A Solar Receiver Delivering Steam at 1500 °C and Above: Experimental Results

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Context: the problem

- Around 1/3 of the industrial total energy consumption in the EU28 is needed for process heat at $T > 1000\ ^\circ$C.[1]
- Few renewable alternatives, *solarization* at the forefront. Are solar high-T receivers available/efficient/economic?

$$\eta_{\text{th}} = \frac{(\dot{m}\triangle h)_{\text{HTM}}}{Q_{\text{solar}}} = \alpha - \frac{\epsilon\sigma T_{\text{r}}^4}{\eta_{\text{SF}} I_{\text{DN}} C}$$

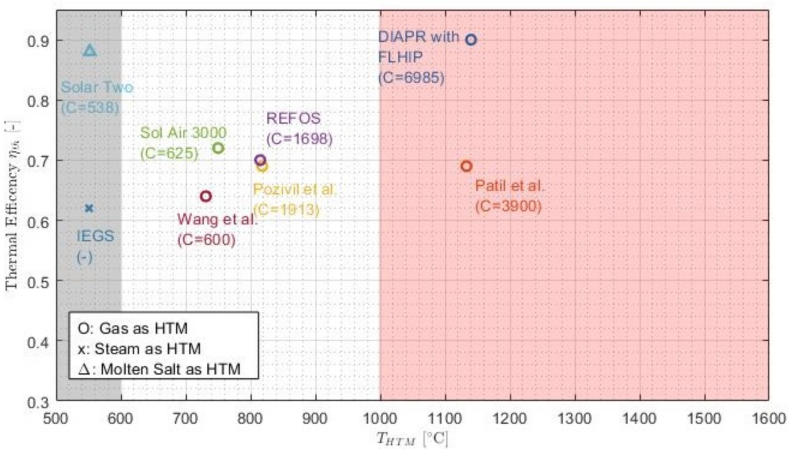
- Heliostats $\sim$ 50% CAPEX ($C < 1000$):[2] $\uparrow\ \eta_{\text{th}}$ to $\downarrow$ CAPEX !!

[1] T. Naegler et al.,*International Journal of Energy Research*, **2015** (*39*), 2019–2030.

[2] C. S. Turchi et al., **2019**, report *NREL/TP-5500-728562019*.

Context: current state.[1]

Caveat: input power? how measured?



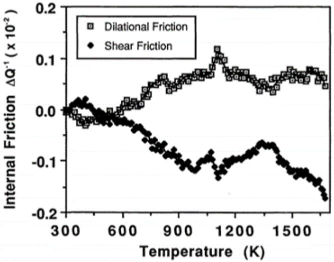
[1] M. Sedighi et al., *Energy Conversion and Management*, **2019** (*185*), 678–717.

Research objectives.

Conceive and demonstrate a solar receiver

- ➨ delivering heat at $T > 1000\ ^{\circ}\mathrm{C}$ with $\eta_{\mathrm{th}} > 50\%$
- ➨ showing enhanced "upscaling potential" ⇔ cold ($T < 300\ ^{\circ}\mathrm{C}$) flat quartz window

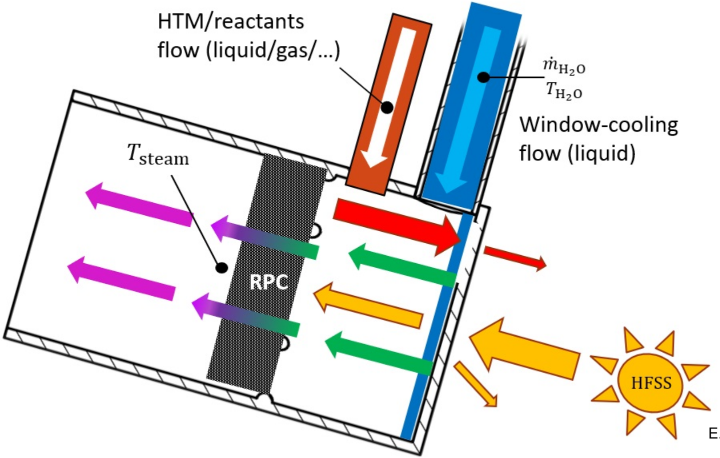
Devitrification is promoted by thermal cycling through inversion T range ($\approx 270\ ^{\circ}\mathrm{C}$).[1]



