EXPERIMENTAL INVESTIGATION OF A HELICALLY COILED SOLAR CAVITY RECEIVER FOR SIMULTANEOUS GENERATION OF SUPERHEATED STEAM AND AIR

10/30/2023, Session-I

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DLR

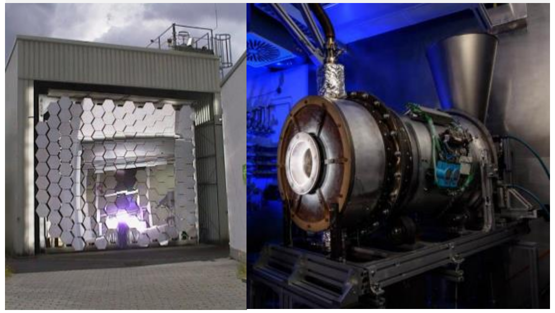
About us – DLR, Institute of Future Fuels

Aim: Development of alternative fuels by using concentrated solar energy

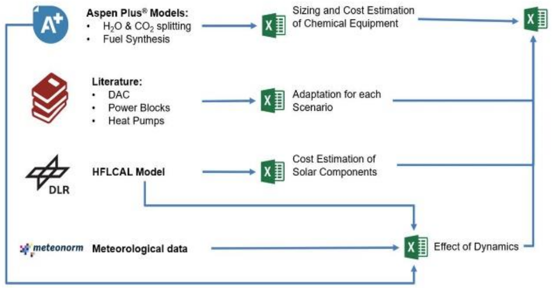
Solar chemical processes

Material and component design

Demonstration

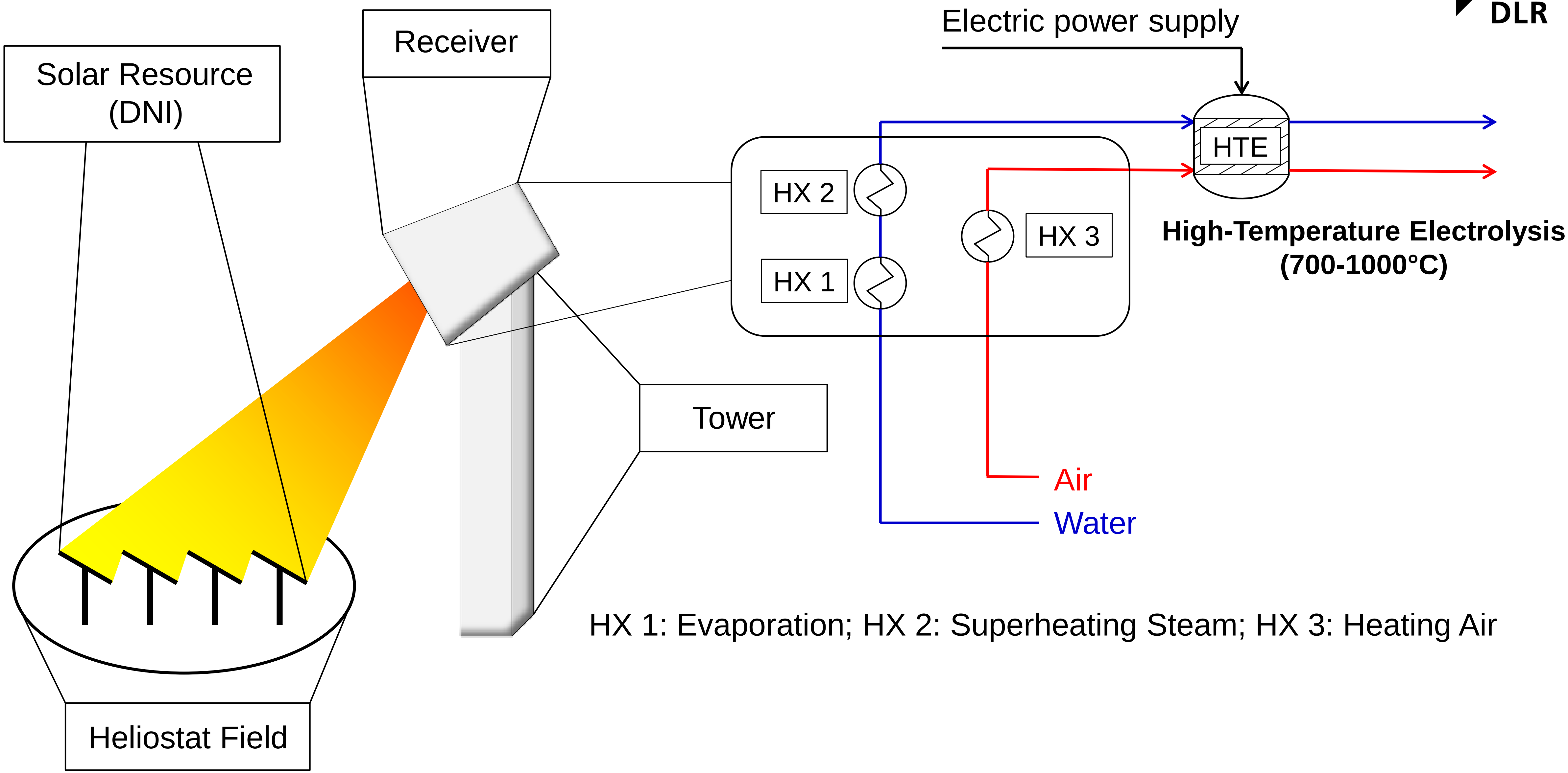


Assessment



- Locations: Jülich and Cologne, increase to 120 employees
- Contributions to the decarbonization of energy, aviation and transport

