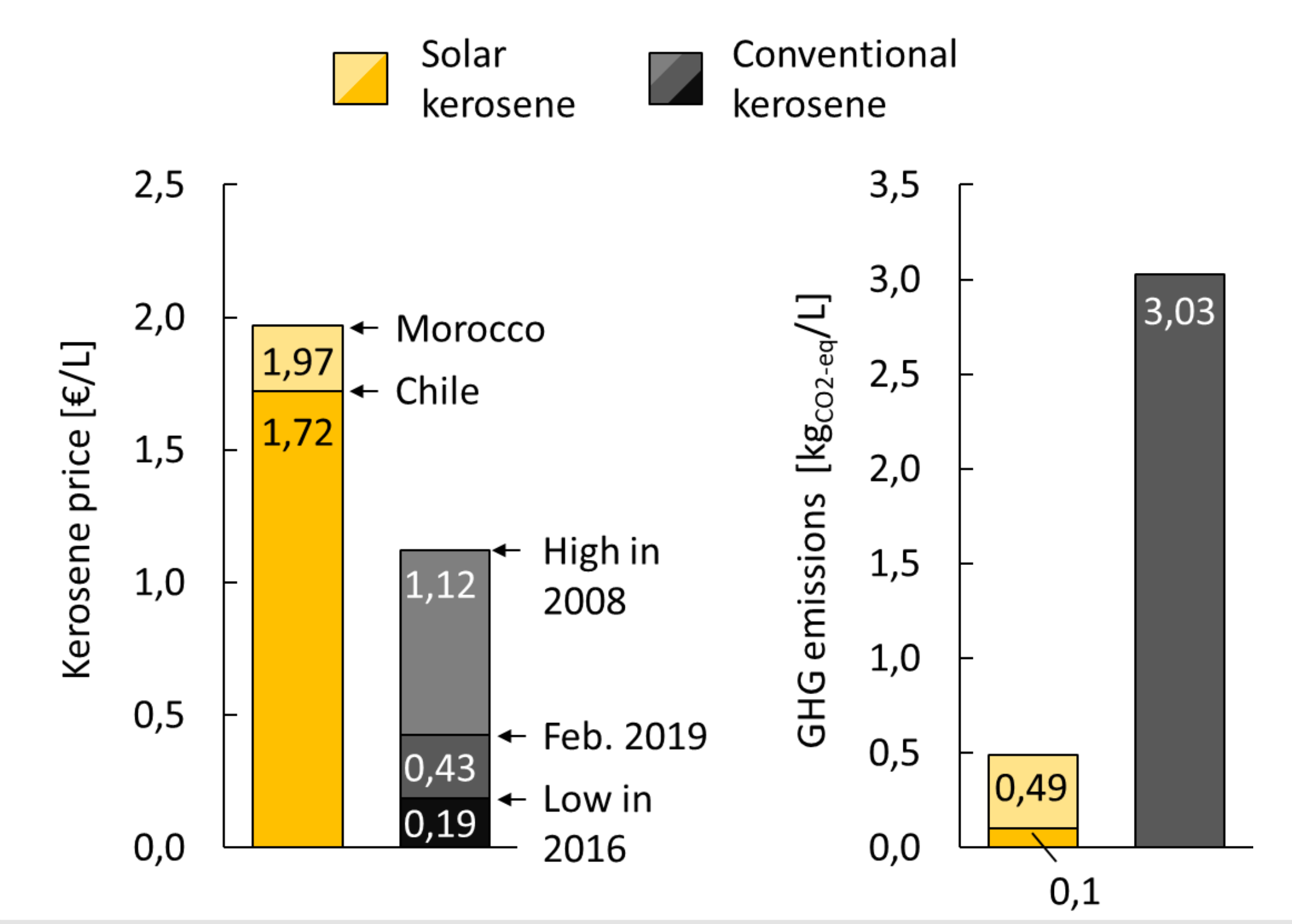

Fig. 3: Solar and conventional kerosene price and GHG emissions, data from [1]

State of the Art

SUN-to-LIQUID Project

- **In-field demonstration of entire process** from H_2O and CO_2 to kerosene in a solar tower using a **50 kW solar reactor** with 18 kg of CeO_2 [3].
- Achieved consecutive cycling for 55 h. Per cycle, 50 L of H_2 and 25 L of CO were produced [4].
- Record demonstrated **Solar-to-syngas efficiency** of **4.1%** at 50 kW.