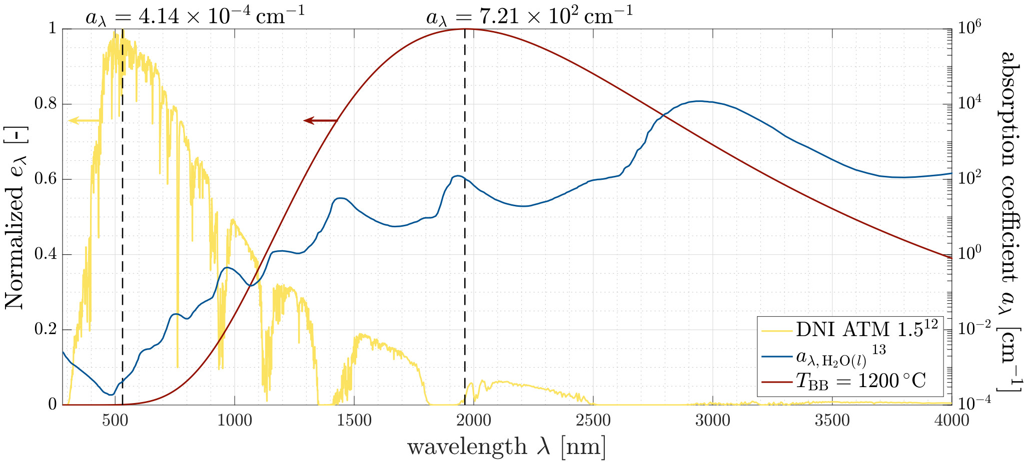
[1] T. L. Wang & M. Hon, *Ceramics International*, **1995** (*21*), 187–193.

Our Concept.

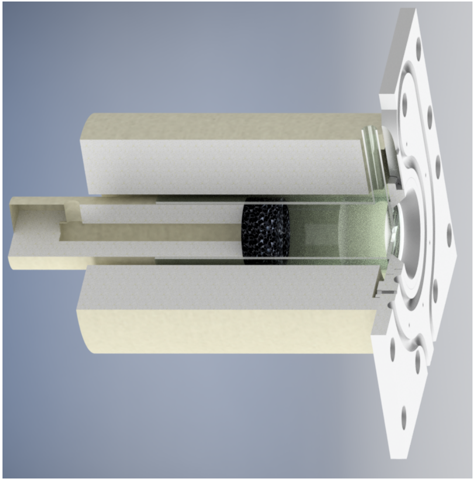
➨ Liquid-vapor transitioning layer onto the window

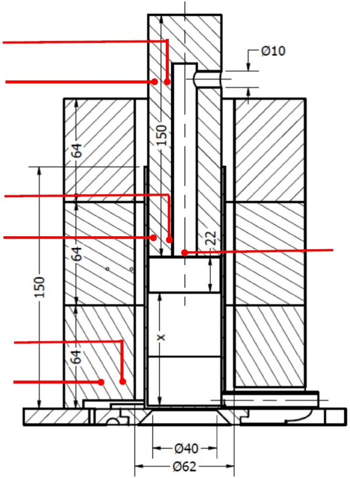


Our Concept. Spectral selectivity.

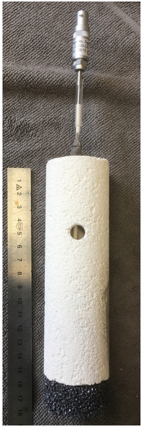


Exp. Setup.

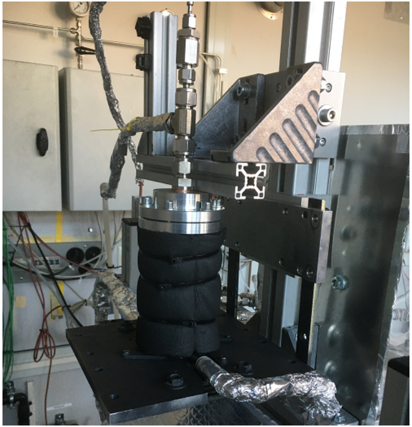


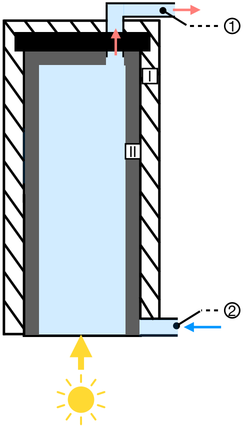


Exp. Setup.