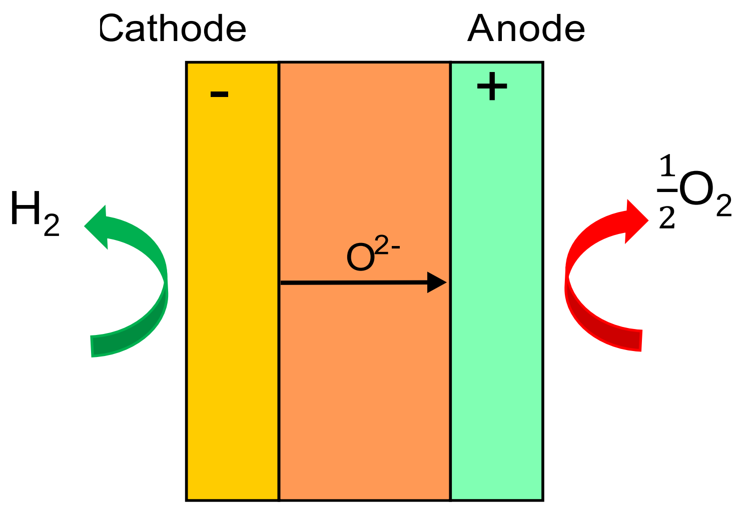
Background



HX 1: Evaporation; HX 2: Superheating Steam; HX 3: Heating Air

Background

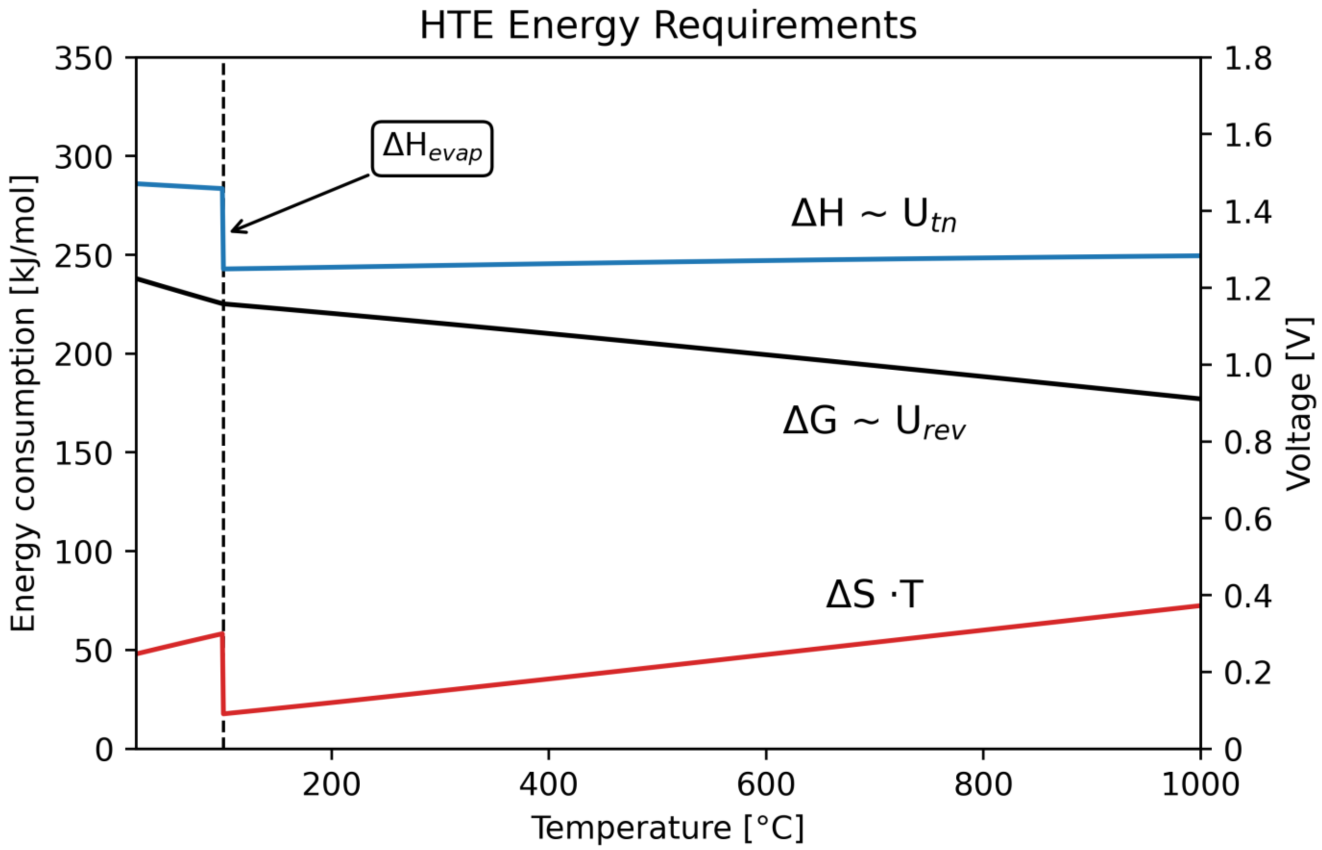
High-Temperature Electrolysis (700-1000°C)



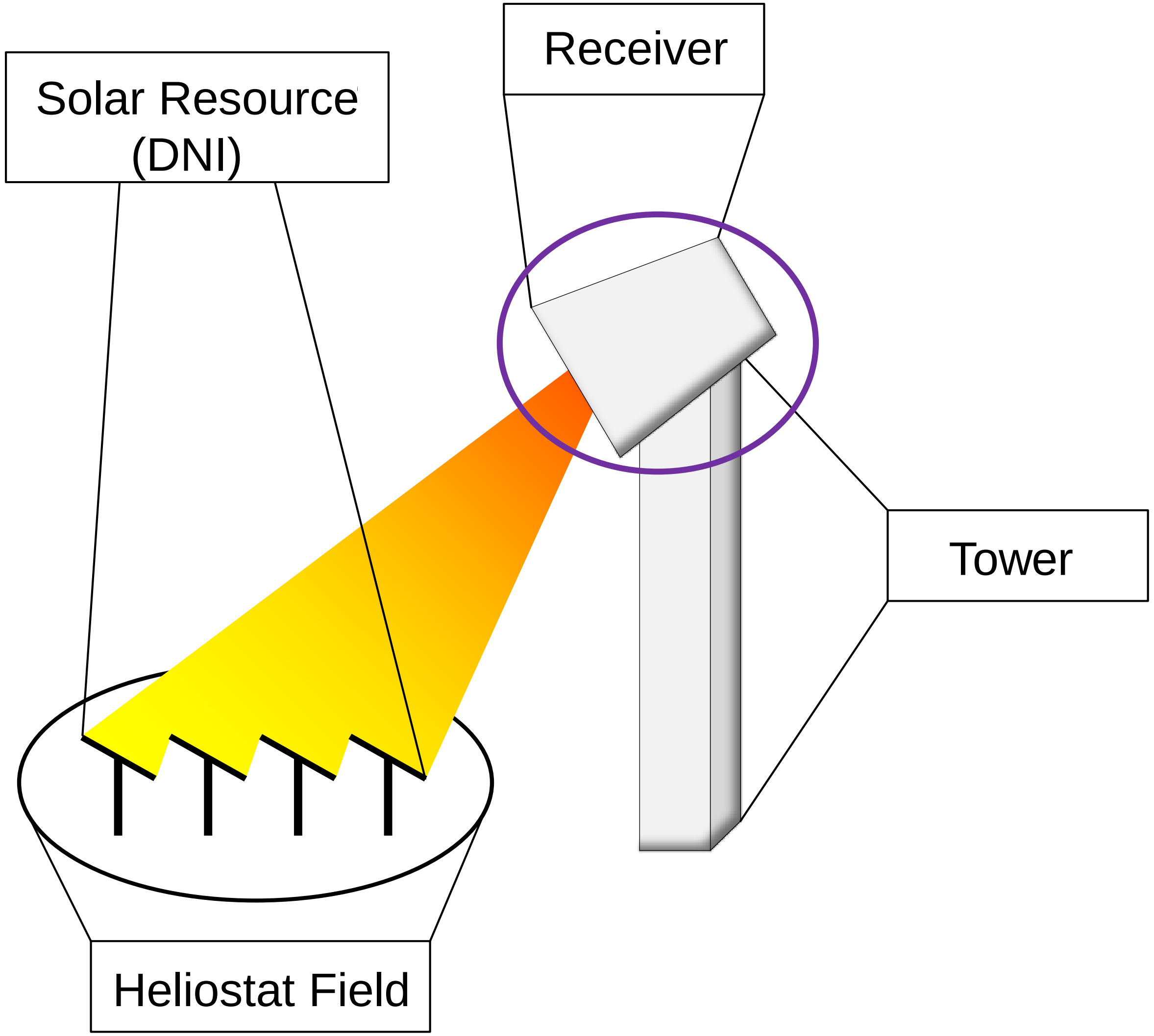
Anode: $O^{2-} \rightarrow 2e^- + \frac{1}{2}O_2$

Cathode: $H_2O + 2e^- \rightarrow H_2 + O^{2-}$

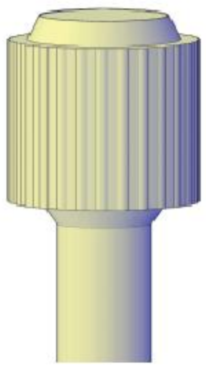
Overall reaction: $H_2O \rightarrow H_2 + \frac{1}{2}O_2$



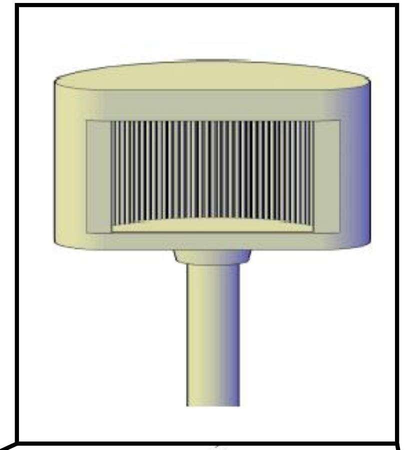
Background

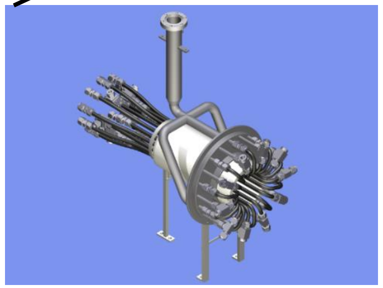


External and cavity solar receiver



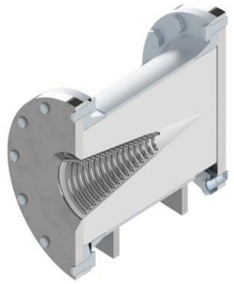
[Shatnawi et al. **2018**]





