2019 Future Energy Systems Technology Conference

Hilton Garden Inn - Troy, New York - 12180

10 April 2019

Taking the Duck out of Water

CSP Innovations for a Green Landscape

Shaun D. Sullivan, Class of '98
Principal Engineer,
R&D Program Manager
BraytonEnergy
sullivan@braytonenergy.com

Rensselaer Polytechnic Institute · 1824
Rensselaer
CFES Center for Future Energy Systems
New York State of Opportunity. Division of Science, Technology & Innovation

Outline

- Introduction to Brayton
- CSP Overview and its Global Market
- Energy Storage
    - The Duck Curve
    - The Promise/Heartbreak of Batteries
    - CSP with Storage: Emerging Tech
        - Thermal Energy Storage
        - Integration
        - Receivers
            - Solar Field Advancements
        - Heat Exchangers
        - Material Advancements
        - Thermal Flow Batteries
- Summary

Ivanpah Solar
Electric Generating System

BraytonEnergy

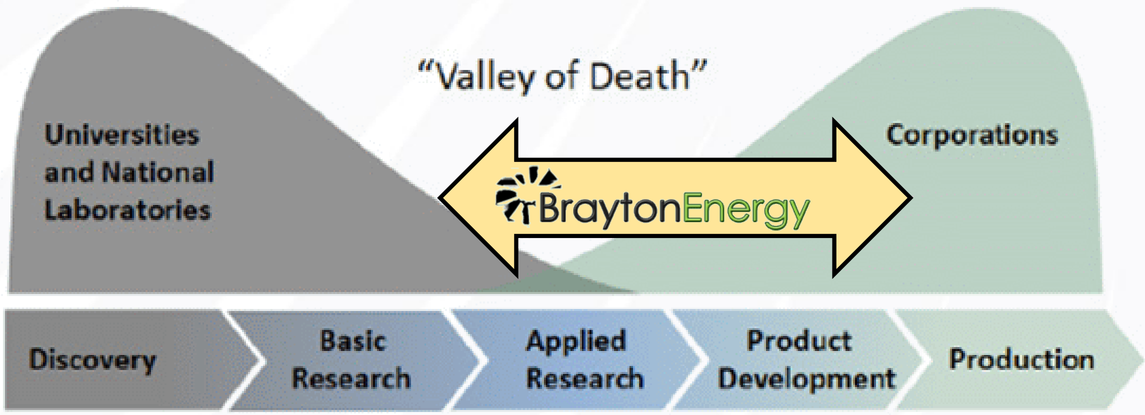
… an innovative R&D firm dedicated to making meaningful contributions in the field of environmentally responsible, sustainable energy production

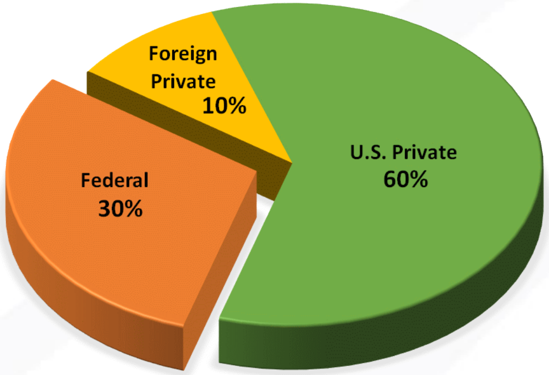
Turbomachinery
- Microturbines
- Dist. Generation
- Hybrid Vehicles
- UAV/Aero Engines
- Supercritical CO_2

Combustor Design
- Multi-Fuel
- Ultra Low Emissions

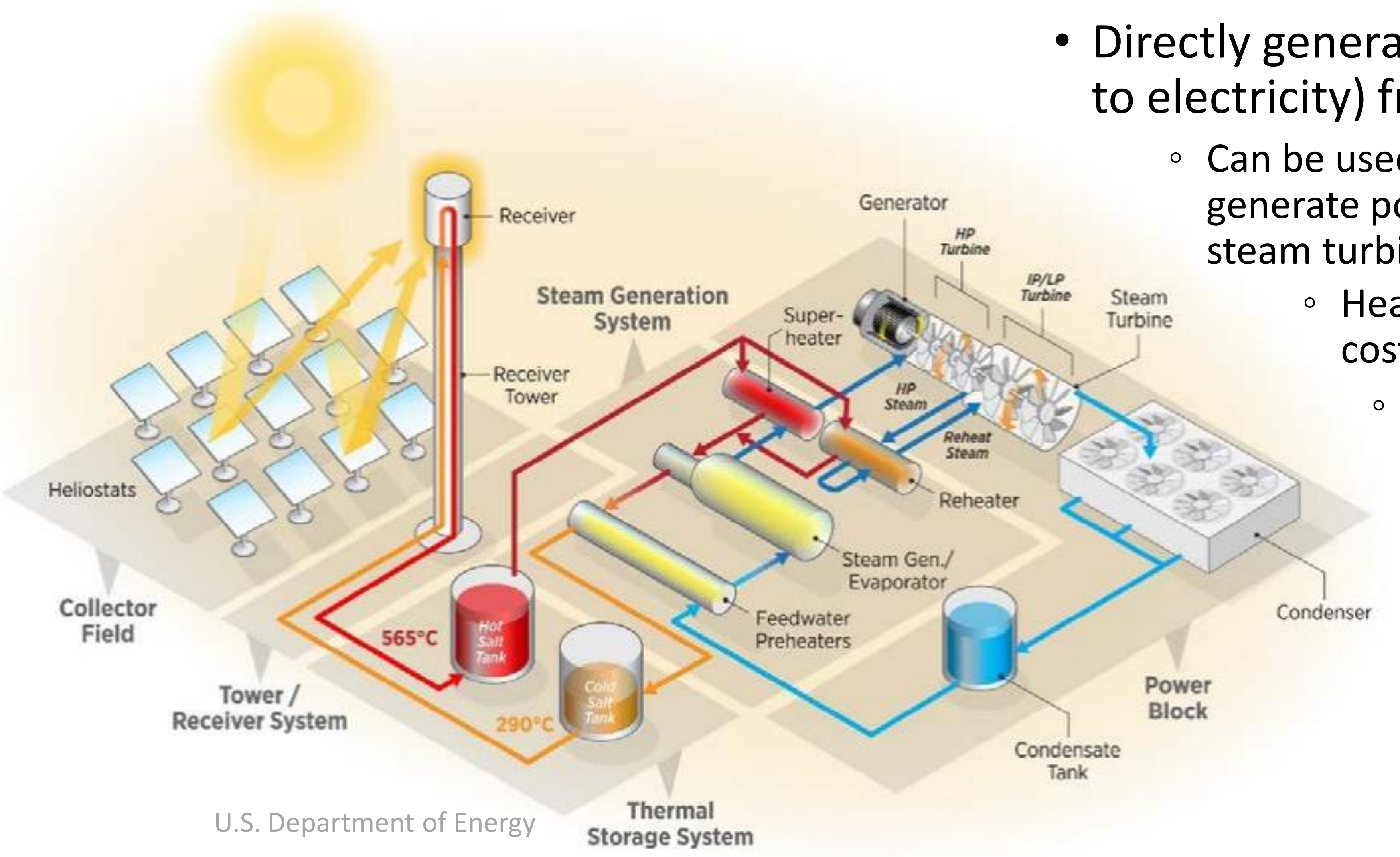
Compact Heat Exchangers
- Gas Turbine Recuperators
- Nuclear Applications
- High Performance
- High Temp., Press.

Renewables
- Concentrating Solar
- Energy Storage
- Biomass Utilization





Concentrating Solar Power (CSP)

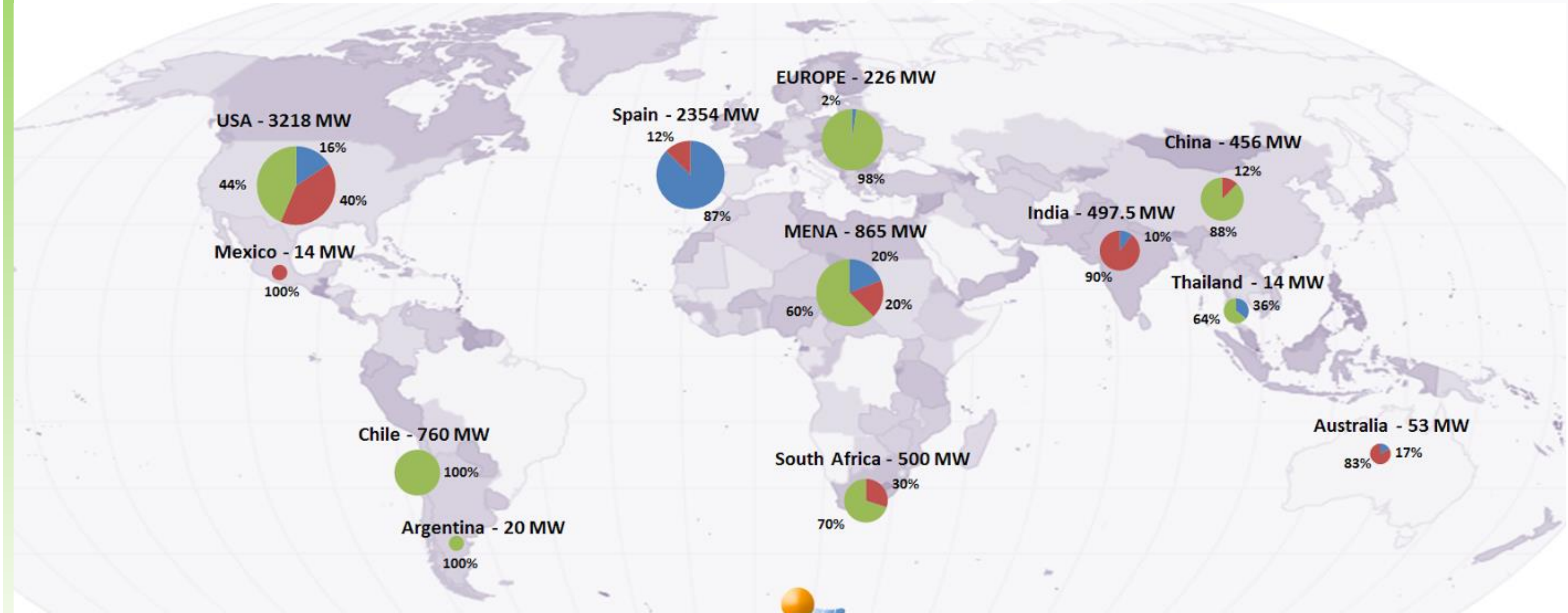


U.S. Department of Energy

- Directly generate heat (as opposed to electricity) from solar insolation
    - Can be used in place of fuel to generate power/electricity via e.g. steam turbines
        - Heat can be stored at low cost and with relative ease
            - Overall higher solar collection area-to-electric conversion efficiencies are possible
                - 25-30% overall
                    - 75% field efficiency
                    - 85% receiver efficiency
                    - 95% storage efficiency
                    - 40% cycle efficiency