Exp. Setup. Calorimetry.





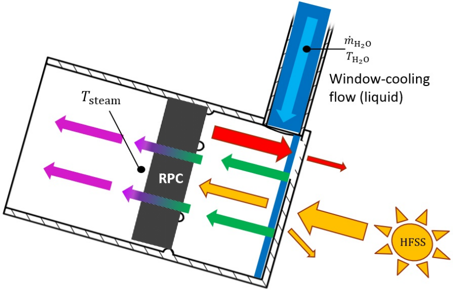
I Insulation

II Graphite

① PT100 - Measuring outlet temperature

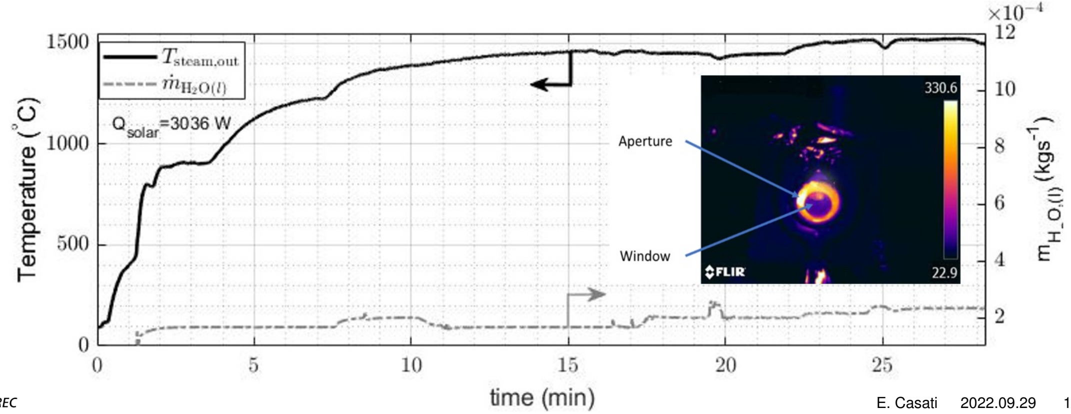
② PT100 - Measuring inlet temperature

Free Water Layer Receiver (FWLR).

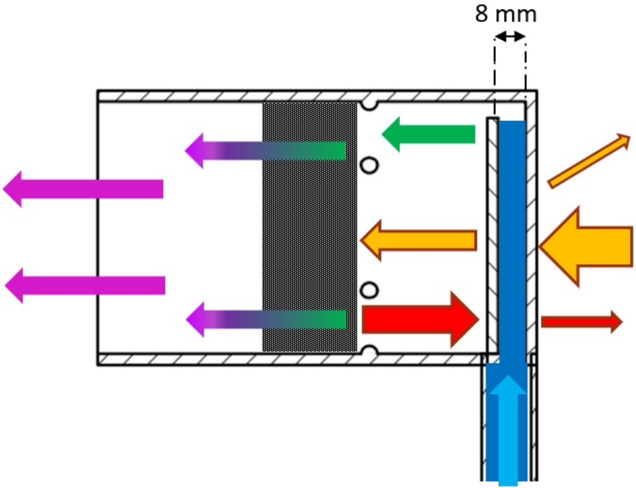


FWLR Receiver. Results.

- $T_{\text{Steam, out}} = 1519 \pm 10$ °C, $Q_{\text{HTM}} = 1368 \pm 80$ W, $\eta_{\text{th}} = 45 \pm 5\%$, $C = 2400$ suns
- Layer of liquid water uniformly cooling the window: $T_W = 150 \pm 5$ °C

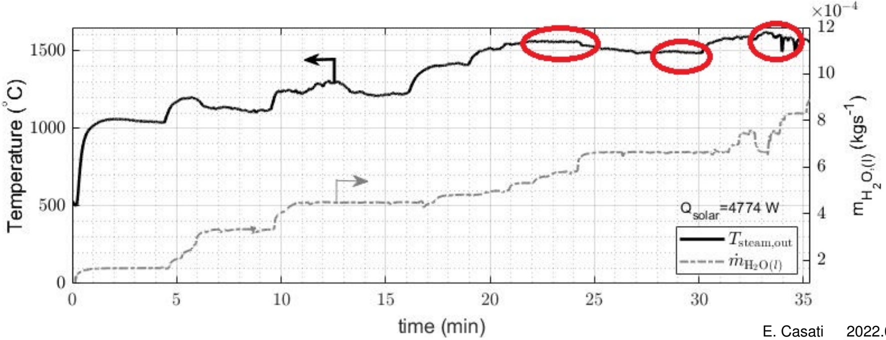


Double Window Receiver (DWR).



