

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

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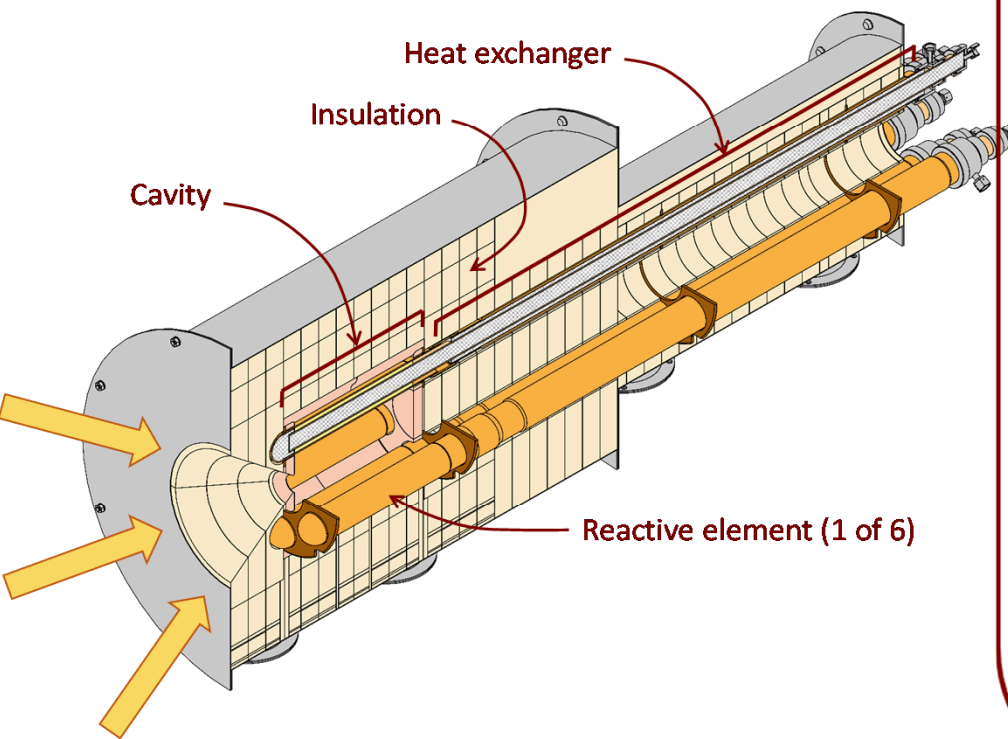
¹Sandia National Laboratories