Cavity receiver-reactor

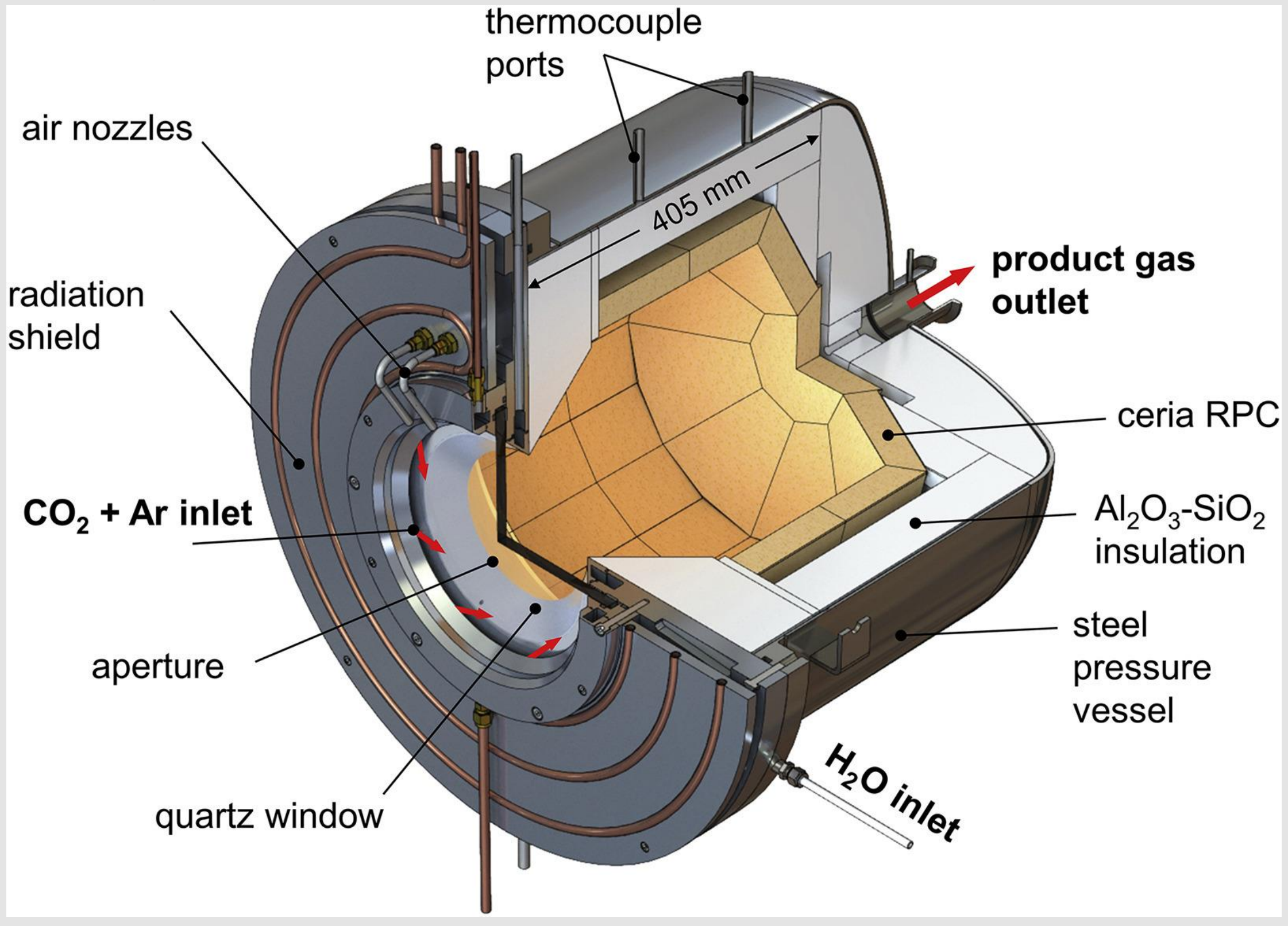

Fig. 5: Cavity receiver-reactor by ETH, reproduced from [4]

Background

Two step thermochemical cycles

- *Step 1*: a **redox material** (here **ceria**) is **reduced** under los oxygen partial pressures (1 mbar) and high temperatures (1500 °C), achieved **by concentrated solar heat.** Oxygen evolves from the redox material.
- *Step 2:* After lowering the temperature to 800 °C, **CO_2 and H_2O** are feed into the reactor and **split** into CO and H_2 while O_2 is taken up **by the redox material.**
- The product CO and H_2 mixture (syngas) can be further processed to **synthetic fuels.**
- To **regenerate** the oxidized ceria the **reduction step** is repeated, creating a cycle.