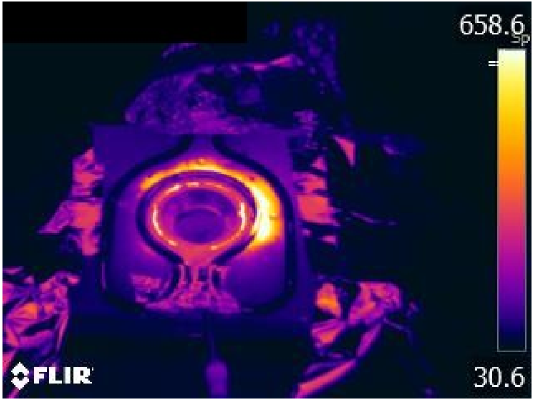
DWR Receiver. Results.

- For all tests: $C \approx 3800$ suns, $Q_{\text{solar}} = 4774 \pm 160$ W
- $T_{\text{Steam, out}} = 1557 \pm 10$ °C, $\eta_{\text{th}} = 73 \pm 7\%$
- $T_{\text{Steam, out}} = 1493 \pm 9$ °C, $\eta_{\text{th}} = 81 \pm 6\%$
- $T_{\text{Steam, out}} = 1612 \pm 15$ °C, $\eta_{\text{th}} =?$

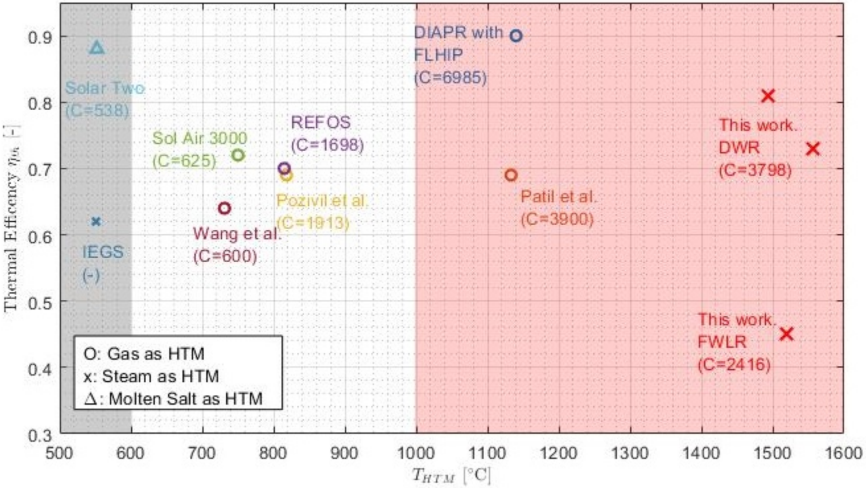


DWR Receiver. Results ($C \approx 3800$ suns).

➨ Confined layer of liquid water uniformly cooling the window: $T_W < 160 \pm 5$ °C



Results.



0.9
0.8
0.7
0.6
0.5
0.4
0.3
Thermal Efficency η_{th} [-]
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
T_{HTM} [°C]
Solar Two
(C=538)
IEGS
(-)
Sol Air 3000
(C=625)
REFOS
(C=1698)
Wang et al.
(C=600)
Pozivil et al.
(C=1913)
DIAPR with
FLHIP
(C=6985)
Patil et al.
(C=3900)
This work.
DWR
(C=3798)
This work.
FWLR
(C=2416)
O: Gas as HTM
x: Steam as HTM
Δ: Molten Salt as HTM

Next ??

- ➨ Consolidate results
- ➨ Test nozzled-version
- ➨ Refine predictive model

THANKS FOR YOUR ATTENTION