Sandia National Laboratories

U.S. DOE Gen3 and SunShot 2030 Concentrating Solar Power R&D: *In search of $0.05/kWh, autonomy and seasonal storage*

SASEC2019
6TH SOUTH AFRICAN SOLAR ENERGY CONFERENCE
25 – 27 November | East London, South Africa

Paul Gauche, Manager CSP Program & NSTTF,
Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY   NNSA

SAND2019-14225 C

Agenda

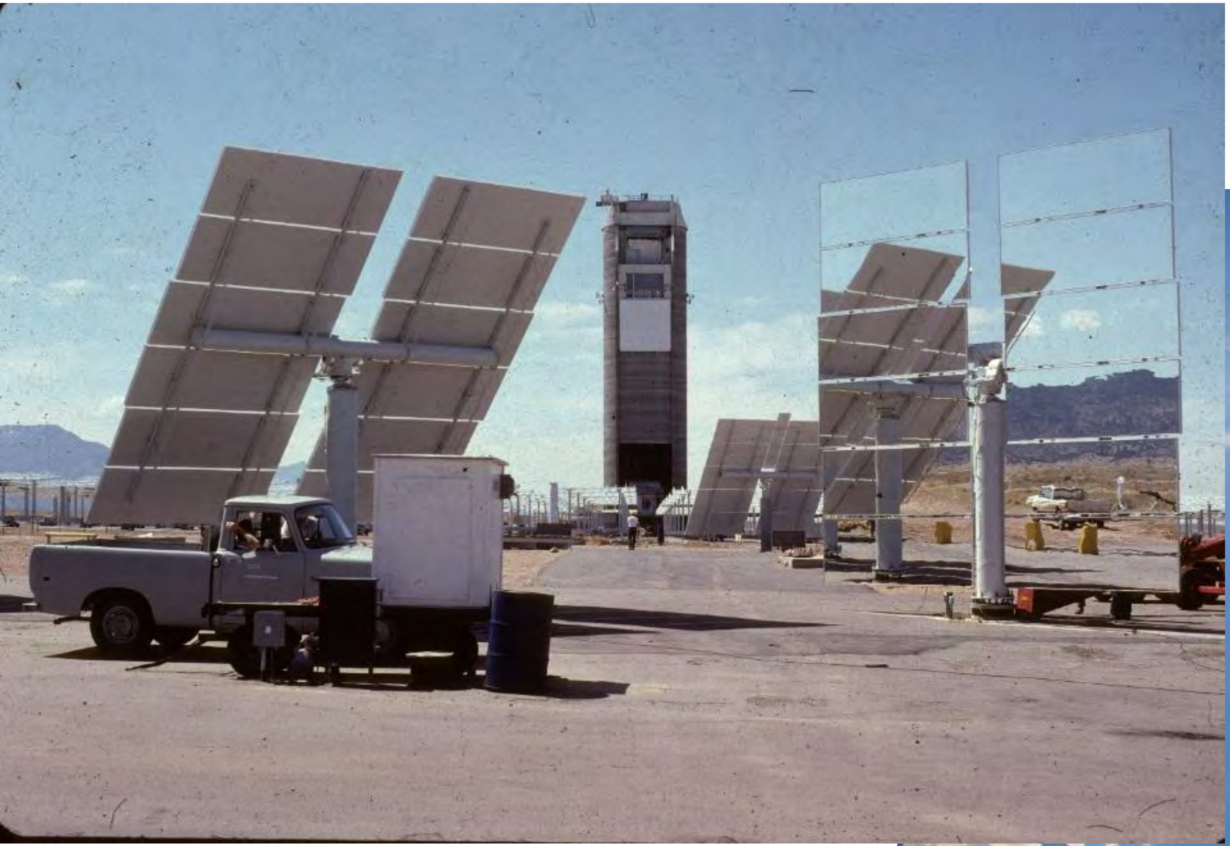
- **About CSP at Sandia National Laboratories**
- **Current and anticipated DOE R&D**
  - Overview by the U.S. Department of Energy
- **Development of sCO2 power cycles**
  - Commercially-relevant sCO2 pilot systems
  - Ongoing sCO2 research and future plans
- **Gen3 projects – The Big 3**
- **Optics and autonomy**
- **Fuels and long duration storage**

About CSP at Sandia Labs

Progress Toward Commercial Deployment of sCO2 Brayton Power Cycles

40 Years of CSP Research

NATIONAL SOLAR THERMAL TEST FACILITY
40 years
1978
2018



Brief History of CSP (Sandia View)

Solar One and
Solar Two
10 MW_e
Daggett, CA
1980’s – 1990’s

Stirling Energy Systems
1.5 MW_e, AZ, 2010

Ivanpah, steam, 377 MW_e, CA, 2014

1970’s → 1980’s – 1990’s → 2000’s → SunShot & Gen3 2011 -

National Solar Thermal Test Facility
6 MW_t, Albuquerque, NM, Open 1978

SEGS, 1980’s
9 trough plants
354 MW_e, CA

Gemasolar, molten salt, 19 MW_e, Spain, 2011

Crescent Dunes, molten salt, 110 MW_e, NV, 2015

Glint/Glare, Thermal Emissions, Avian Hazards

Glint and glare may cause unwanted visual impacts

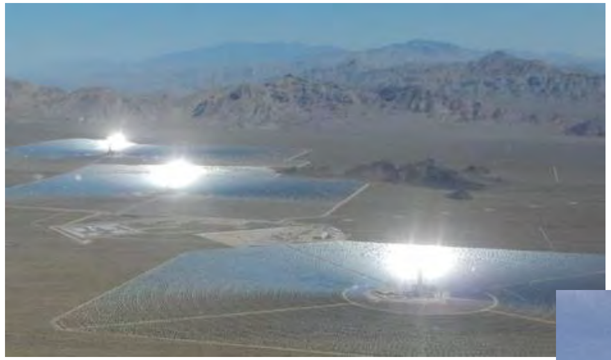
- Pilots, air-traffic controllers, motorists
- Retinal burn, temporary after-image, veiling, distraction

Infrared emissions

- Heated objects can emit infrared radiation that may interfere with infrared sensors

Avian Flux Hazards

- Concentrated sunlight can singe birds

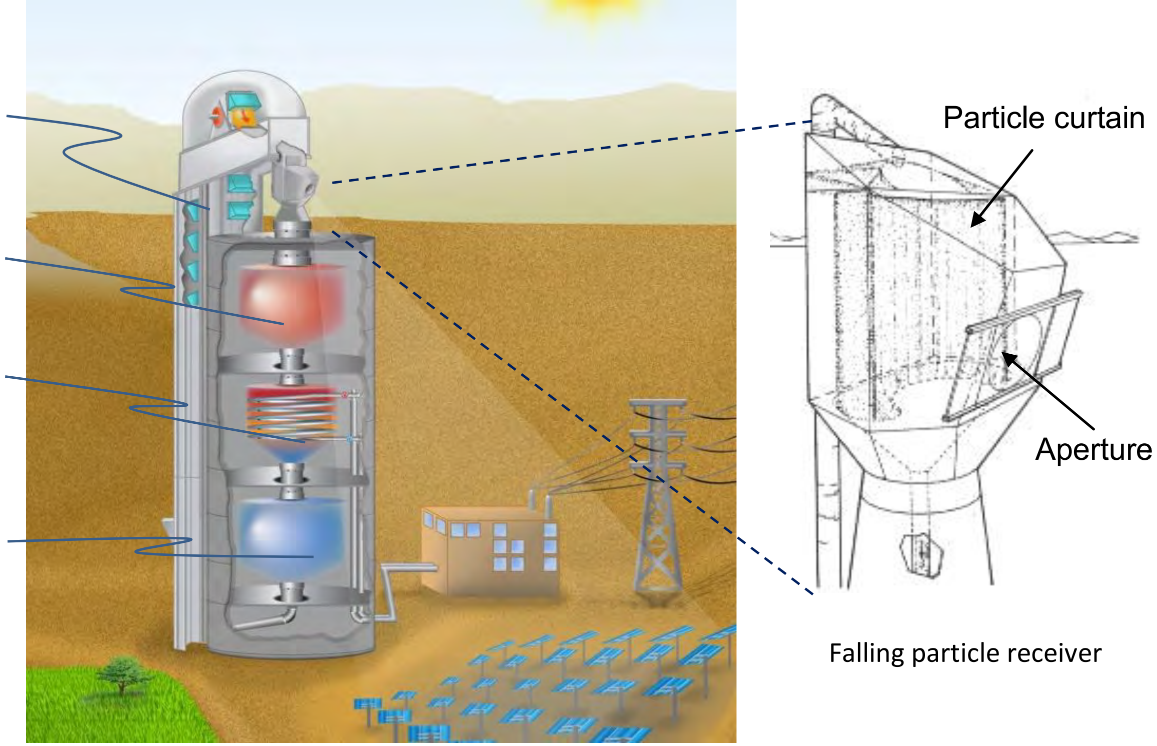


Glare from Ivanpah CSP Plant

Thermal emission from receiver at ~600 C

MacGillivray Warbler with “Grade 3” solar flux injury found at Ivanpah CSP Plant (Kagan et al., 2014);

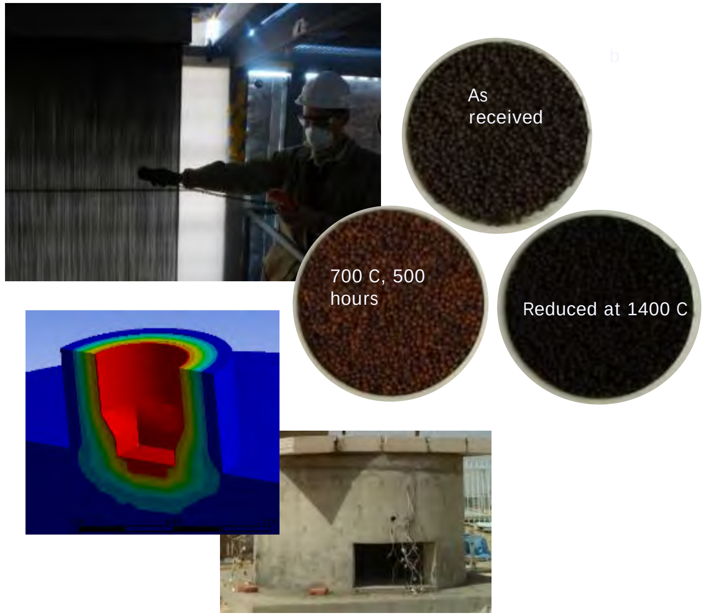
High Temperature Falling Particle Receiver (DOE SunShot Award FY13 – FY16)



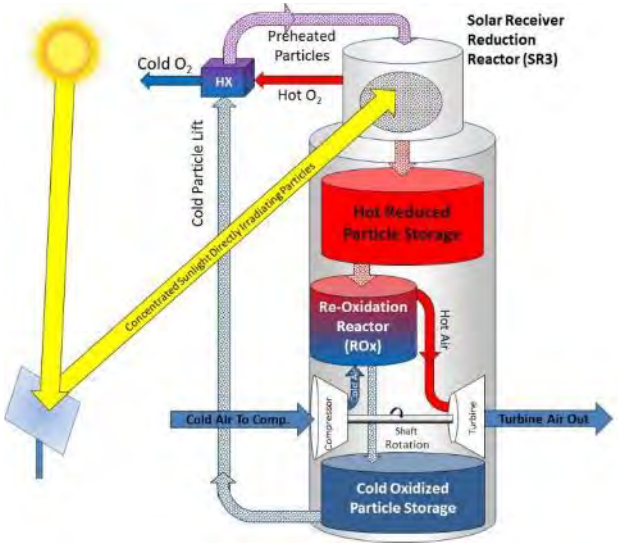
On-sun testing of the high-temperature falling particle receiver at NSTTF

Sandia Research in Thermal Energy Storage

Corrosion studies in molten salt up to 700 C in "salt pots"

