Solar thermochemical reactor design space overview

Peter G. Loutzenhiser
Solar Fuels and Technology Laboratory
Woodruff School of Mechanical Engineering

Unlocking Solar Thermochemical Potential: Receivers, Reactors, and Heat Exchangers Workshop

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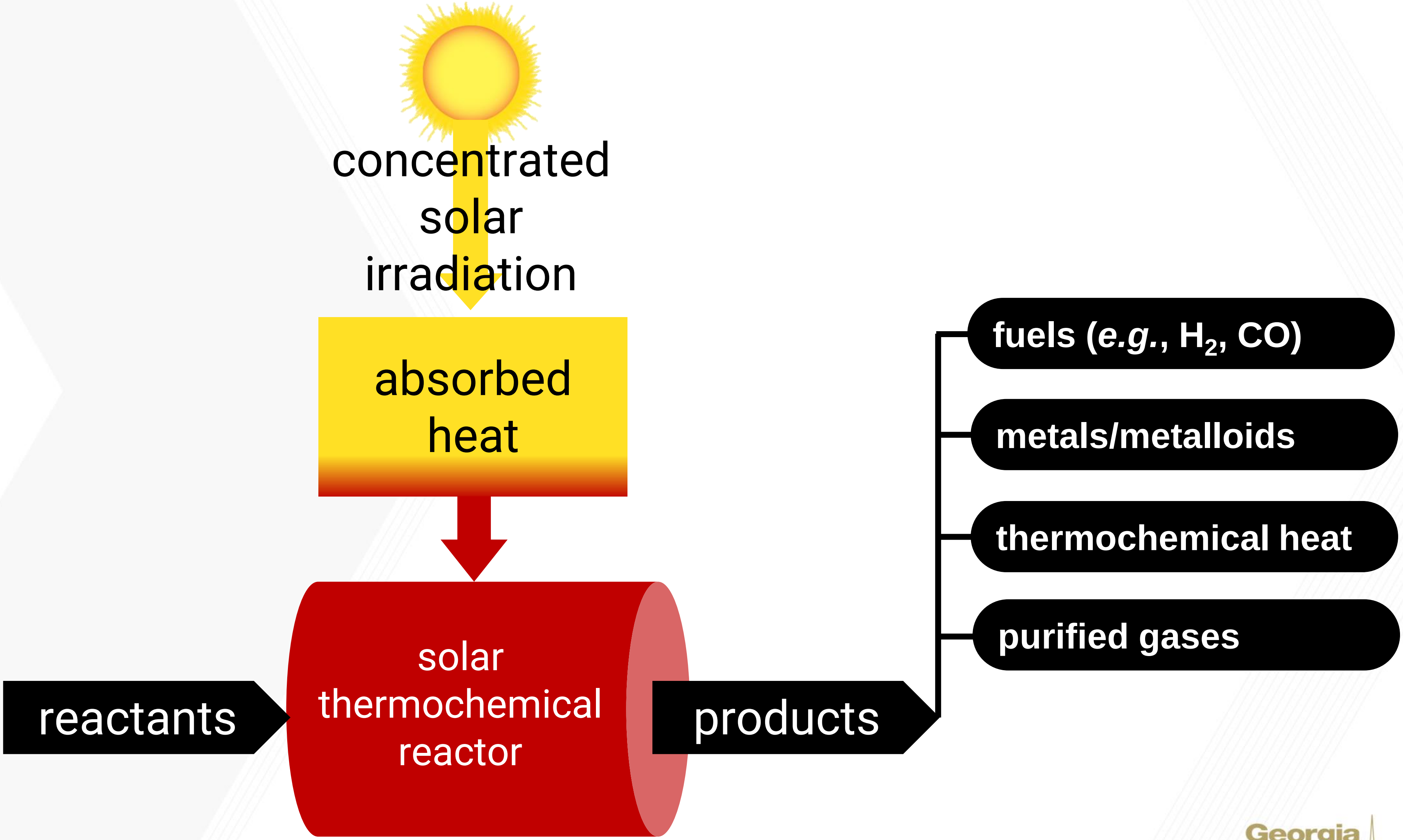
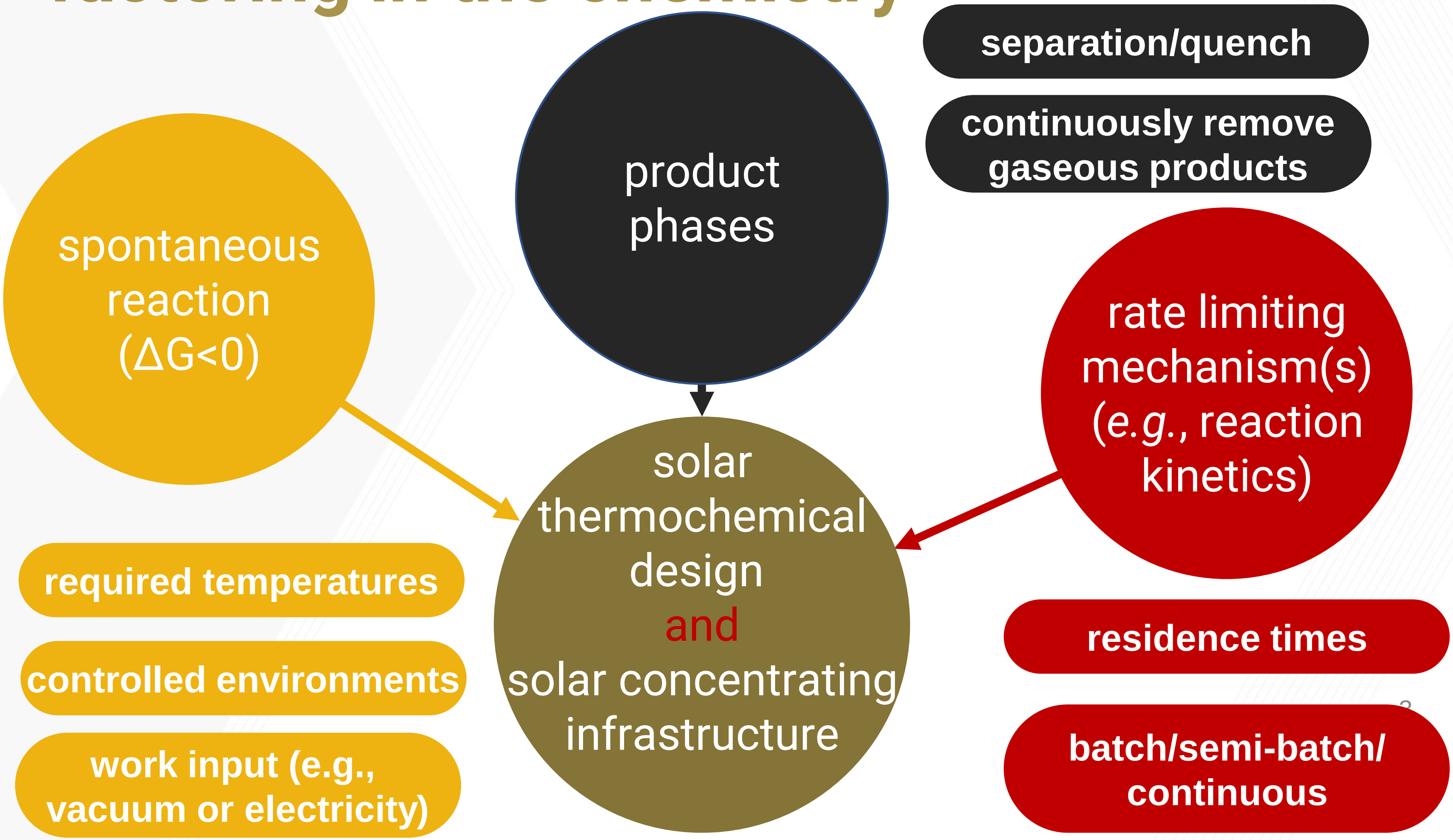
Solar thermochemical reactors