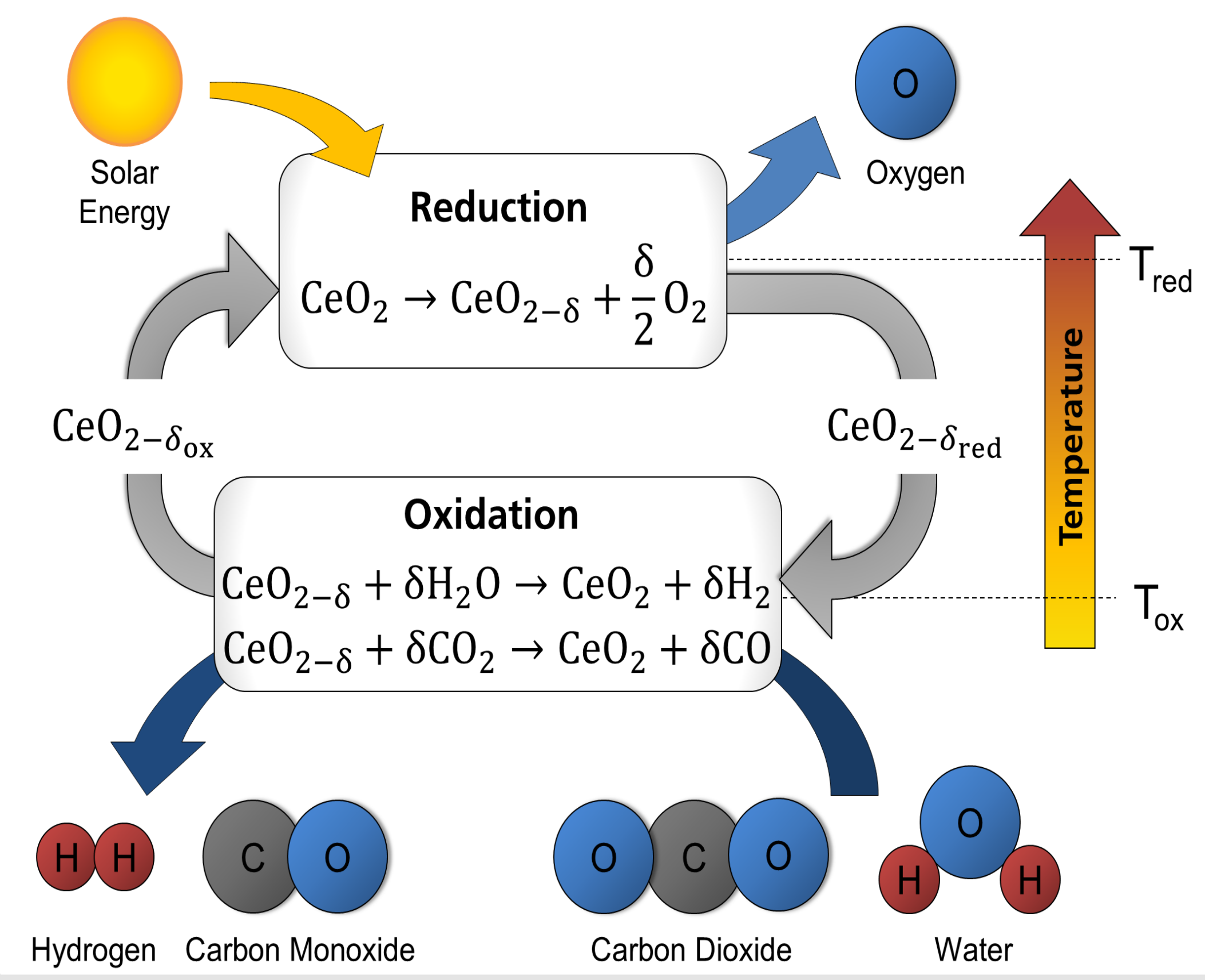

Fig. 4: Schematic of thermochemical cycle for CO_2 / H_2O splitting

Limitations

- **Batch operation:** Reticulated porous ceramic (RPC) ceria bricks are directly exposed to concentrated **solar radiation during the reduction** step (1500 °C). **During** the **oxidation** step (800 °C) **solar input** is **stopped.** Inert reactor parts have to be heated/cooled cyclically.
- **No heat recovery.** Concepts exist but their implementation is challenging. With heat recovery, efficiencies up to 51% are expected [5].
- **Scale–up** of technology is **challenging** due to quartz **window size** limitations. Also there is a **reduced efficiency increase** with scale-up.
- **Commercial scale** foresees **arrays of solar reactors** being irradiated simultaneously. Leading to **off-design point operation**, which is **poor.**

R2Mx receiver-reactor

Operation

- **Mobile redox material assemblies (RMA)** are vertically **moved between** a continuously irradiated **solar receiver**, where reduction occurs, **and separate oxidation reactors**.
- **Heat recovery systems** intermediately store heat from the redox material by using wall elements.
- The **atmospheres** of the two reaction spaces **are separated** by a gate.

