Taking the Duck out of Water

CSP Innovations for a Green Landscape

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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
Turbomachinery
• Microturbines
• Dist. Generation
• Hybrid Vehicles
• UAV/Aero Engines
• Supercritical CO₂

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

Renewables
• Concentrating Solar
• Energy Storage
• Biomass Utilization

... an innovative R&D firm dedicated to making meaningful contributions in the field of environmentally responsible, sustainable energy production
Concentrating Solar Power (CSP)

• 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
Global CSP Market (Currently 5 GW)

http://www.nrel.gov/csp/solarpaces/
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

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Demand

Surplus (stored)

Dispatch
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.
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?)

- 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)
# Energy Storage Programs

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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.
1. RCBC sCO₂ power block
   ◦ nominally the STEP engine
2. Low temp. (~570 °C) piping
3. Low temp. (~570 °C) valves (x2)
4. 27.0 MWₜ open receiver
5. High Temp (~760 °C) piping
6. 5.5 MWₜ HTMH TES HEX (x3)
7. 5.5 MWt cavity receiver (x2)
8. Hydrogen (~720 °C) transport pipe
9. Regenerator
10. ~3 MWₜ LTMH TES HEX
Receivers for sCO$_2$ (750 °C, 25 MPa)

- Fully-welded pressure boundary ensures sealing
- Individually tested for quality control
- Braided fins react high internal pressures by acting as tensile support members
- Small hydraulic diameters, densely-packed fins, and thin walls enhance heat transfer
- Customizable fin geometry
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
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
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

TC or PCM media is packed within inter-cell spaces
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

• Adoption 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