Multi-straight tube

[Houaijia et al. **2014**]



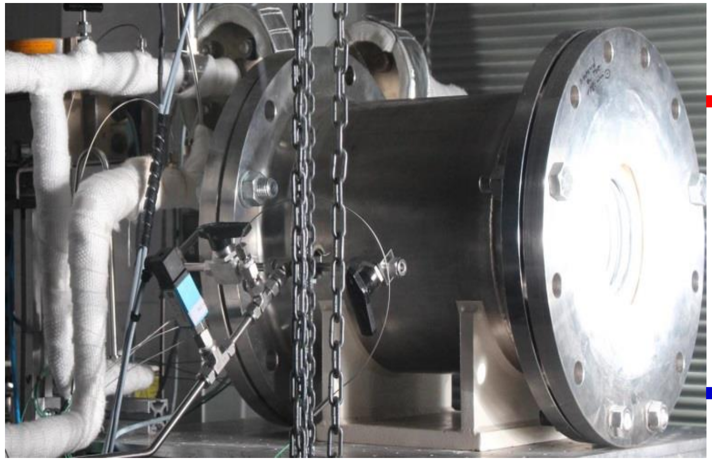
Helical tube (Conical)

[Schiller et al. **2019**]

Objective

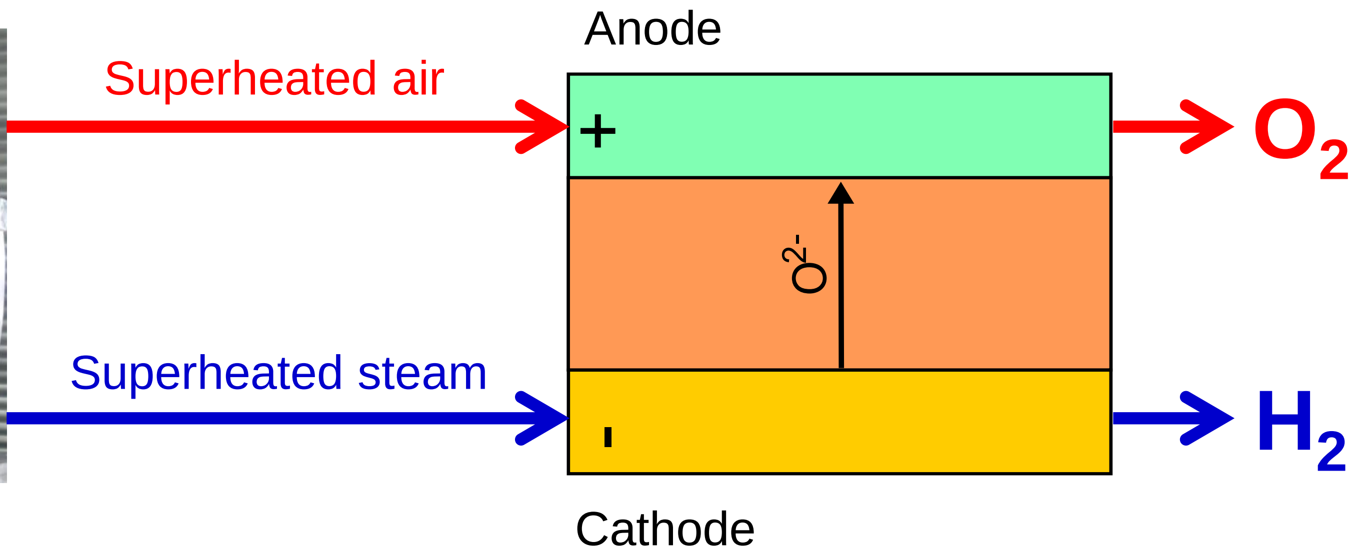
- Design a solar cavity receiver that simultaneously produces hot air (850°C) and steam (820°C) for coupling with high-temperature electrolysis.
- Analyze the receiver performance numerically and experimentally.