²Bucknell University



University of Minnesota Ceria-based Solar Redox Reactors

Produces syngas by splitting H_2O and CO_2

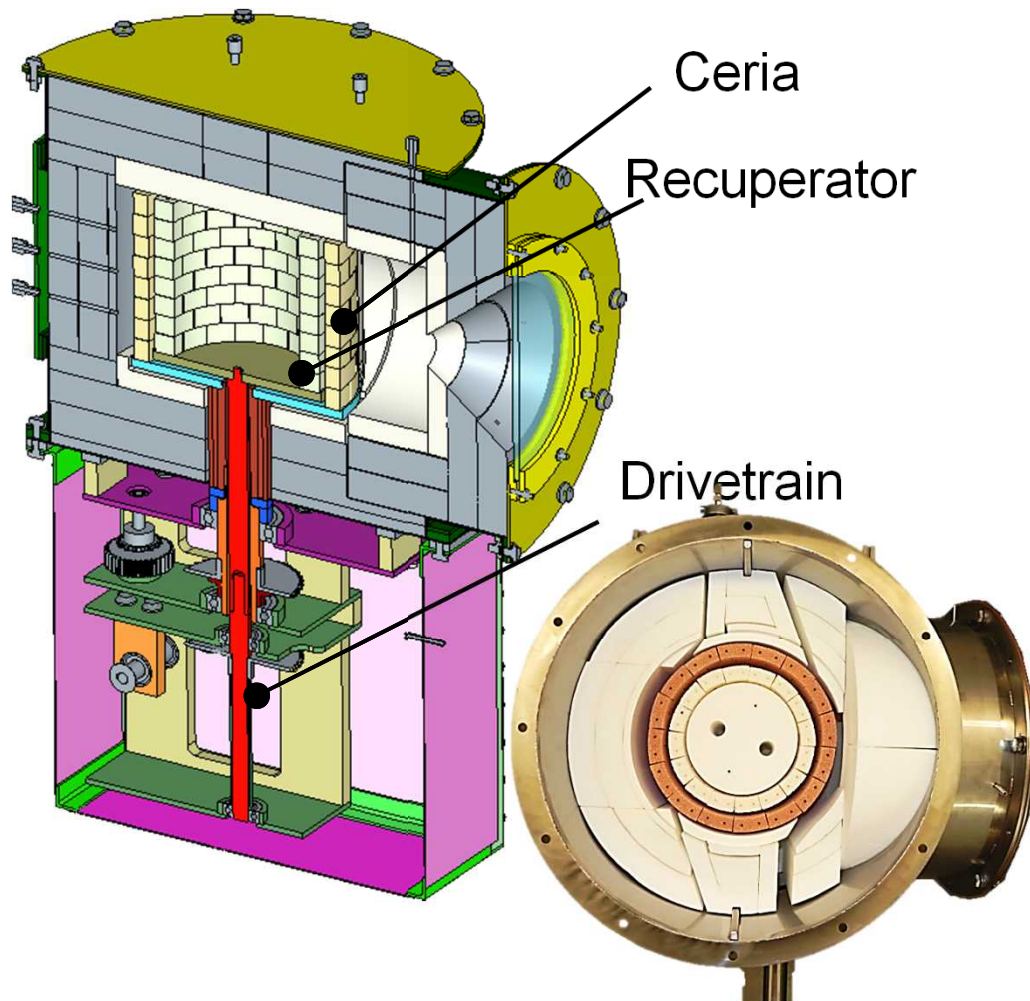


Isothermal Reactor

- 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

University of Minnesota Ceria-based Solar Redox Reactors

Produces syngas by splitting H_2O and CO_2



Temperature Swing

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

Integrated solid phase heat recovery system

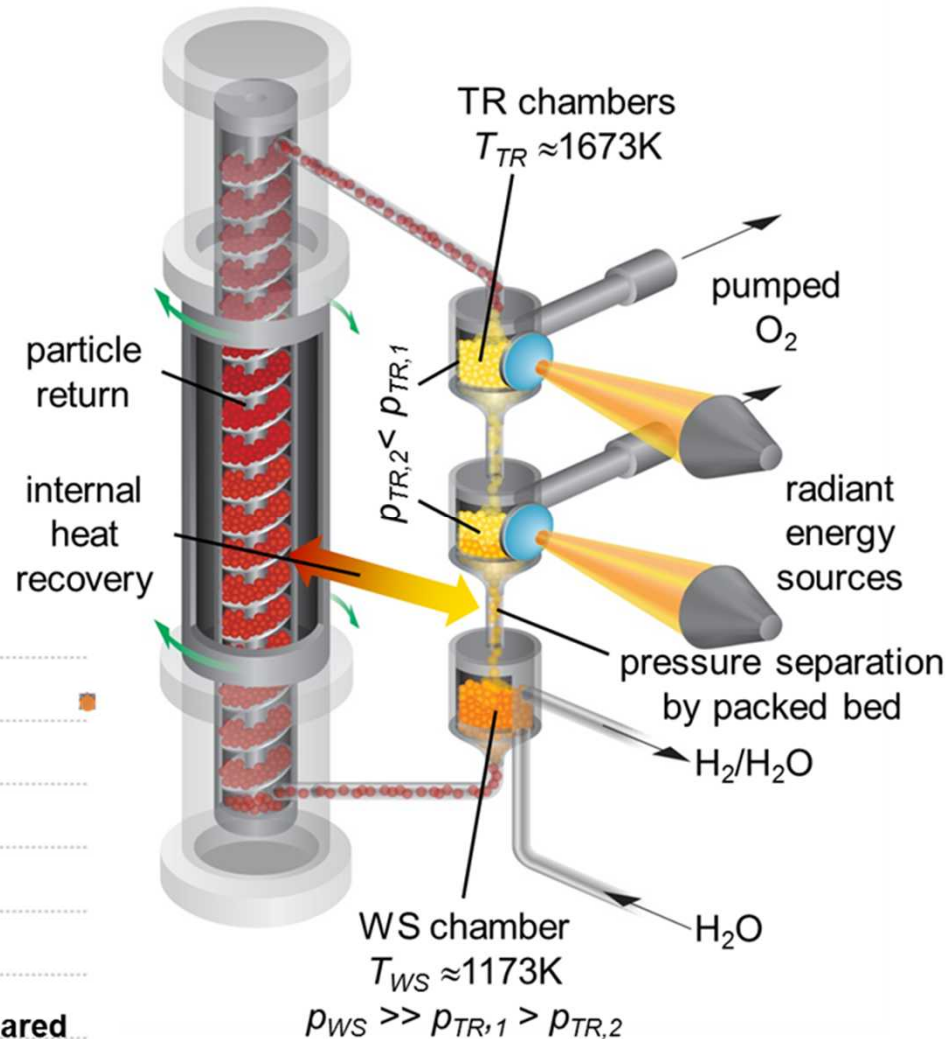
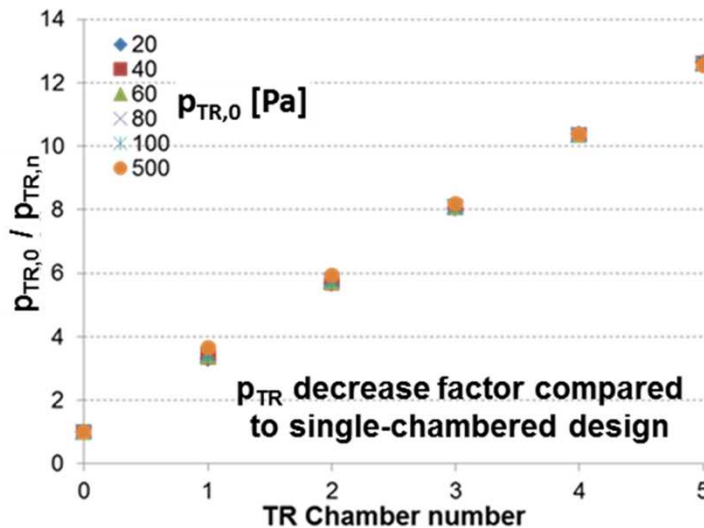
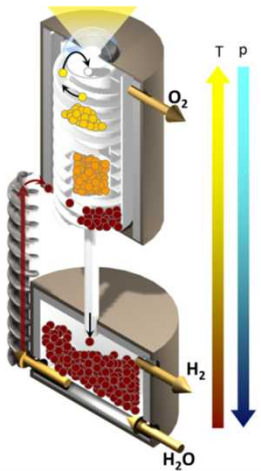
- Counter-rotating alumina cylinder designed to recuperate 50% of the sensible heat of the ceria as it cycles

Continuous on-sun fuel production

- In process of testing in UMN high flux simulator
- Tested up to 1400°C to-date

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/ vacuum pumping
- Non-monolithic, particulate oxide
- Reaction kinetics mutually decoupled
- Low thermal reduction pressure (0.1-10Pa)
- Decreased solid heat recovery requirement
- Decreased pump work requirement
- Compatibility with MW-scale plant



