



sCO₂ Research at NREL

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Thermal Systems Research at NREL

Current Research

CSP/CST

- Next Generation Concentrating Solar Power (CSP) systems
- Concentrating Solar Thermal (CST) for industrial process heat

Solar and Hybrid Systems Optimization

- CSP-TES/PV-Batt hybrid systems optimization and operation
- Optimized design and dispatch of hybrid utility-scale generation

Thermal Energy Storage

- Pumped thermal energy storage, Electric thermal energy storage
- “Low” temperature molten salt storage systems
- High-temperature particle storage systems

Solar Thermal Fuels

- Solar thermochemical hydrogen (STCH)
- High-temperature electrolysis

Materials Science → Engineering Design and Analysis → Lab & Field Characterization → Systems Integration → Grid Optimization

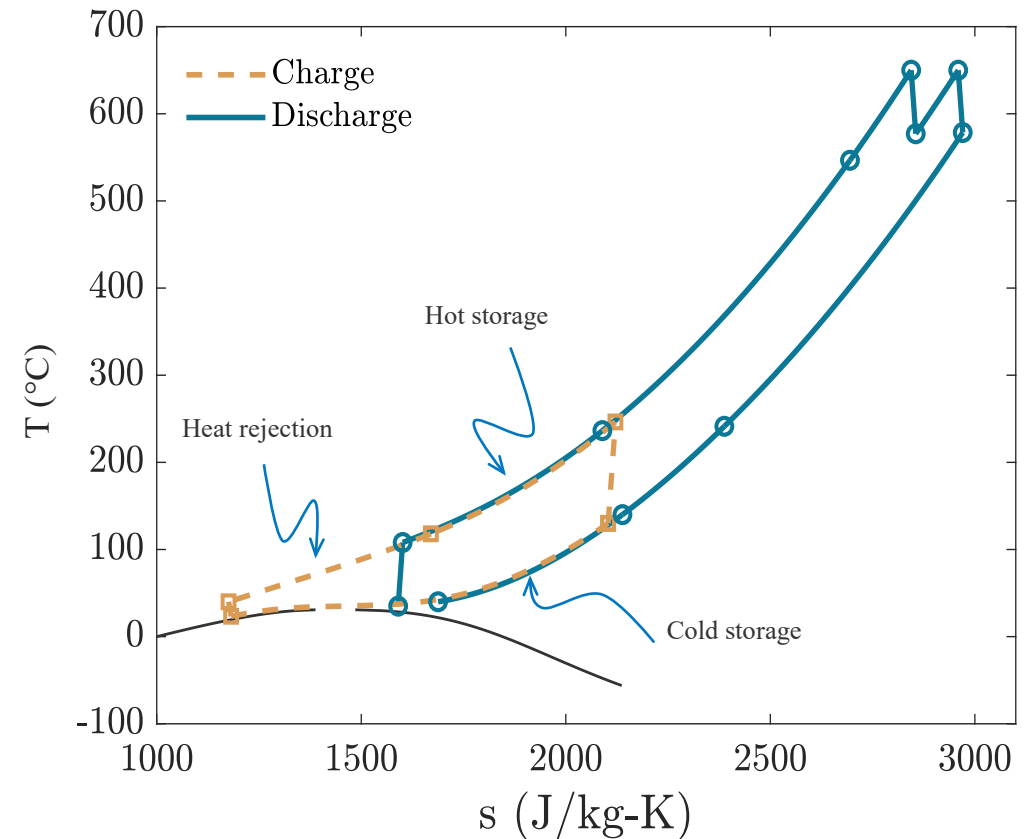
Overview of NREL's sCO₂ Research

Focused on integration with renewable energy

- Pumped thermal energy storage (PTES)
 - Supercritical CO₂ based PTES & PTES+CSP designs
 - PTES performance and dispatch modeling
- Concentrating solar power (CSP)
 - [Gen3 Gas Phase](#) led by Brayton Energy
 - Direct sCO₂ receiver, cycle, and system modeling & optimization
 - [Gen3 Liquid Phase](#) led by NREL
 - Salt-to-sCO₂ HX led by VPE and SNL
 - Cycle design and configuration optimization
 - Off-design modeling