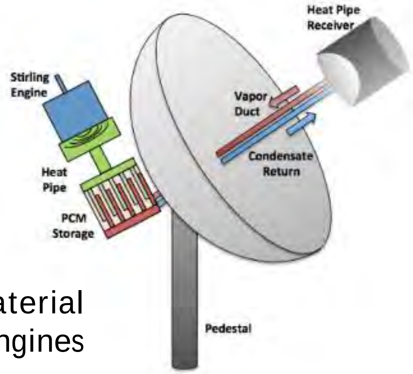


Ceramic particle storage and heating with falling particle receiver



Thermochemical particle storage with reduction/oxidation of perovskites

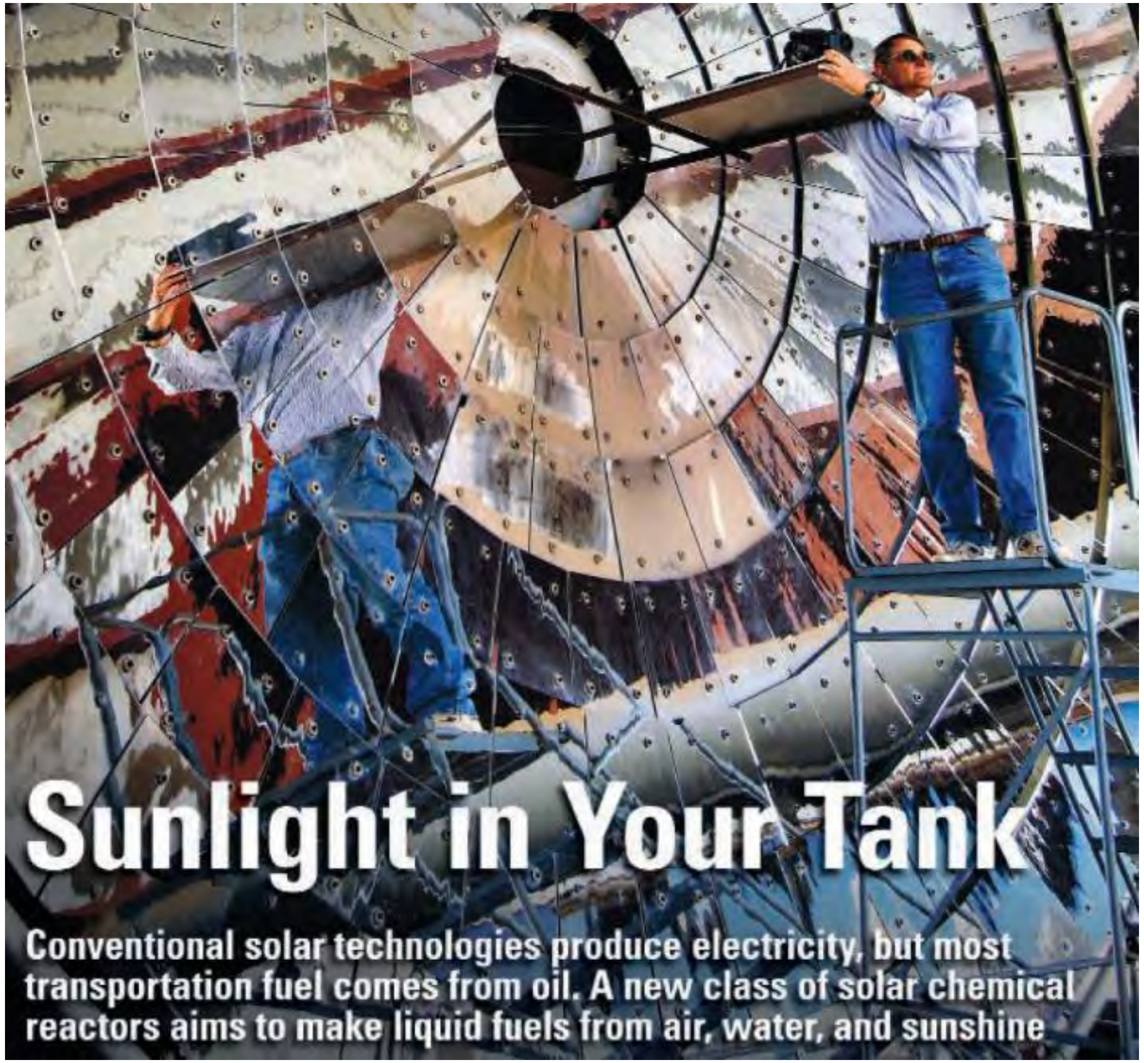
Component testing with molten-salt test loop



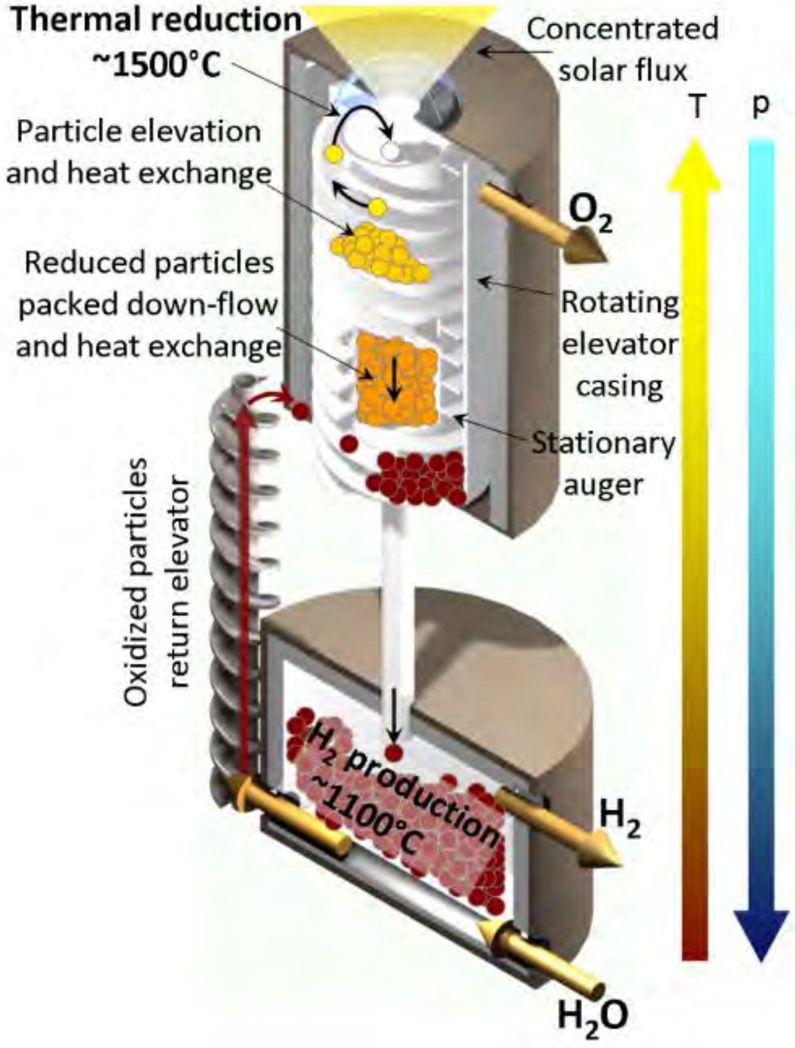
Latent phase-change material storage in dish engines

Solar Fuels

Creating hydrogen and liquid fuels with concentrated sunlight

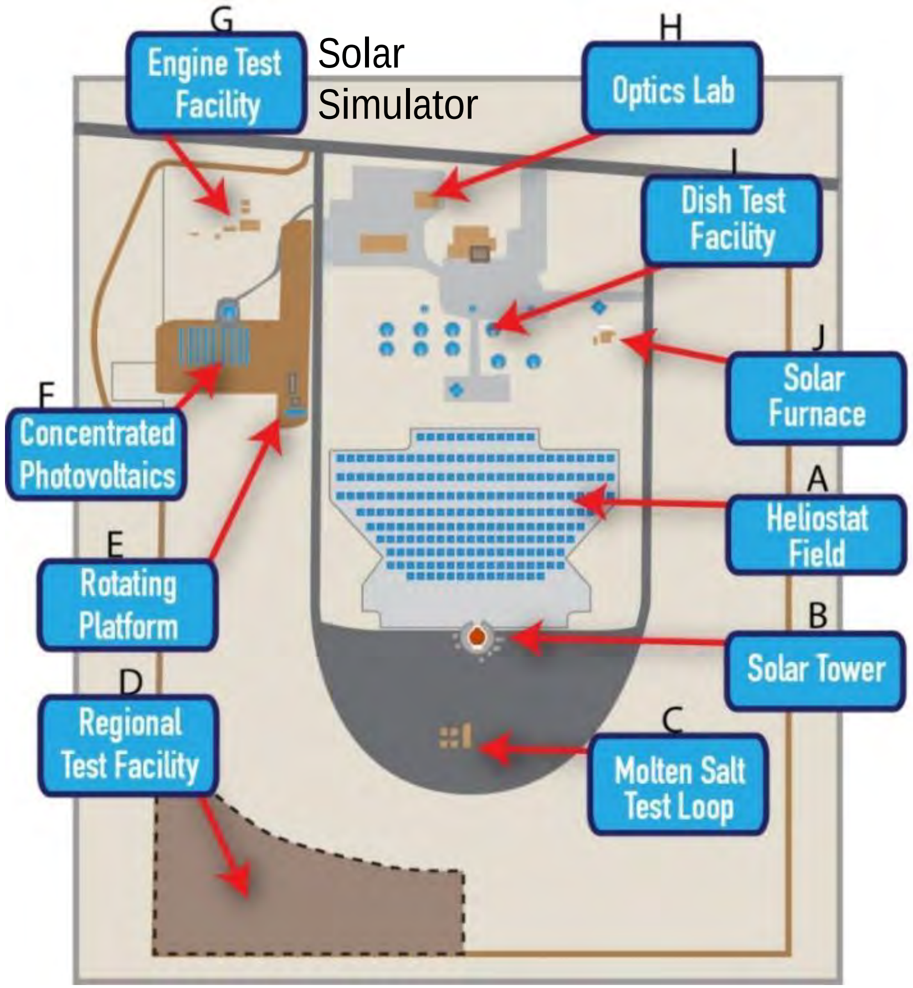


Science (2009)



Ermanoski et al.

The National Solar Thermal Test Facility



NSTTF is a DOE Designated User Facility

- Strategic Partnerships Projects (SPP)
- Cooperative Research And Development Agreement (CRADA)

Solar Tower

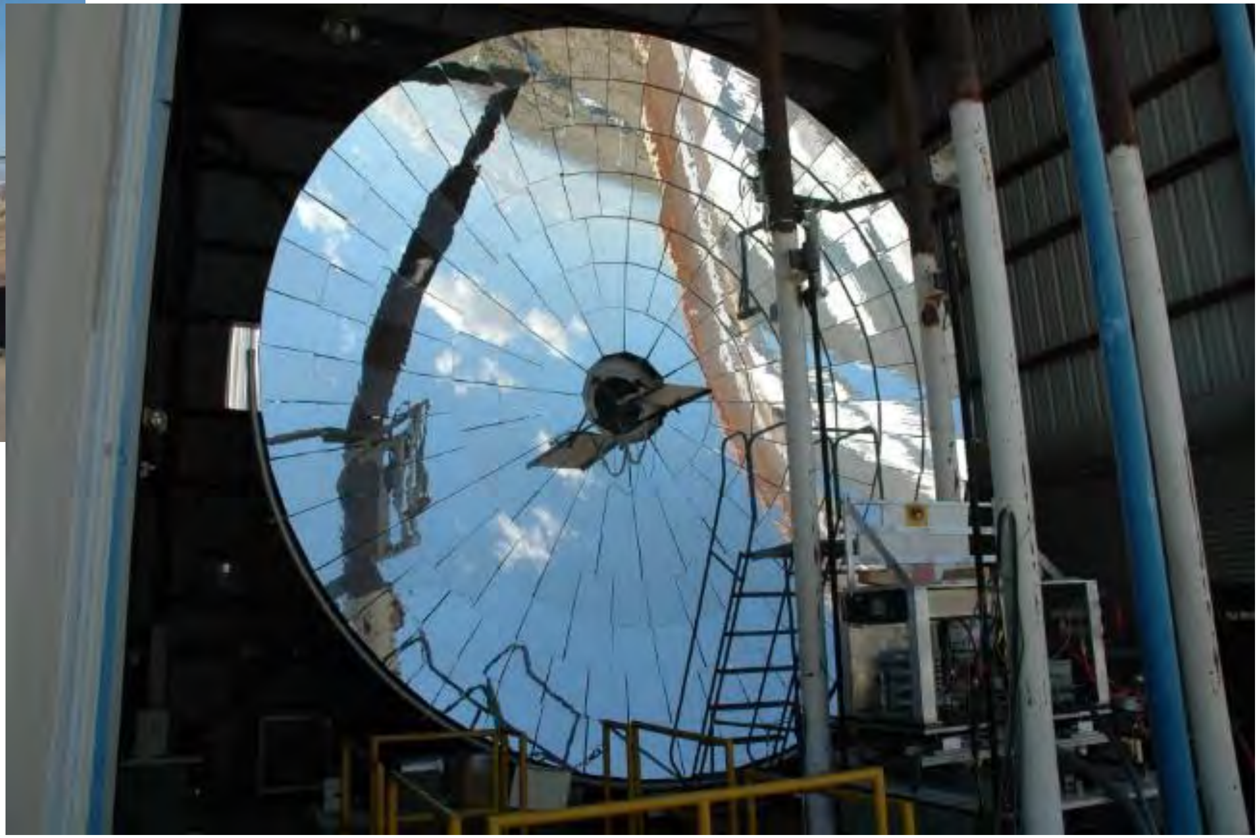
- 218 heliostats - 37 m^2 each
- 6 MW optical power
- > 3,000 suns (with canting tool optimization)
- 200 ft concrete tower with 3 test bays and large "module"
- "Module" includes an 800,000 lb (400 ton) elevator for 45 ft testing structure on top of tower