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

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

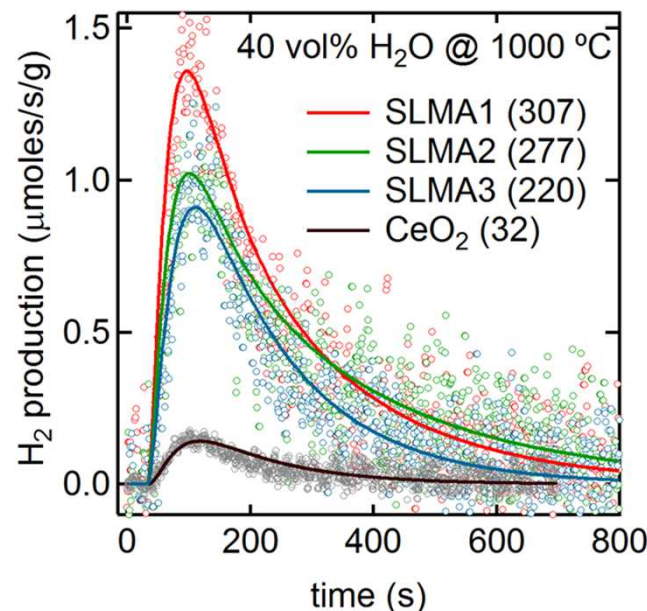
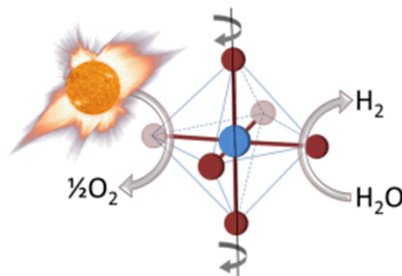
Anthony H. McDaniel,^{*a} Elizabeth C. Miller,^{‡ab} Darwin Arifin,^{Sa} Andrea Ambrosini,^b Eric N. Coker,^b Ryan O'Hayre,^c William C. Chueh^{¶a} and Jianhua Tong^{*c}

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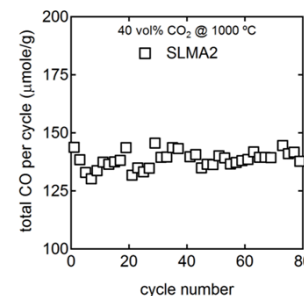
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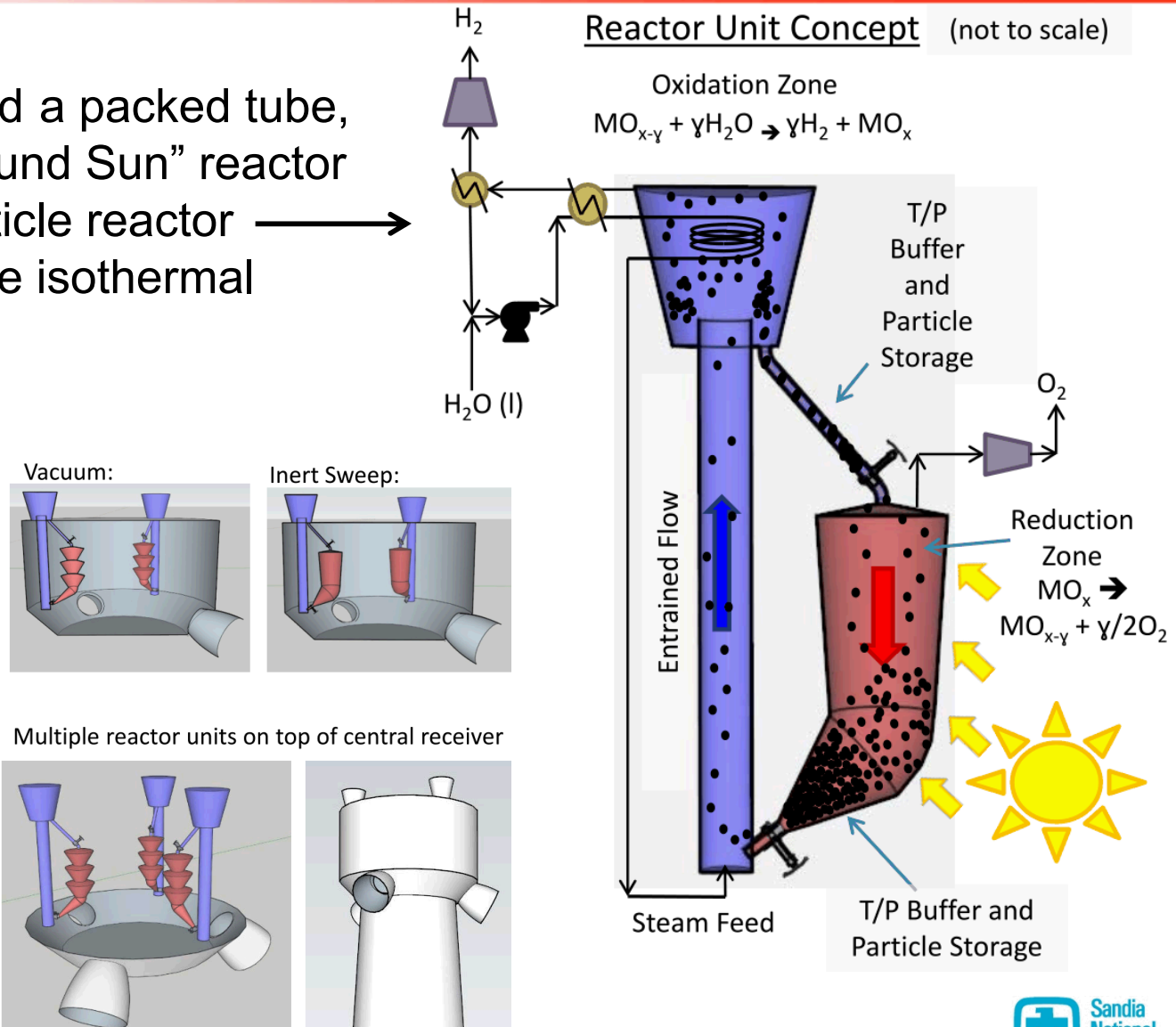