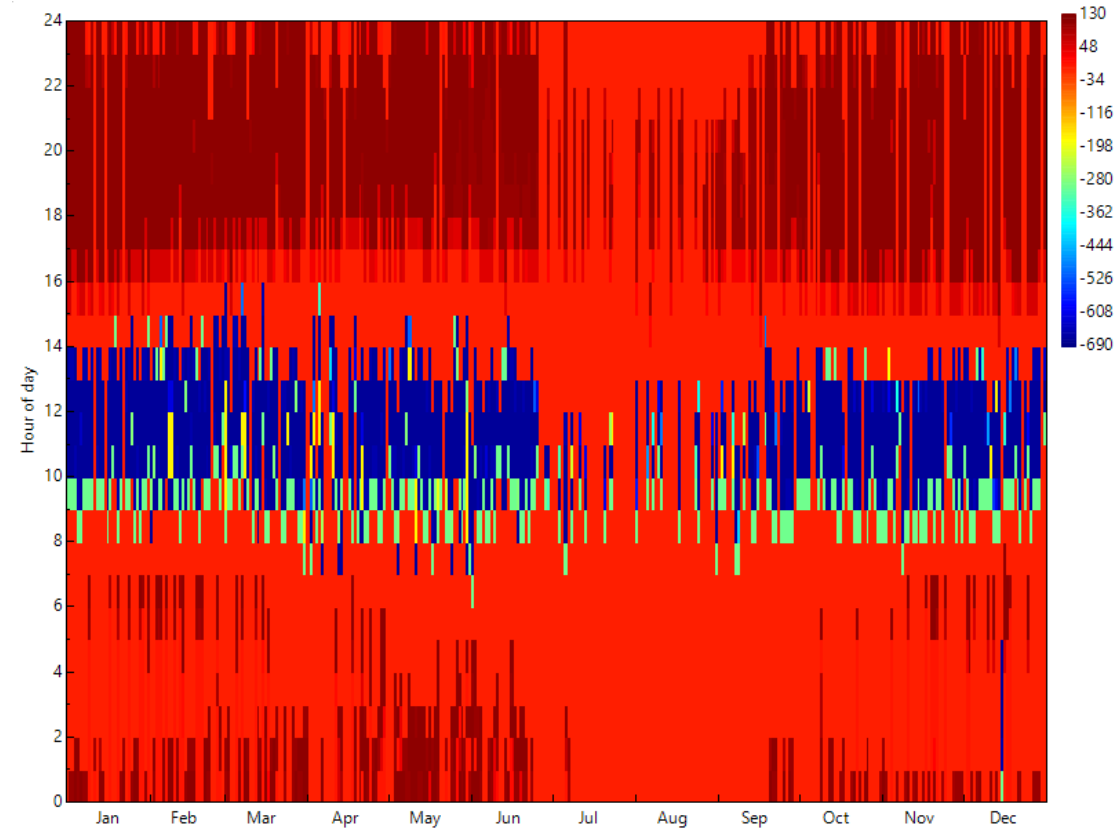
sCO₂ PTES & PTES+CSP

- Research by Dr. Josh McTigue; [2019 SolarPACES paper](#)
- Supercritical simple recuperated cycle solution had lower RTE than ideal gas
 - Did not evaluate transcritical cycles!
- Hybridize CSP & PTES w/ “Time-shifted” recompression
 - Charges low temp TES from grid
 - Replaces recompressor
 - Higher solar efficiency and power during discharge