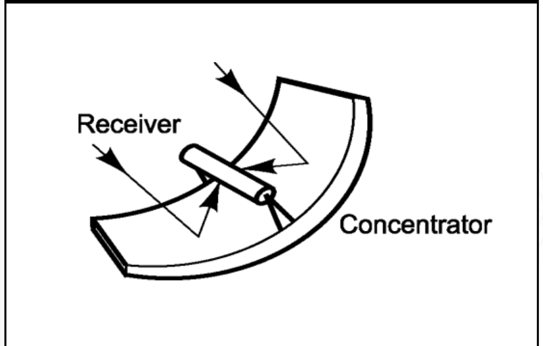


Considerations to inform thermochemical reactor design factoring in the chemistry

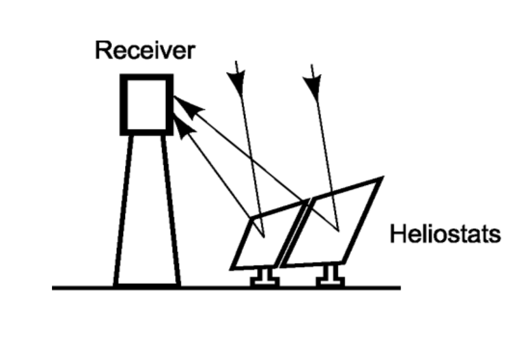


Concentrating solar irradiation infrastructure

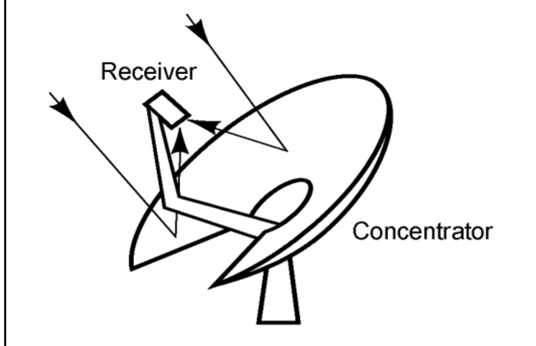
Trough
Solar concentrations of < 100 suns



Tower
Solar concentrations of 500 – 2500 suns with secondary



Dish
Solar concentrations of 5000 – 10,000 suns



Steinfeld and Meier, *Encyclopedia of Energy* 2004, 623-637

Maximum work potential extraction

$$\eta_{overall,ideal} = \eta_{absorption}\eta_{Exergy} = \underbrace{\left(1-\frac{\sigma T^4}{I_{DN}C}\right)}_{\frac{\dot{Q}_{solar}-\dot{Q}_{re-radiation}}{Q_{solar}}} \cdot \underbrace{\left(1-\frac{T_{ambient}}{T}\right)}_{\text{theoretical work potential from heat (exergy)}}$$

$$\eta_{overall,ideal} = 0 \rightarrow T_{stagnation} = \left(\frac{I_{DN}C}{\sigma}\right)^{0.25}$$

