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Solar Fuels R&D in the United States of America: SolarPACES Task II

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Overview

- **Active Projects**
  - Solar Thermochemical Hydrogen Production (STCH)
    - Sandia, Bucknell, Colorado School of Mines
    - University of Colorado
  - Photoelectrochemistry
    - Stanford
  - Magnetically Stabilized Thermochemistry (HEATS-ARPAe)
    - University of Florida
  - Liquid metal heat transport in solar-thermochemical fuels
    - Georgia Tech
  - Ceria-Based Solar Thermochemistry (HEATS-ARPAe)
    - University of Minnesota

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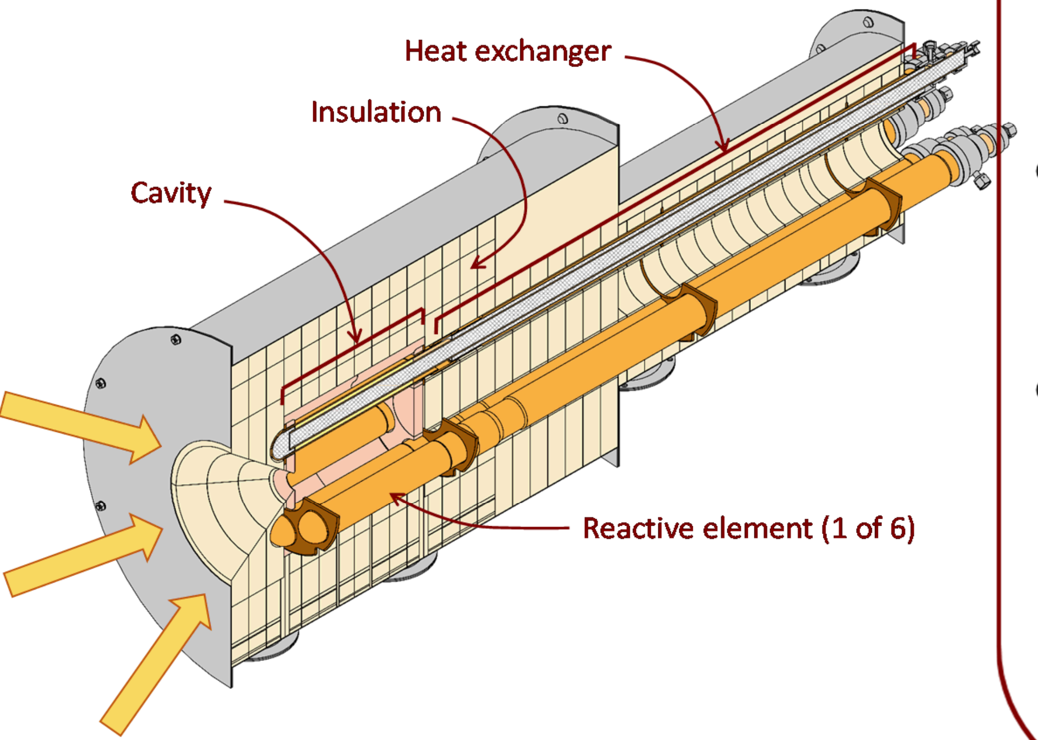
University of Minnesota Ceria-based Solar Redox Reactors

Produces syngas by splitting H_2O and CO_2



Isothermal Reactor

- No moving high temperature components
- Mechanically robust, fixed bed reactor using porous fibrous particles

- Integrated gas phase heat recovery system
  - 90% of sensible heat of reactant and product gases recovered
- Continuous on-sun fuel production
  - Demonstrated for 1000s cycles
  - 1% efficiency including the solar equivalent parasitic work requirements
  - Adaptable to other isothermal cycles that promise much higher efficiency