PTES Performance and Dispatch Modeling

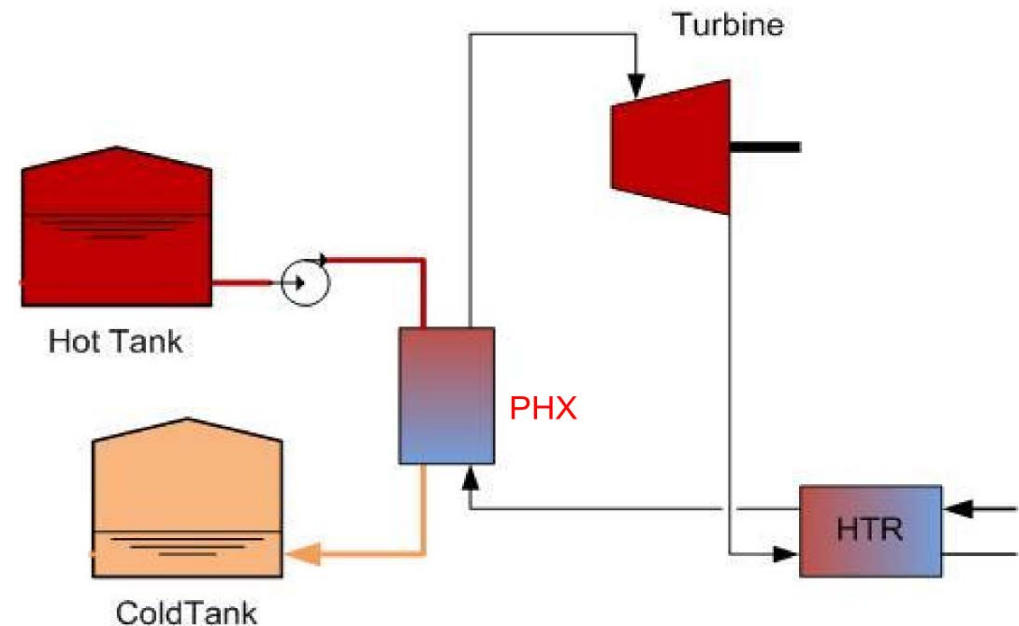
- Performance, dispatch, and techno-economics of PTES
- Current model in NREL's System Advisor Model ([SAM](#)) uses resistive heater
 - Developing high-level Brayton-cycle PTES option
 - Planned work to expand components & systems in model



Integration of Air-Cooled sCO₂ w/ TES

- As temperature difference over the primary heat input increases:
 - Cycle efficiency likely decreases
 - Storage (sensible heat) cost decreases
 - Pumping power decreases
 - Receiver thermal losses decrease
- Air-cooled performance and optimal design point conditions
- Ramping
- Performance at smaller capacity (10-50 MW)

$$Volume_{tank} = \frac{Stored\ Energy}{c_p \rho (T_{hot} - T_{cold})}$$



Cycle Configuration and Design-Point Optimization

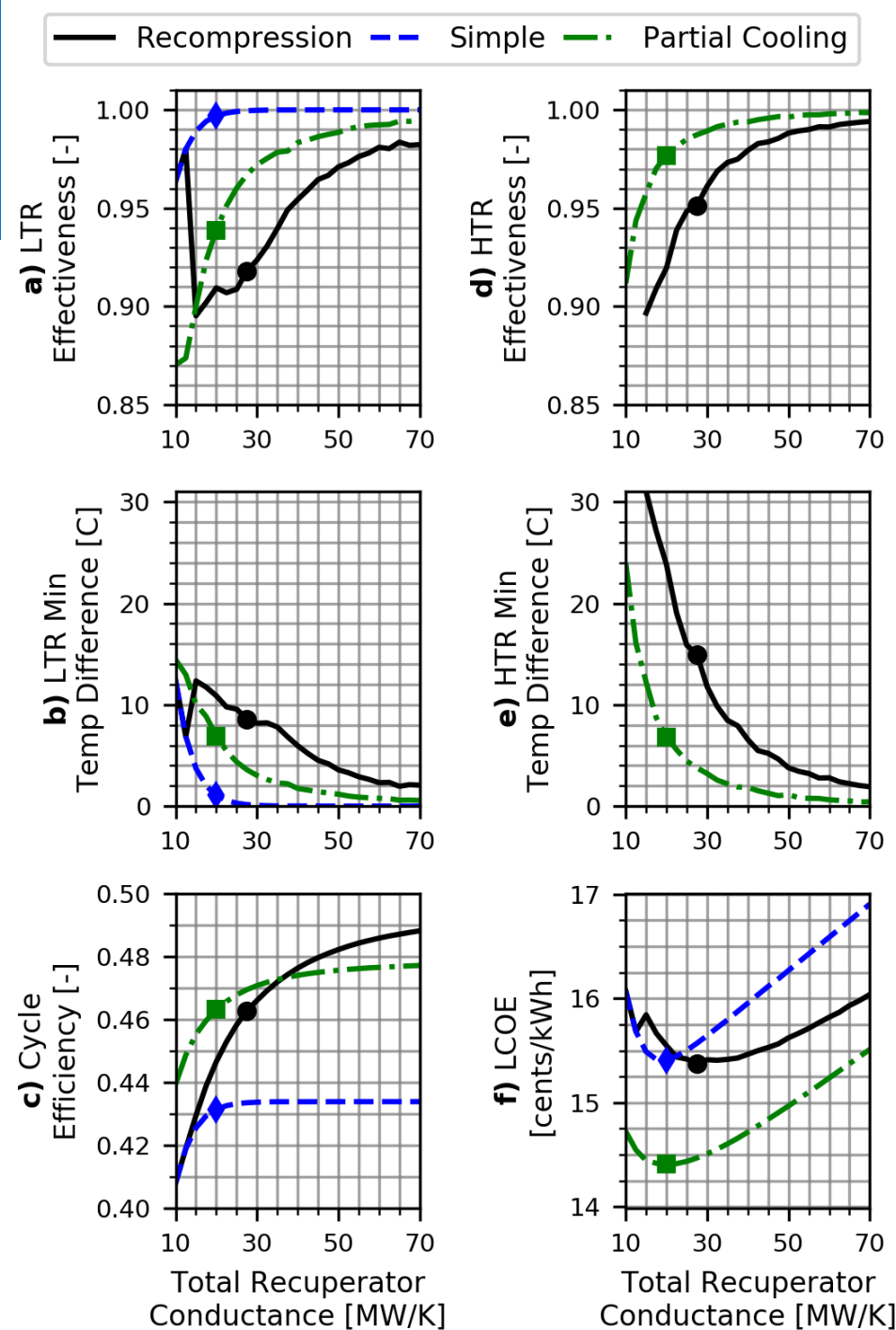
- [2019 journal paper](#)
- Compared simple, recompression, partial cooling cycles
- For *fixed recuperator conductance*, optimize free parameters to maximize efficiency
- Use cycle design solution to inform CSP molten salt tower design
 - Efficiency, Cost, ΔT
 - 10 hrs TES: more stored energy for lower efficiency cycles
- Annual simulation assumes efficiency constant at off-design