- Perovskite compounds split H_2O in a thermochemical cycle.
 - First of a kind observation, also demonstrated durability
- Kinetics benchmarked against CeO_2 .
 - Similarly fast oxidation rates
- Make $\sim 9\times$ more H_2 than CeO_2 at $T_{\text{TR}} = 1350\text{ }^\circ\text{C}$.



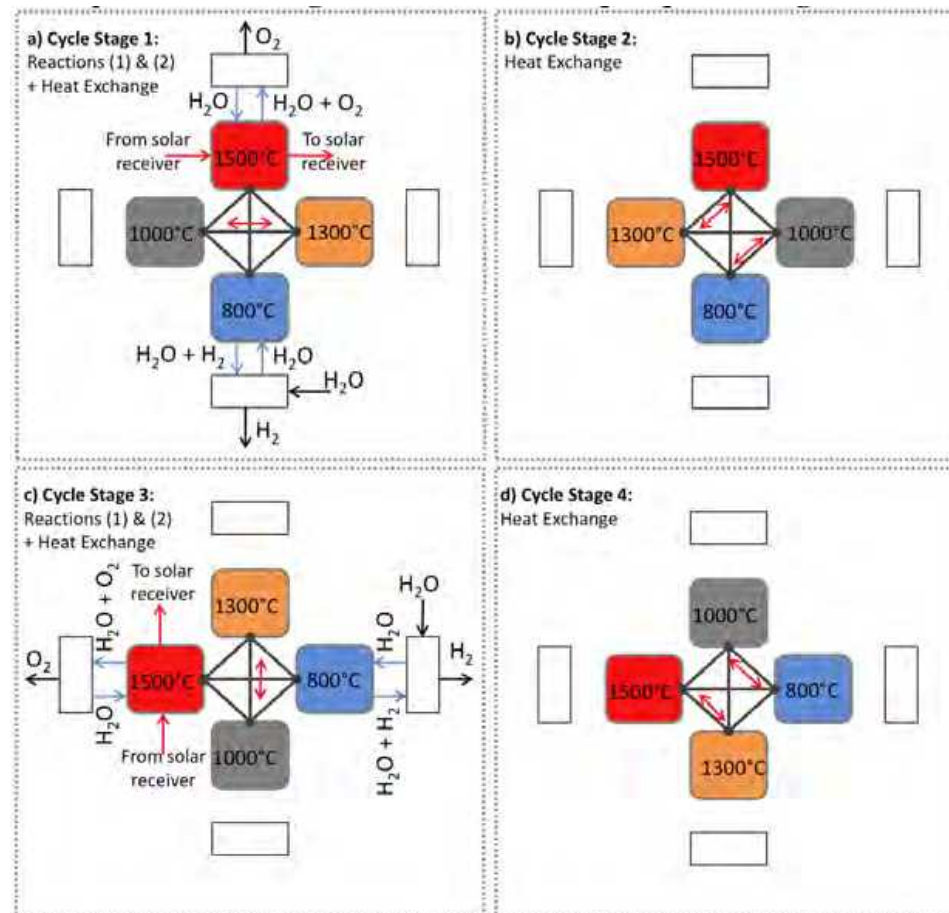
STCH: University of Colorado at Boulder, NREL