Credit: UMN Solar Energy Laboratory, Jane Davidson group

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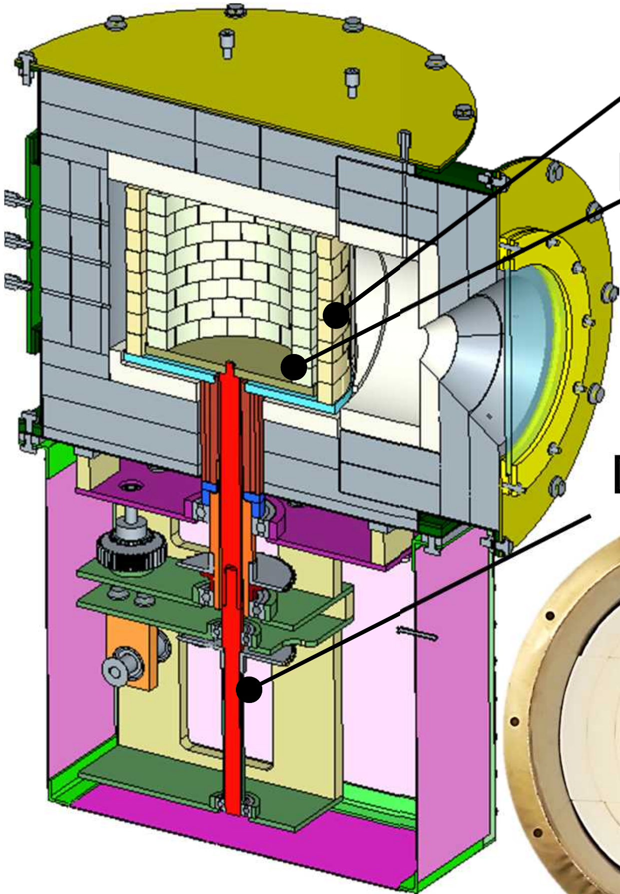
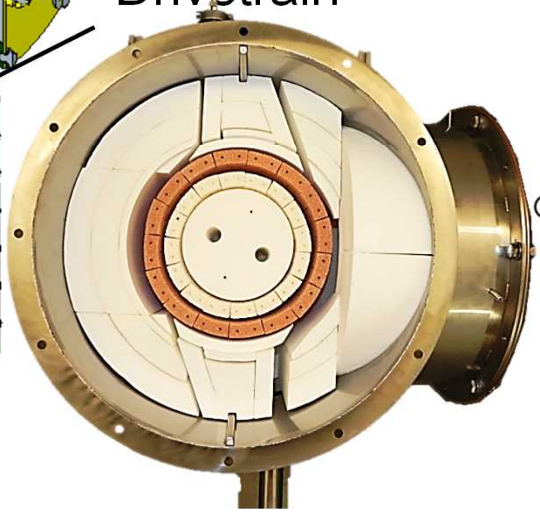




Temperature Swing

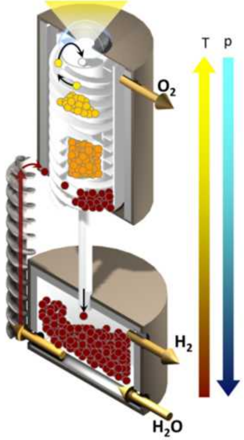
- Designed for 200-500 °C swing between reduction/oxidation
- Rotation of RPC ceria structures between temperature zones allows continuous fuel production

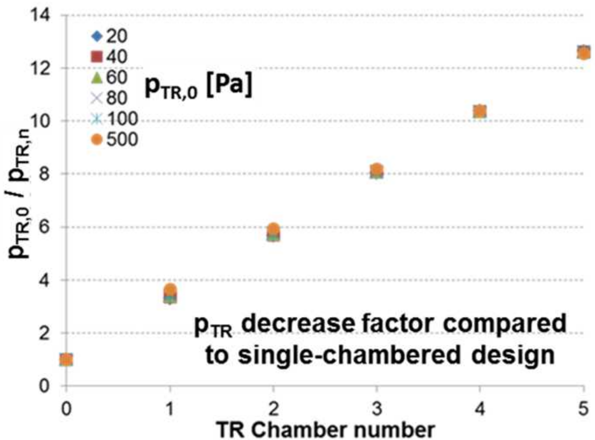
- Integrated solid phase heat recovery system
  - Counter-rotating alumina cylinder designed to recuperate 50% of the sensible heat of the ceria as it cycles
- Continuous on-sun fuel production
  - In process of testing in UMN high flux simulator
  - Tested up to 1400°C to-date