100 kWth



Solar cavity receiver

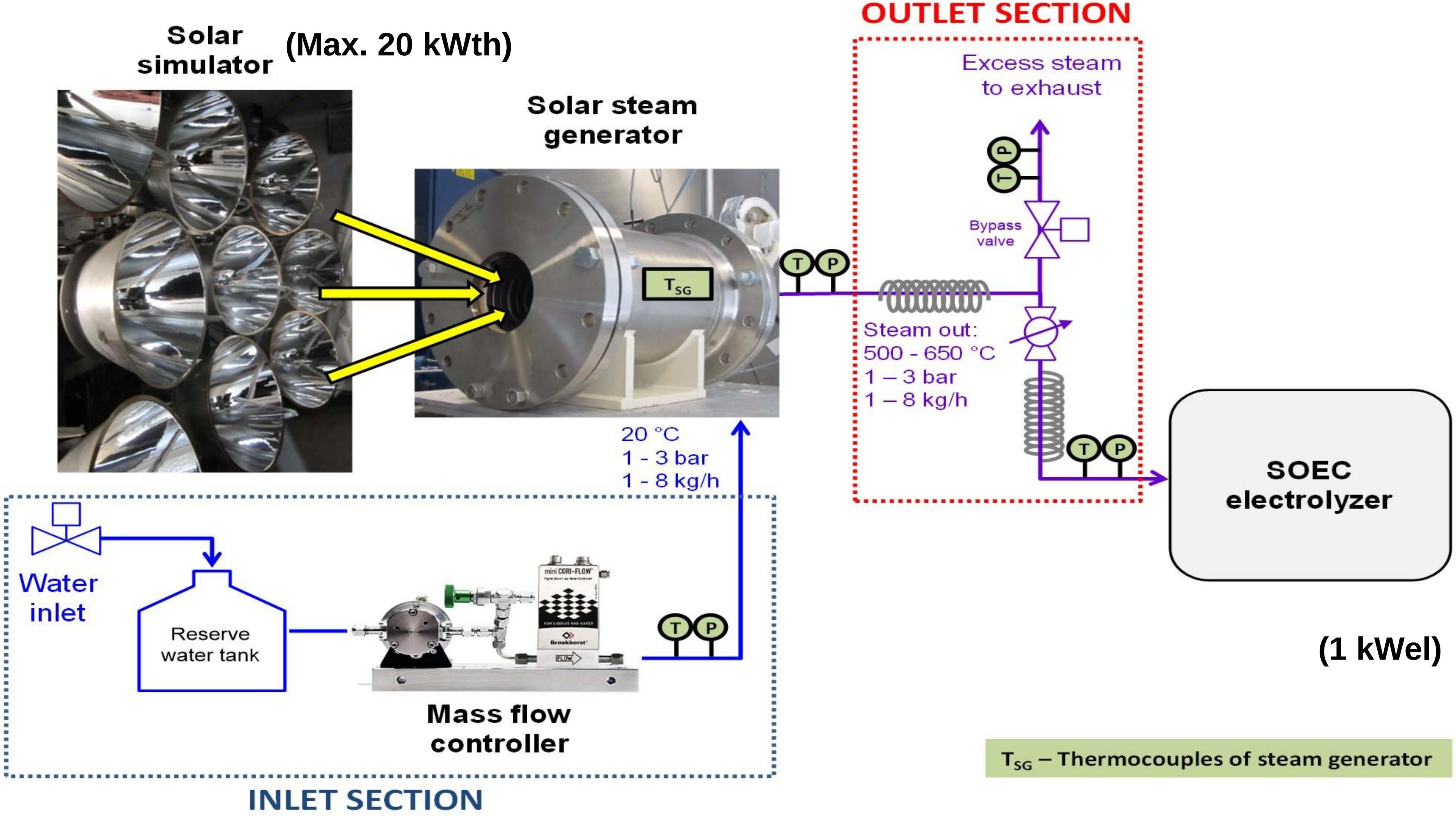
50 kWel



High-temperature electrolysis

Small scale (5 kWth) experiment at DLR Cologne

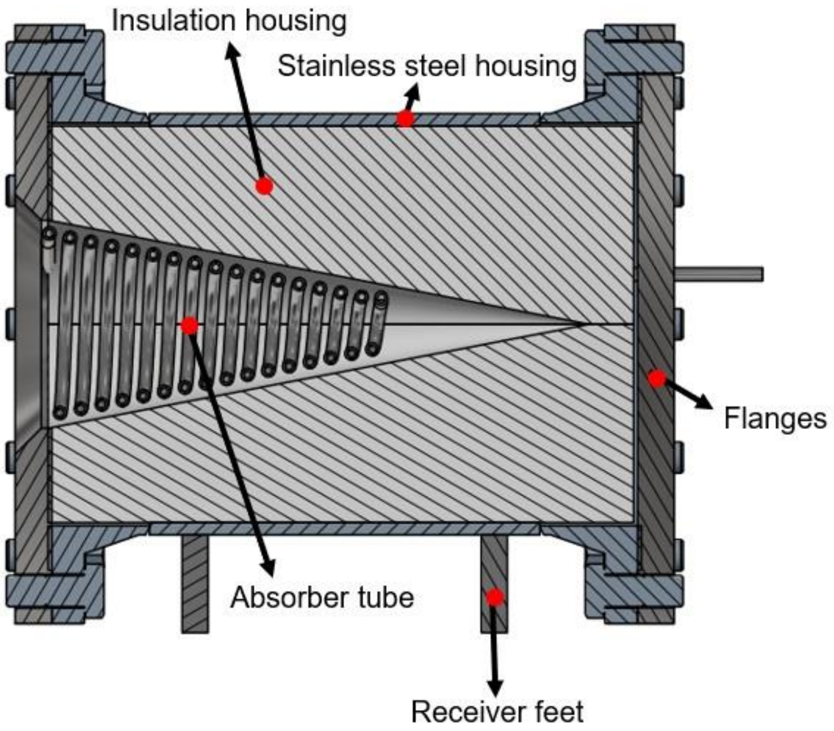
Process flow diagram



[Kadohiro et al. **2023**]

Small scale (5 kWth) experiment at DLR Cologne

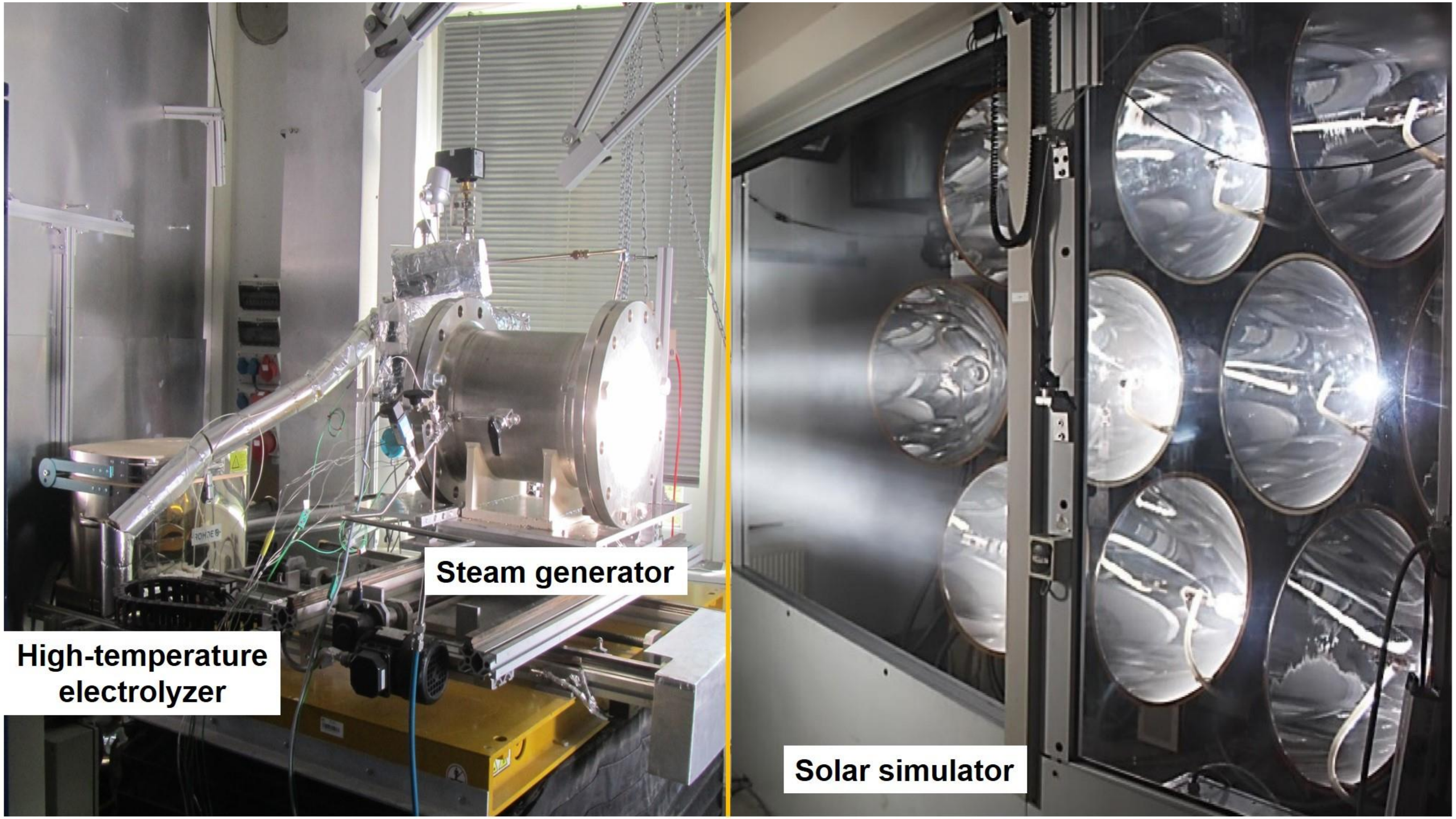
Detailed description of solar steam generator



- Cavity aperture diameter: 0.16 m
- Helical tube inner diameter (thickness): 0.06 m (0.02 m)
- Helical tube length: 4.428 m
- Helical tube pitch: 0.012 m
- Helical tube taper angle: 14°
- Insulation length: 0.45 m
- Surface emissivity of tube: 0.93

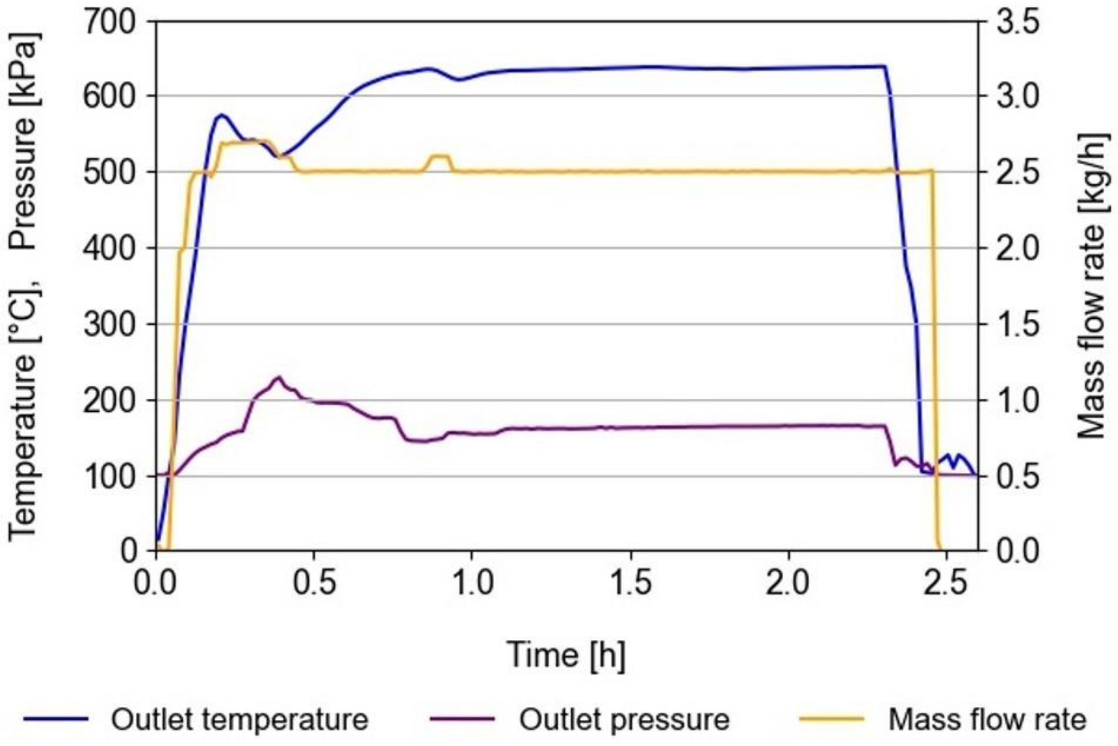
Small scale (5 kWth) experiment at DLR Cologne