BraytonEnergy

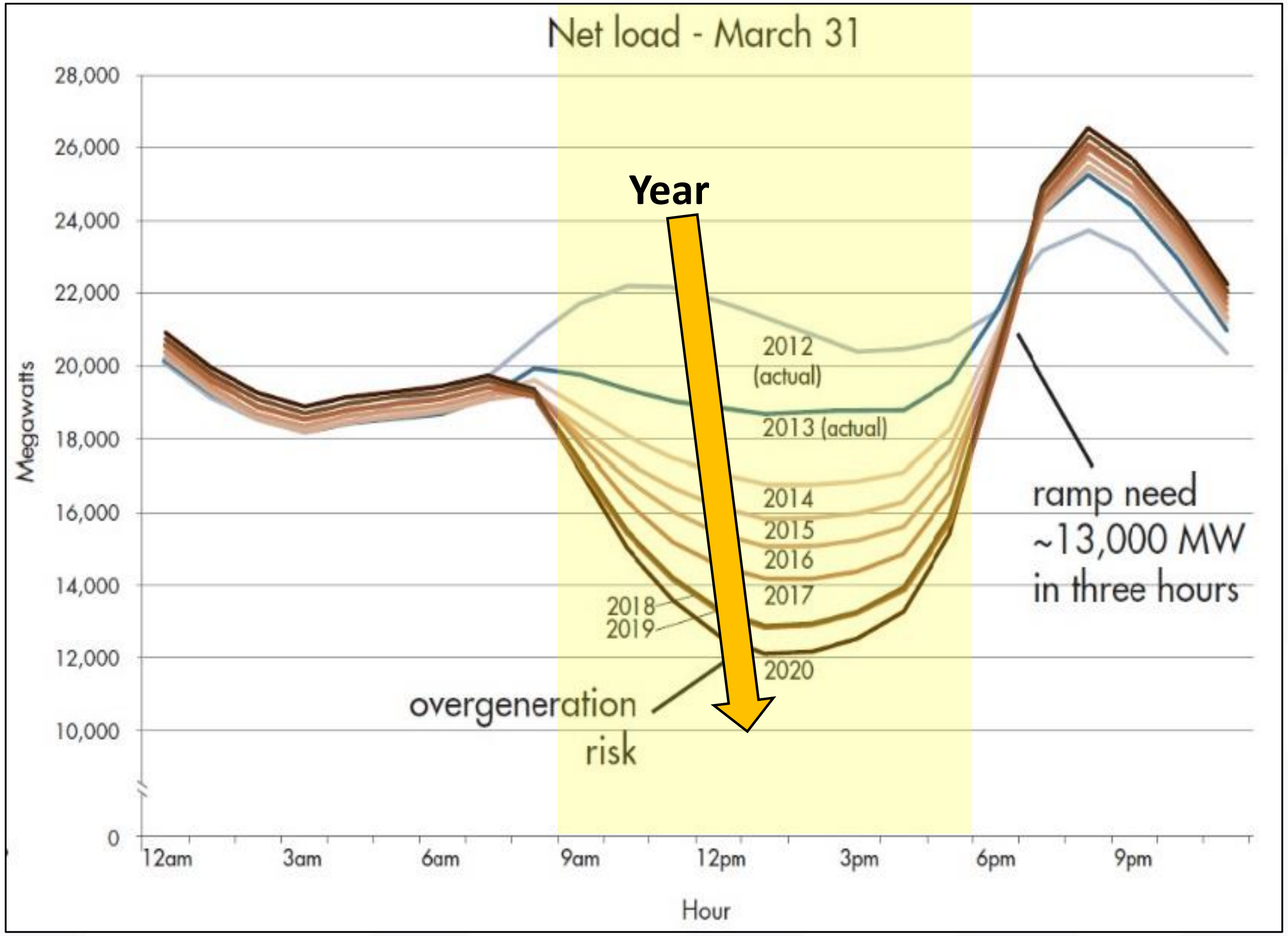
Global CSP Market (Currently 5 GW)



NREL
NATIONAL RENEWABLE ENERGY LABORATORY

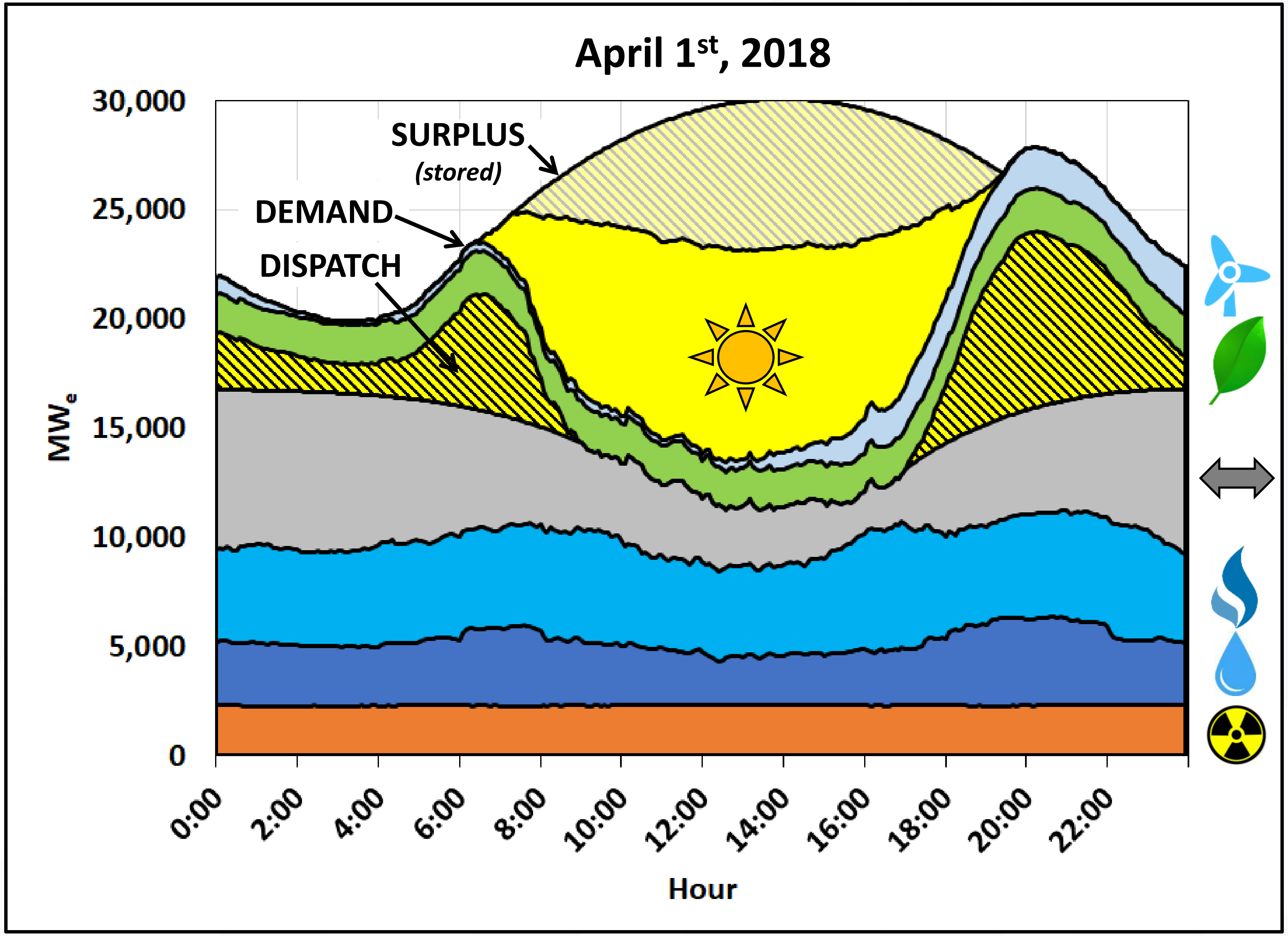
BraytonEnergy

The Duck Curve



- Graph shows the power demand *after* solar energy is provided
  - As more solar capacity comes online during the day, the power required by other source diminishes