Nominal design assumptions

Cycle net output (<u>MW_e</u>)	115
Hot HTF temperature (°C)	650
Turbine inlet temperature (°C)	630
Ambient temperature (°C)	35
Compressor inlet temperature (°C)	45
Compressor isentropic efficiency	0.89
Turbine isentropic efficiency	0.9
Compressor outlet pressure (MPa)	25
Air cooler fan power % of gross (%)	2
Heat exchanger pressure drop (% of inlet pressure)	0.5
Total recuperator conductance (MW/K)	parametric
Main compressor inlet pressure (MPa)	optimized
Recompression fraction (-)	optimized
Fraction of recuperator conductance to LTR (-)	optimized
<u>Precompressor inlet pressure (MPa)</u>	optimized

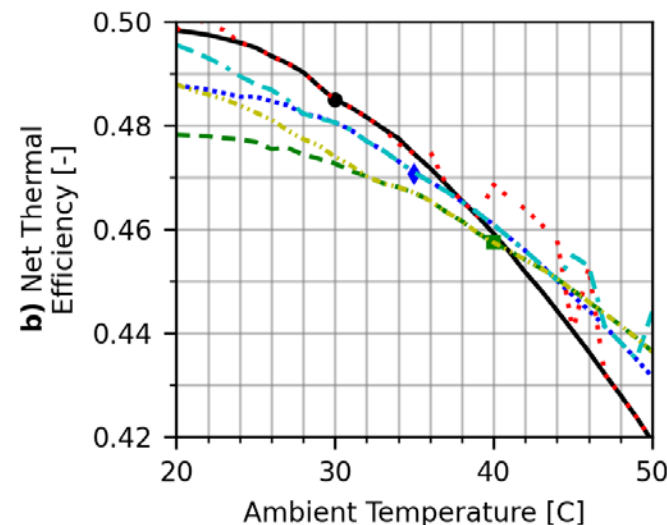
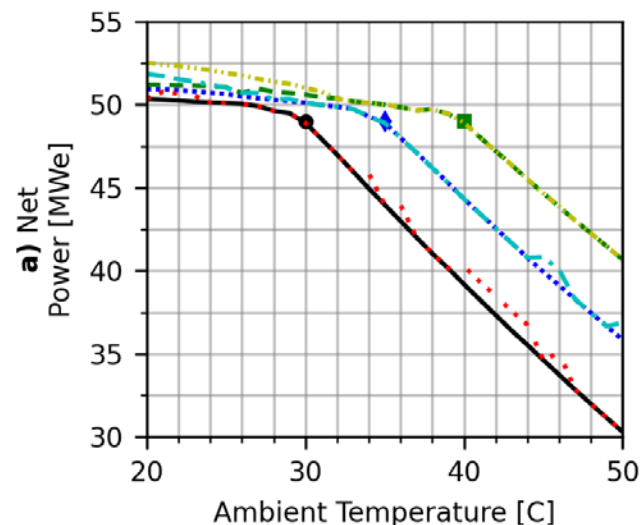
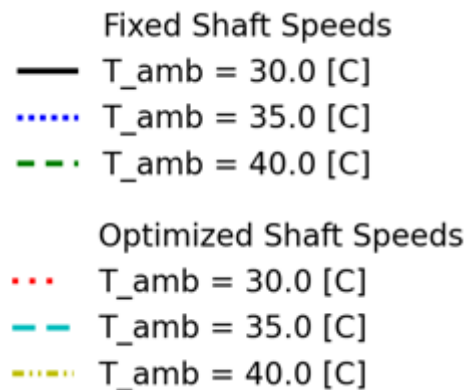
Cycle Configuration and Design-Point Optimization