Photograph of the experiment at DLR Cologne

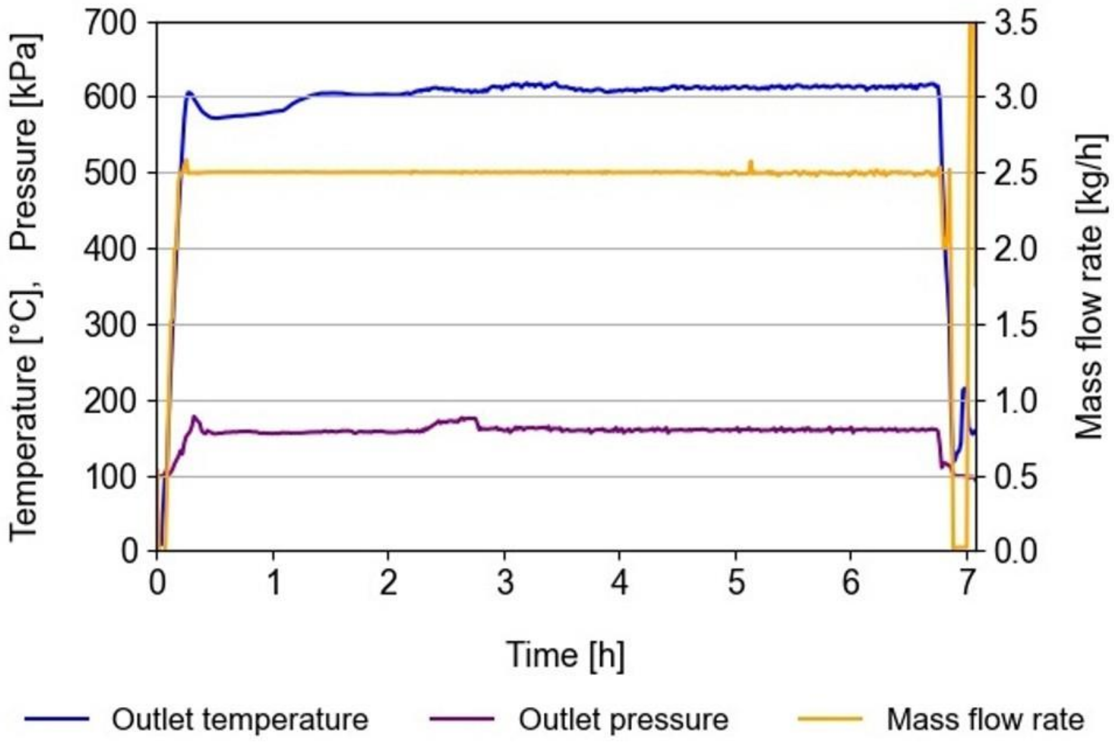


Small scale (5 kWth) experiment at DLR Cologne

Experimental results



(i)



(ii)

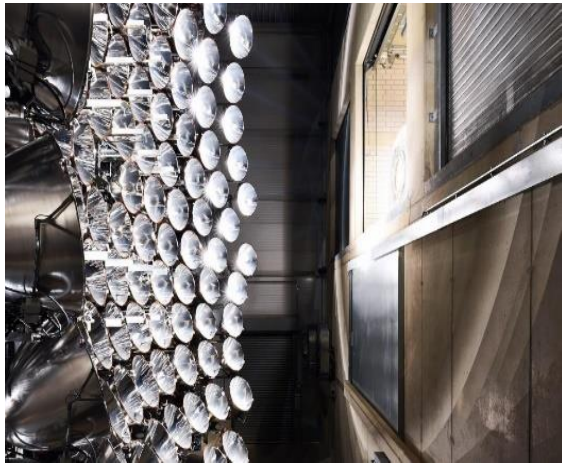
- Steam temperature: 600-700°C.
- Mass flow rate: 2.5 kg/h
- Fluid pressure: 100-200 kPa

[Kadohiro et al. **2023**]

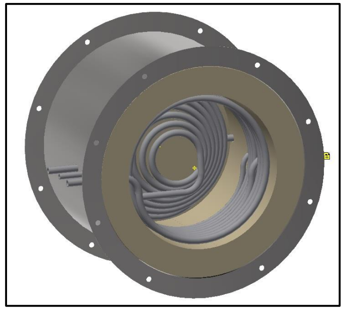
Upscaled (100 kWth) experiment at DLR Jülich

Process flow diagram

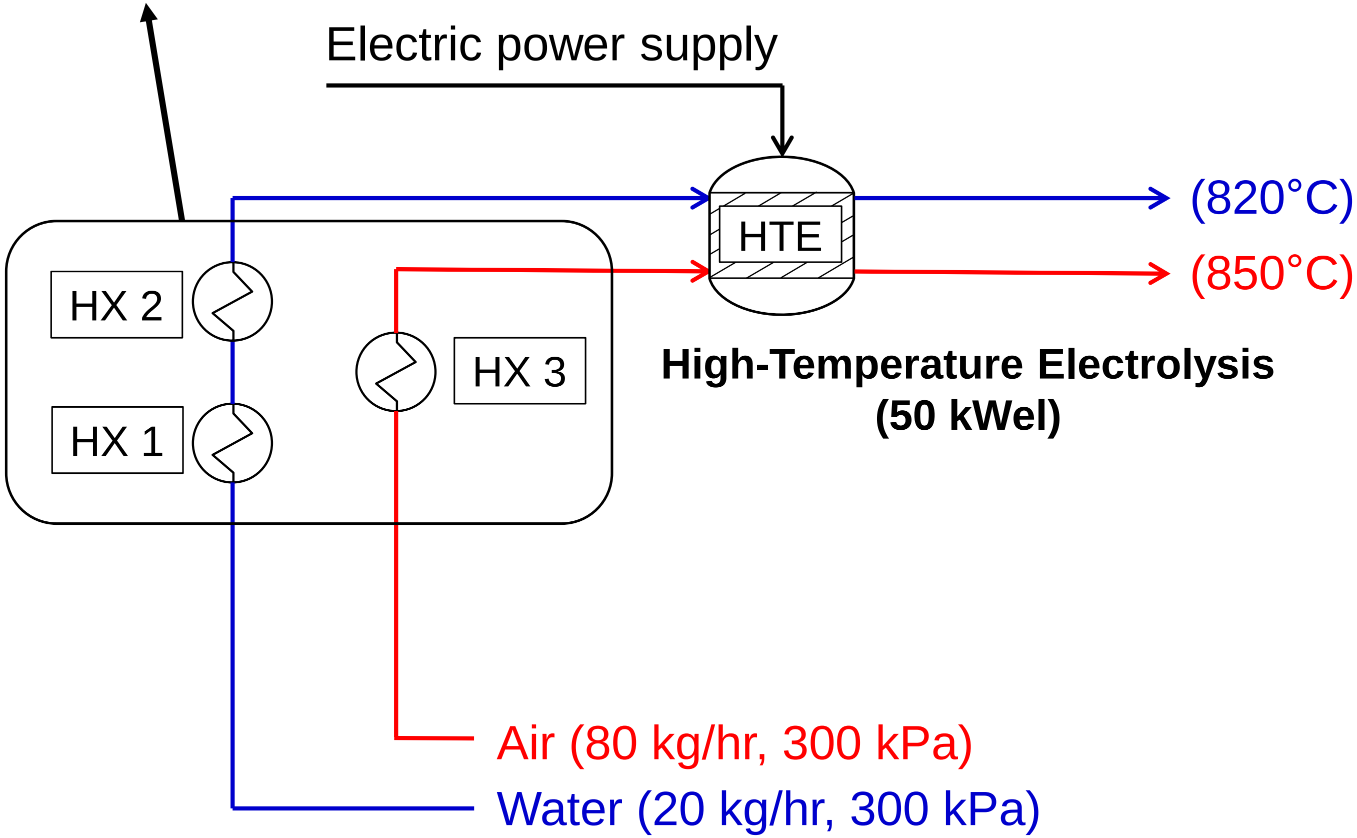
Solar simulator in Cologne (Max. 20 kWth)