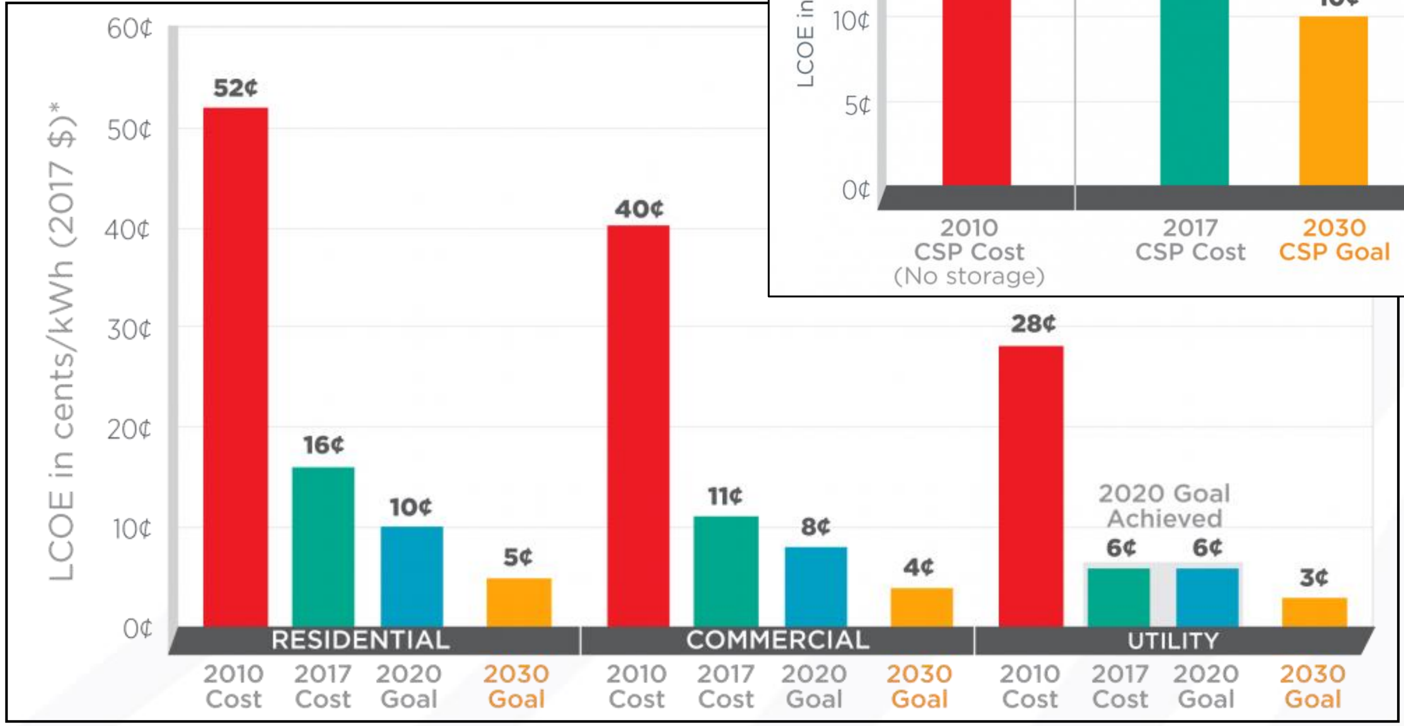
Supply and Demand



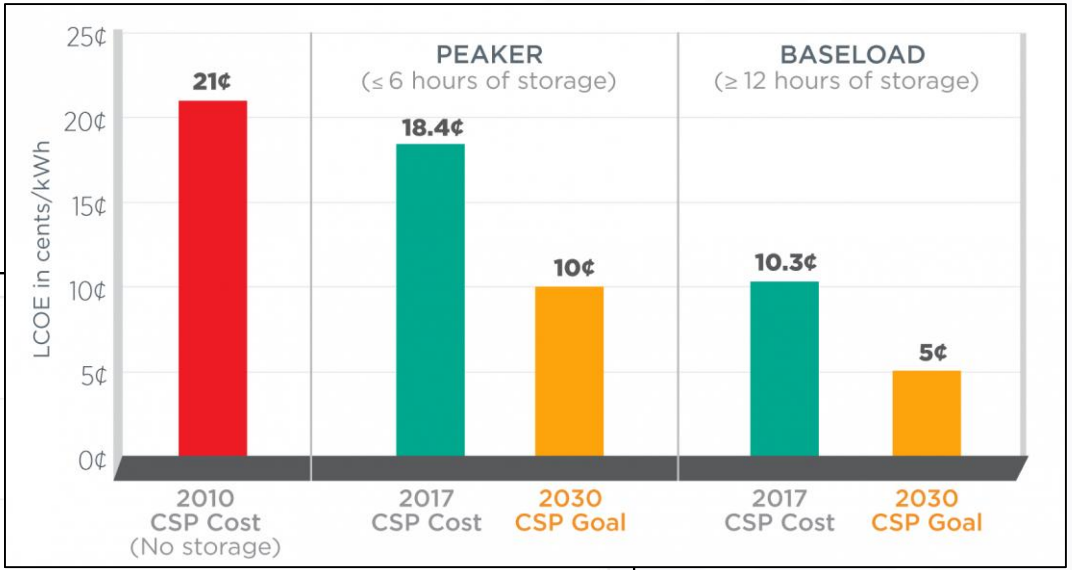
BraytonEnergy

Department of Energy SunShot LCOE Targets

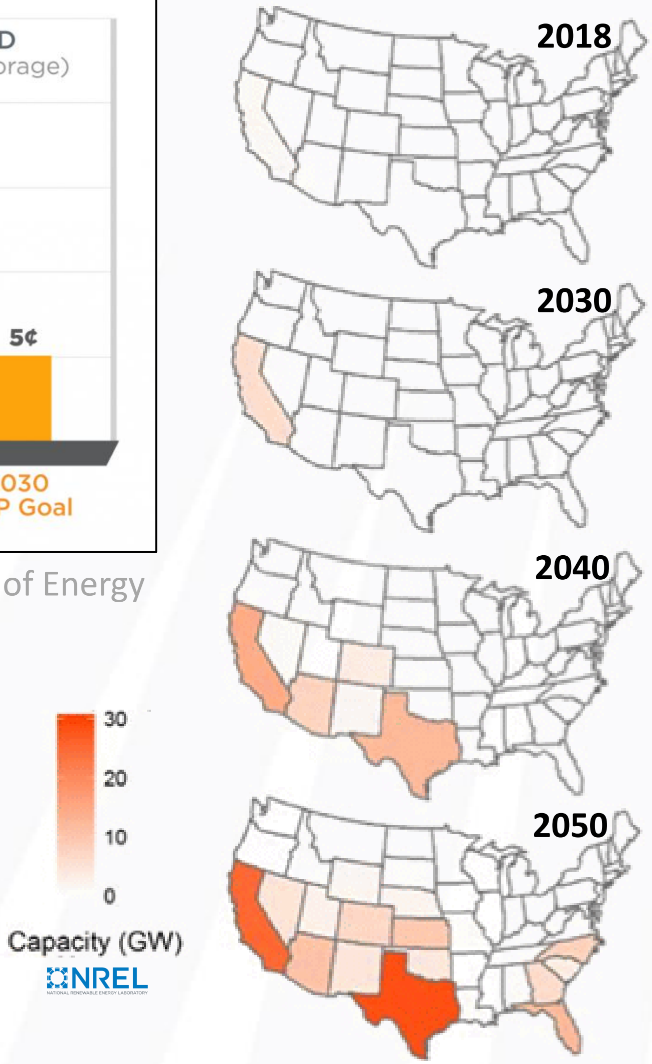
- PV (below): 3-4 ¢/kWh$_e$
- CSP (right): 5-10 ¢/kWh$_e$ …
  - *… w/ 4-6 hours of storage*



*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. The residential and commercial goals have been adjusted for inflation from 2010–17.



U.S. Department of Energy



The Promise and Heartbreak of Batteries

- Current prices range from \$380 (for 4 hours) to \$900 (for 0.5 hours) per kWh_e
  - Extrapolations indicate 2030 prices in the \$120-150 per kWh_e range
- Uncertain extended storage (>2-4 hours) solutions
- Heavy metals
- Limited life (7 years?)

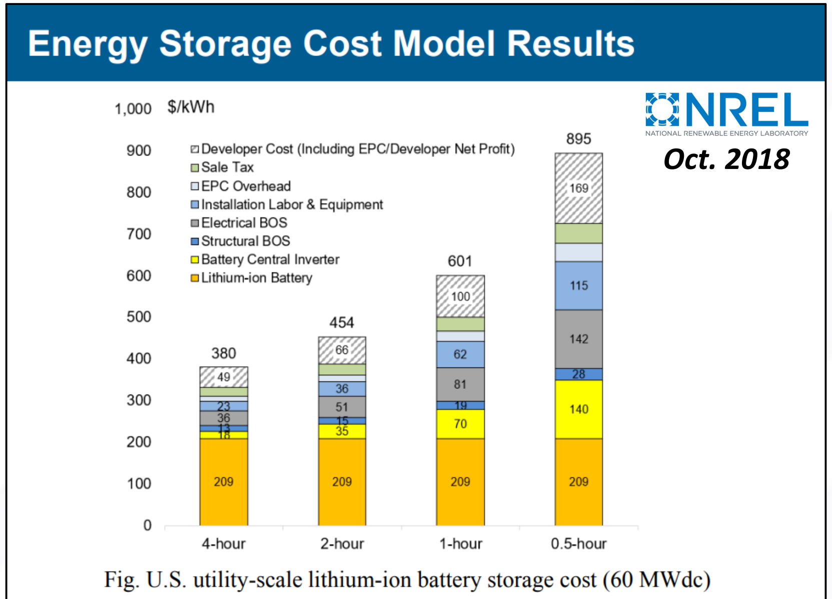
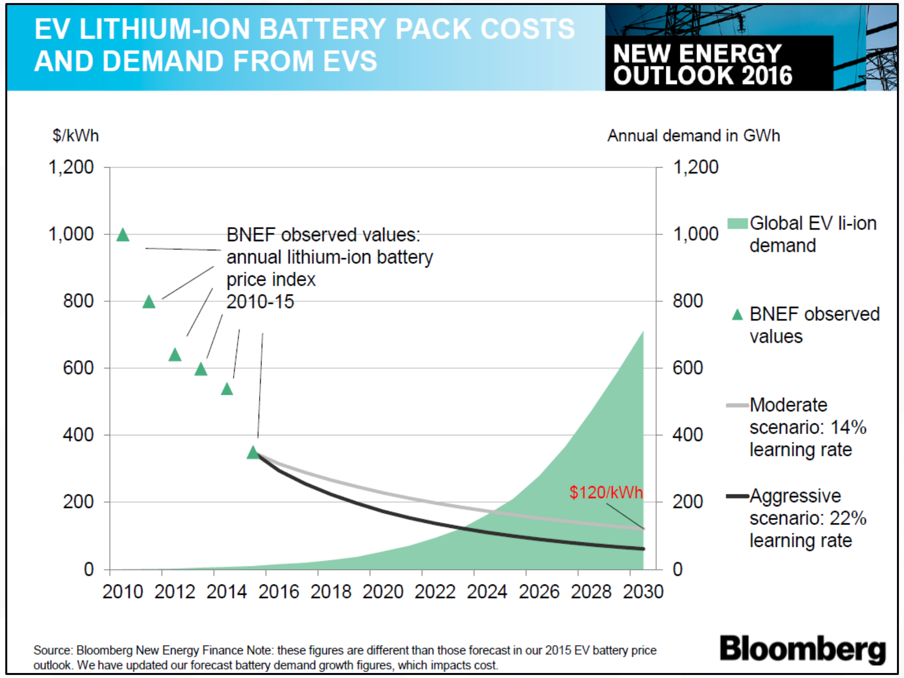