Solar Furnace

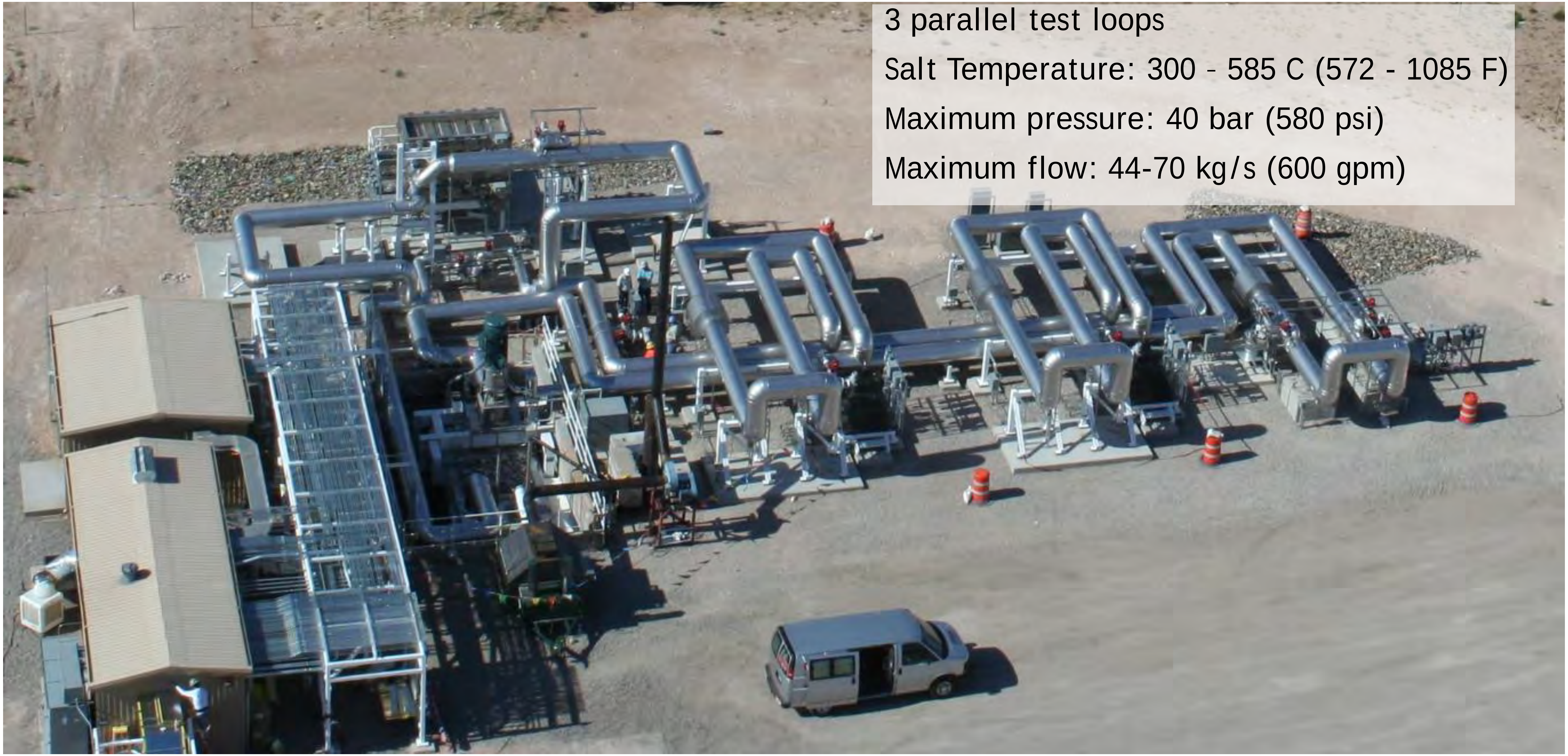
16 kW Solar Furnace

Peak flux ~600 W/cm^2 (6000 suns)

5 cm spot size



Molten-Salt Test Loop



3 parallel test loops

Salt Temperature: 300 - 585 C (572 - 1085 F)

Maximum pressure: 40 bar (580 psi)

Maximum flow: 44-70 kg/s (600 gpm)

Current and anticipated DOE R&D

Progress Toward Commercial Deployment of sCO2 Brayton Power Cycles

2018 – 2020 DOE Research Themes

- **2018: Gen3 CSP**: The final program for SunShot2020
  - Large funded projects culminating in a new high temperature + sCO2 pilot (2019 – 2023)

- **2019: Beyond Gen3**: Towards SunShot 2030 ($0.05/kWh for baseload or $0.10/kWh peaking)
  - **Firm Thermal Energy Storage**
    - Long-term TES: Systems storing energy for weekly or seasonal dispatch
    - Pumped heat electricity storage for CSP: Concepts to enable charging of TES via off-peak grid electricity
    - Commercializing TES: Projects pursuing near-term market adoption
  - **Materials & Manufacturing**
  - **Autonomous CSP Collector Field**

- **2020: RFI: Supercritical Carbon Dioxide Power Cycles Integrated with Thermal Energy Storage**
  - *"…feedback on technologies to integrate and demonstrate advanced supercritical carbon dioxide (sCO2) Brayton power cycles that are indirectly heated via thermal energy storage at a turbine inlet temperature (TIT) range between 550 and 630°C…"*

Gen3 FOA, FY19 DOE/SETO FOA, FY20 DOE/SETO RFI

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES OFFICE

U.S. DEPARTMENT OF ENERGY | Fossil Energy

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

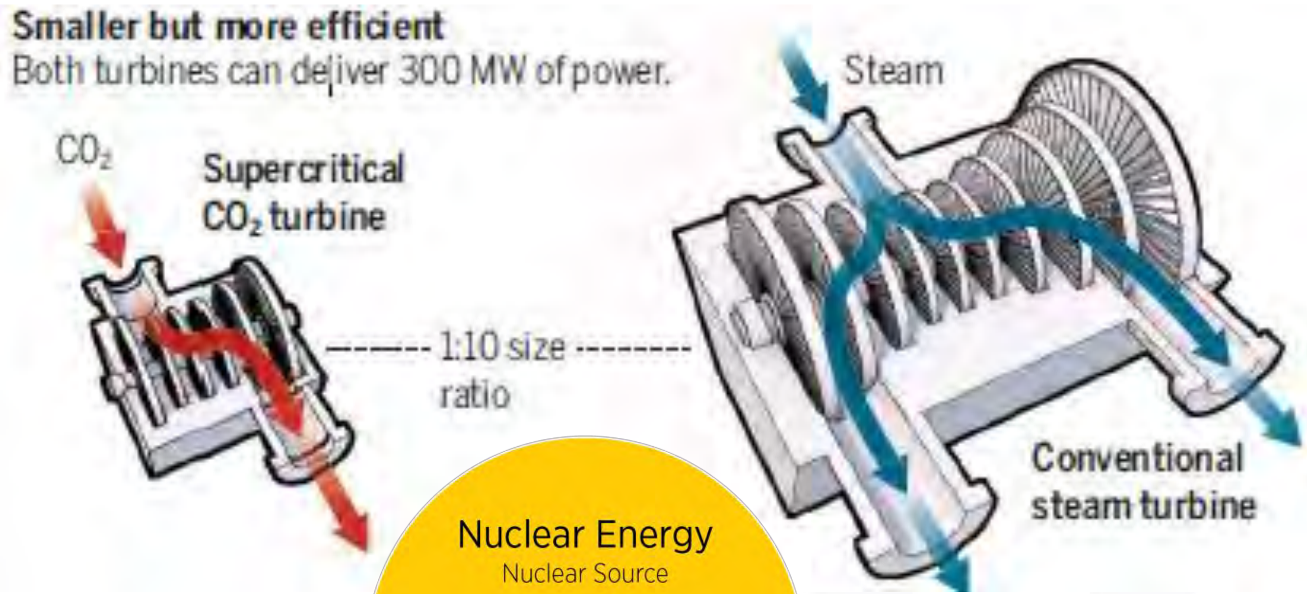
DOE Research and Development on sCO_2 Power Cycles

Dr. Avi Shultz
Program Manager
Solar Energy Technologies Office

DOE sCO_2 Workshop
October 31-November 1, 2019
National Renewable Energy Laboratory, Golden, Colorado

energy.gov/solar-office

Next Generation CSP will Leverage Next Generation Power Cycles

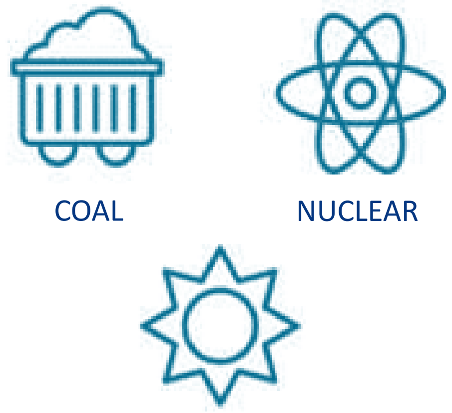


Advantages of the sCO_2 Brayton Cycle:

- Higher Efficiency (*50% at TIT of 720 °C*)
- Compact Components
- Smaller Turbine Footprint (by a factor > 10)
- Reduced Power Block Costs
- Amenable to Dry Cooling
- Scalability (Sub 100 MW)
- Operational Simplicity (No Phase Change)

Irwin, Le Moullec. "Turbines can use CO_2 to cut CO_2." *Science* 356.6340 (2017): 805-806.

Thermal Energy Storage + sCO_2 Power Cycles



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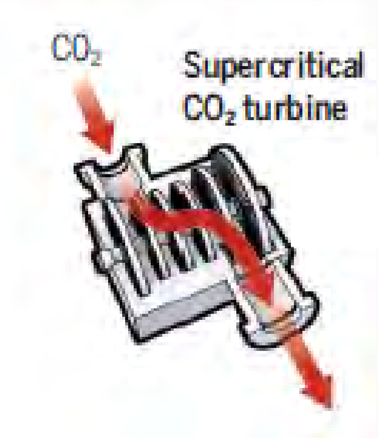


Thermal Resource Limitations:

- **Difficult to modulate** heat generation from nuclear fission
- Ramping coal boilers significantly **reduces lifetime**
- Solar thermal is a **variable energy resource**

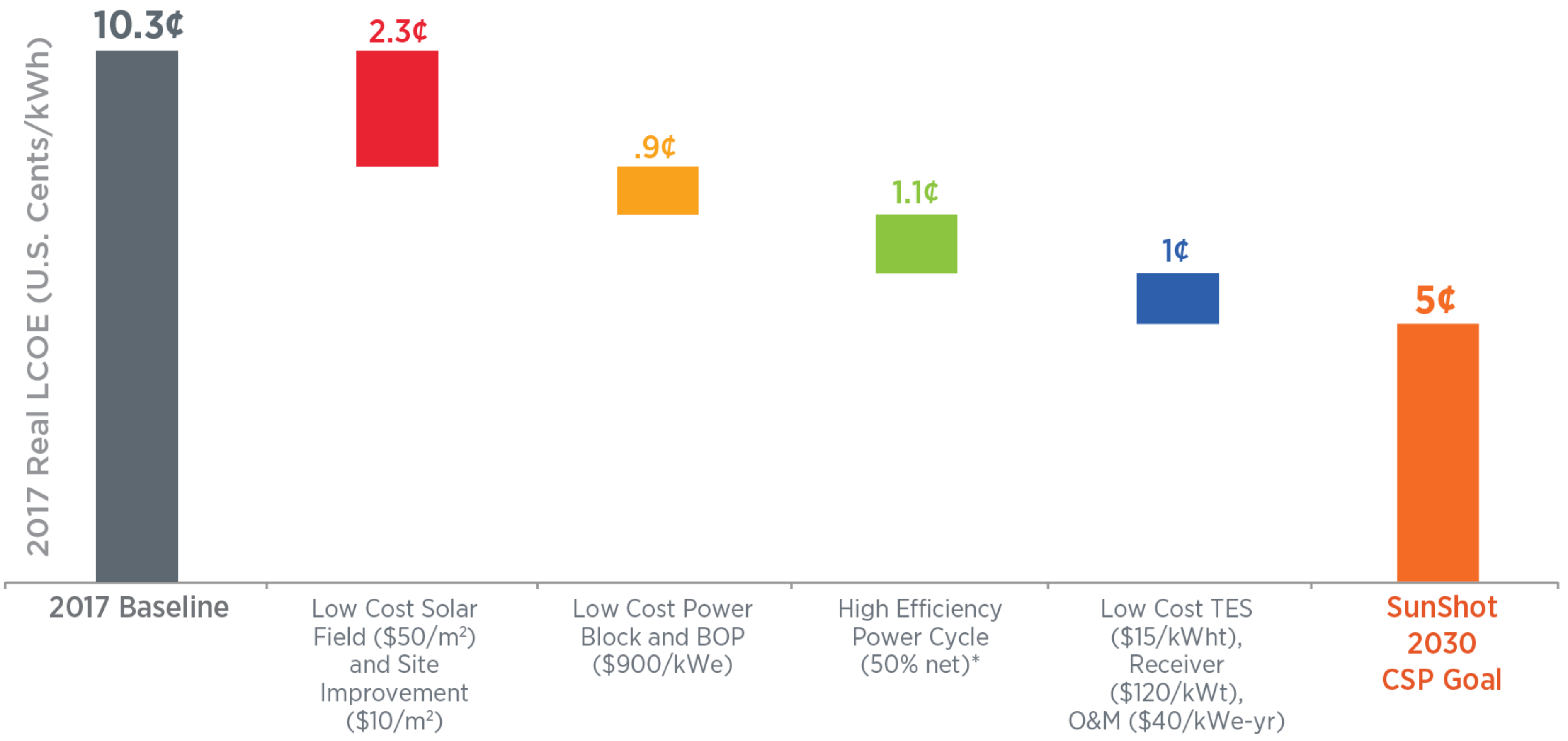
Thermal Energy Storage:

- **On-demand**, dispatchable energy generation
- **Increased reliability** due to buffering of variations in primary energy resource
- Technology readily scales to **long duration** (≥ 10 hours)

sCO_2 Power Cycles:

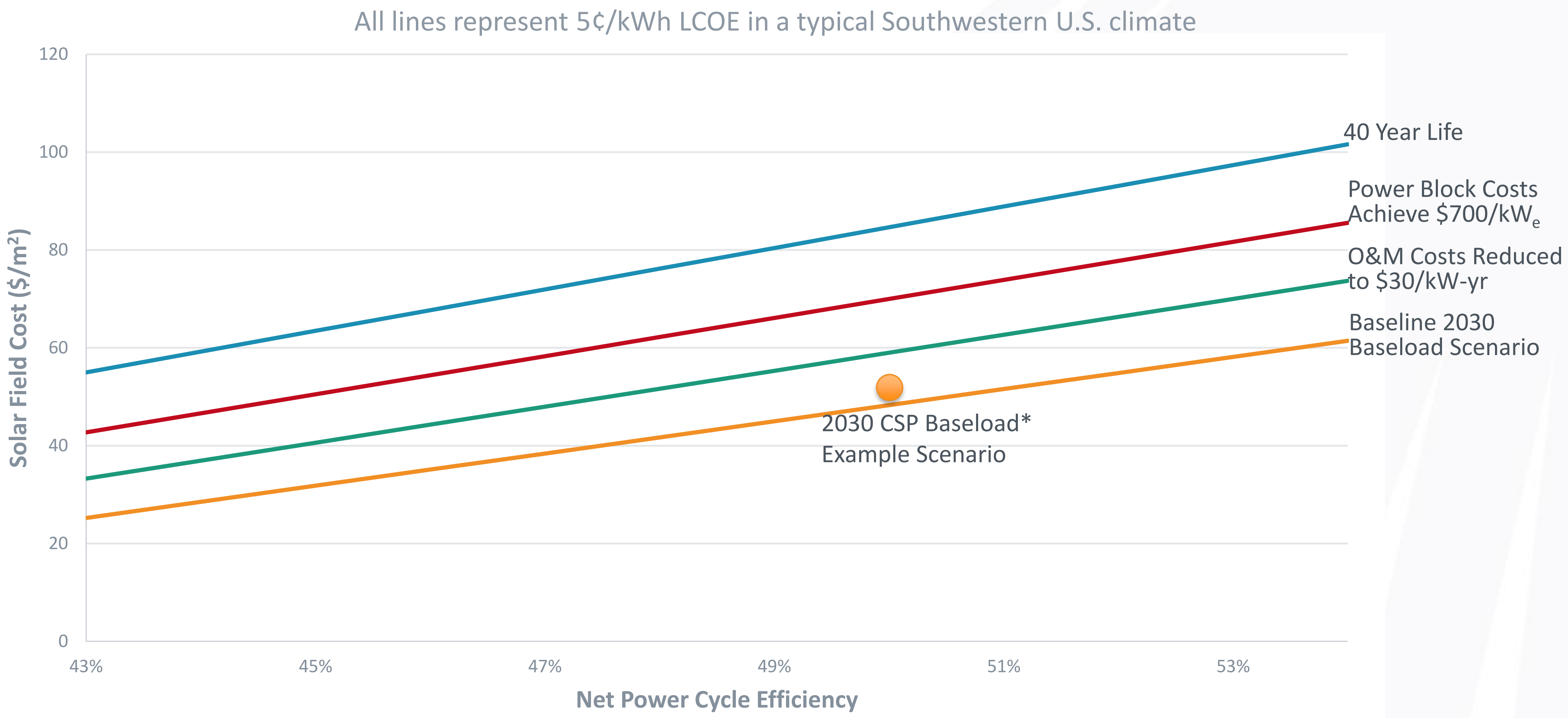
- Readily scalable to **< 100 MW** without significant loss in efficiency for **improved flexibility and siting**
- **Similar or higher efficiency** than steam cycles
- **Compact components** and **lower capital cost** for the same power output
- Much more amenable to **dry cooling** than conventional power cycles

A Pathway to 5 Cents per KWh for Baseload CSP



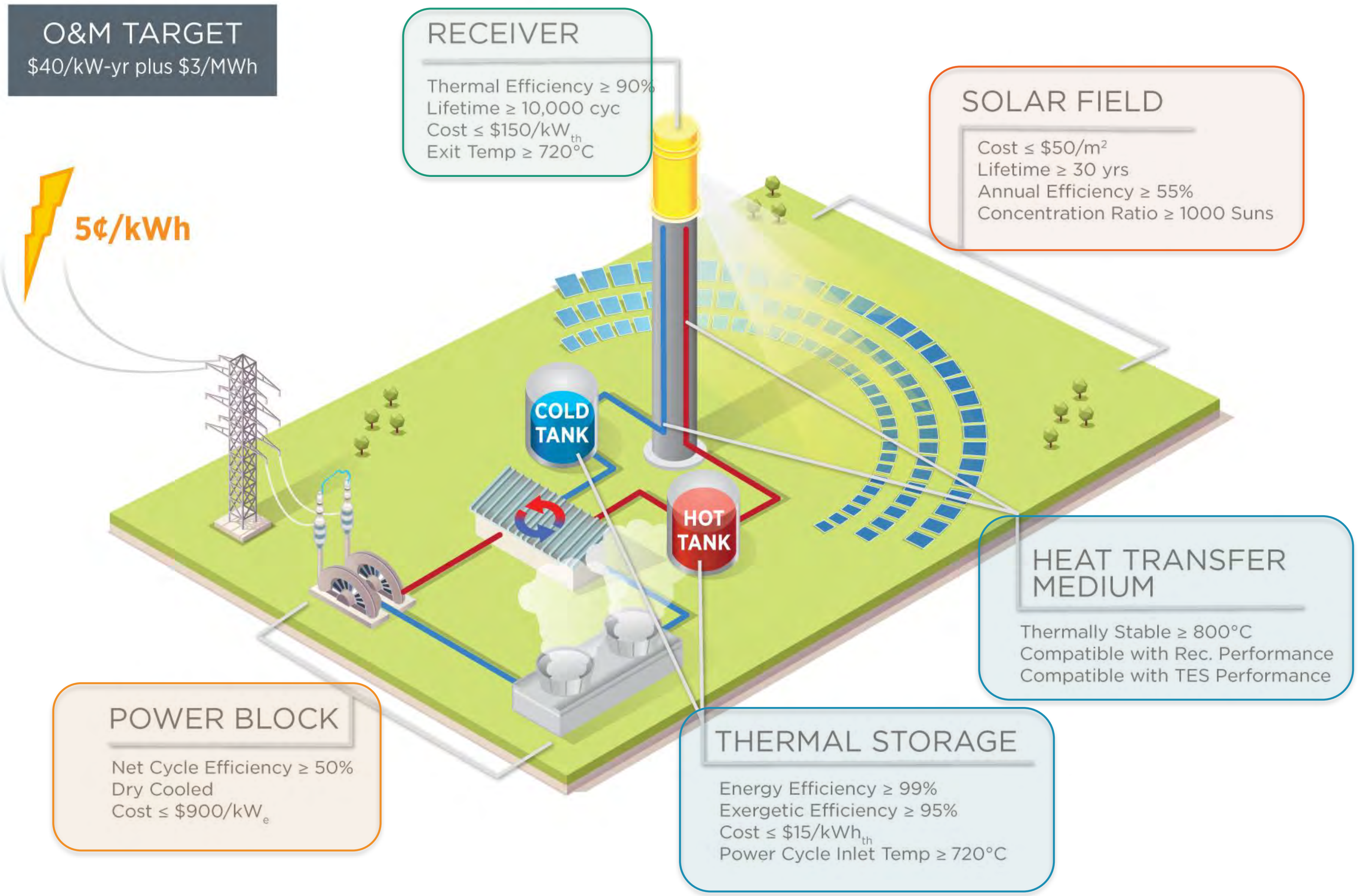
*Assumes a gross to net conversion factor of 0.9

Pathways to Achieving SunShot 2030 Goals



*Baseload power plant is defined as a CSP plant with greater than or equal to 12 hours of storage

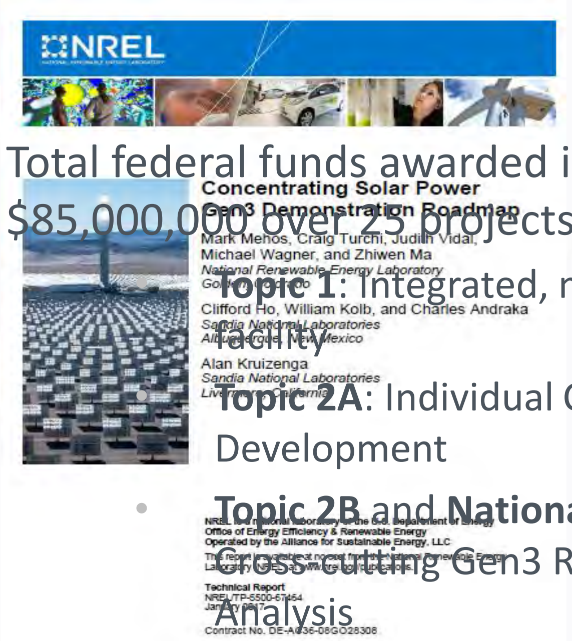
CSP Program Technical Targets



Competitive Programs

$33M	FY19 SETO FOA (2019)
$22M	FY18 SETO FOA (2019)
$21M	Solar Desalination (2018)
$22M	FY19-21 National Lab Call (2018)
$70M	Gen3 CSP Systems (2018)
$15M	Gen3 CSP Lab Support (2018)
$9M	COLLECTS (2016)
$32M	CSP: APOLLO (2015)
$29M	CSP SuNLaMP (2015)
$1.4M	SolarMat II (2014)
$10M	CSP: ELEMENTS (2014)
$1.1M	SunShot Incubator (Recurring)
$4M	PREDICTS (2013)
$2M	SolarMat (2013)
$10M	CSP-HIBRED (2013)
$27M	National Lab R&D (2012)
$10M	SunShot MURI (2012)
$56M	CSP SunShot R&D (2012)
$0.5M	BRIDGE (2012)
$62M	CSP Baseload (2010)

Gen3 CSP: Raising the Temperature of Solar Thermal Systems



Total federal funds awarded in 2018: $85,000,000 over 25 projects in 3 Topics:

- **Topic 1**: Integrated, multi-MW test facility
- **Topic 2A**: Individual Component Development
- **Topic 2B** and **National Lab Support**: Cross-cutting Gen3 Research and Analysis