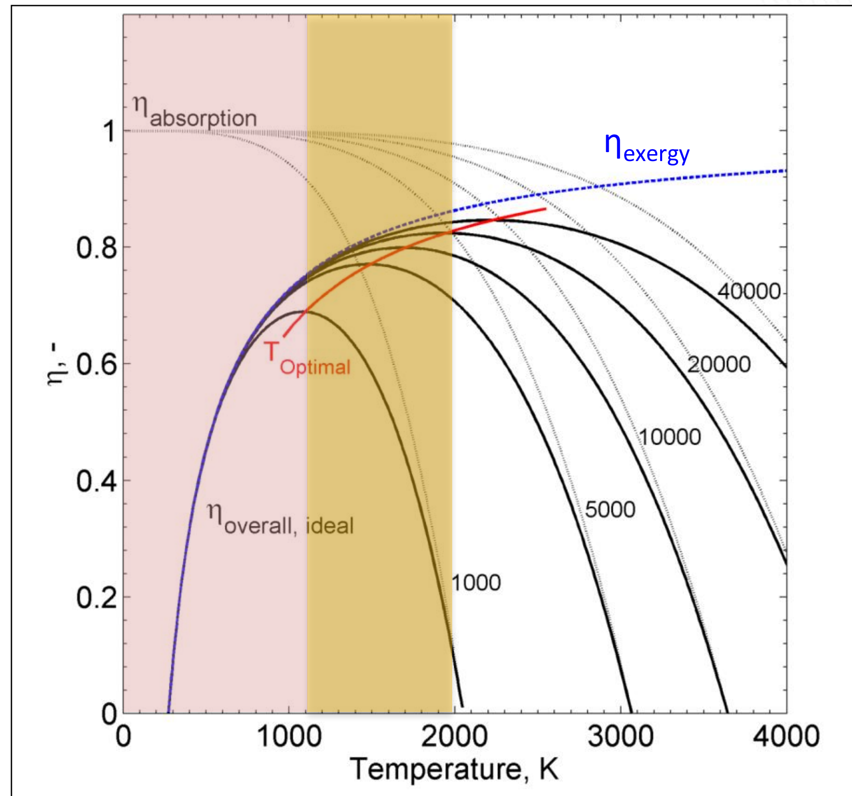
$$\frac{\partial \eta_{overall,ideal}}{\partial T_{optimal}} = 0$$

$$0 \rightarrow \left(T_{optimal}\right)^5 - 3/4T_{ambient}\left(T_{optimal}\right)^4 - \left(\frac{T_{ambient}I_{DN}C}{4\sigma}\right) = 0$$

C	1000 suns	5000 suns	10000 suns
$T_{stagnation}$	2049 K	3064 K	3644 K
$T_{optimum}$	1106 K	1507 K	1724 K