Synlight (Max. 400 kWth)



Solar cavity receiver (100 kWth)

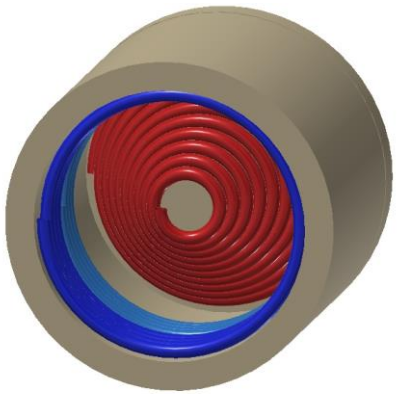


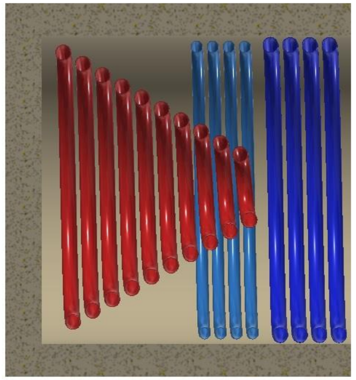
High-Temperature Electrolysis (50 kWel)

HX 1: Evaporation; HX 2: Superheating Steam; HX 3: Superheating Air

Upscaled (100 kWth) experiment at DLR Jülich

Numerical analysis





Input solar power	100 kWth
Outlet temperature in EW section	175.8 °C
Outlet temperature in SS section	831.2 °C
Outlet temperature in SA section	855.3 °C
Lamp-to-Thermal efficiency	67.0%

Blue: Evaporating water (EW)

Light blue: Superheating steam (SS)

Red: Superheating air (SA)

Lamp-to-Thermal efficiency (lamps' electrical efficiency is not considered!)

$$\eta_{ltt} = \eta_{opt} \cdot \eta_{th} = \frac{\dot{Q}_{cap}}{\dot{Q}_{input}} \cdot \frac{\dot{Q}_{ab}}{\dot{Q}_{cap}}$$

$\dot{Q}_{input}$: total input energy from the light source [W]

$\dot{Q}_{cap}$: total energy captured by the cavity receiver [W]

$\dot{Q}_{ab}$: total energy absorbed by the heat transfer fluid [W]