Fig. U.S. utility-scale lithium-ion battery storage cost (60 MWdc)

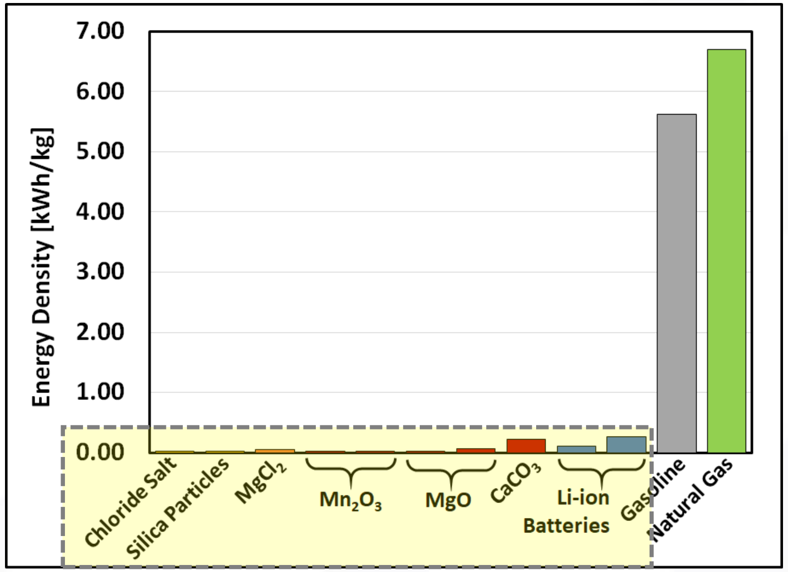
Energy storage cost (\$/kWh) = battery cost (\$/kWh) + other cost components (\$) ÷ storage system size (kW) ÷ duration (hours).

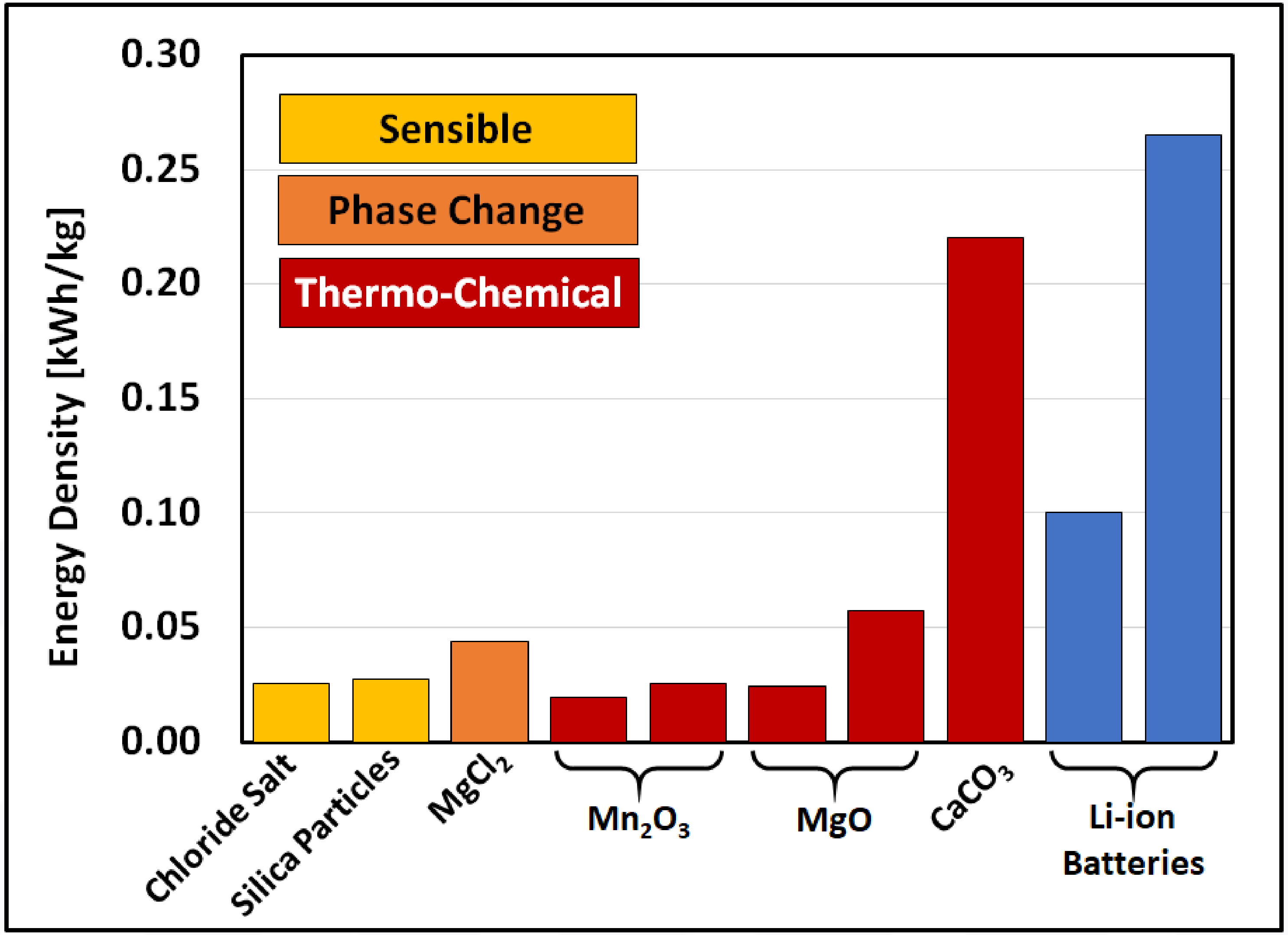


- *Current targets for thermal energy storage are \$33 to \$63 per* kWh_e
  - The value in CSP – up to 15 GW/year by 2030 – is in its potential for inexpensive energy storage and dispatch

Energy Storage Capacity

For storage conditions corresponding to the nominal 10-MW_e DoE-funded Supercritical Transformational Engine Program (STEP)





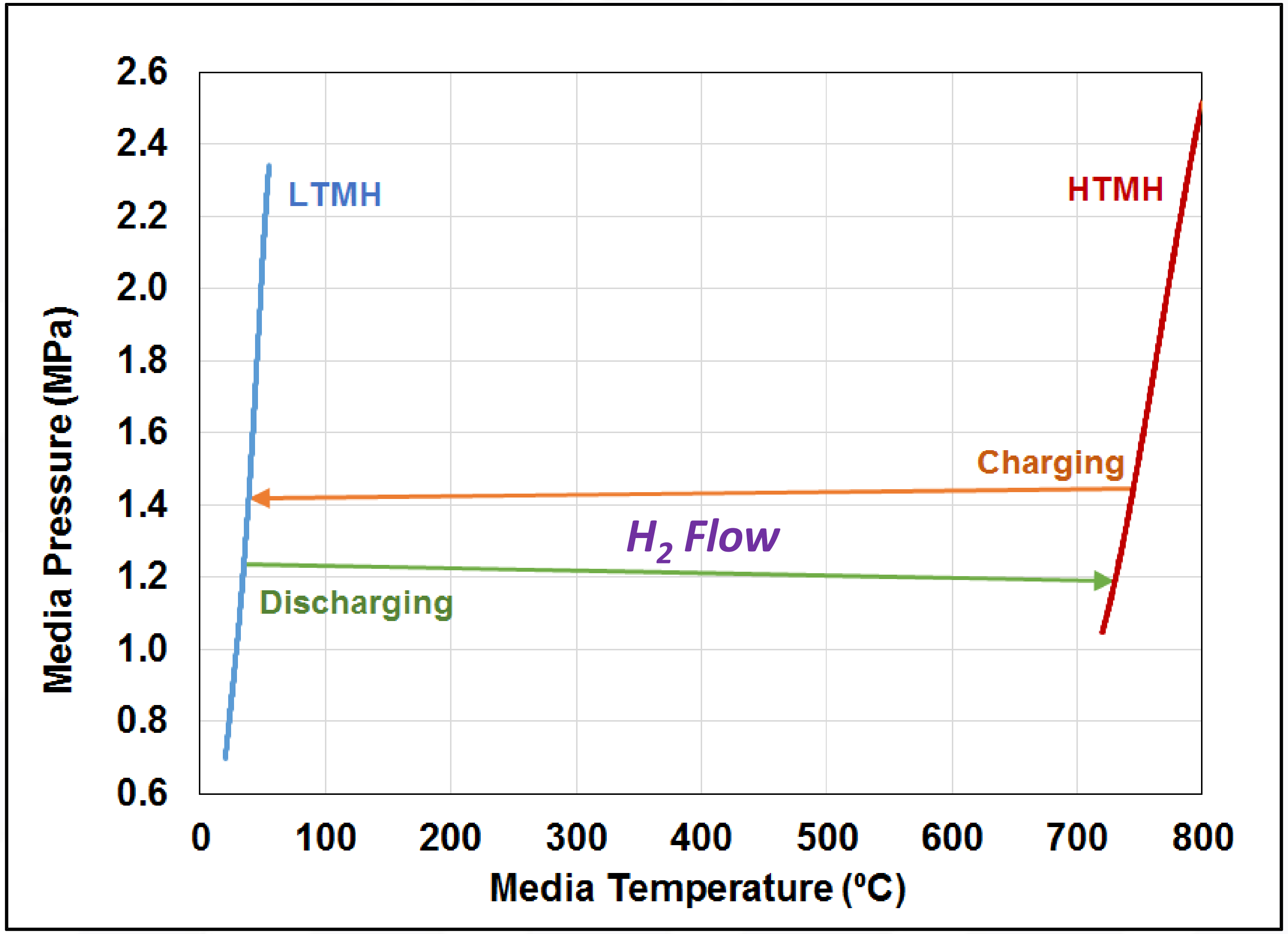
BraytonEnergy

BraytonEnergy Energy Storage Programs

CONFIGURATION	TROUGH	DISH	TOWER		
STORAGE \ CYCLE	**Steam**	**Air**	**Steam**	**Air**	**sCO_2**
None		*DoE Solar America*		*Commercial Partnership*	*DoE SunShot*
Compressed Air		*DoE Solar America*			
Molten Salt	*DoE SunShot*		*Commercial Partnership*	*Commercial Partnership**	
Solid Particle				*DoE Gen3 Topic 1*	*DoE Gen3 Topic 1*
Phase Change					*DoE Gen3 Topic 2*
Thermo-Chemical					*DoE APOLLO*

