sCO_2 Research at NREL

Ty Neises
2022 sCO_2 Symposium
February 24, 2022
(ty.neises@nrel.gov)

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

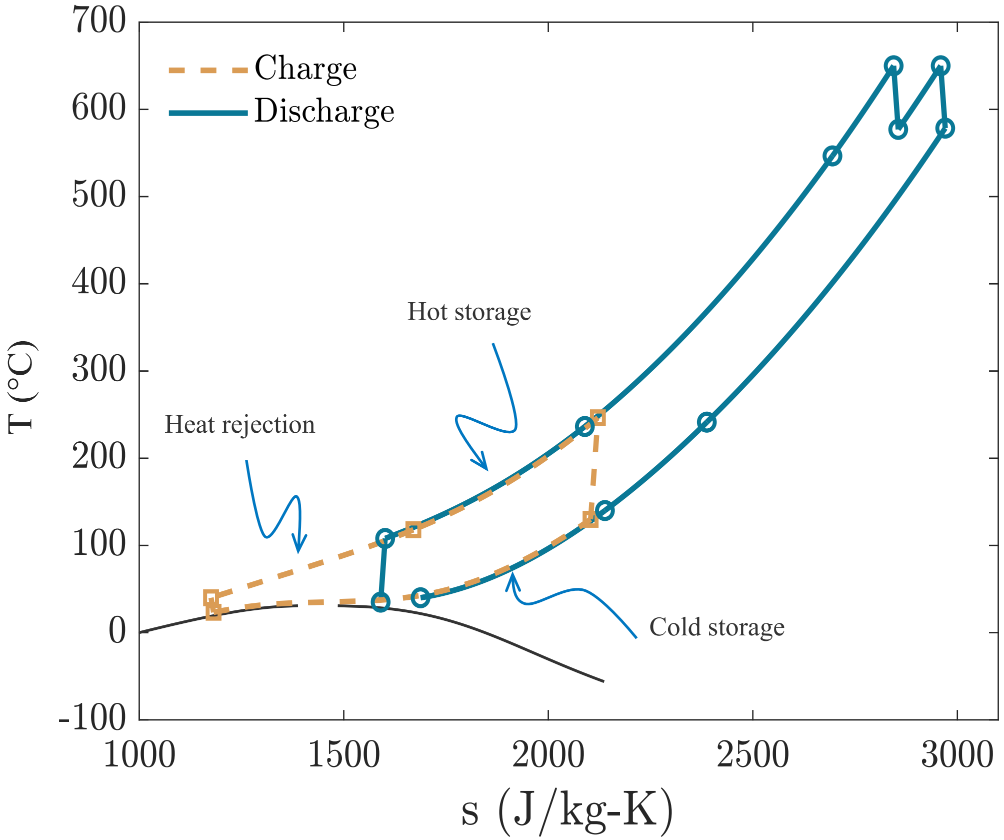
Overview of NREL's sCO_2 Research

Focused on integration with renewable energy

- Pumped thermal energy storage (PTES)
  - Supercritical CO_2 based PTES & PTES+CSP designs
  - PTES performance and dispatch modeling
- Concentrating solar power (CSP)
  - Gen3 Gas Phase led by Brayton Energy
    - Direct sCO_2 receiver, cycle, and system modeling & optimization
  - Gen3 Liquid Phase led by NREL
    - Salt-to-sCO_2 HX led by VPE and SNL
  - Cycle design and configuration optimization
  - Off-design modeling