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



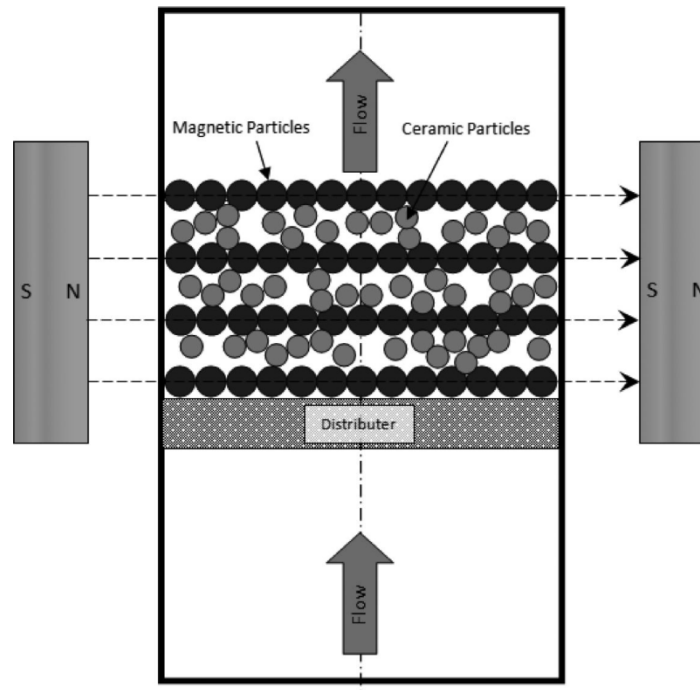
Georgia Tech (ARPA-E)

- 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.



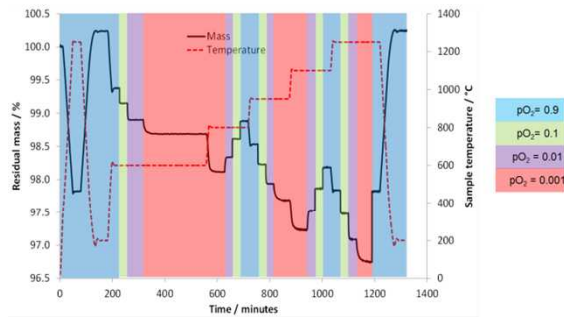
University Of Florida (ARPA-E)

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



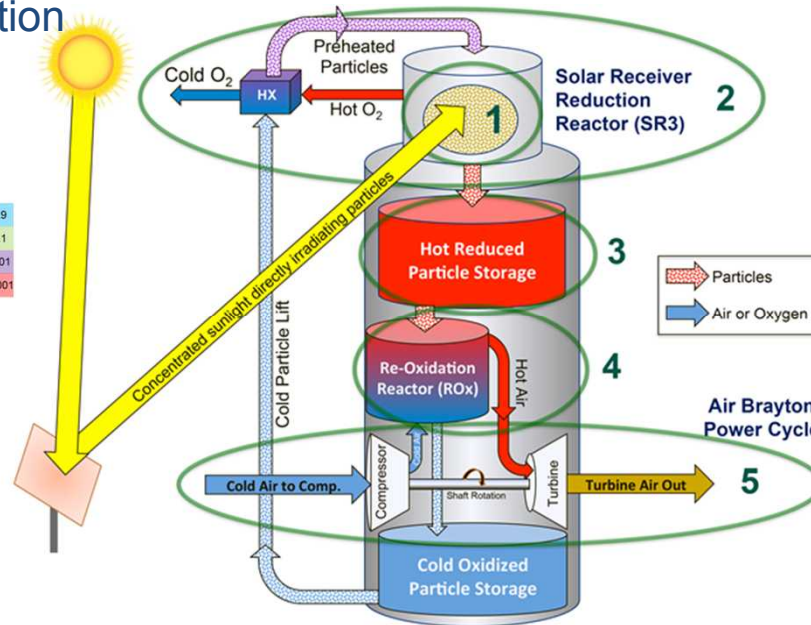
PROMOTES: High Performance Reduction/Oxidation Metal Oxides for Thermochemical Energy Storage