Thermochemical Energy Storage: Metal Hydrides

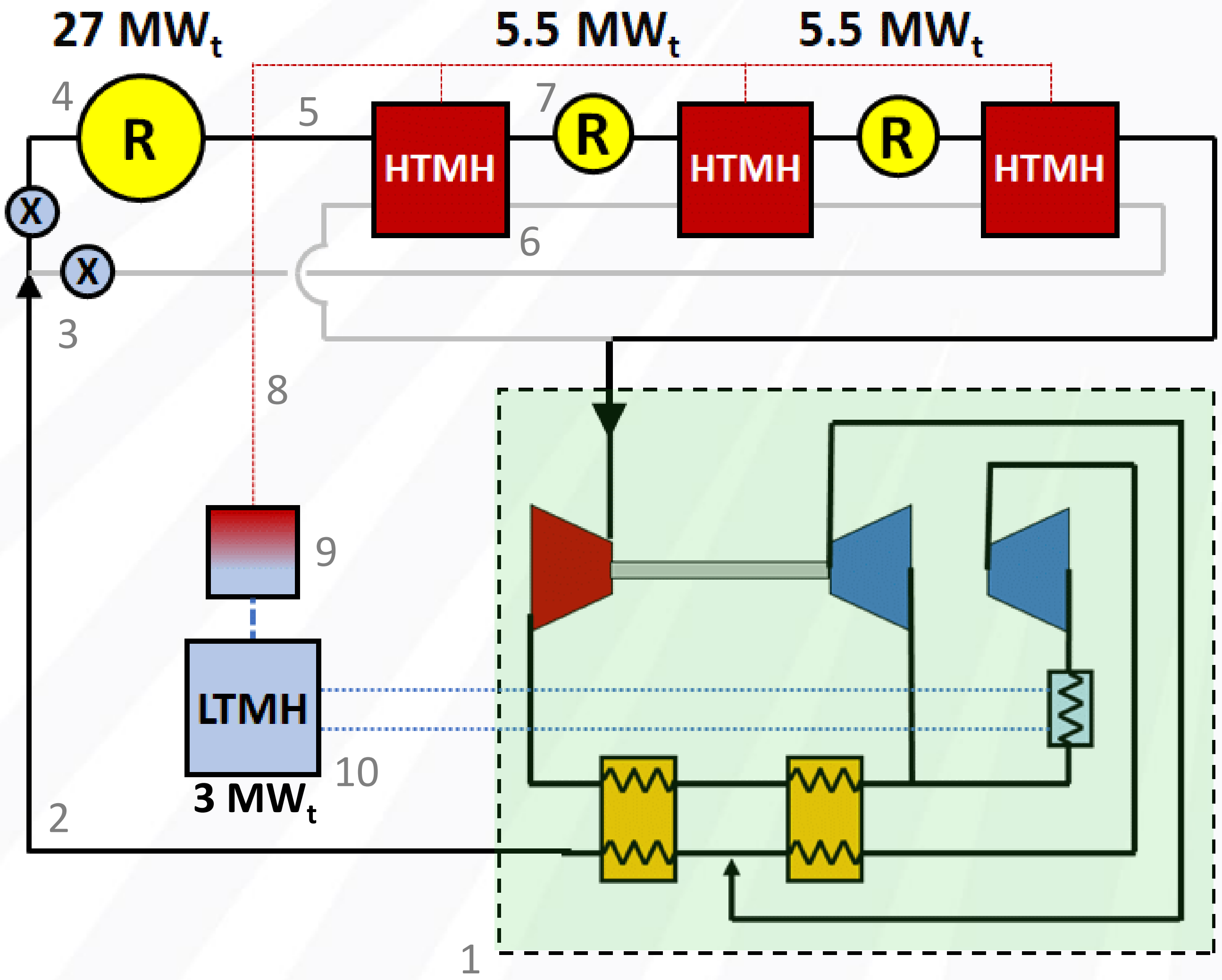
- A well-chosen pairing of metal hydrides will enable the free flow of H_2 between the two media at the desired temperatures.
- Connecting pipes must be sized for the appropriate pressure drop to maintain intended operating temps.



BraytonEnergy

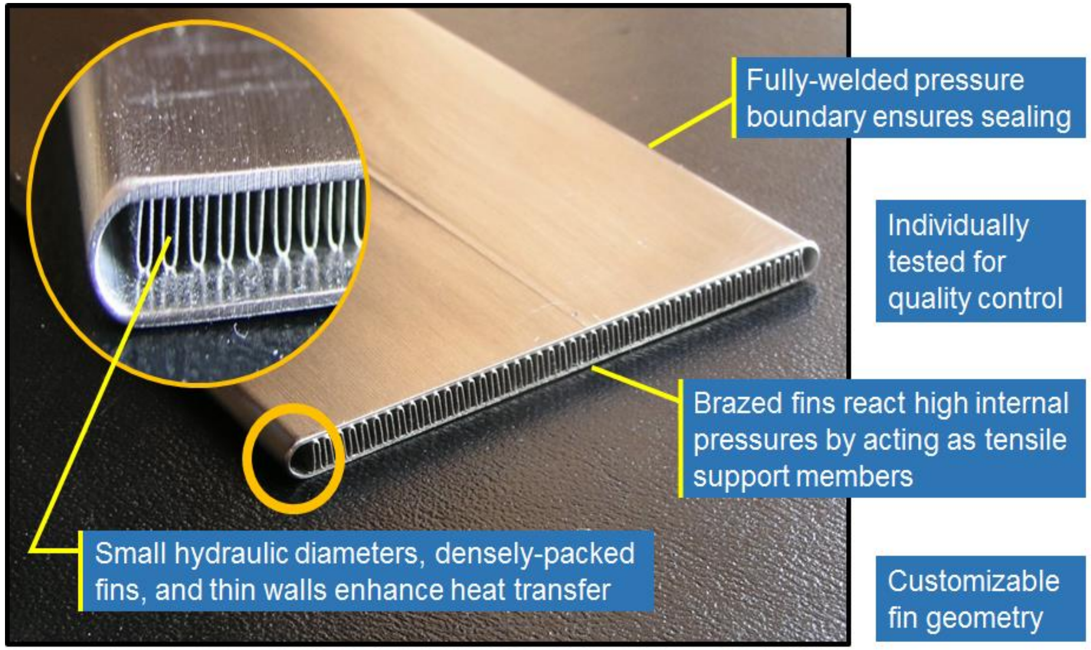
Integrated System Layout

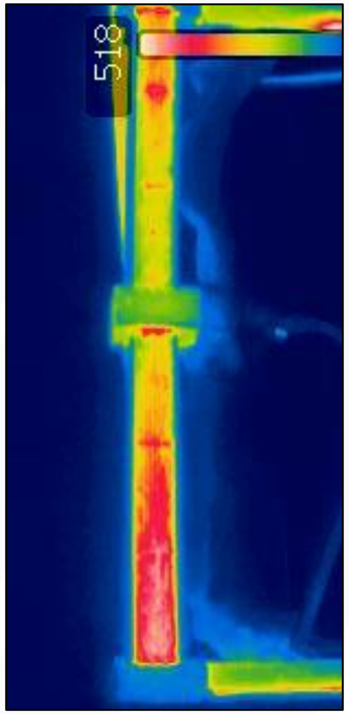
1. RCBC sCO_2 power block
   - *nominally the STEP engine*
2. Low temp. (~ 570 °C) piping
3. Low temp. (~ 570 °C) valves (x2)
4. 27.0 MW_t open receiver
5. High Temp (~ 760 °C) piping
6. 5.5 MW_t HTMH TES HEX (x3)
7. 5.5 MWt cavity receiver (x2)
8. Hydrogen (~720 °C) transport pipe
9. Regenerator
10. ~ 3 MW_t LTMH TES HEX

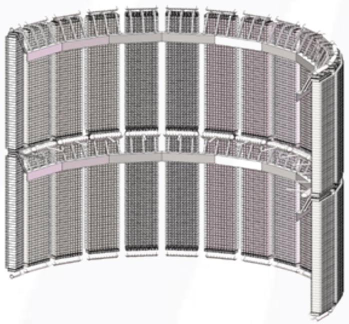


BraytonEnergy

Receivers for sCO_2 (750 ºC, 25 MPa)