http://www.nrel.gov/docs/fy17osti/67464.pdf

Gen3 CSP Topic 1 Awardees

Sandia National Laboratories

DOE Award (P1-2): $9,464,755

NREL NATIONAL RENEWABLE ENERGY LABORATORY

DOE Award (P1-2): $8,067,661

BraytonEnergy

DOE Award (P1-2): $7,570,647

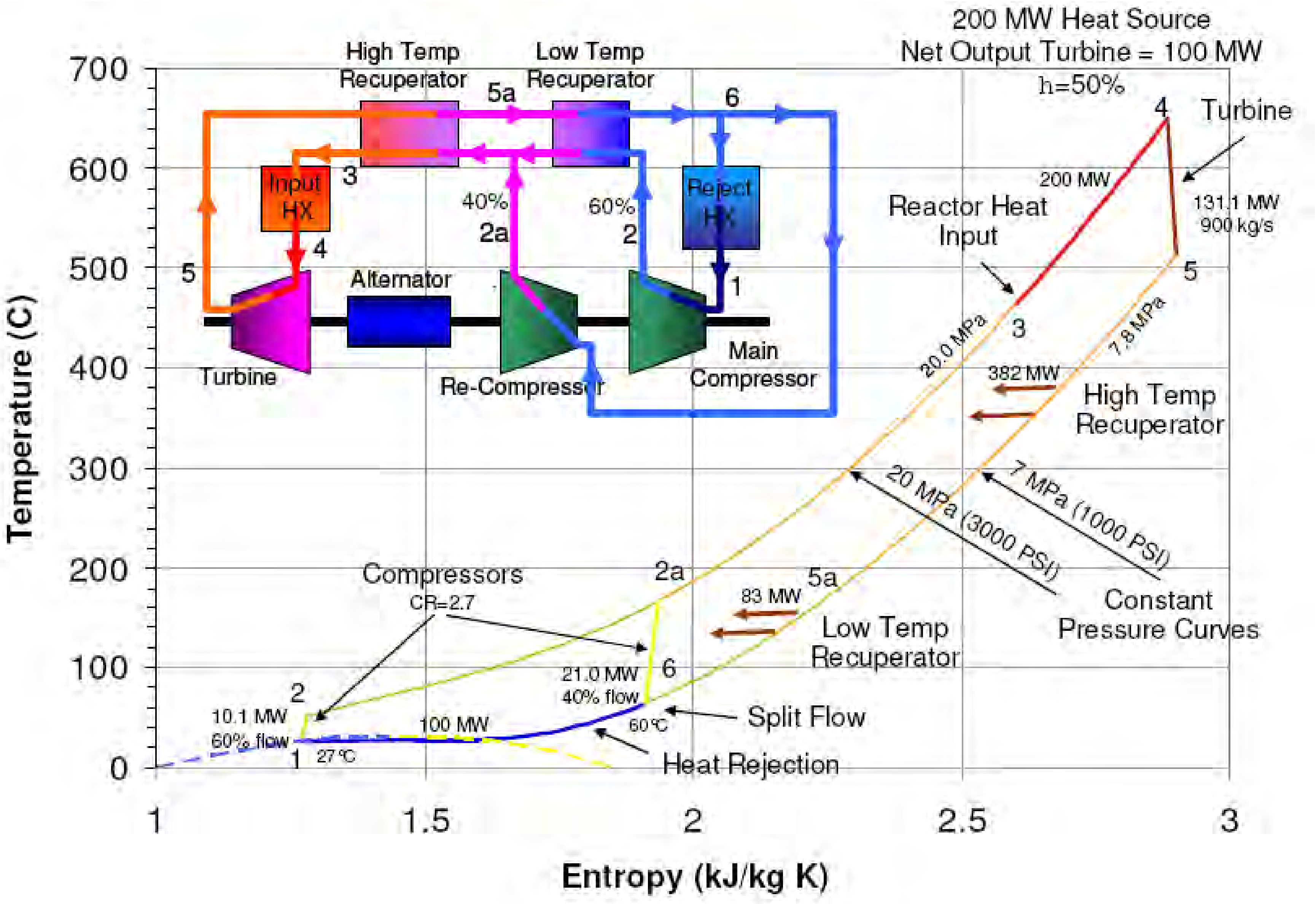
COLLECTOR FIELD	RECEIVER	THERMAL TRANSPORT	THERMAL STORAGE	HEAT TRANSFER MEDIA	HEAT EXCHANGE	POWER CYCLE
SOLID MEDIA	• Thermal Efficiency: • Particle Loss • Flow Velocity Control and Monitoring	• Reliability • Mechanical and Thermal Efficiency • Scalability • Insulation	• Charging and Discharging Particle loss, Efficiency, Scalability	• Particle Attrition • Optimized Performance Character	• Low Cycle Fatigue • Particle Mass Flow Control • Ramp Rates & Transients	
MOLTEN SALT	• Thermal Conductivity • Thermal Stability • Tube Strength and Durability	• Pipe Material Compatibility • Freeze Recovery • Pumps Valves Seals • Leak Detect	• Corrosion Behavior • Chemistry Monitoring and control • Tank Cost	• Characterize Material Properties • Cost / Supply Chain	• Material Compatibility w/ salt & CO_2 • Freeze Protection • Thermal Ramp Rates	
GAS	• High Pressure Fatigue • Absorptivity Control and Thermal Loss Management	• Recirculator Cost & Operating Power • Large Pipes High Cost	• Storage Concept not Determined	• Low Thermal Conductivity • Low Heat Capacity	• Requires High Area • Multiple Heat Exchangers • Cascading Temperature	

Development of sCO2 power cycles

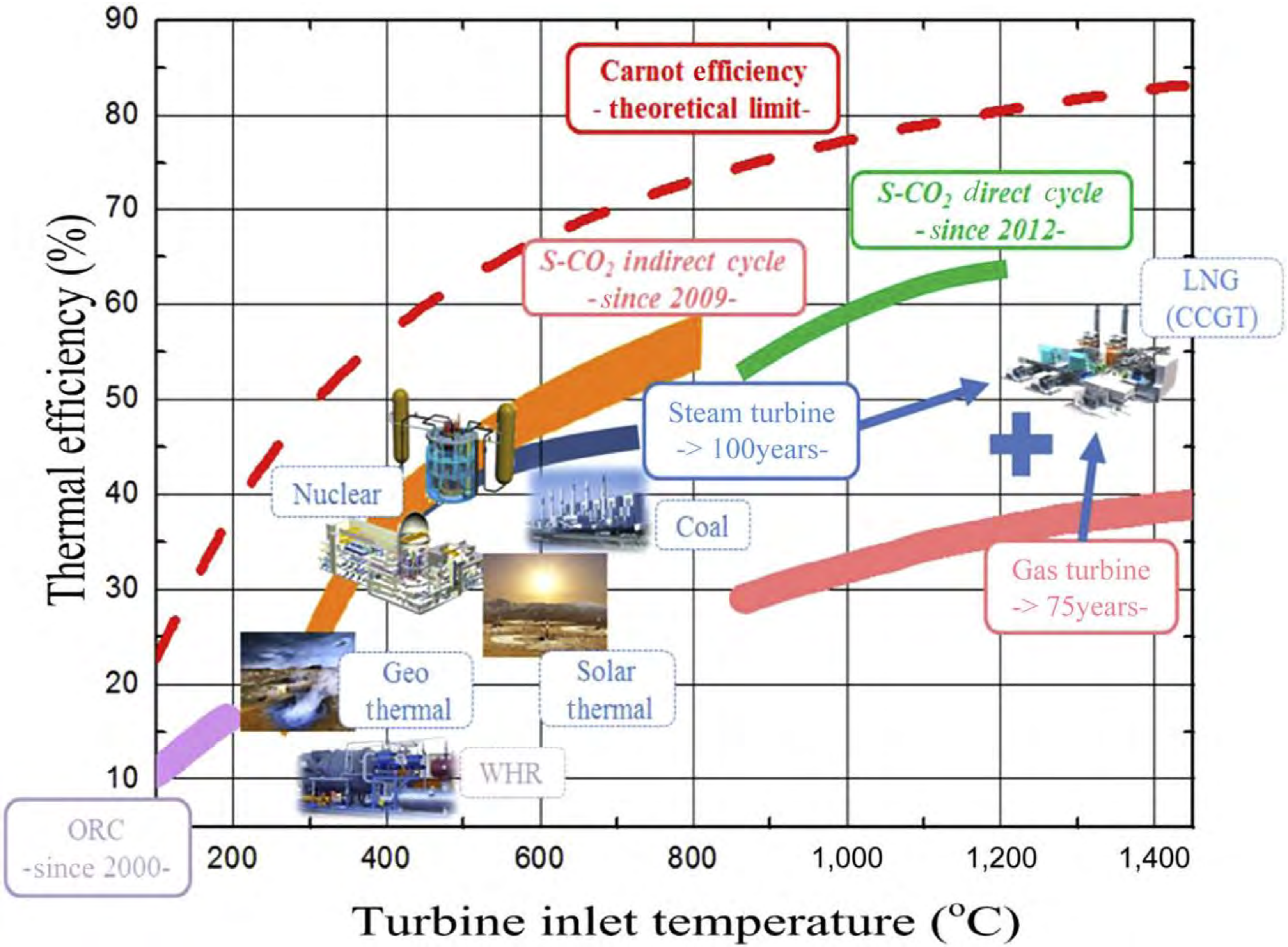
Progress Toward Commercial Deployment of sCO2 Brayton Power Cycles

Matthew D. Carlson, Sandia National Laboratories

The sCO2 Brayton Cycle [1]

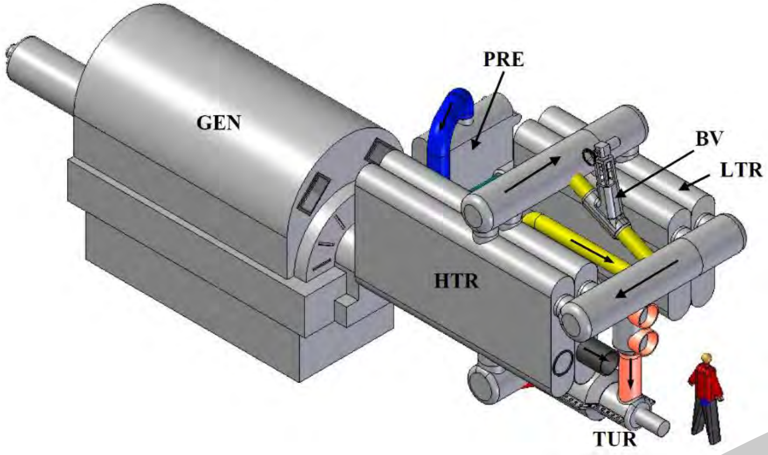


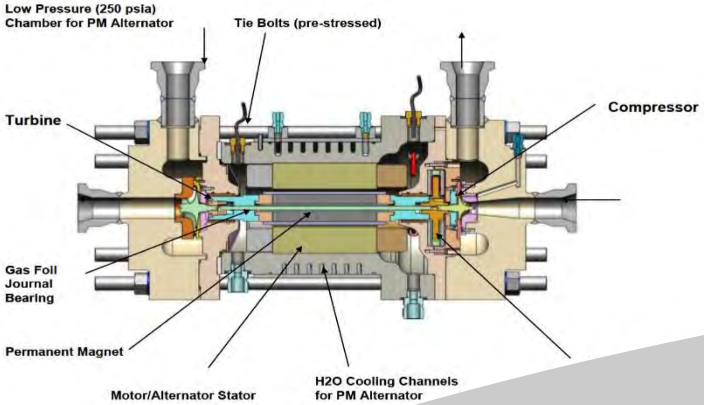
Comparison to Other Power Cycles [2]

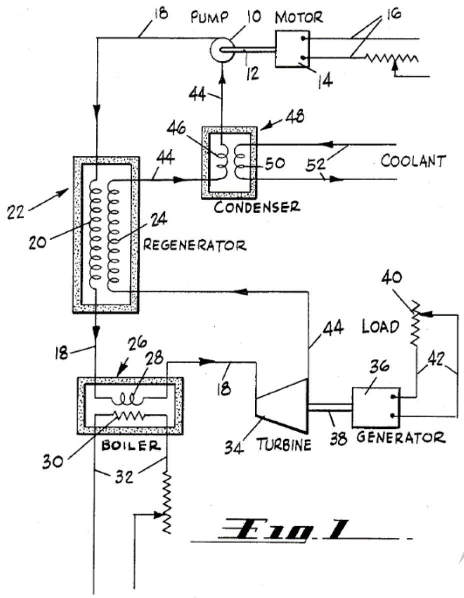


Critical Milestones in sCO2 R&D

1985
Heatric







1963
Cycle Concept

1997
Research Revival

2007
Prototypes
First sCO2 Symposium

2013
Widespread Interest
ASME Turbo Expo Track

[3-6]

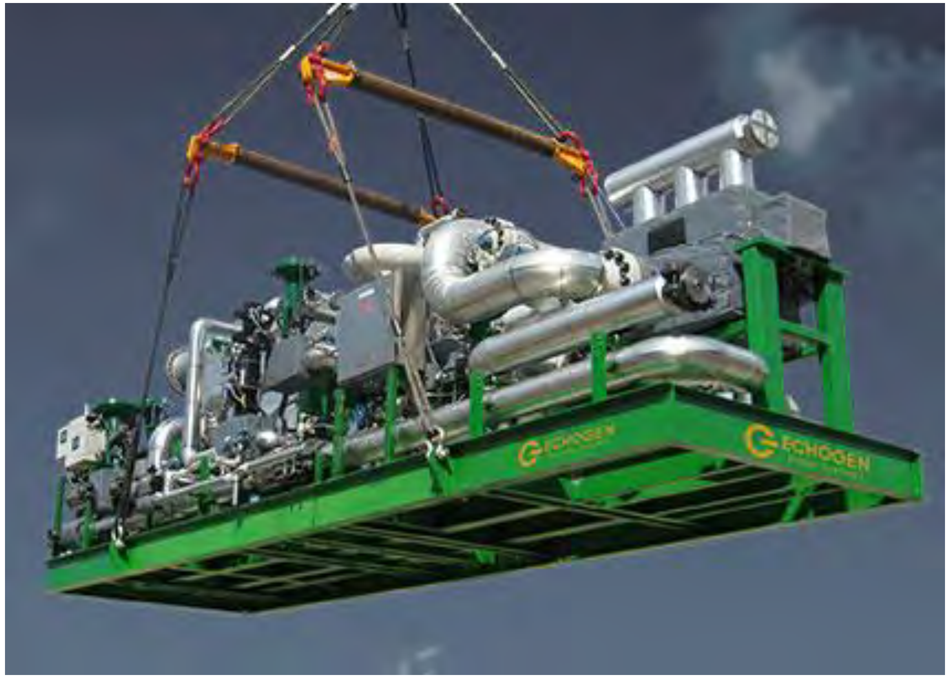
Commercially-relevant sCO2 pilot systems