1. Materials Enabled Innovation ($\Delta H_{\text{total}} > 1200 \text{ kJ/kg}$)

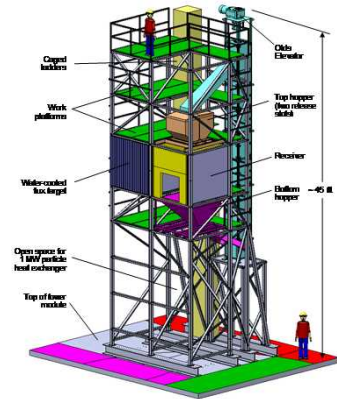


5. High Temp/High Efficiency Air Brayton Power Cycle.

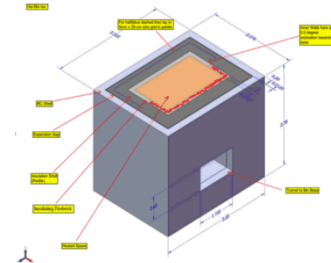
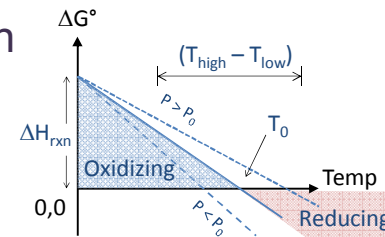
4. Pressurized oxidation reactor. Air acts as reactant and heat transfer fluid. Open cycle – no gas storage.