Advantages

- **Continuous on-sun operation** and fuel production -> improved solar field efficiency.
- **No thermal cycling of inert reactor components** translates to lower heat losses.
- **High theoretical efficiency 12-14%,** considering a non optimized model without heat recovery [6].
- **Predicted heat recovery** rate of **~20%,** would result in ~17% efficiency [6].
- **Independent RMA operation:** good part-load operation and further optimization potential.

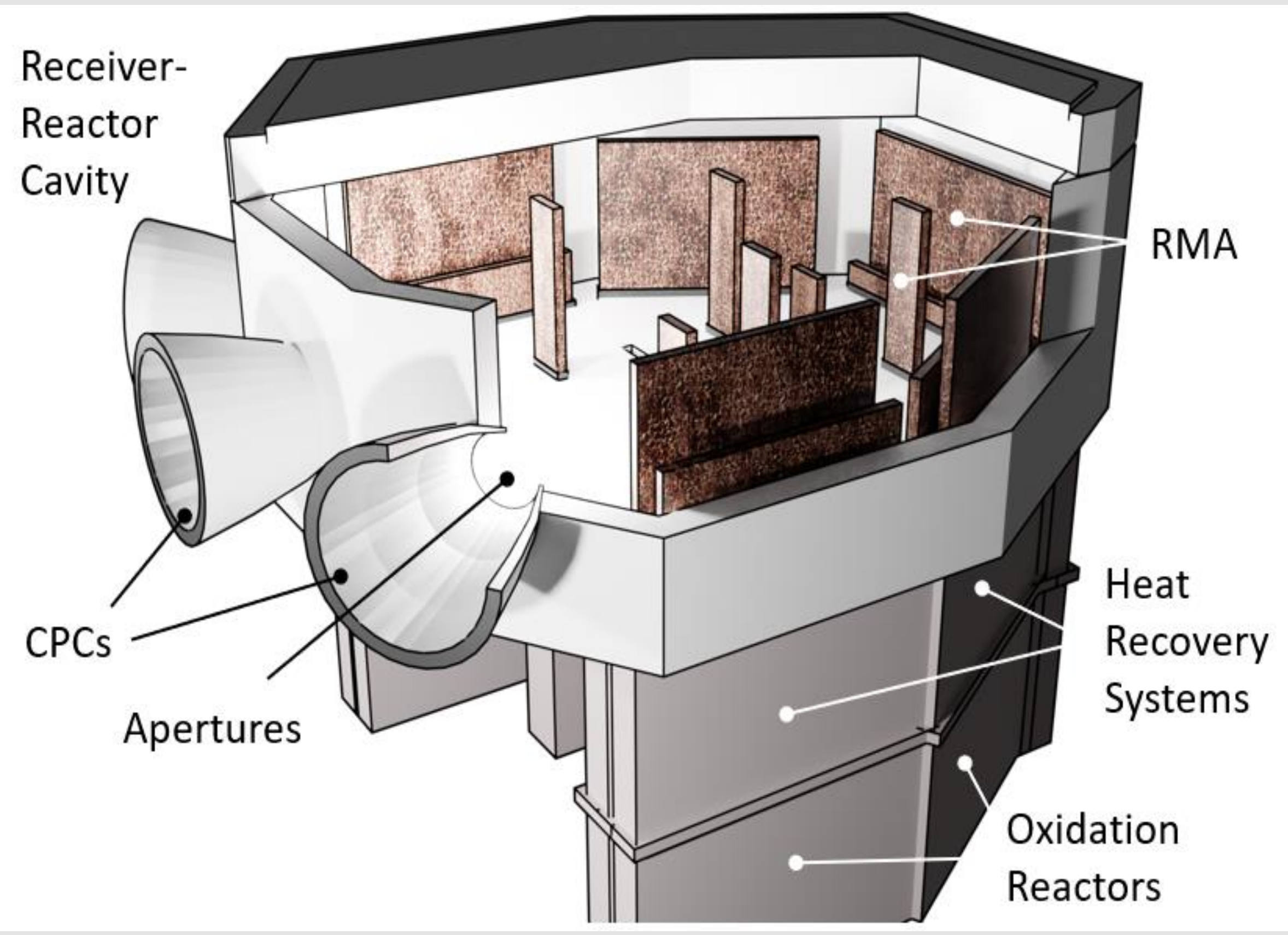

Fig. 6: MW-scale vision of R2Mx concept, reproduced from [6]