- Recompression cycle has highest efficiency but requires the most conductance
- Partial cooling cycle has ~30% larger ΔT
- May be beneficial to trade efficiency for ΔT
- System level analysis important to optimize cycle design



Off-Design Analysis of Air-Cooled sCO₂ for Gen3 CSP

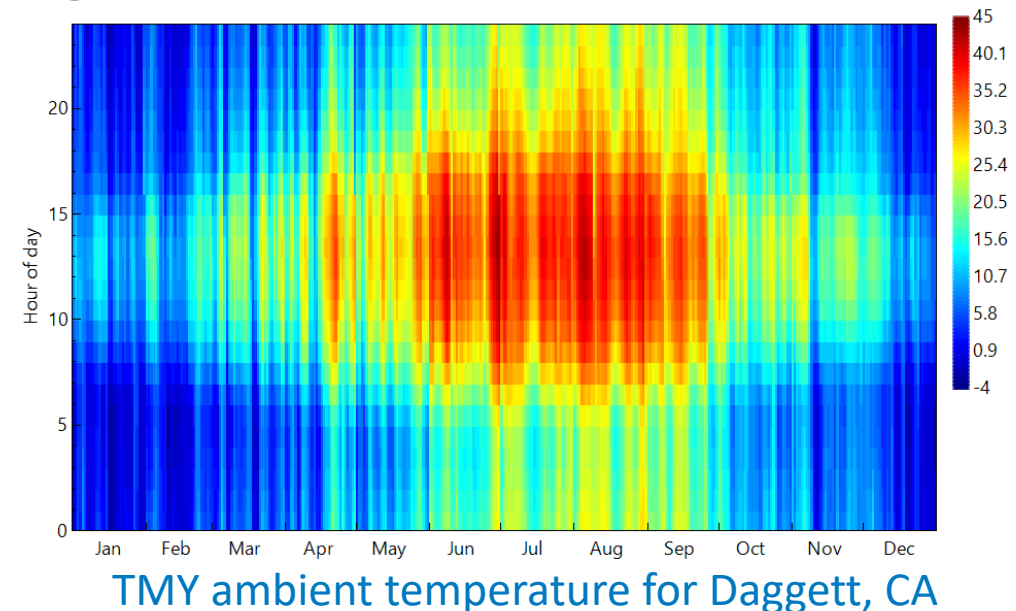
- [2020 journal paper](#)
- Available as [open-source code](#)
- Recompression cycle
- Controls
 - Inventory control
 - Variable air cooler fan power
 - Optional compressor speed control
- Constraints
 - Max pressure = design
 - Max comp speed = design
 - HTF cold temp = design (if possible)
 - Compressor inlet temp $\geq 32^{\circ}\text{C}$



HTF mass flow rate at design for all cases. Hotter-than-design solutions have a HTF cold temperature greater than design.

Current and Planned Work

- Current: design-point optimization of RCBC to maximize revenue-based financial return
- Planned: repeat off-design and optimization for RCBC w/ Preheat and Partial Cooling cycles



Seeking Input from sCO₂ Community

- Compressor design assumptions and off-design constraints
- Air-cooling assumptions
- Control strategies and operation at varying ambient temperature

Thank you!

www.nrel.gov

<https://www.nrel.gov/csp/research.html>

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