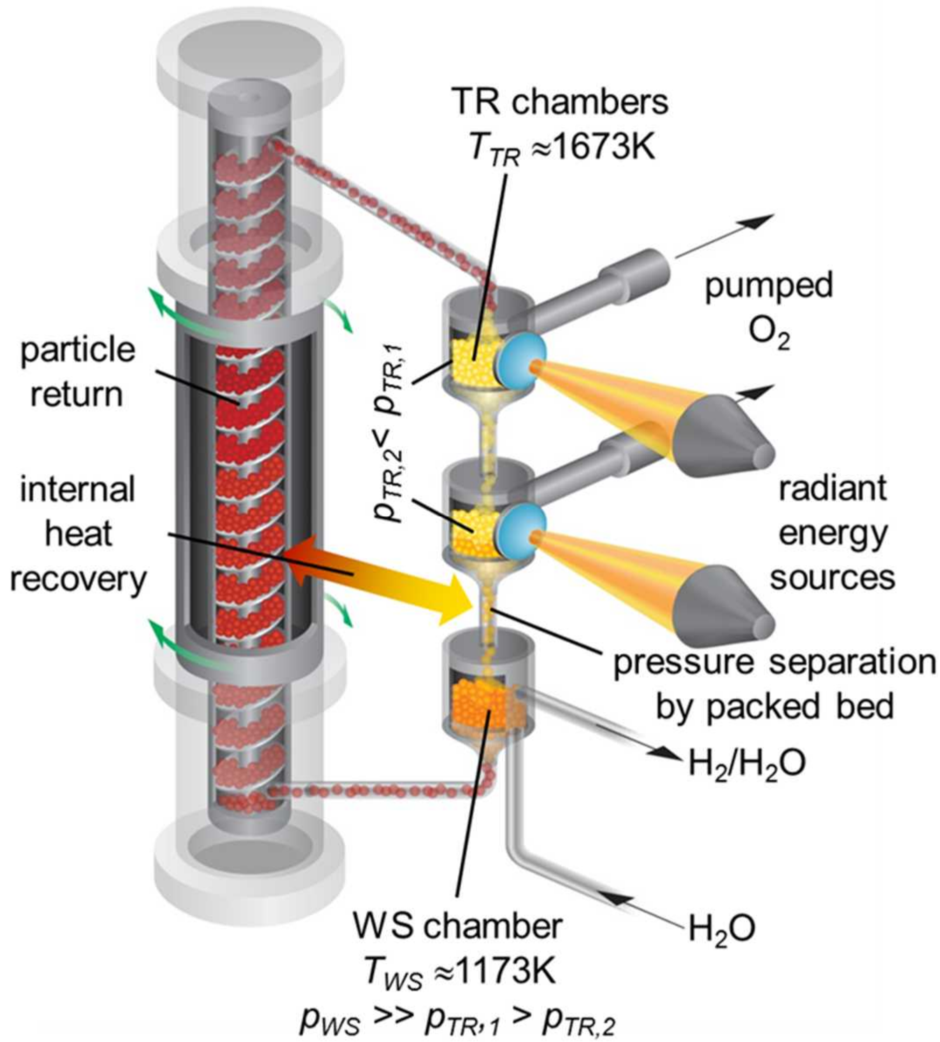
Credit: UMN Solar Energy Laboratory, Jane Davidson group

STCH: Sandia, DLR, ASU, Bucknell, CS Mines

- Direct solar absorption
- Internal heat recovery between T_{TR} and T_{WS}
- Continuous on-sun operation
- Temperature and product separation
- Pressure separation (thermal reduction step vacuum pumping)
- Non-monolithic oxide
- Reaction kinetics decoupled from reactor operation
- Thermal reduction pressure (0.1-10Pa)
- Decreased solid-solid heat recovery requirement
- Decreased pump work requirement
- Compatibility with MW-scale plant







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STCH: Sandia, DLR, ASU, Bucknell, CS Mines

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Sr- and Mn-doped $LaAlO_{3-\delta}$ for solar thermochemical H_2 and CO production†