nuclear range

ideal thermochemical cycles

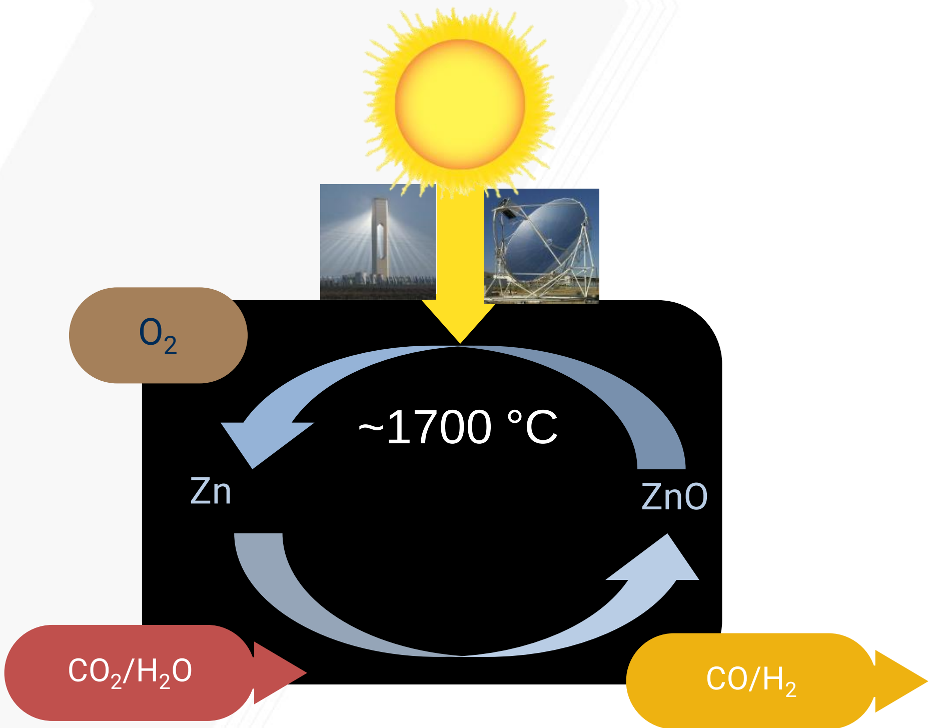


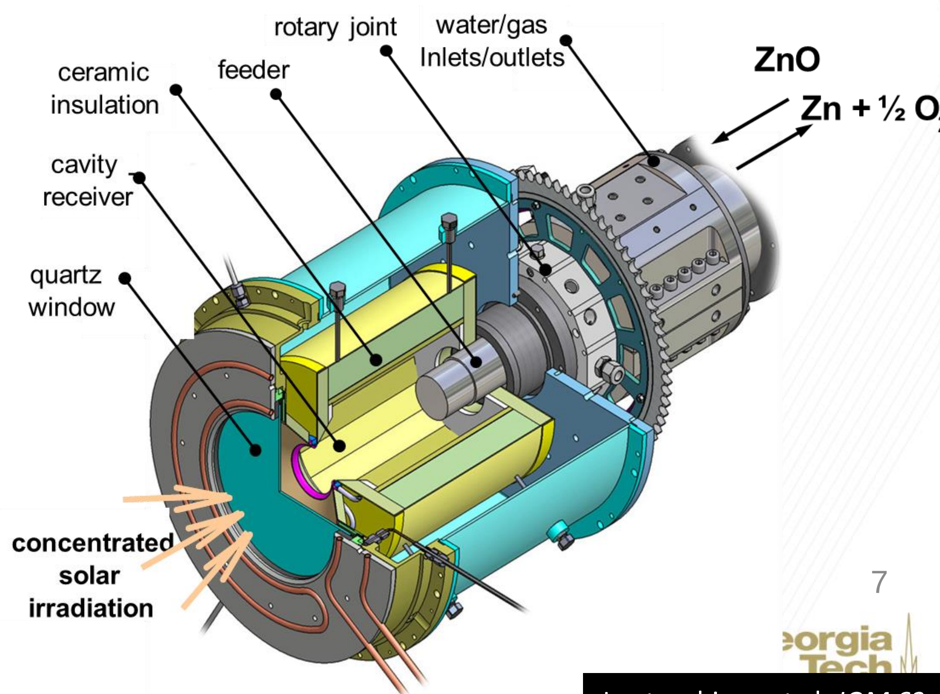
Design considerations

- Scale required for the applications
  - Solar thermochemical storage for electricity productions needs to be scaled for integration with power block
  - Fuels production and materials processing varies between modular units and/or large scale production but necessitates storage
- Temperatures required for different applications
  - Windowed reactors allow for direct exposure to solar concentrated irradiation with losses due transmission and limited scales
  - Indirect reactors heat an absorber plate composed of resilient, highly conductive materials that conducts heat to reactants mitigate depositions with irreversibilities (temperature drops due to heat transfer)
  - Resilient reactor materials required for high temperatures
- Optimizing absorption of concentrated solar irradiation
  - Spectral selectivity for low temperatures
  - Cavity reactors for high temperatures
  - Optimized reactant geometries to ensure deep penetration of solar irradiation (e.g., reticulate porous structures, etc.)

CO_2/H_2O splitting based on ZnO/Zn redox reactions

- Ultra high-temperatures necessitated a window and inert environment
- Zn(g) produced requires a quench process
- Goal to maximize Zn production for subsequent H_2 and/or CO production