Upscaled (100 kWth) experiment at DLR Jülich

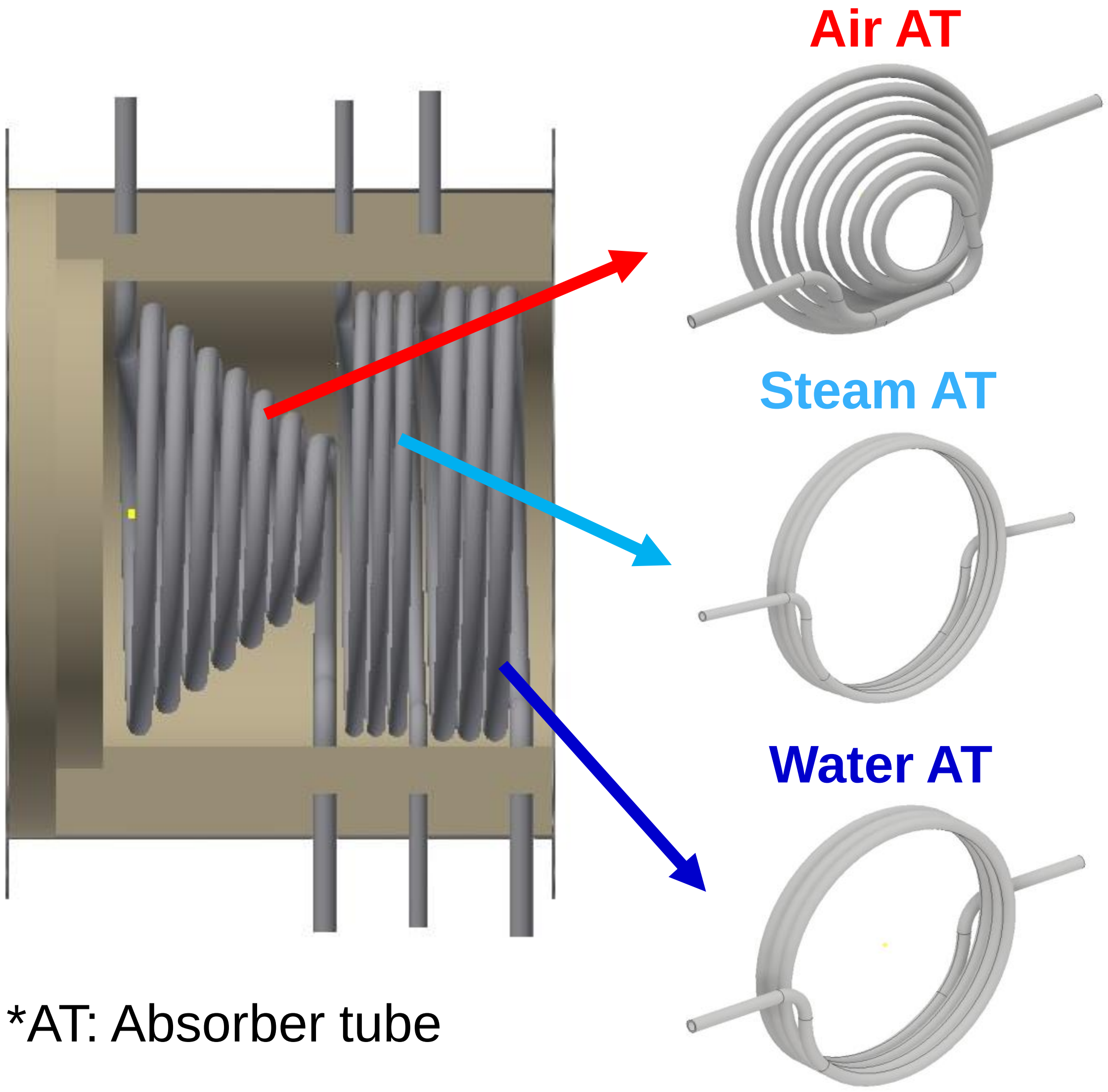
DLR

Detailed description of solar cavity receiver

Cavity inner diameter; 0.545 m

Cavity outer diameter; 0.745 m

Cavity length; 0.5735 m

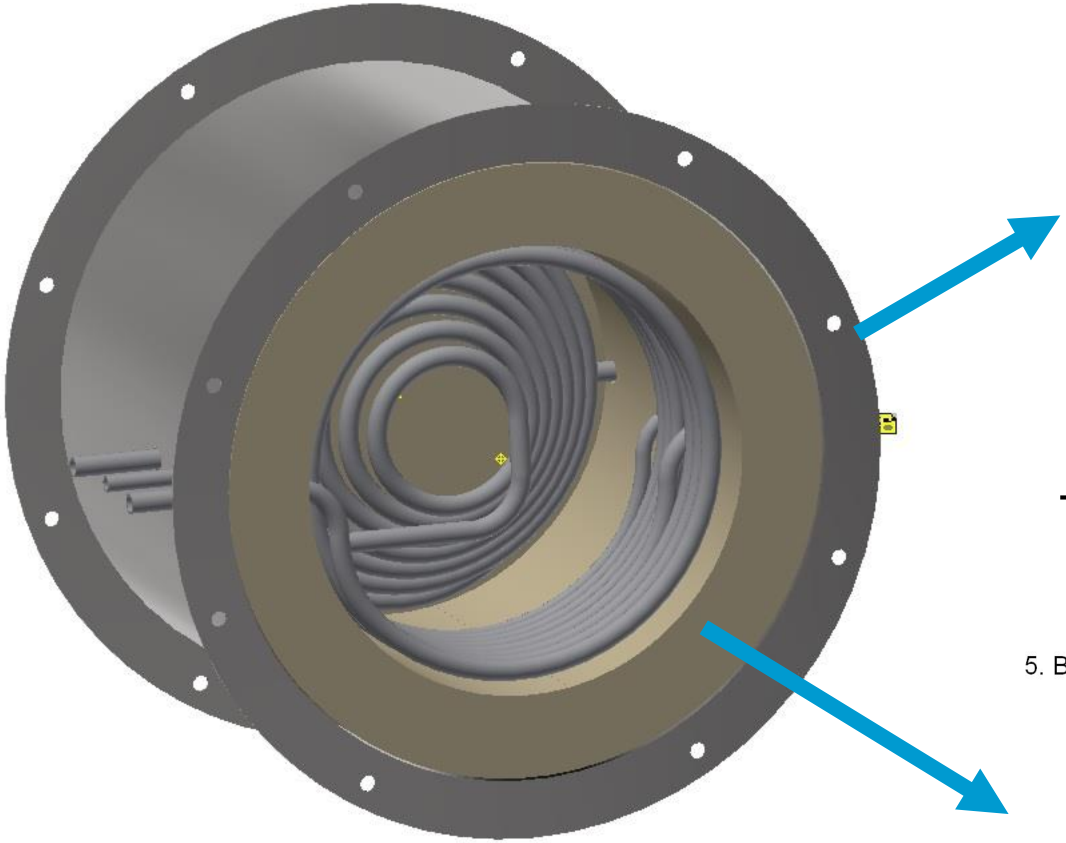


*AT: Absorber tube

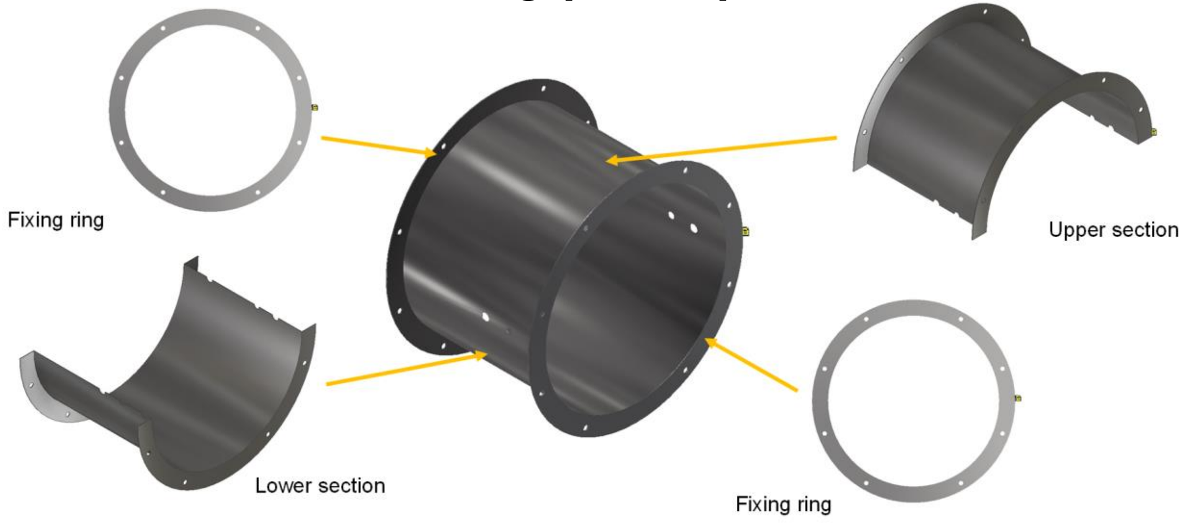
	Evaporating water	Superheating steam	Superheating air
Mass flow	20 kg/h	20 kg/h	80 kg/h
Inner tube diameter	0.019 m	0.014 m	0.019 m
Outer tube diameter	0.025 m	0.020 m	0.025 m
Tube length	5.97 m	5.90 m	8.37 m
Inlet temperature	20 ℃	133.54 ℃	20 ℃
Outlet temperature	133.54 ℃	820 ℃	850 ℃
Pressure	3 bar (a)	3 bar (a)	3 bar (a)

Upscaled (100 kWth) experiment at DLR Jülich

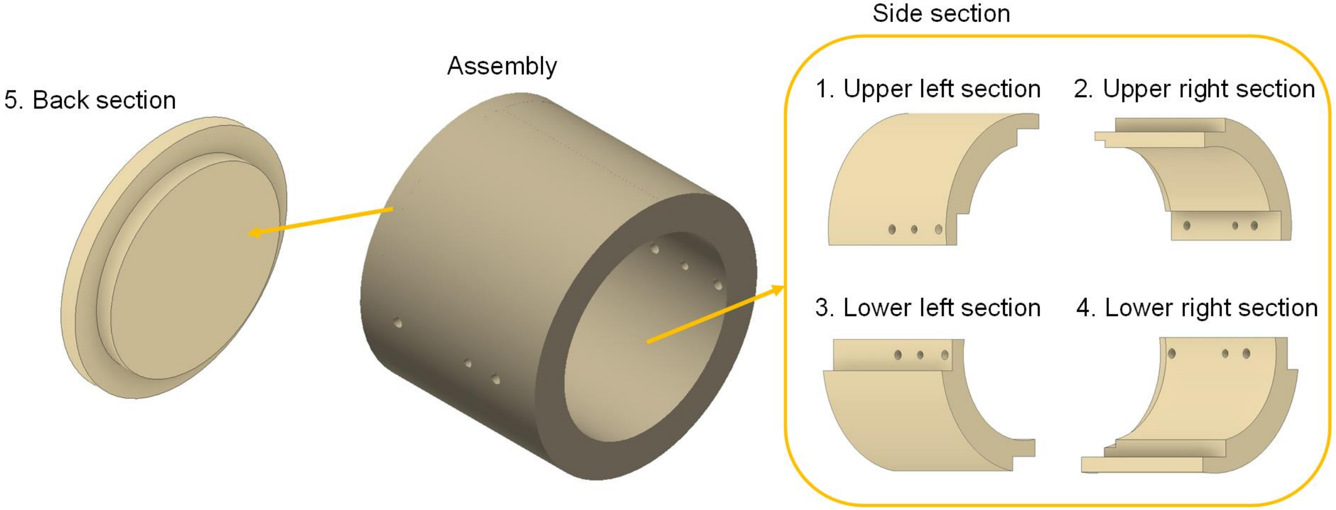
Detailed description of solar cavity receiver



Stainless steel housing (1.4301)



Insulation (Polycrystalline high-alumina wool)