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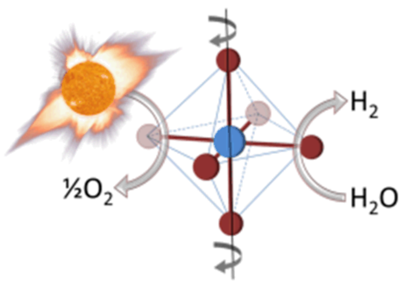
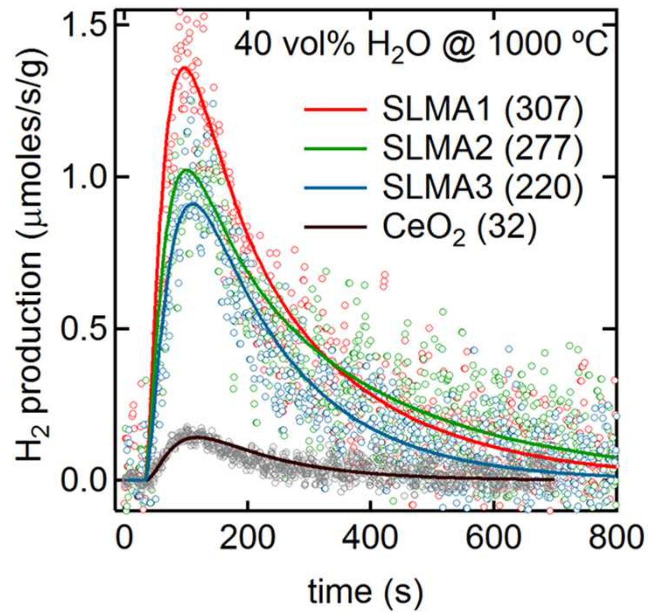
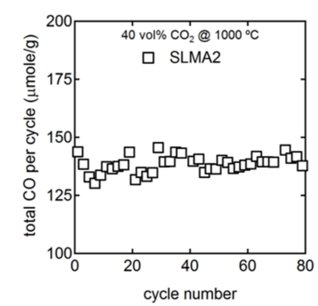


$SLMAn = Sr_xLa_{1-x}Mn_yAl_{1-y}O_{3-\delta}$



- Perovskite compounds split H_2O in a thermochemical cycle.
  - First of a kind observation, also demonstrated durability
- Kinetics benchmarked against CeO_2.
  - Similarly fast oxidation rates
- Make ~9× more H_2 than CeO_2 at T_{TR} = 1350 °C.



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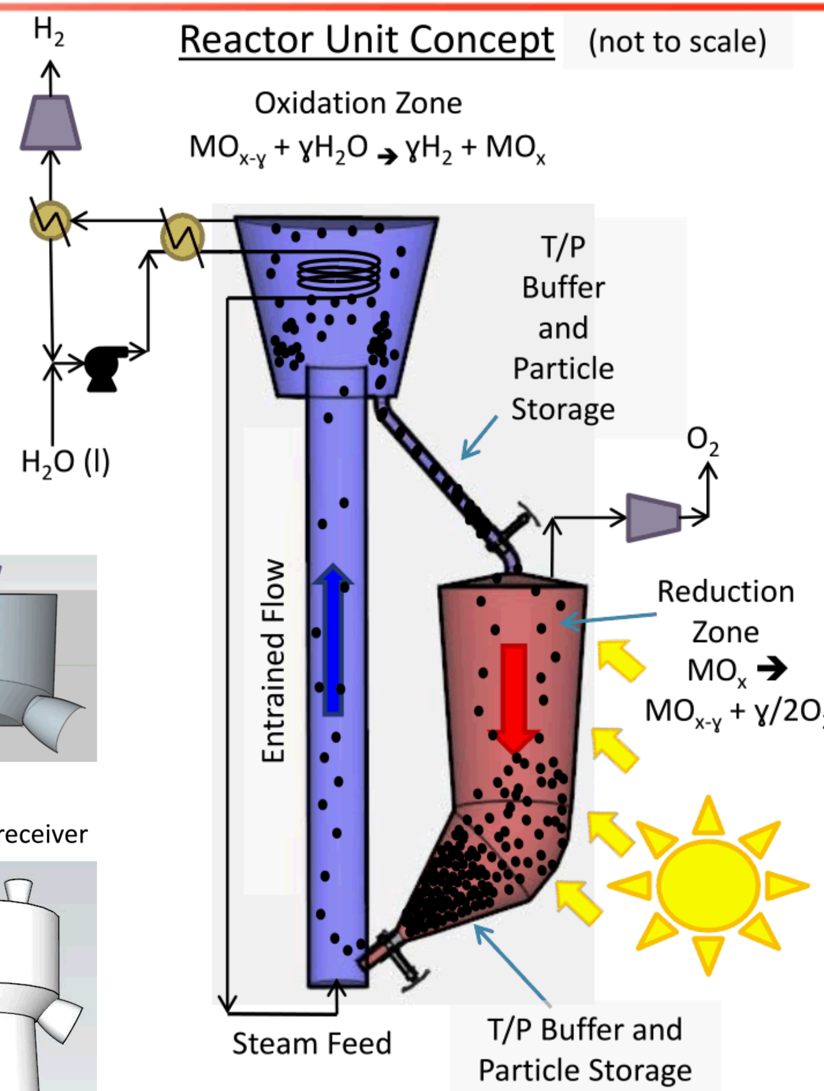
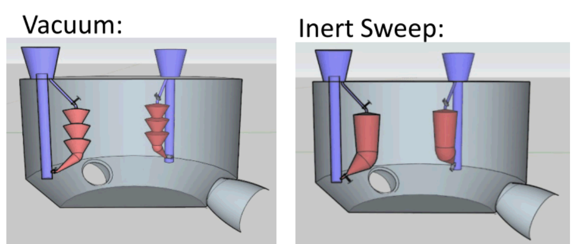
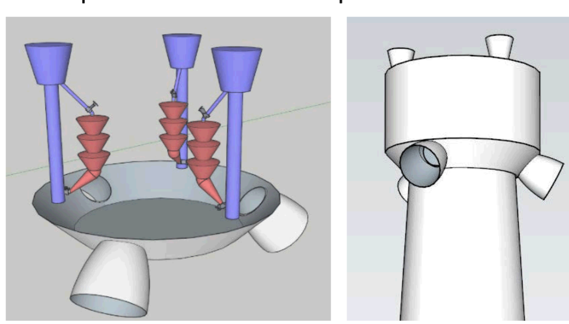
STCH: University of Colorado at Boulder, NREL