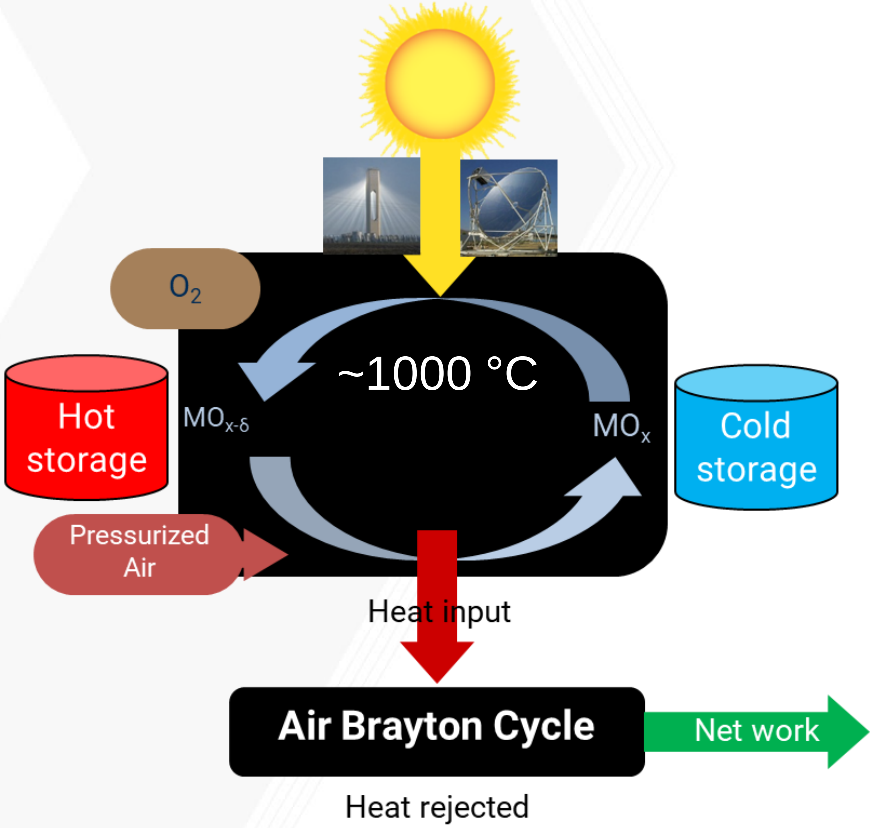




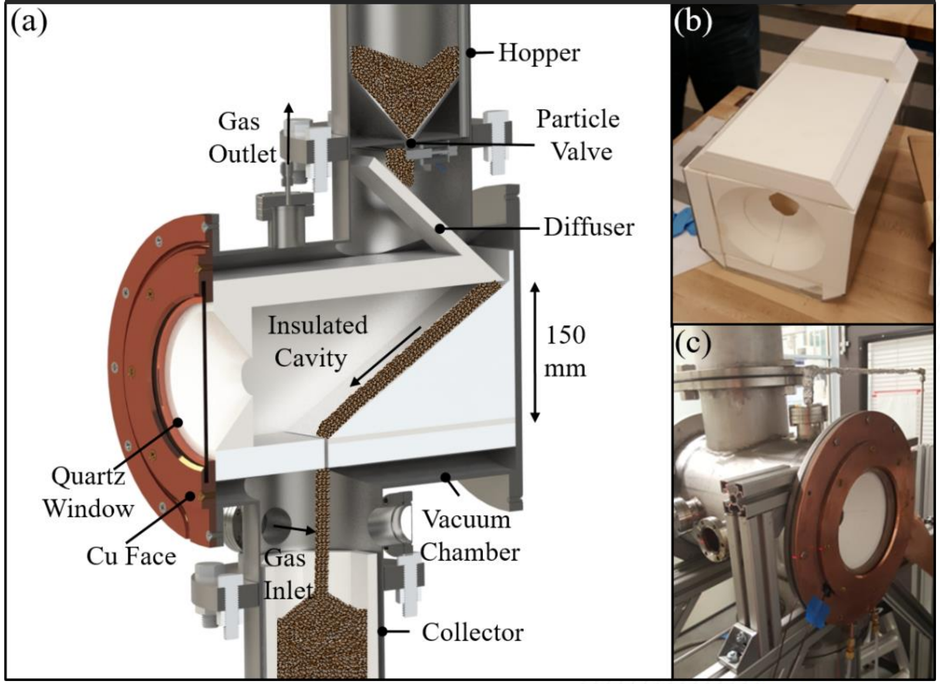
Loutzenhiser, et al. *JOM 63 (2011) 32 - 34*

Solar thermochemical storage based on $CaAl_{0.2}Mn_{0.8}O_{3-\delta}$ redox reactions

- Higher temperatures, continuous flows, and heat and mass transfer limitations required window
- A roughened incline slope controlled residence and distributed concentrated irradiation over a thin particle flow