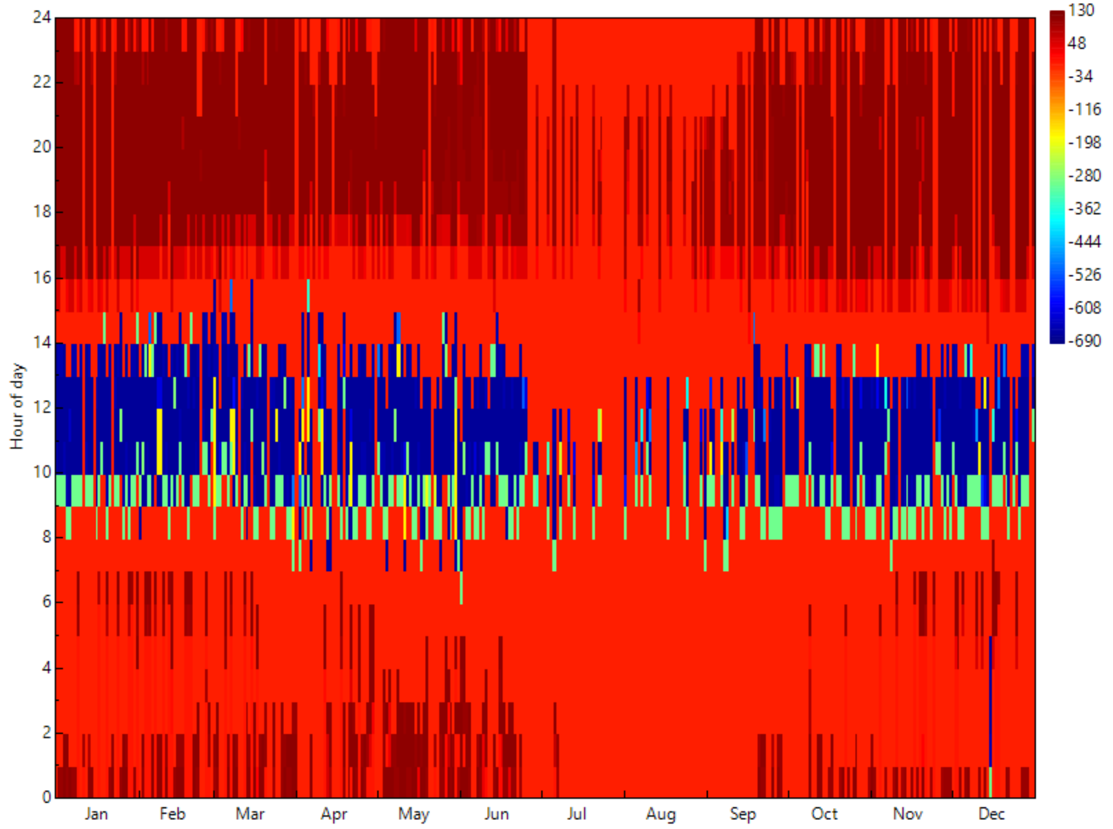
sCO_2 PTES & PTES+CSP

- Research by Dr. Josh McTigue; [2019 SolarPACES paper]
- Supercritical simple recuperated cycle solution had lower RTE than ideal gas
  - Did <u>not</u> 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

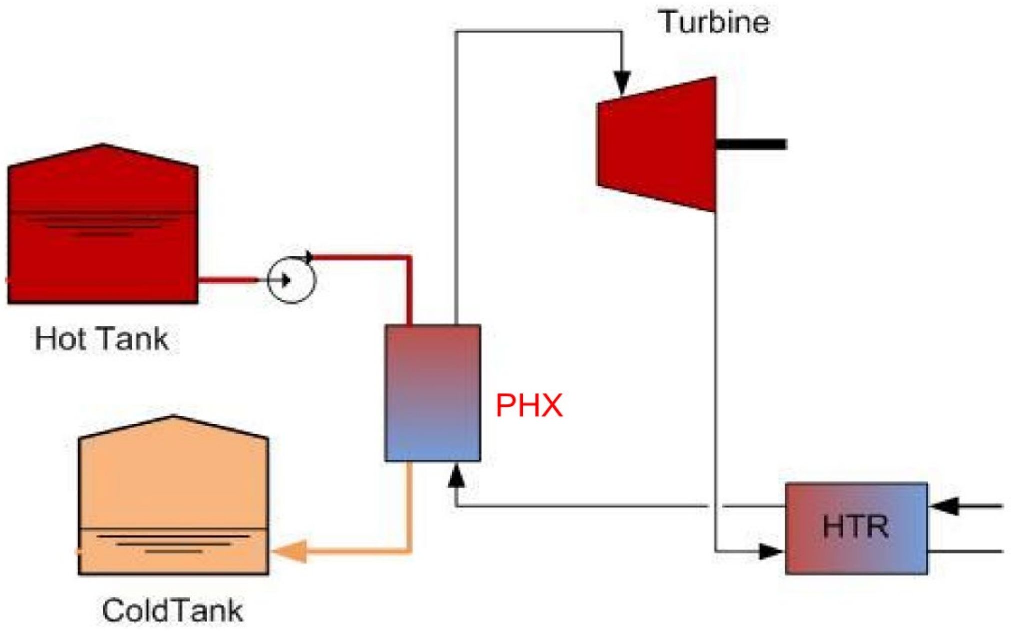
- Performance, dispatch, and techno-economics of PTES
- Current model in NREL’s System Advisor Model (SAM) uses resistive heater
    - Developing high-level Brayton-cycle PTES option
    - Planned work to expand components & systems in model