- Previously developed a packed tube, inert-flushed, “Surround Sun” reactor
- Sandia-Inspired particle reactor →
- Investigating the isothermal hercynite cycle





Multiple reactor units on top of central receiver



Credit: CU Boulder, Al Weimer group

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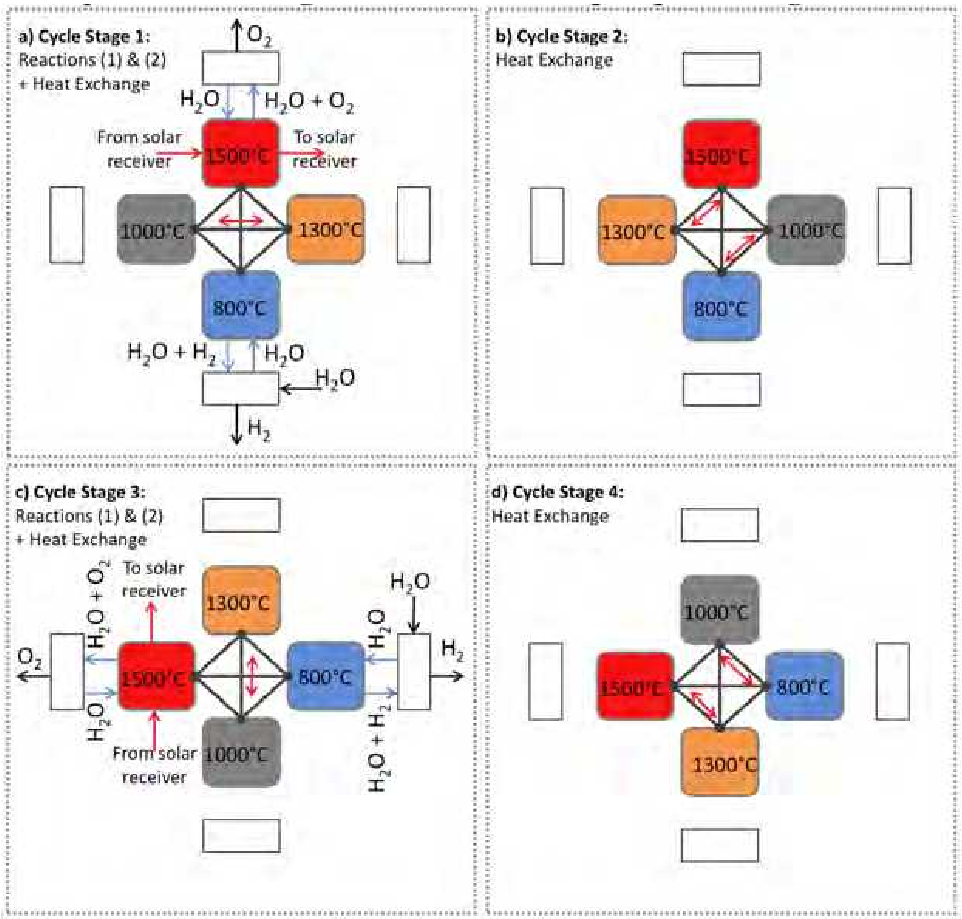
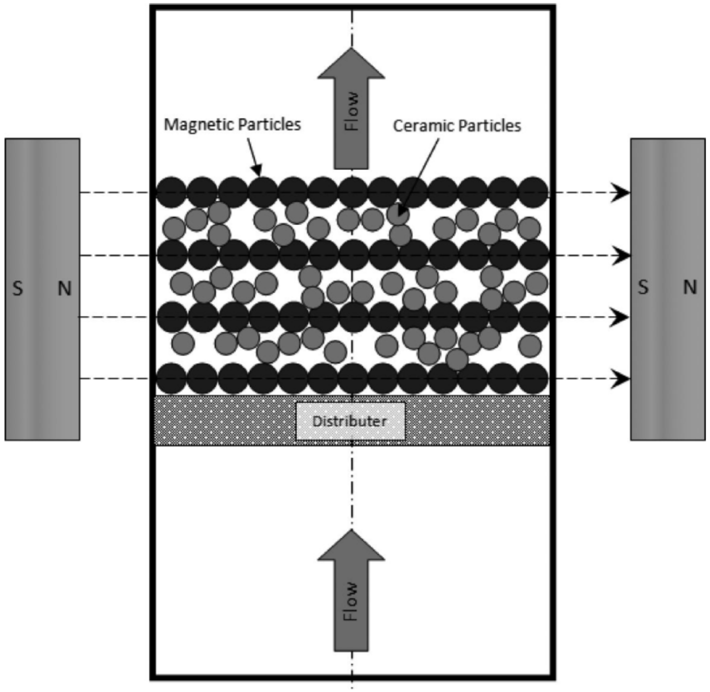
Georgia Tech (ARPA-E)