Progress Toward Commercial Deployment of sCO2 Brayton Power Cycles

Matthew D. Carlson, Sandia National Laboratories

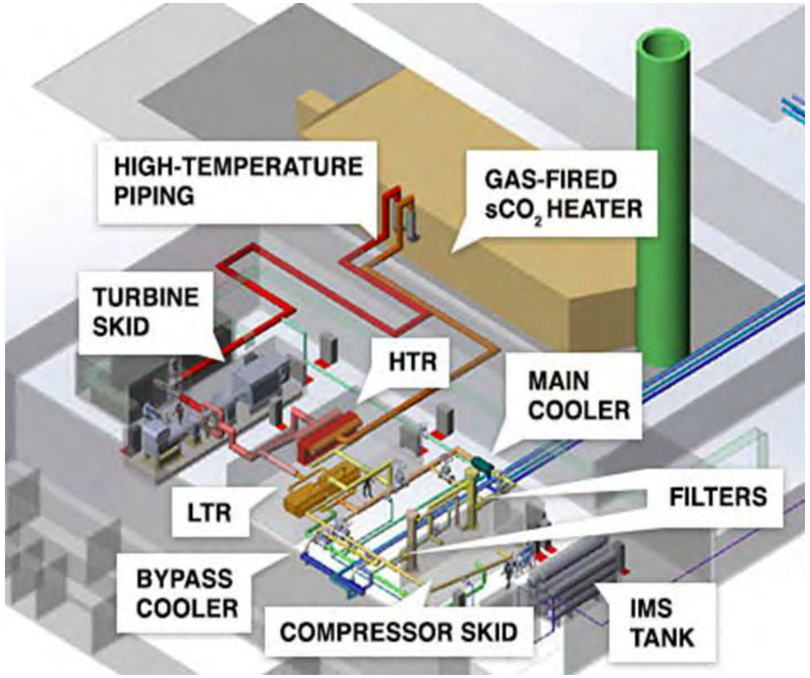
Echogen Power Systems – Akron, Ohio, USA [7,8]

- First commercial sCO2 Brayton power system
- Significant technical milestones including:
  1. Transportable skid-mounted system
  2. 7.3 MW_e design, 3.1 MW_e demonstrated
  3. 16 MW_{th} sCO2 recuperator (200 kW/K)
  4. Validation of design and transient models



STEP 10 MW Demonstration – San Antonio, Texas, USA [9]

- Largest indirect-fired sCO2 Brayton cycle
- Significant technical milestones including:
  1. 16 MW_{th} SwRI/GE turbine design
  2. 700 °C 740H turbine stop/control valve
  3. 715 °C 740H gas-fired heater
  4. Scheduled for operation in 2021



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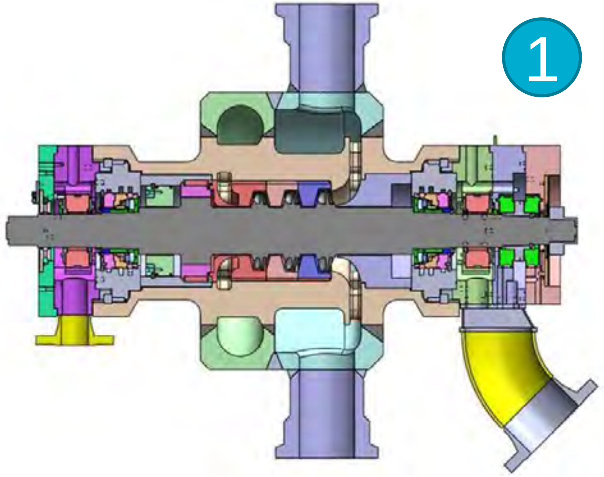

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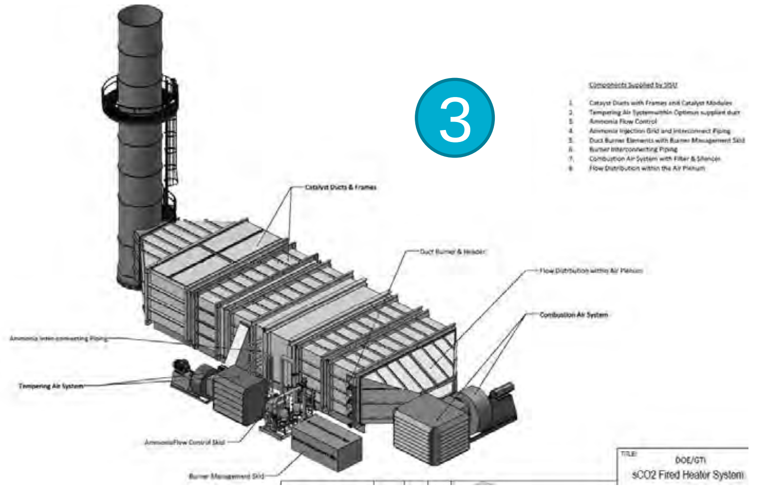
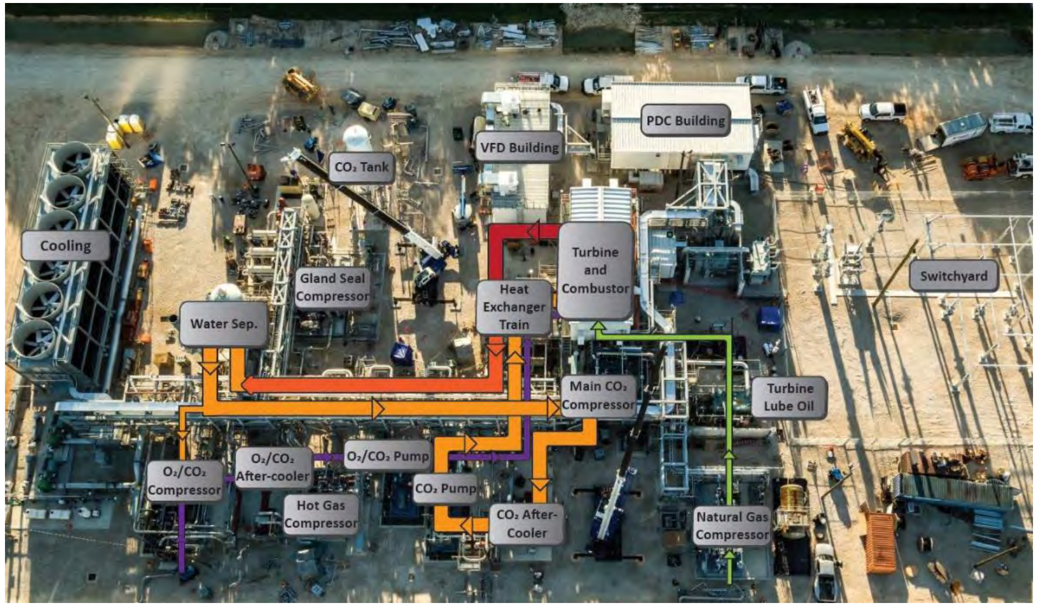
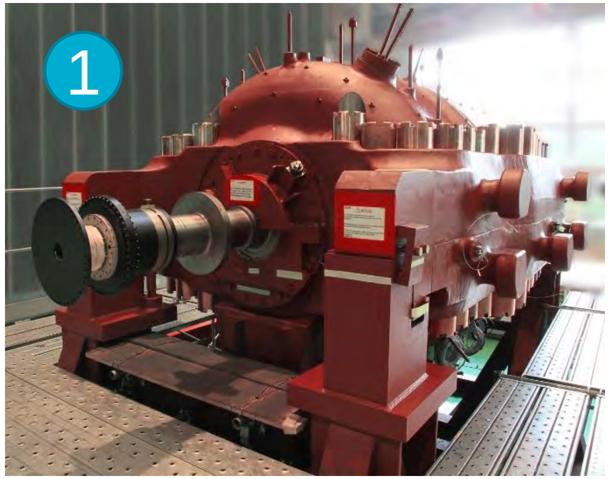
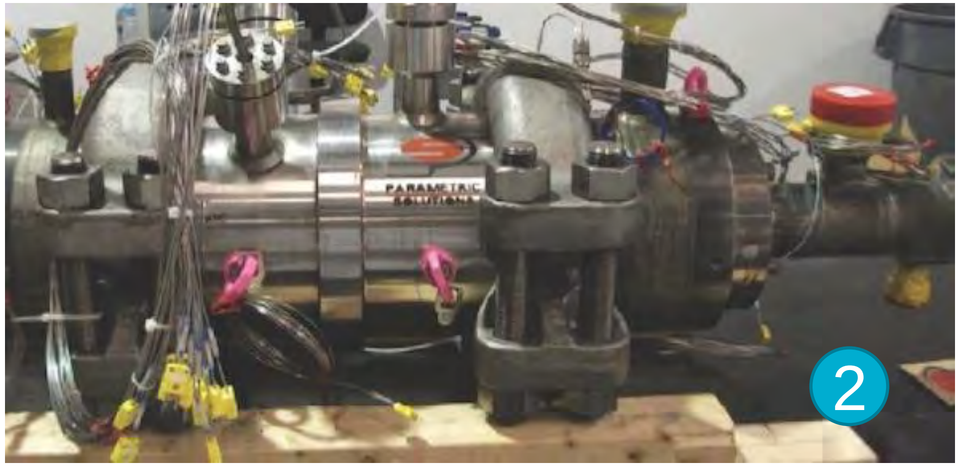


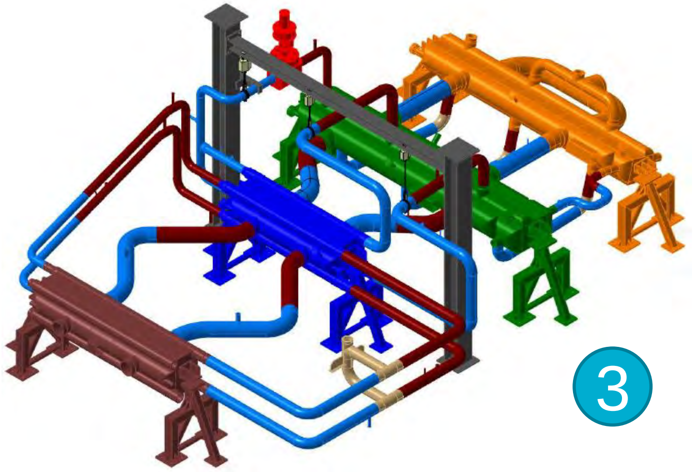
NET Power 50 MW_{th} Demonstration – La Porte, Texas, USA [10-13]

- Largest sCO2 Brayton power system
- Significant technical milestones including:
  1. 50 MW_{th} Toshiba turbine
  2. High pressure oxyfuel combustor
  3. Alloy 617 diffusion bonded heat exchanger
  4. First fire on 2018-05-30









Ongoing sCO2 research and future plans

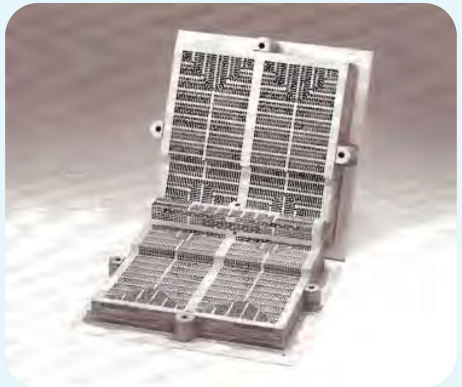
Progress Toward Commercial Deployment of sCO2 Brayton Power Cycles

Matthew D. Carlson, Sandia National Laboratories

R&D to Reduce the Cost of Heat Exchangers

Design [14,15]

Chemically Milled Diffusion Bonded



Chemically Blanked Diffusion Bonded

Micro-Tube and Shell

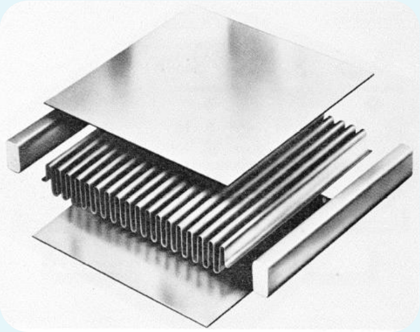
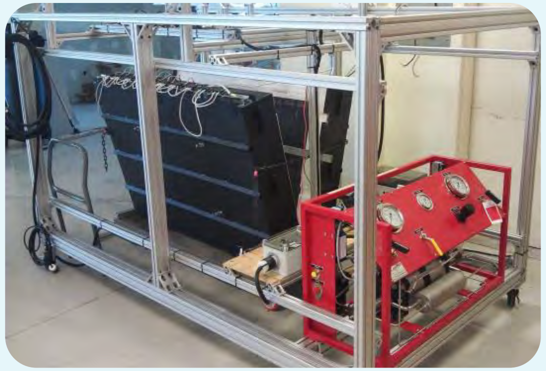


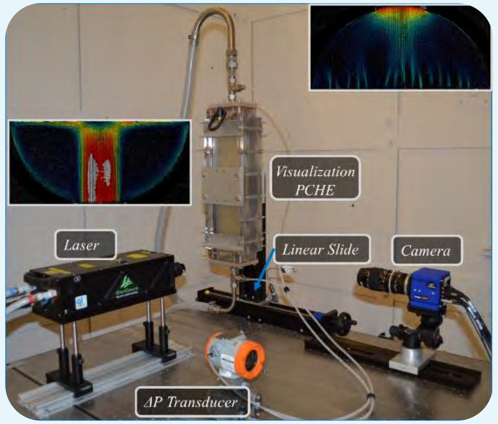
Plate-Fin

Testing [16]