Outlook

- **3 kW** laboratory-scale proof of concept comprising one RMA - **2024**
- **10 kW** reactor with solar interface - **2025**

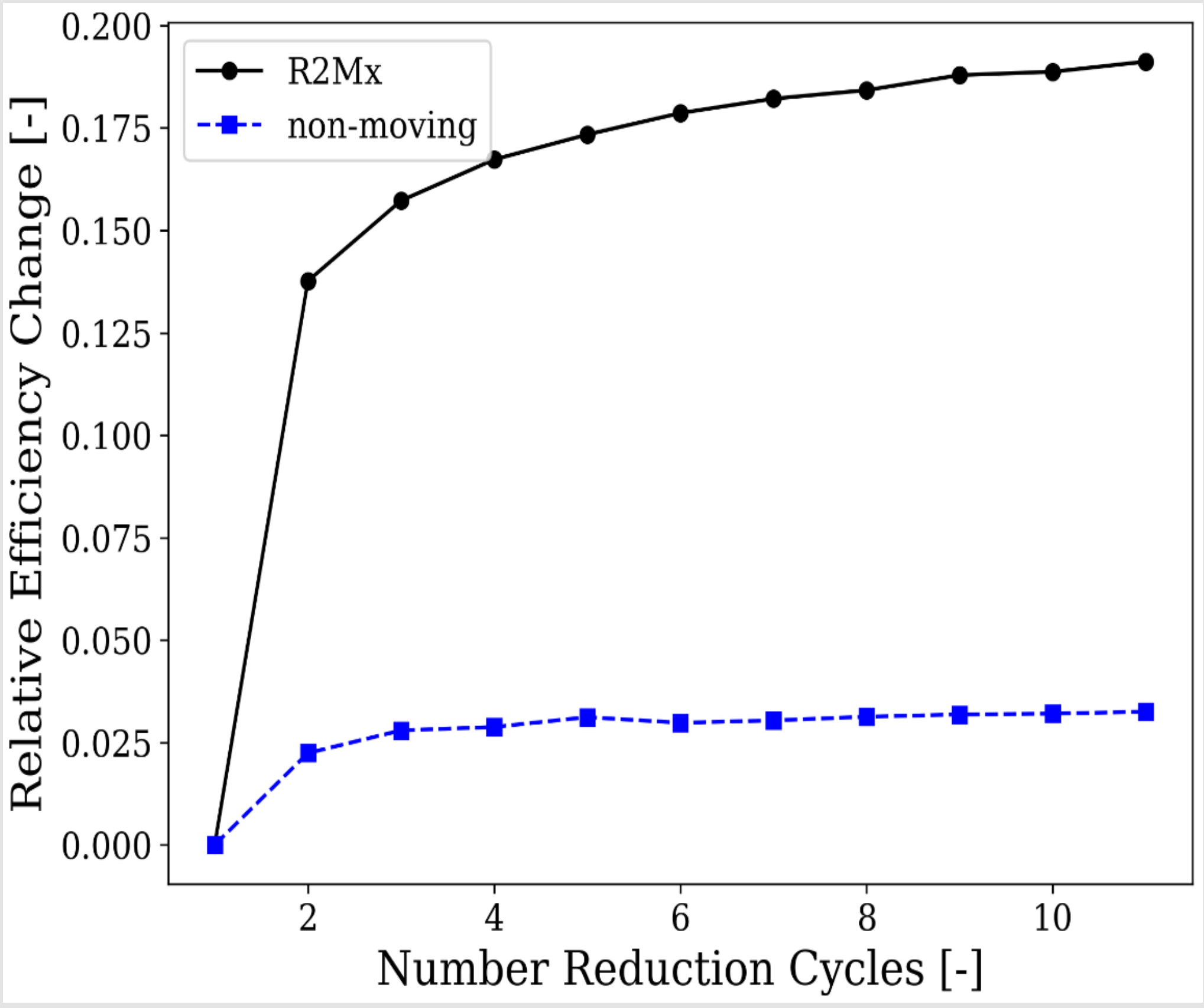

Fig. 7: Relative efficiency increase with reduction cycles for R2Mx vs the State of the Art, reproduced from [6]

References

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