Integration of Air-Cooled sCO$_2$ 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

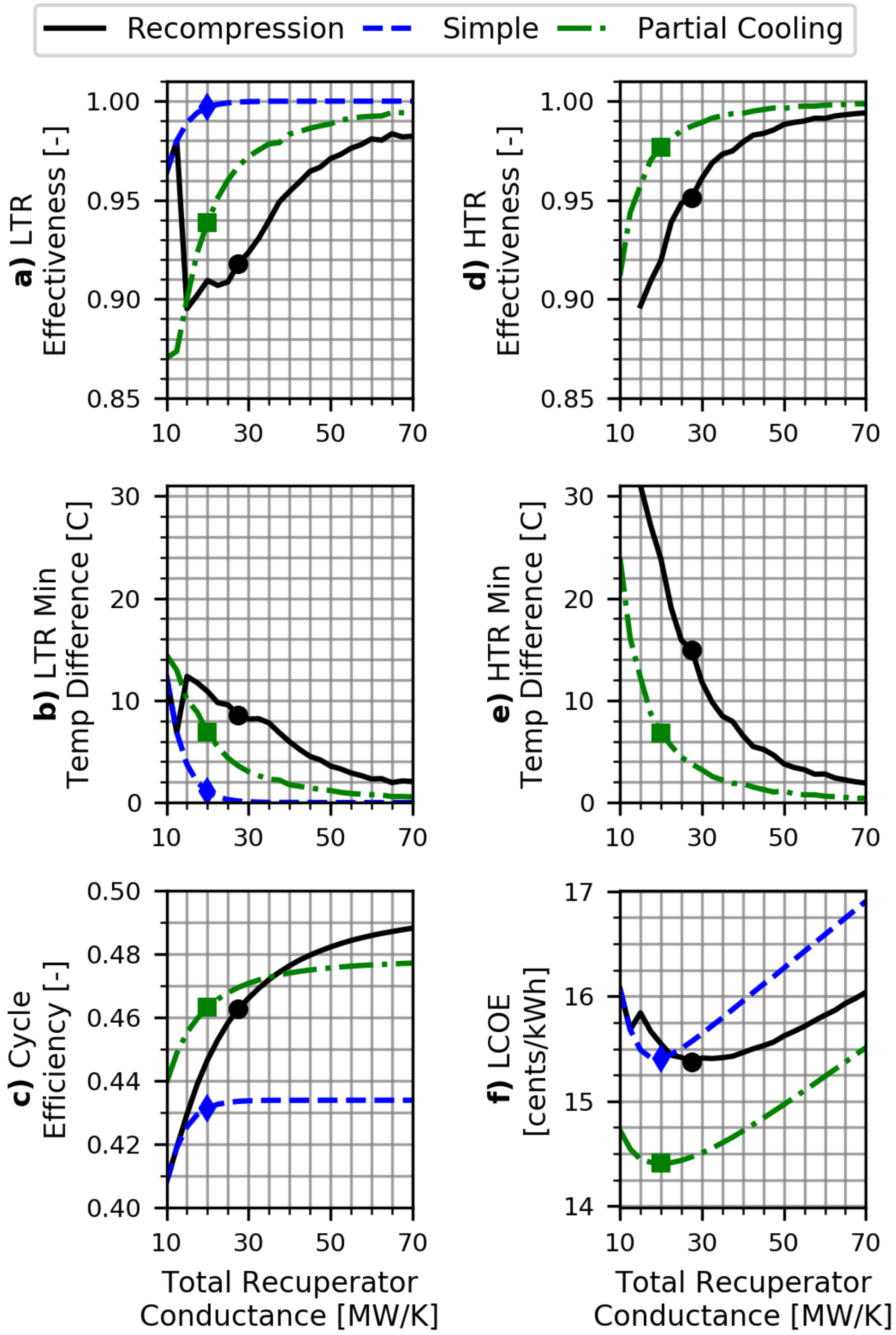
- 2019 journal paper
- Compared simple, recompression, partial cooling cycles
- For *fixed recuperator conductance*, optimize free parameters to maximize efficiency
- Use cycle design solution to inform CSP molten salt tower design
  - Efficiency, Cost, ΔT
  - 10 hrs TES: more stored energy for lower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

Nominal design assumptions

Cycle net output (MW_e)	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
Precompressor inlet pressure (MPa)	optimized