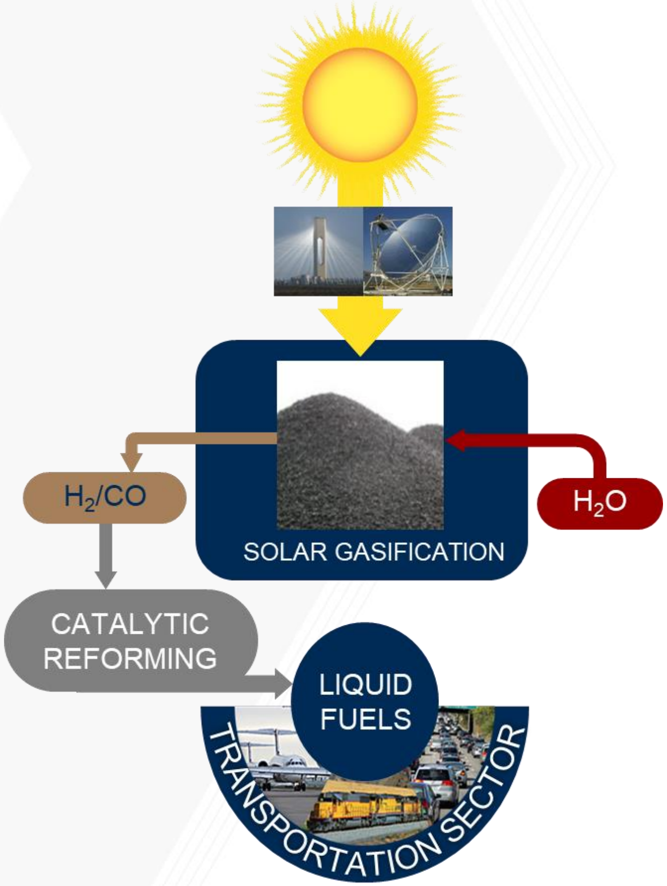


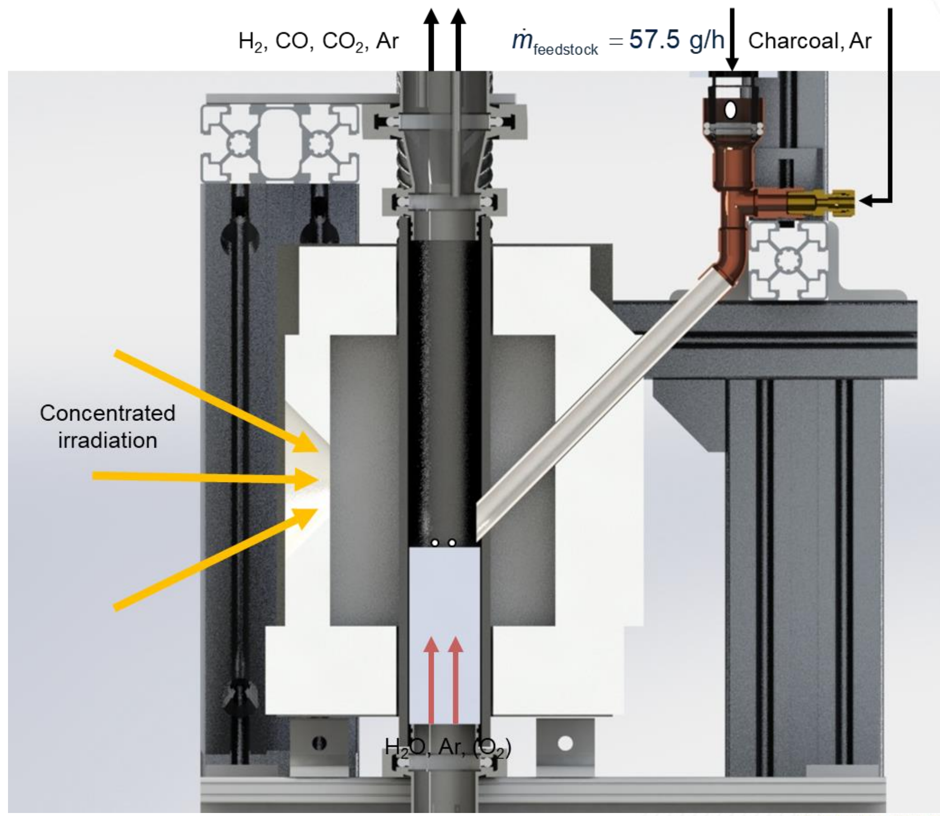
Solar thermochemical reactor (a) schematic, (b) cavity, and (c) assembled