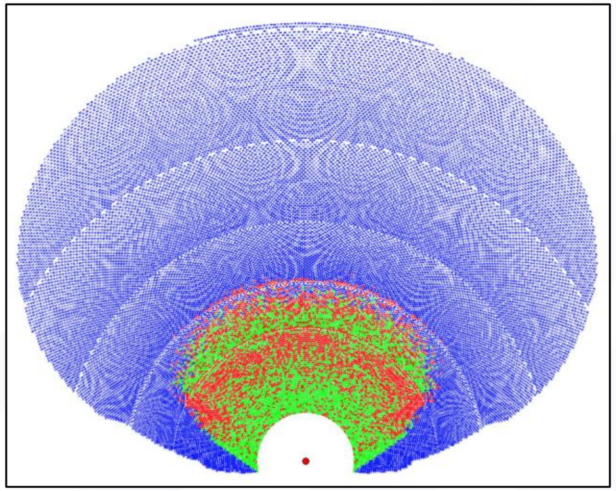




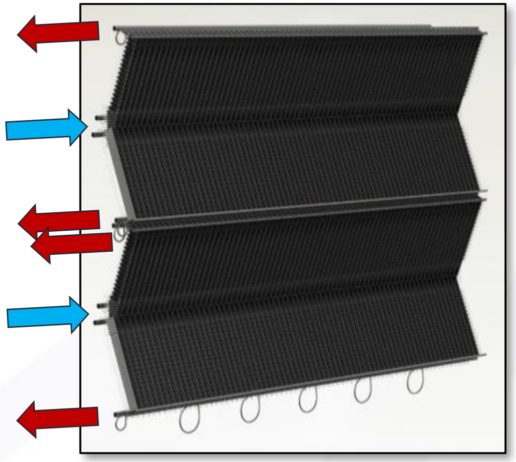
Crescent Dunes Molten Salt Solar

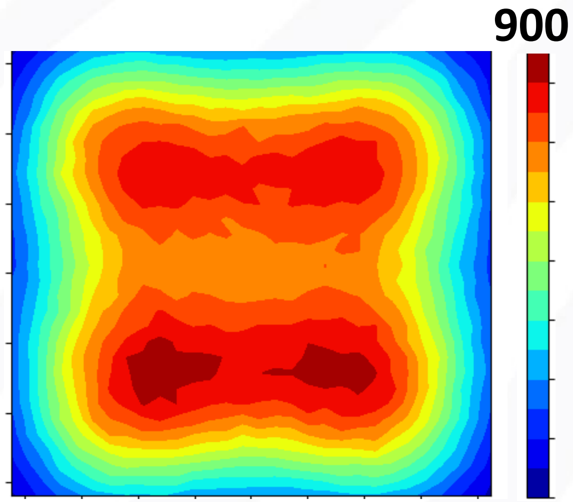
Multiple-Aimpoint + Flux Control

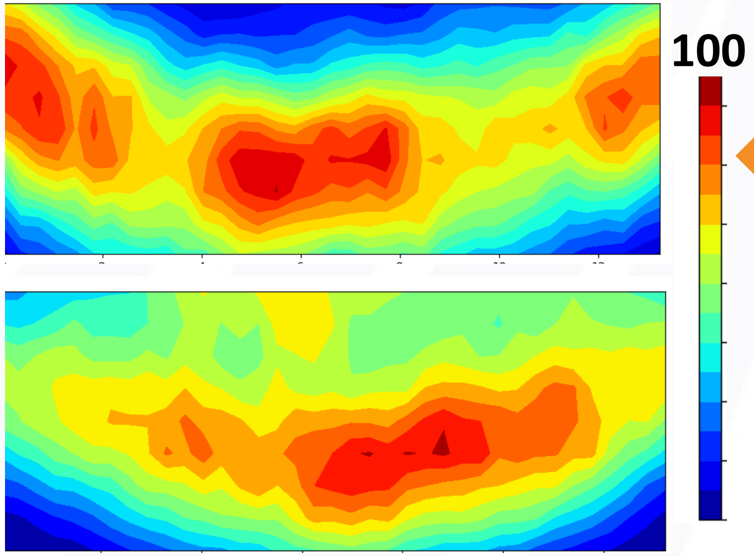
Program leverages Gen3 advancements in heliostat control to expand system capabilities



- Multi-receiver targeting
  - Closest heliostats are allocated to cavity receivers
    - *Reduced spillage*
    - *Small apertures*



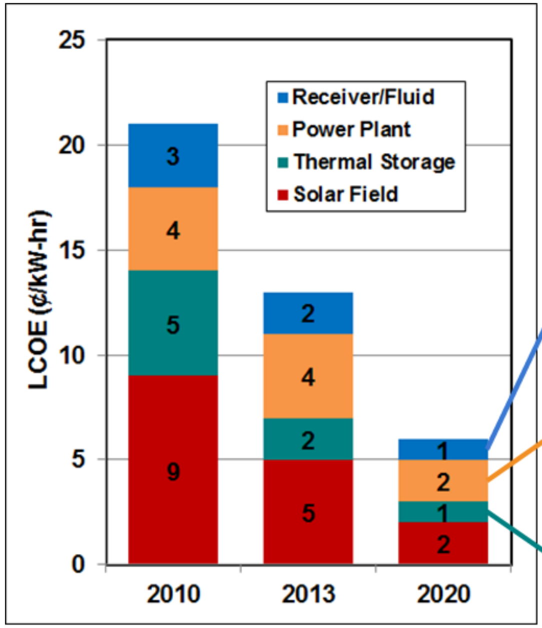




- Flux Profiling
  - Aligns peak fluxes in open receiver with coldest fluid

BraytonEnergy

sCO_2 Heat Exchangers

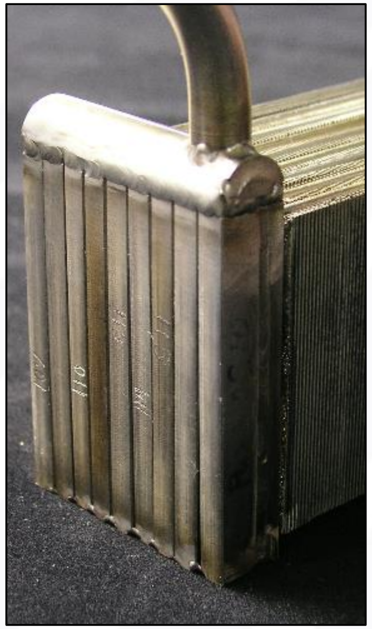


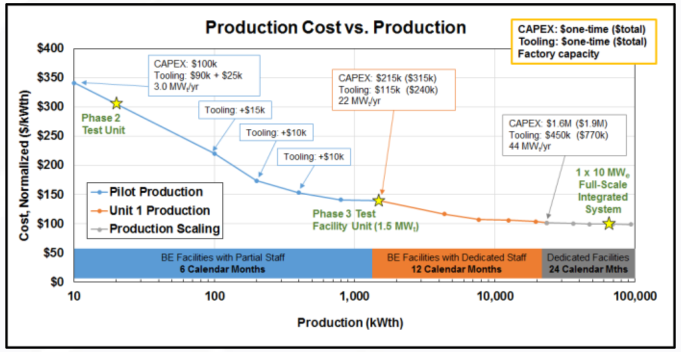
- Broad application across emerging sCO_2 systems

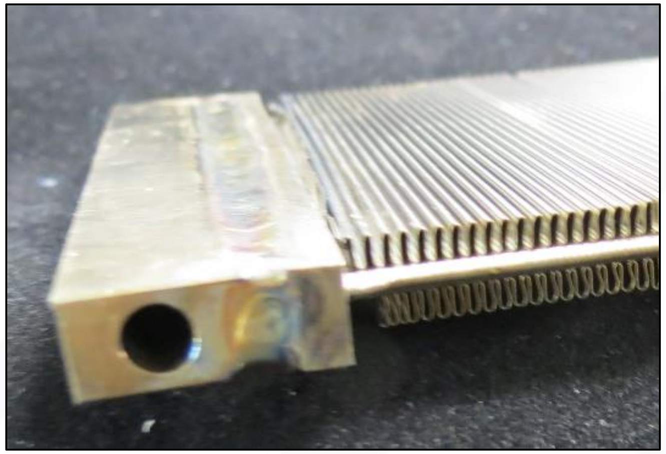
Low-cost modular panel solar receivers for high-efficiency engine configurations

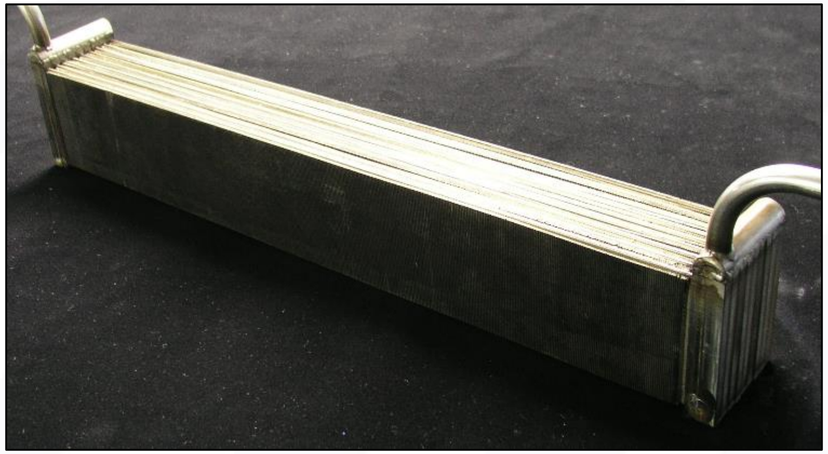
Low-cost compact high-temperature heat exchangers and recuperators for high-efficiency power cycles

Low-cost compact high-temperature working fluid (sCO_2) to molten salt heat exchangers