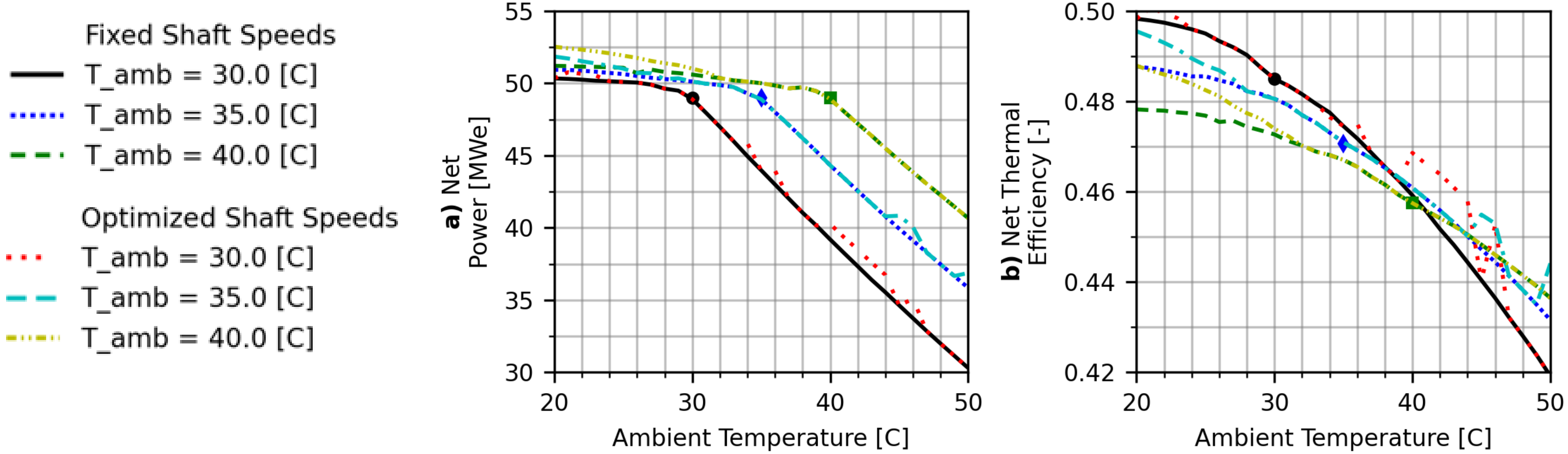
Cycle Configuration and Design-Point Optimization

- 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

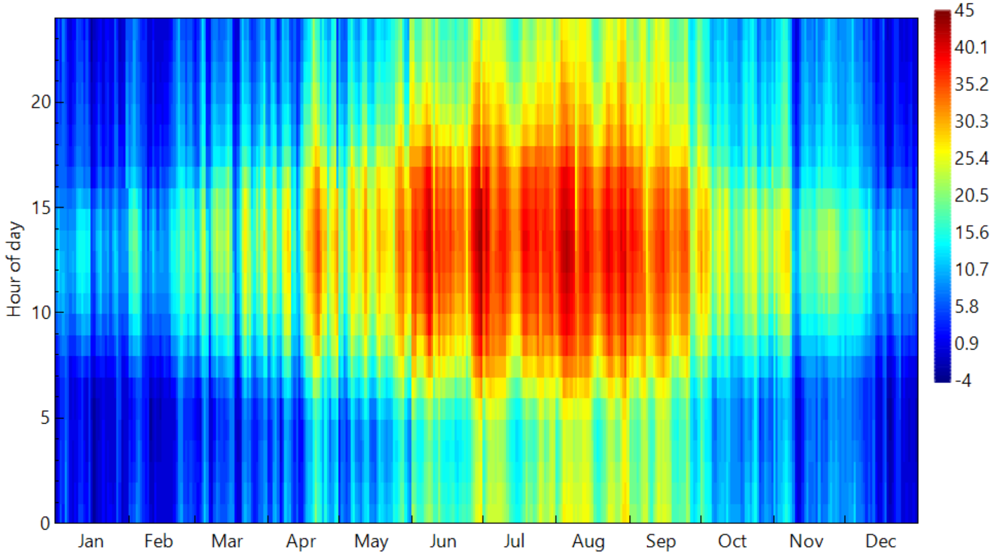
- 2020 journal paper and available as open-source code
- Recompression cycle
- Controls
  - Inventory control
  - Variable air cooler fan power
  - Optional compressor speed control
- Constraints
  - Max pressure = design
  - Max comp speed = design
  - HTF cold temp = design (if possible)
  - Compressor inlet temp >= 32°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



TMY ambient temperature for Daggett, CA

Seeking Input from sCO_2 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

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL

Transforming ENERGY