2. Falling Particle Receiver + Reactive Metal Oxides

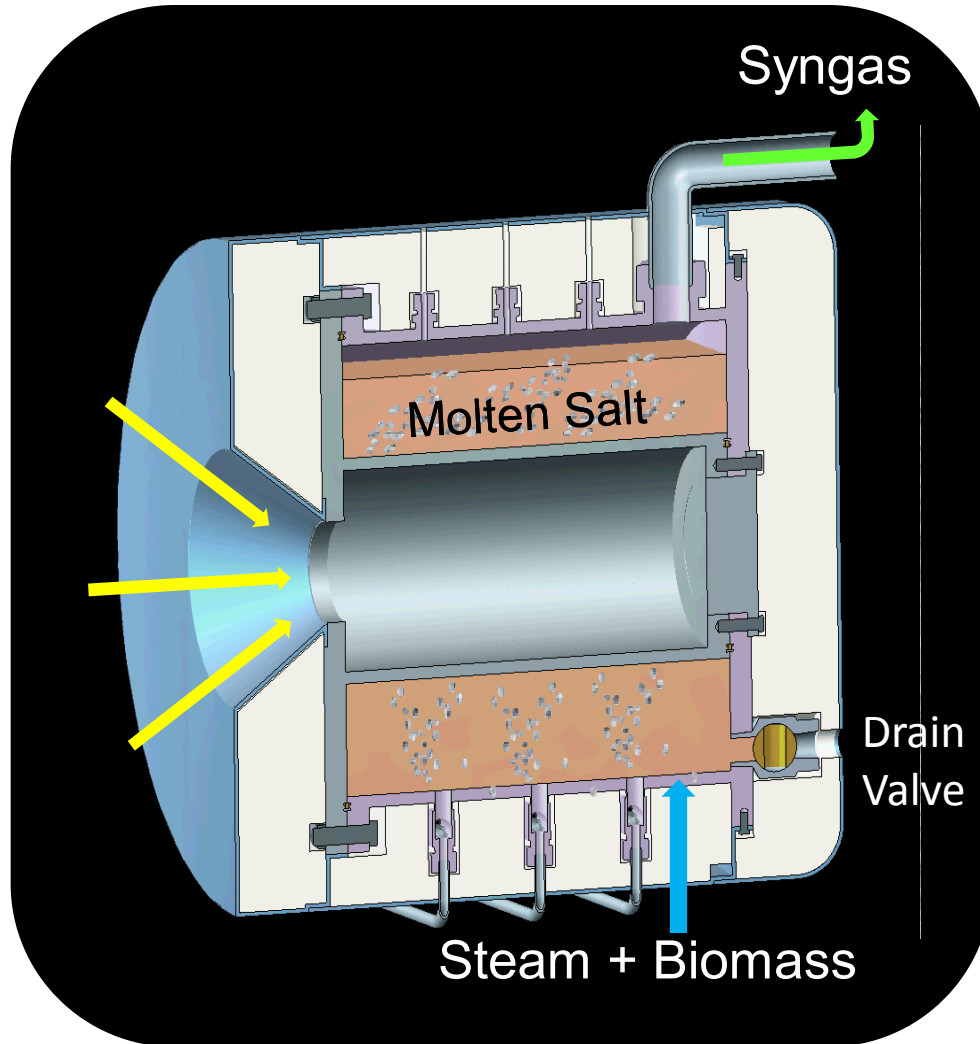


3. Particle Storage at $T > 1000^\circ \text{C}$



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

University of Minnesota Molten Salt Solar Gasifier



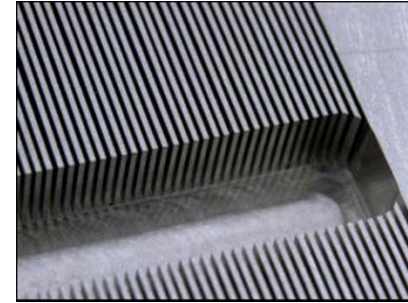
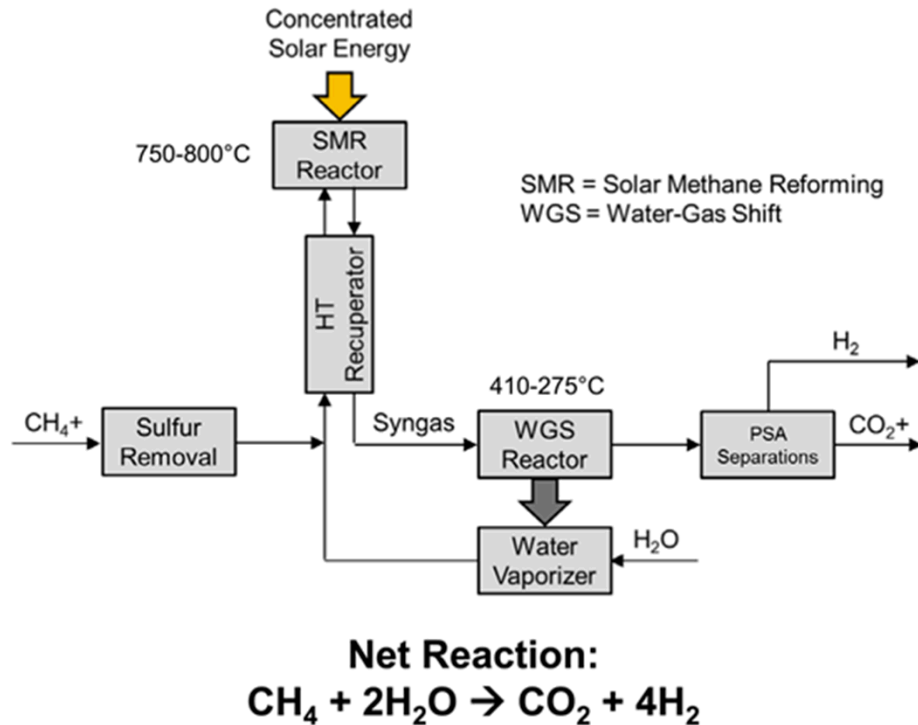
Carbonate Salts

Ternary eutectic blend of
Li, K, and Na carbonates

$$T_{\text{melt}} = 670 \text{ K}$$

- 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.

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



Key element: heat exchange in thin engineered channels