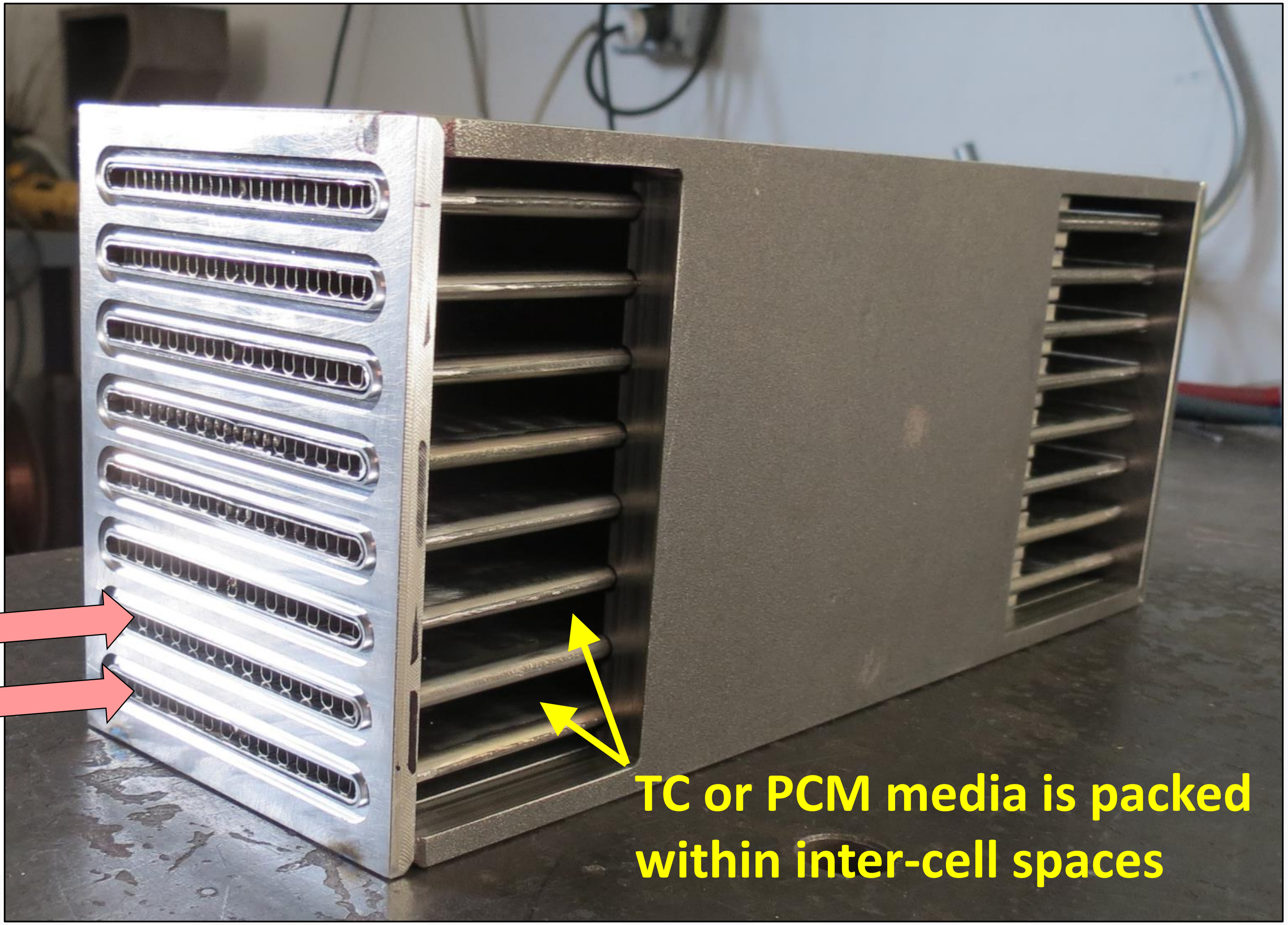


BraytonEnergy

Energy Storage Heat Exchangers

- Enables efficiency usage of all TES media
  - High-effectiveness design provides large heat transfer area
  - Promotes linear temperature gradients

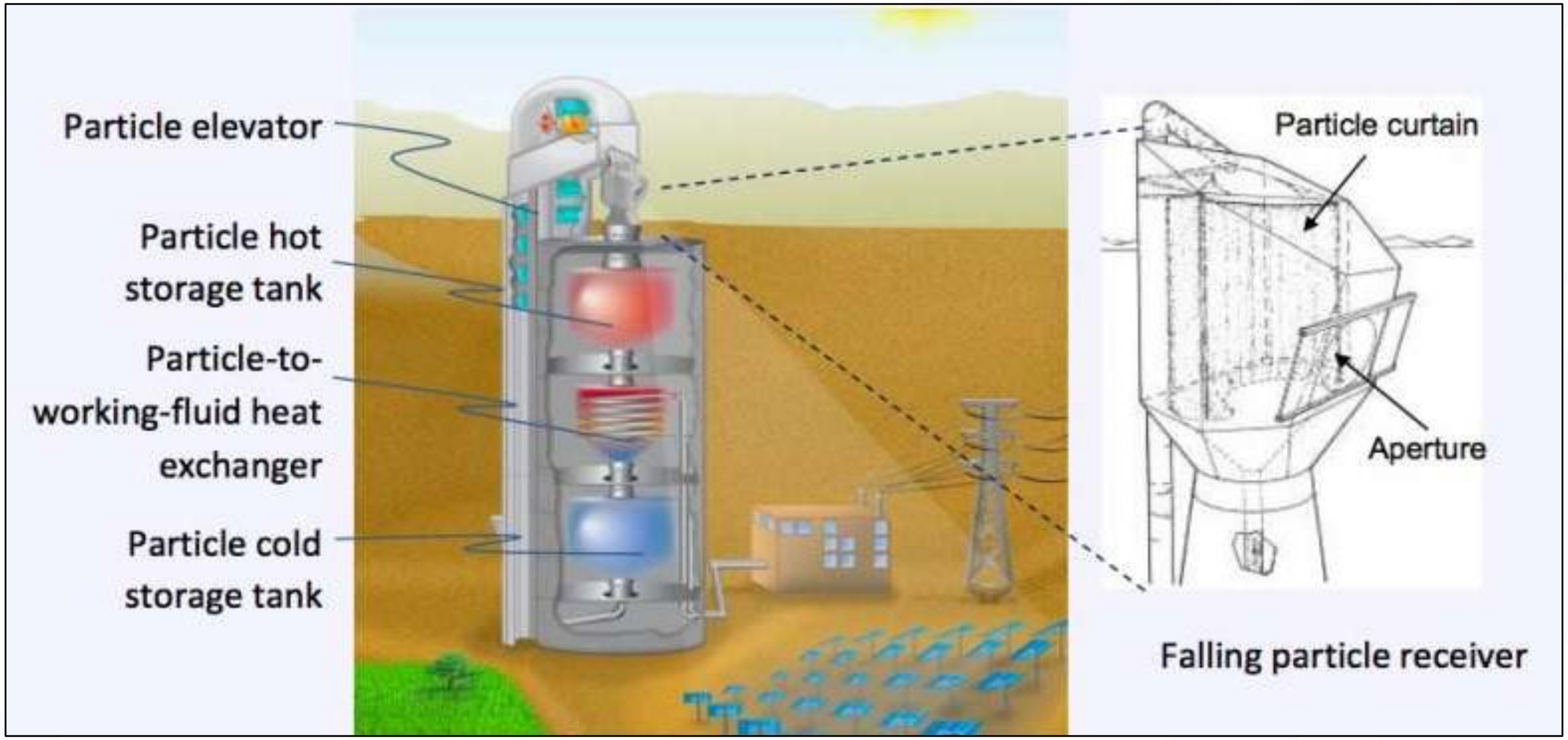
HTF flows within internally-supported and heat-transfer enhanced cells

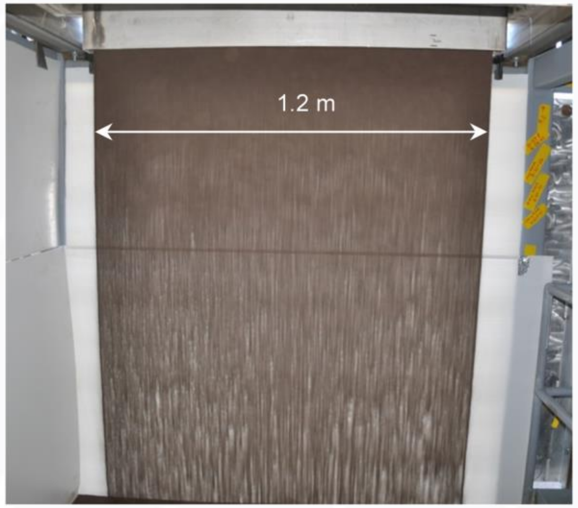


BraytonEnergy

Falling Particle Receivers

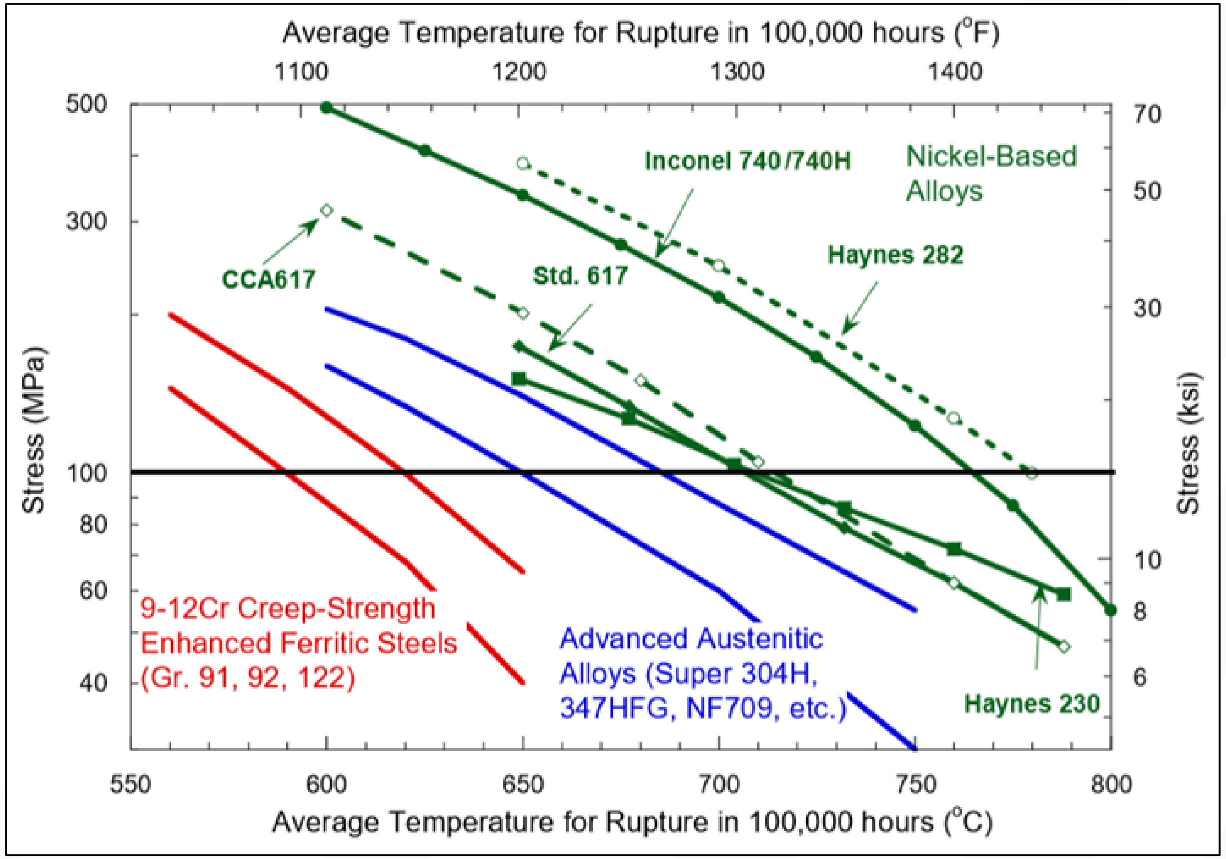
- Directly irradiates a flow of solid particles
  - *Particles used as absorber and storage medium*