Solar gasification

- Semi-batch mode with gaseous products exiting the top facilitated an solar gasifier and associated chemical kinetics
- Inert bed mixed with activated carbon and H_2O in a SiC tube for gasification at 900 °C for indirect heating



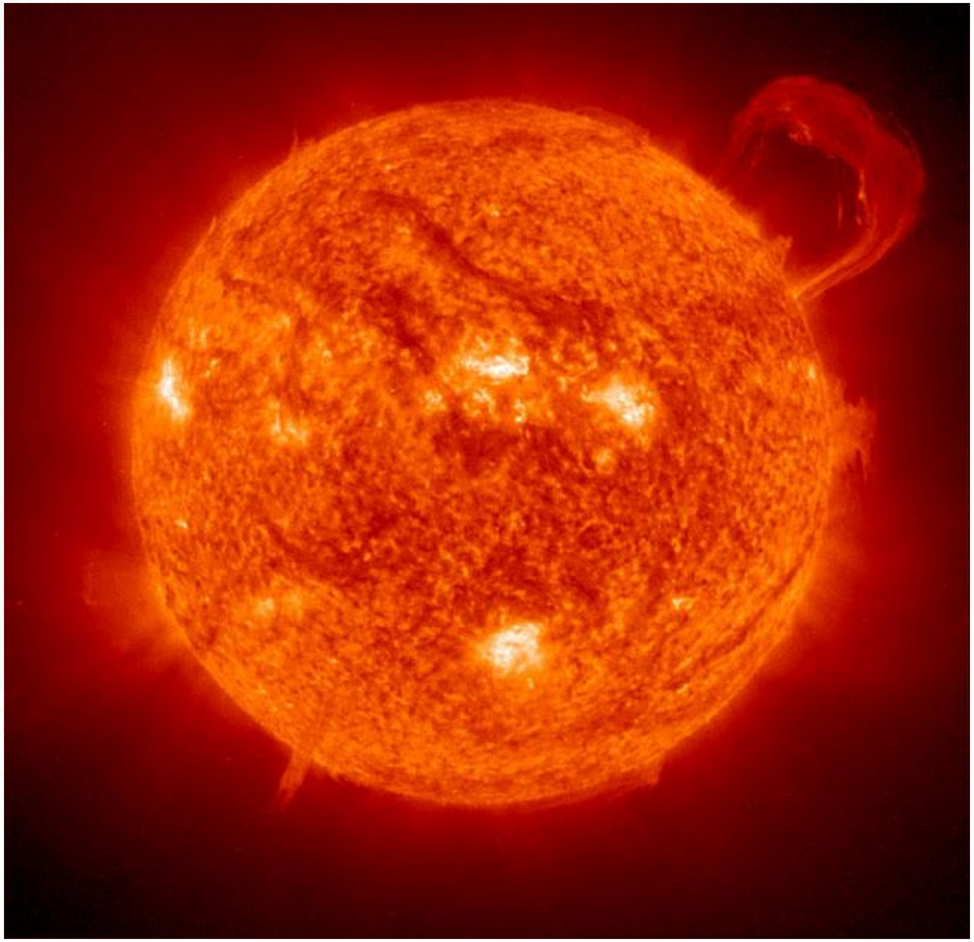


Summary and conclusions

- Solar thermochemical reactor design must coupled to detailed knowledge of the reaction chemistry
- Different chemical reactions will inherently lead to different solar thermochemical reactor designs, including direct (with window) or indirect (absorber plates) with different scaling obstacles and losses

Outlook

How does the future look?



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