- Development of a high-efficiency solar reactor to produce solar fuel. Using liquid metal, the reactor transports heat away from the sunlight-collection point to a chemical reaction zone, minimizing the loss of solar heat.



University Of Florida (ARPA-E)

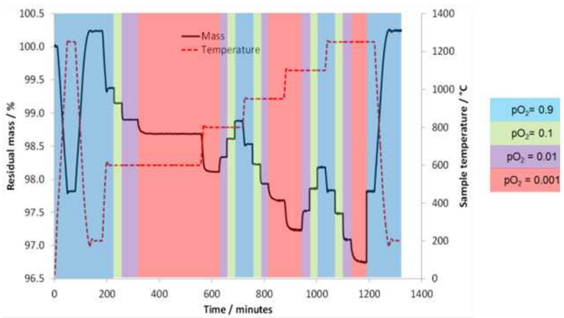
- Solar Thermochemical Fuel Production via a Novel Low Pressure, Magnetically Stabilized, Non-volatile Iron Oxide Looping Process



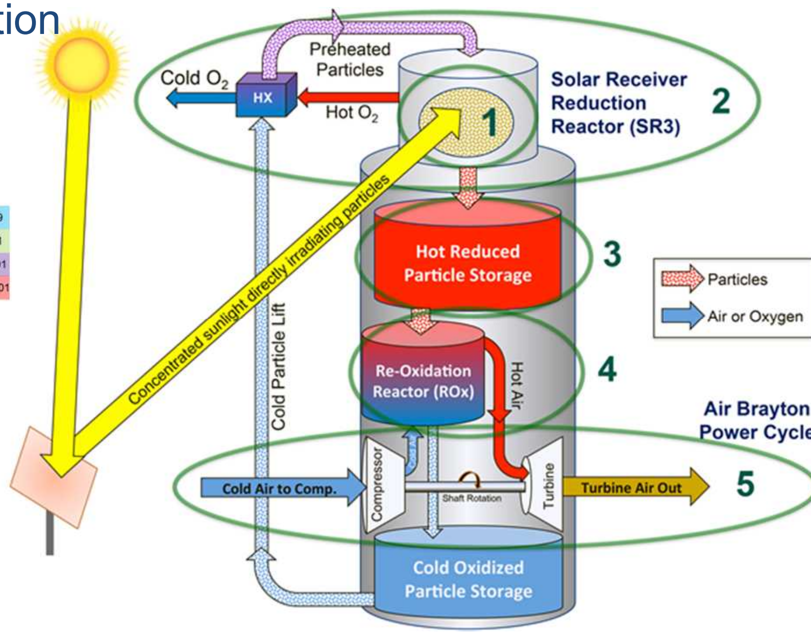
Credit: University of Florida

PROMOTES: High Performance Reduction/Oxidation Metal Oxides for Thermochemical Energy Storage