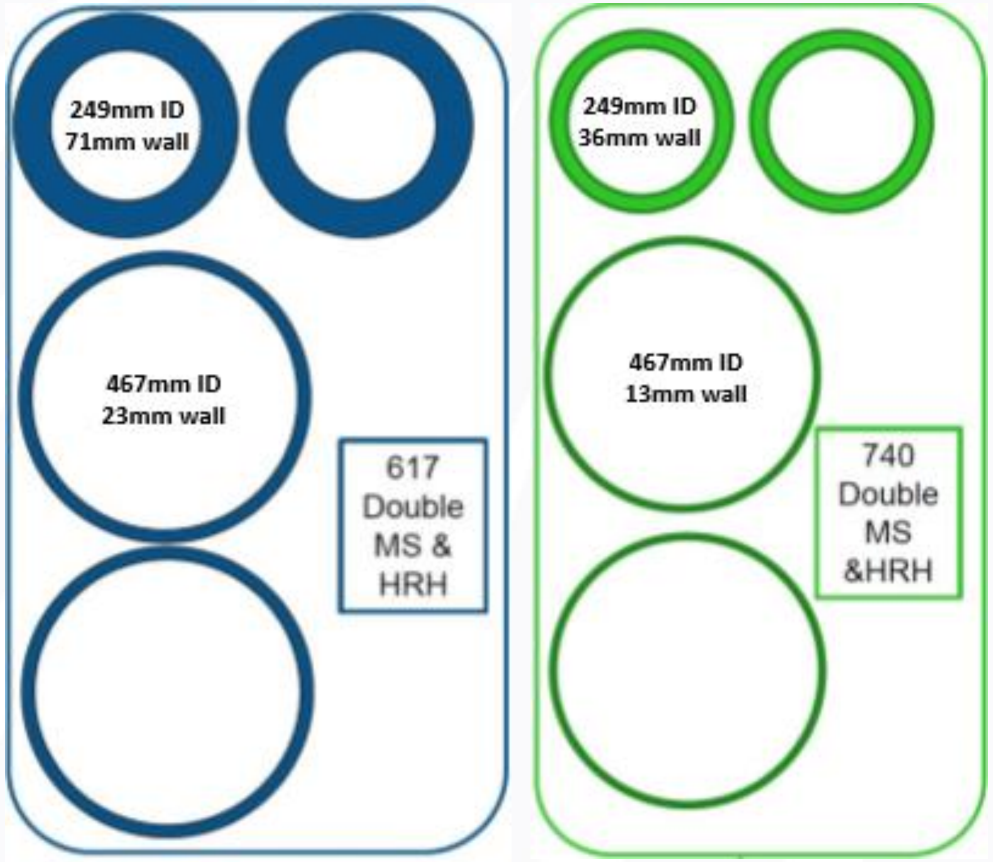




New Materials: Inconel 740H

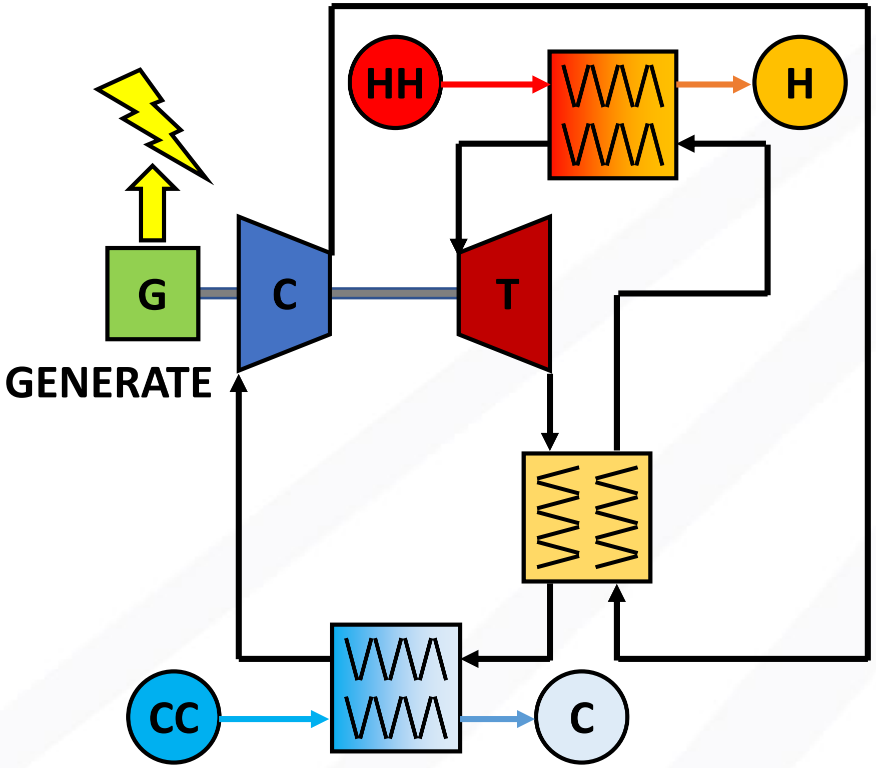
- High strength at high temperature
  - Developed for supercritical steam applications



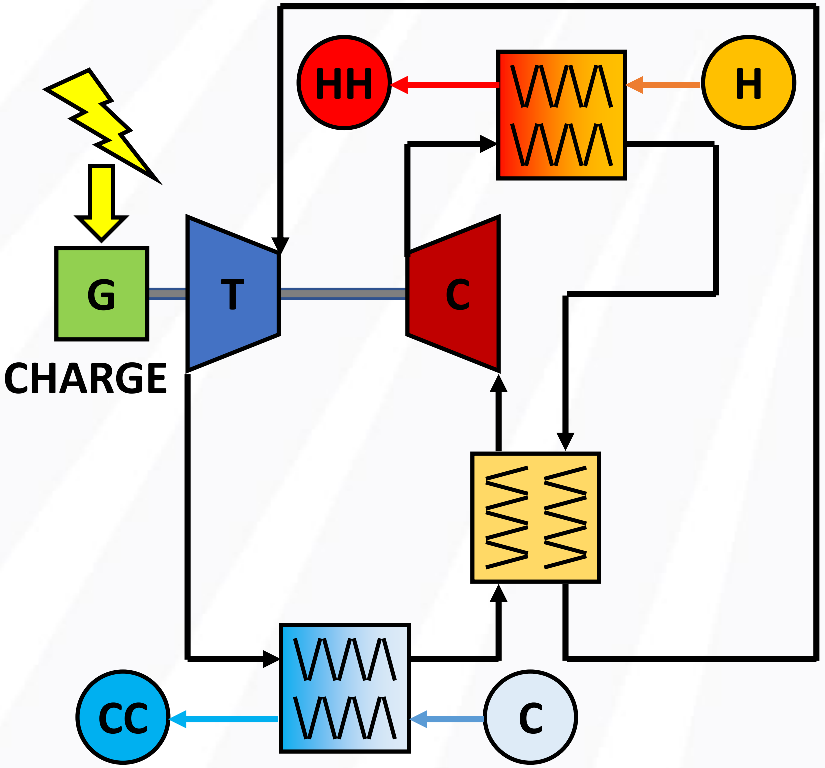


Thermal Batteries ($\eta_{\text{round trip}} > 50\%$)

- Use the temperature difference between hot and cold tanks to drive a Brayton Cycle and generate electricity



- Excess power from the grid runs the engine in reverse; expansion across the cold turbine recharges the cold tank, and compression across the hot compressor recharges the hot tank

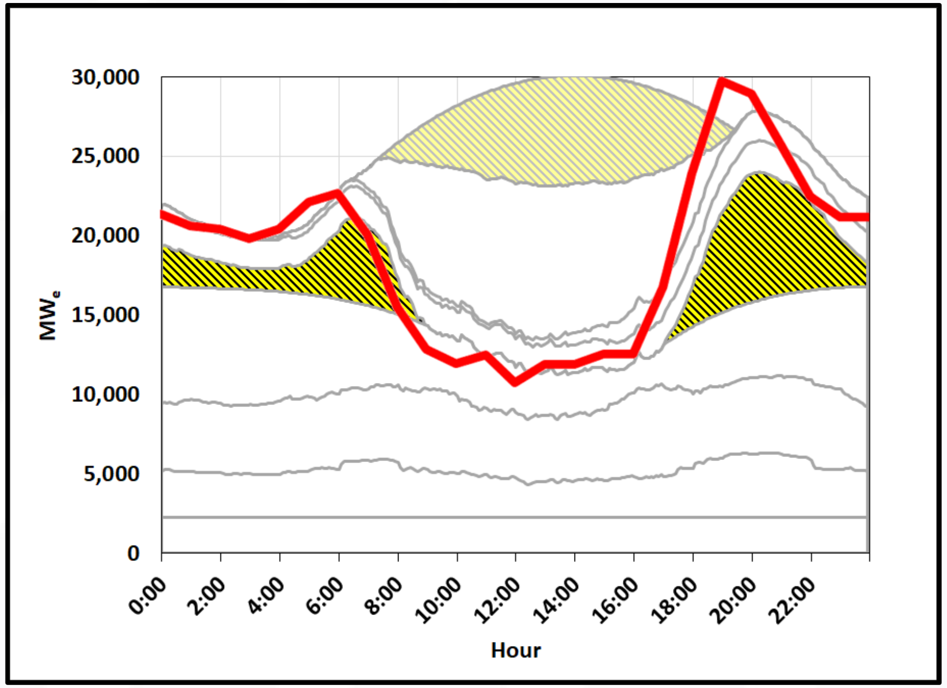


Summary

- Adopption of CSP has historically been cost-challenged
  - The evolving power and climate landscape emphasizes ***storage***, which CSP accomplishes through low-cost heat retention
    - The primary alternative – batteries - are currently ~10-20x more expensive on a capacity basis, and limited to short-duration storage applications

- Growing demand for [Solar + Storage] has generated significant research investment in CSP development
  - Multiple pathways towards commercially-viable designs are emerging, and technological advances have been rapid

- Traditional economic evaluation has been via LCOE
  - Evolving to a PPA understanding, which enables systems that operate profitably by dispatching only during high-value periods



Thank you for your attention

Shaun D. Sullivan
Principal Engineer,
R&D Program Manager
BraytonEnergy
sullivan@braytonenergy.com