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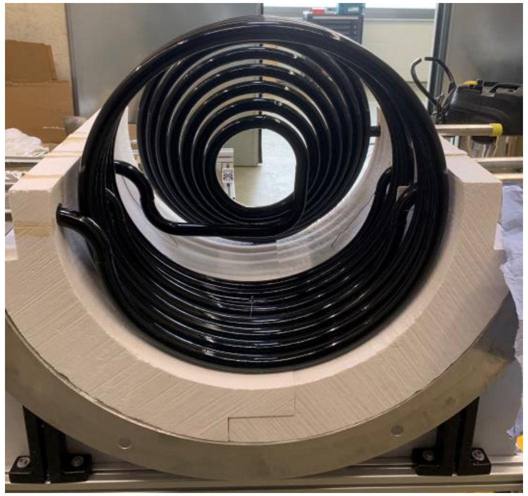
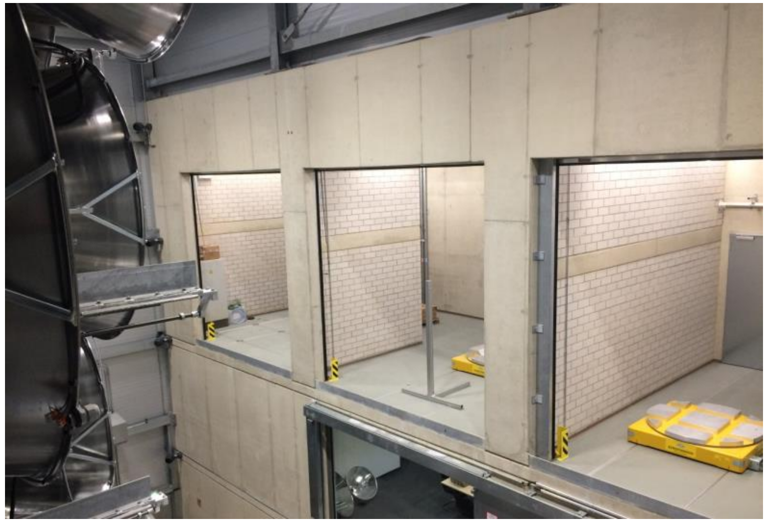
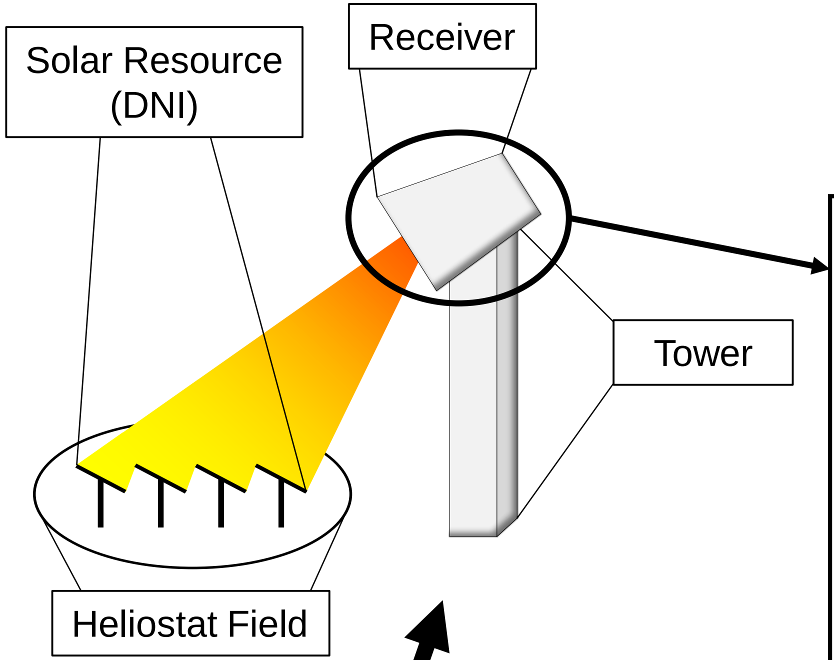
Upscaled (100 kWth) experiment at DLR Jülich

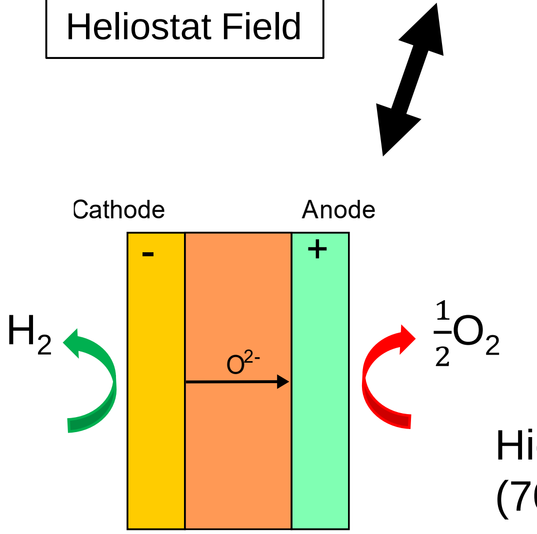
Photograph of the experimental setup





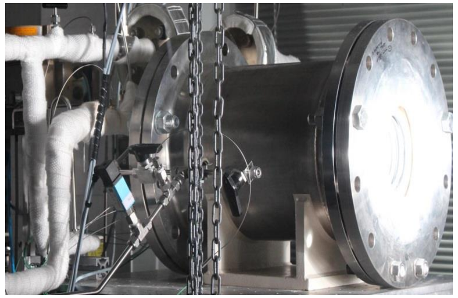
Summary and outlook

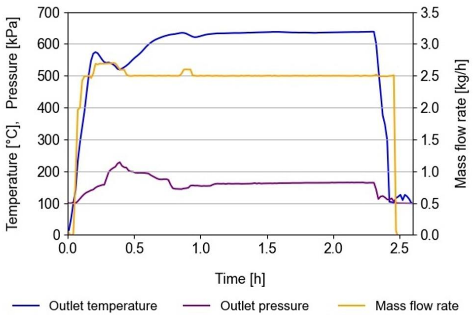




High-Temperature Electrolysis
(700-1000°C)

5 kWth





100 kWth

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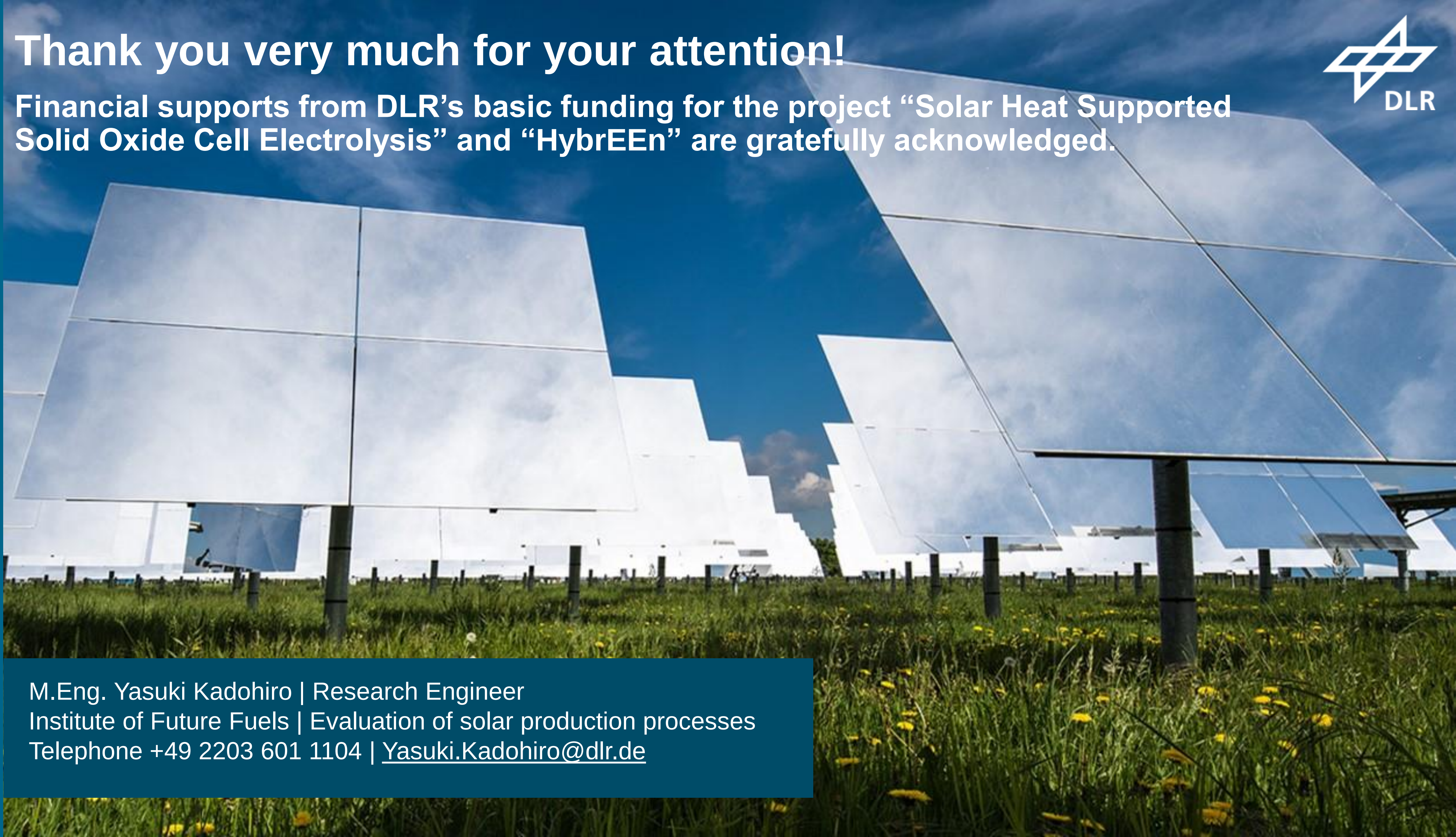

Thank you very much for your attention!

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