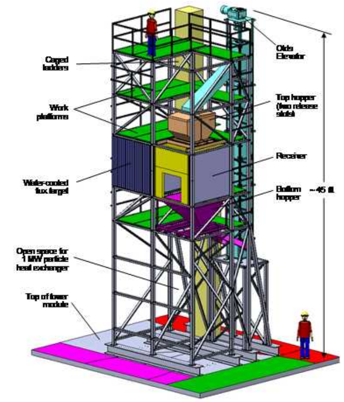
1. Materials Enabled Innovation (ΔH_{total} > 1200 kJ/kg)



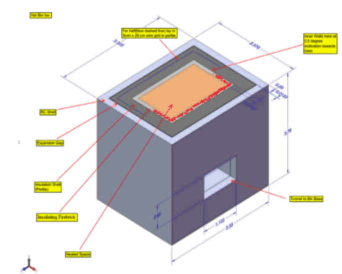
5. High Temp/High Efficiency Air Brayton Power Cycle.



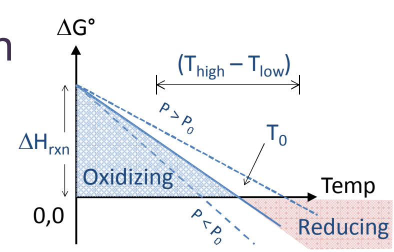
2. Falling Particle Receiver + Reactive Metal Oxides



3. Particle Storage at T > 1000 ° C



4. Pressurized oxidation reactor. Air acts as reactant and heat transfer fluid. Open cycle – no gas storage.



KEY PARTNERS: Sandia National Laboratories, Georgia Institute of Technology, King Saud University, Arizona State University

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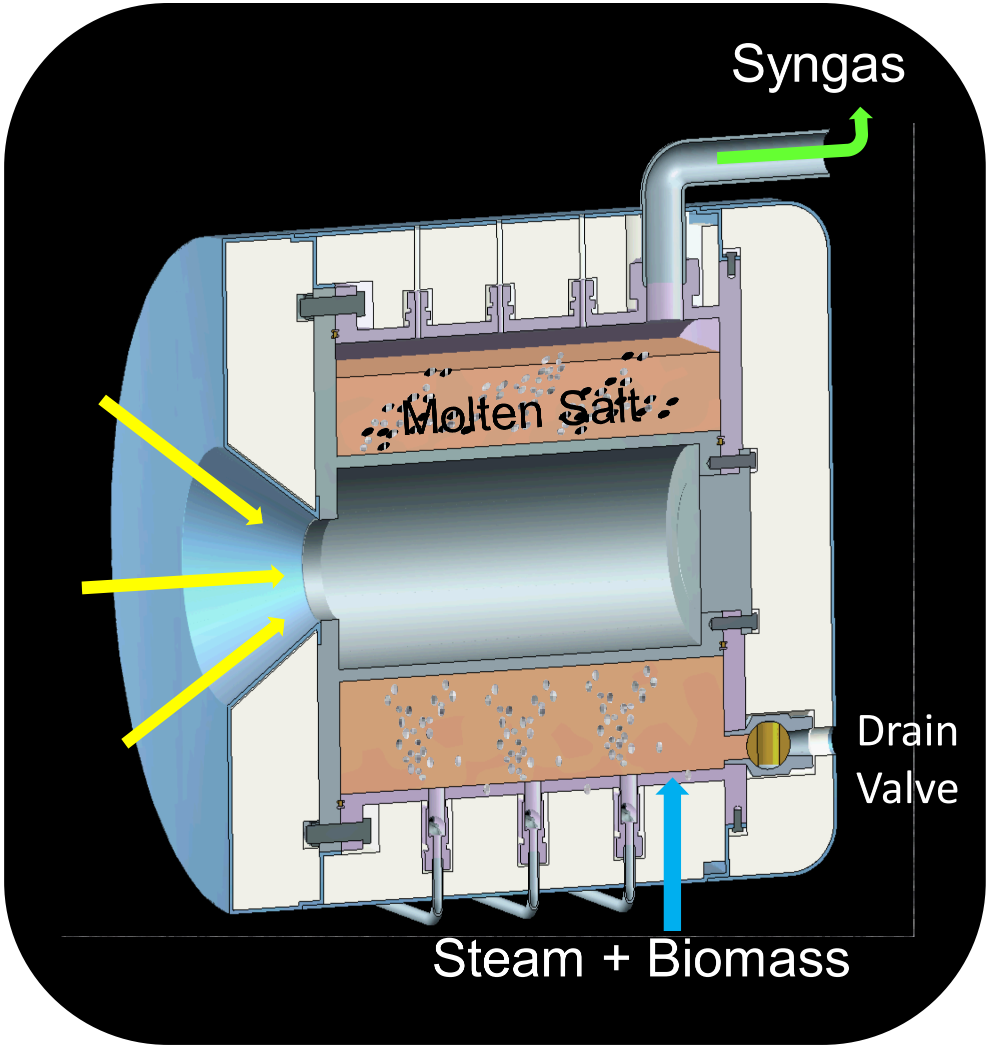
University of Minnesota Molten Salt Solar Gasifier



Carbonate Salts

Ternary eutectic blend of Li, K, and Na carbonates

$T_{melt} = 670\ K$

- Provides thermal storage to enable continuous operation during solar transients
- Provides excellent transfer of solar energy to the reaction site
- Catalyzes the gasification reactor producing a ten-fold increase in reaction rates
- Yields clean product gas – retains ash, tar and sulfur
- 4 kW prototype reactor has been successfully demonstrated in UMN's solar simulator.

Credit: UMN Solar Energy Laboratory, Jane Davidson group

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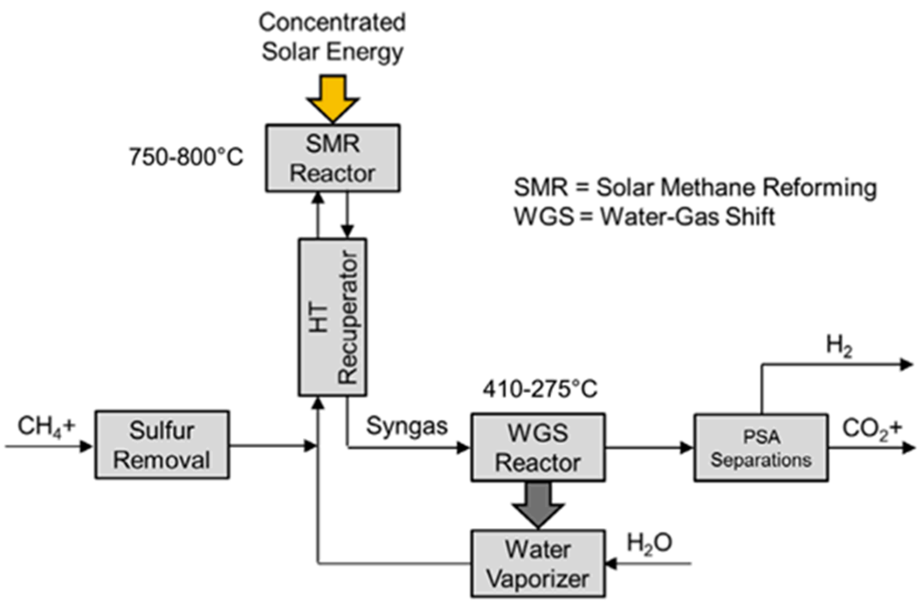
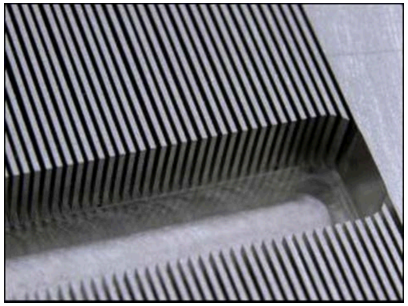
Solar Methane Steam Reforming: PNNL, SoCal Gas, Diver Solar, Infinia, OSU

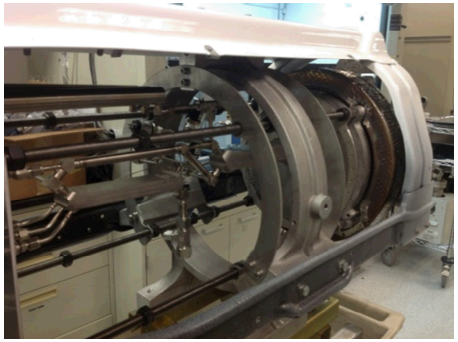


Net Reaction:

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$$



Key element: heat exchange in thin engineered channels



Credit: PNNL