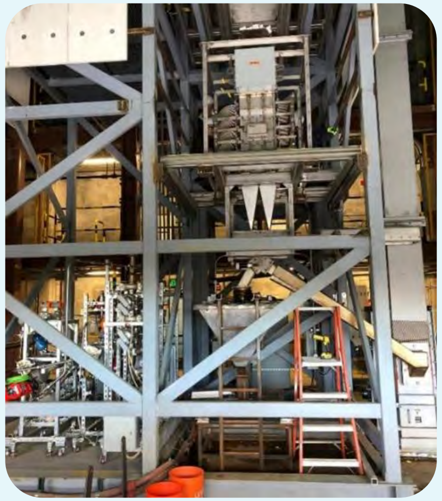
Pressure Fatigue



Thermal Fatigue & Creep



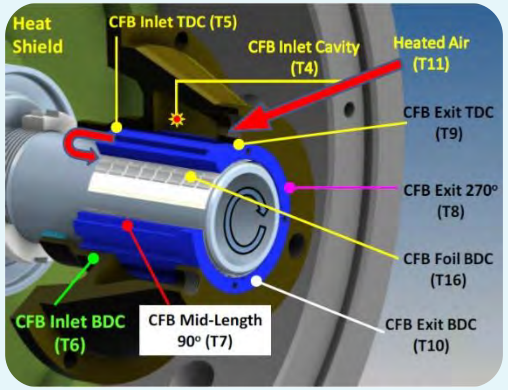
Flow Distribution



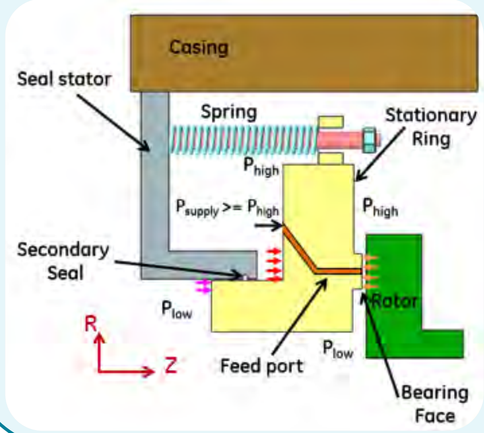
Performance

R&D to Increase the Reliability of Turbomachinery Systems

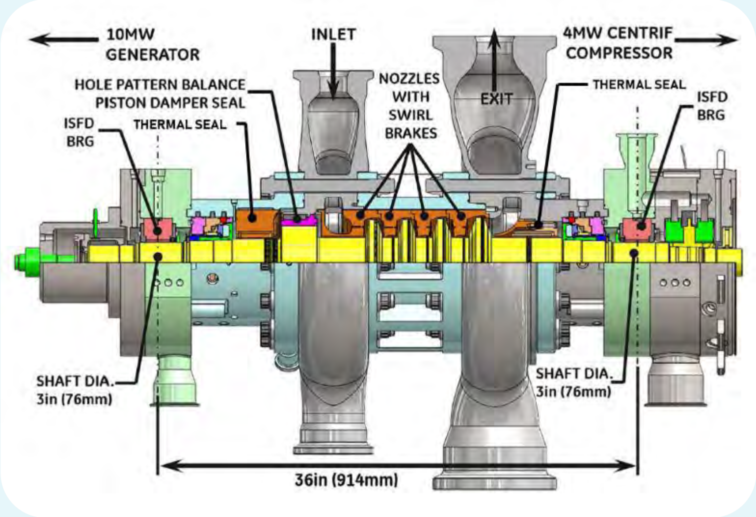
Bearings [17]

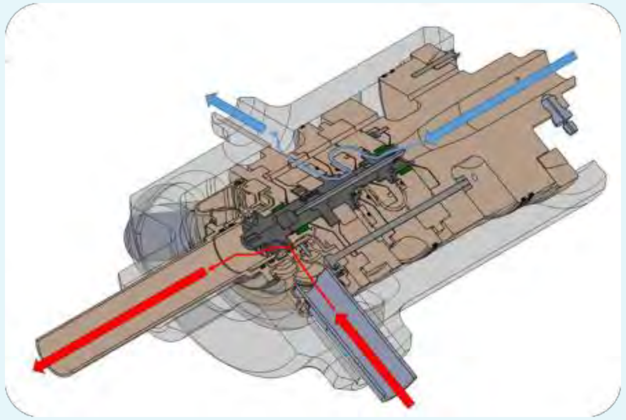


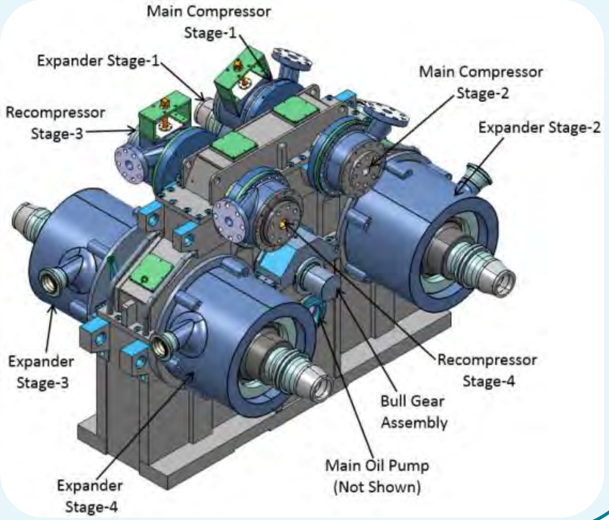
Seals [18]



Integration [19-21]



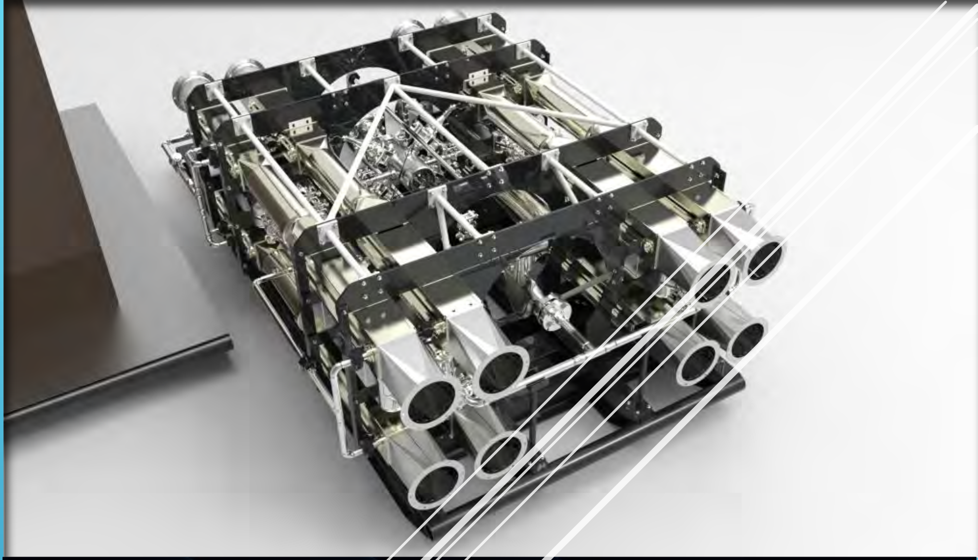




NREL SCO2 POWER CYCLE WORKSHOP 2019

David Stapp
CEO/CTO
Peregrine Turbine Technologies, LLC

October 31, 2019

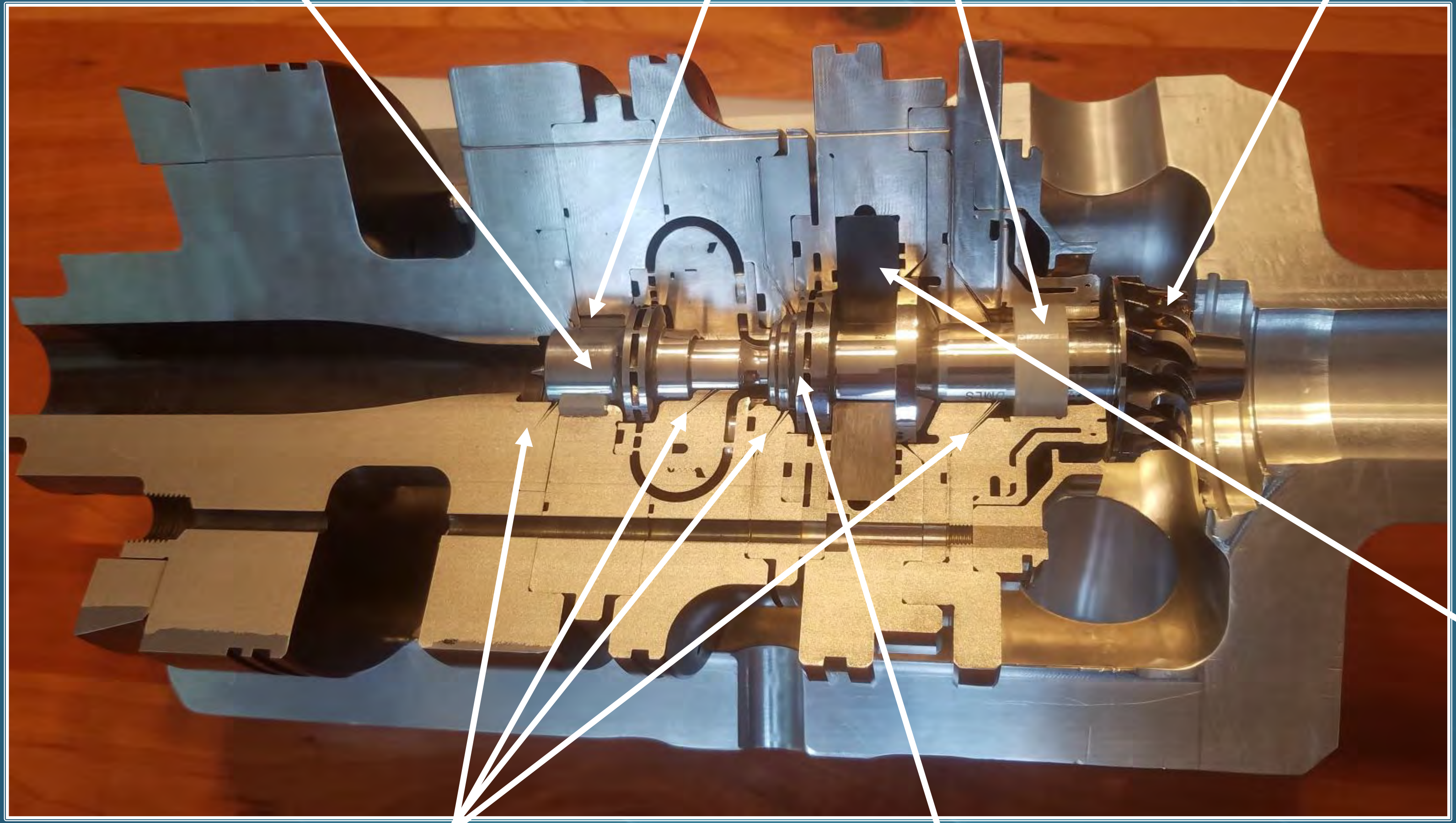


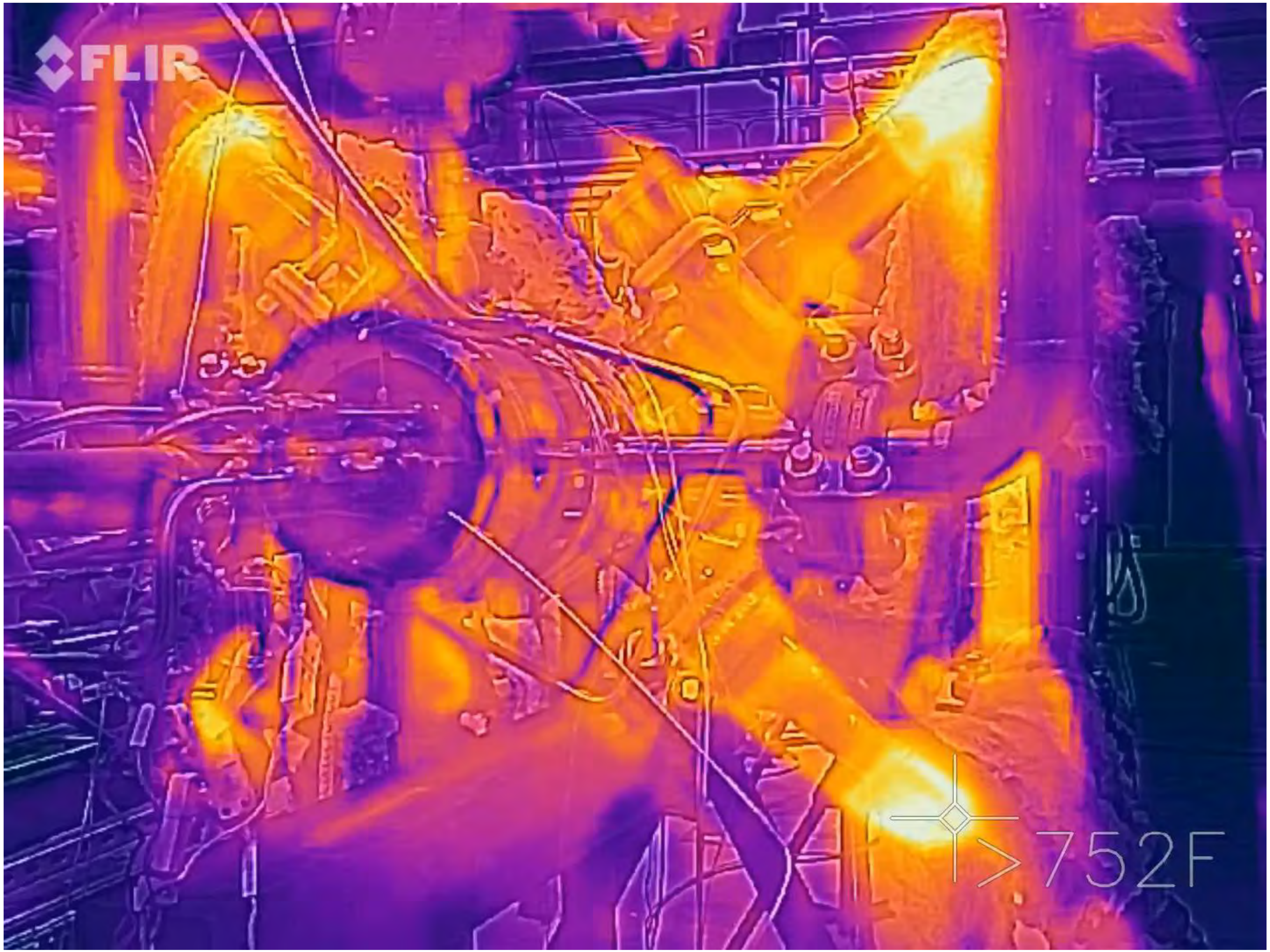
Peregrine Turbopump:

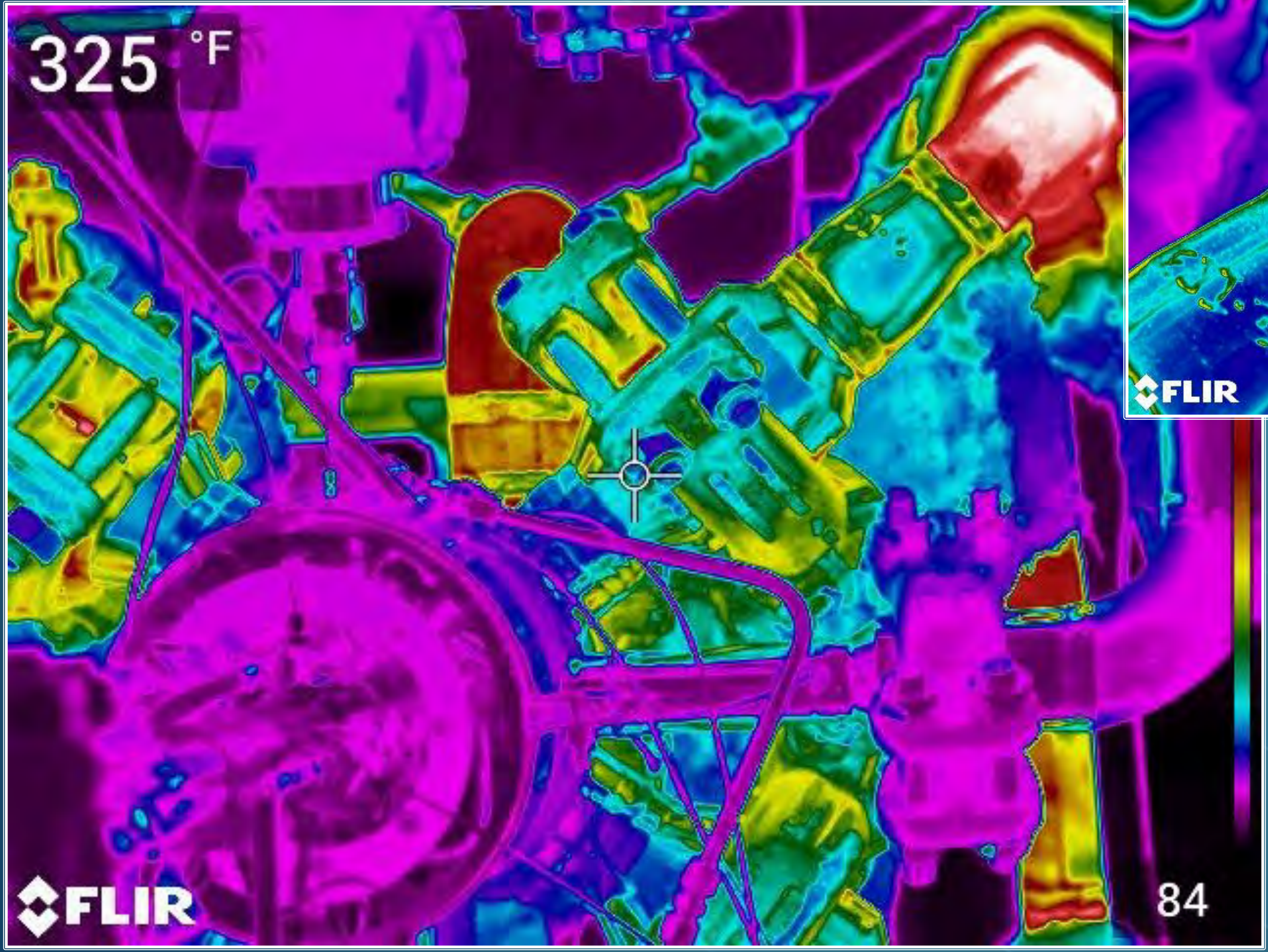
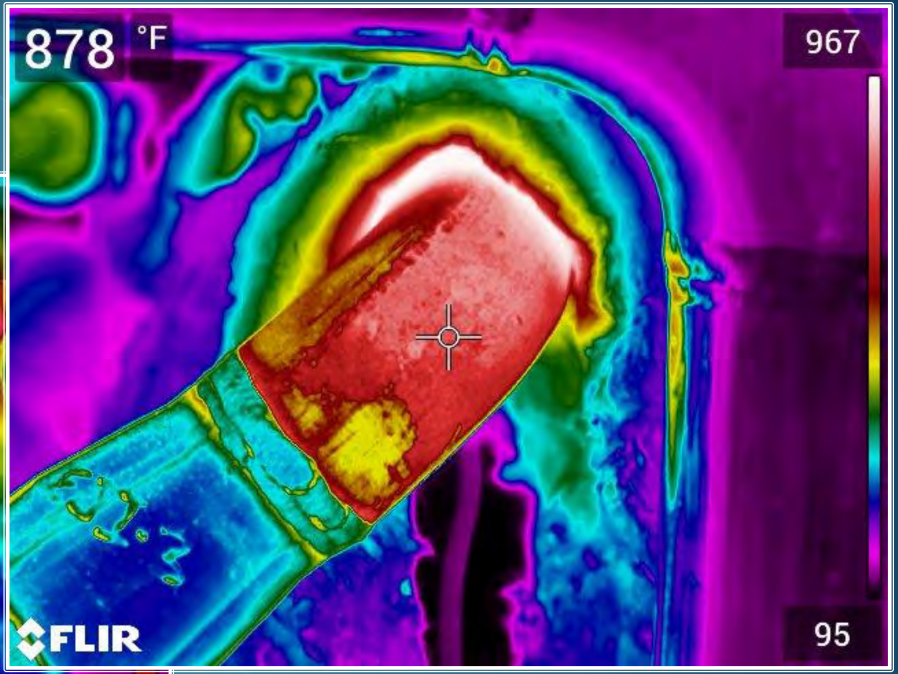
Designed under an AFRL SBIR Phase III with private match. Part of a two-spool 1MW asynchronous electric power generator.

- Motorless Operation, blowdown start
- CDP – 6220 psi (42.9 MPa)
- Mass Flow Rate – 12.13 lbm/s
- Pressure Ratio – 5.5
- Turbine Inlet Temp - 1382°F (750°C)
- Design Speed – 118,350 rpm

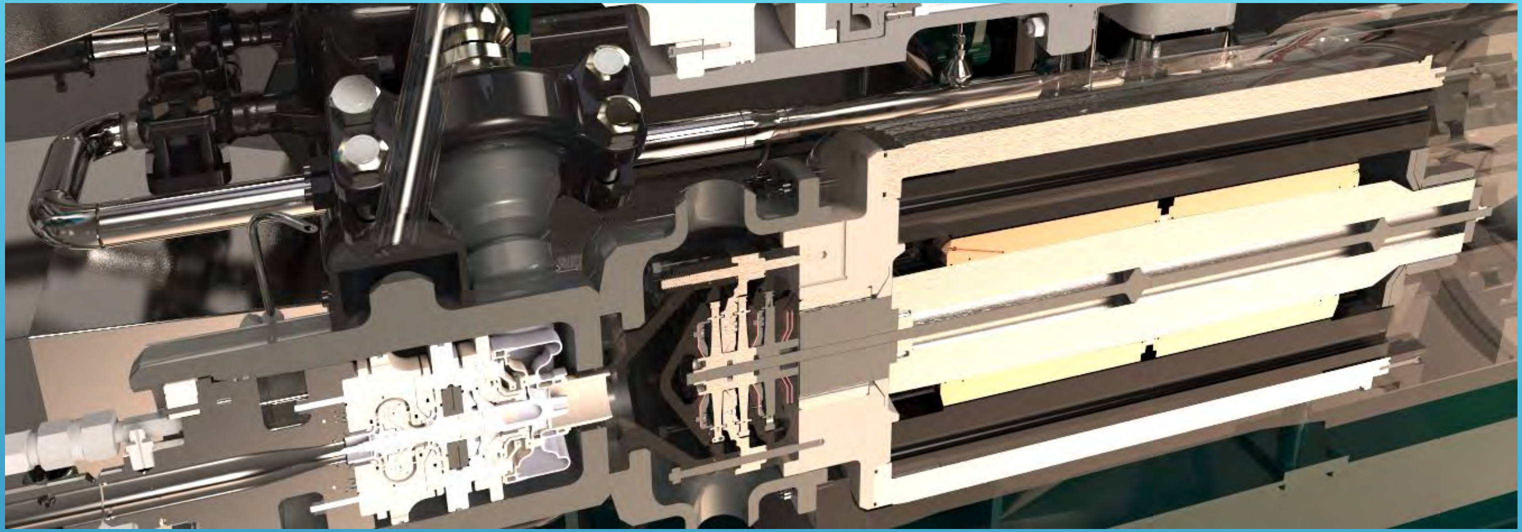
Approximately 40 hrs of testing completed at Sandia to date with speeds up to 91krpm and turbine inlet temps of 1000°F. Expect to surpass 200 hrs by year end.

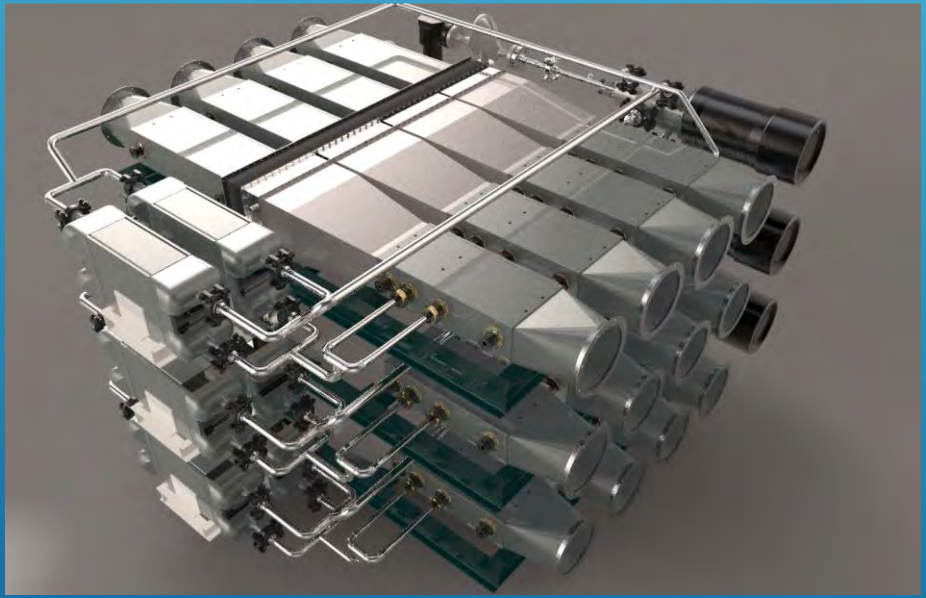

Stg 1 Radial Compressor
Gas Foil Radial Bearings
HP Radial Inflow Turbine
Gas Static Thrust Bearings
Pressure Activated Leaf Seals
Stg 2 Radial Compressor


FLIR
752F


325 °F
84
FLIR

878 °F
967
95
FLIR

- Application of Modular Design Solutions





Future Conferences with an sCO2 R&D Focus

7th International sCO_2 Power Cycles Symposium – 2020

Tutorial Sessions: March 30, 2020

Conference: March 31-April 2, 2020

Gen3 projects – The Big 3

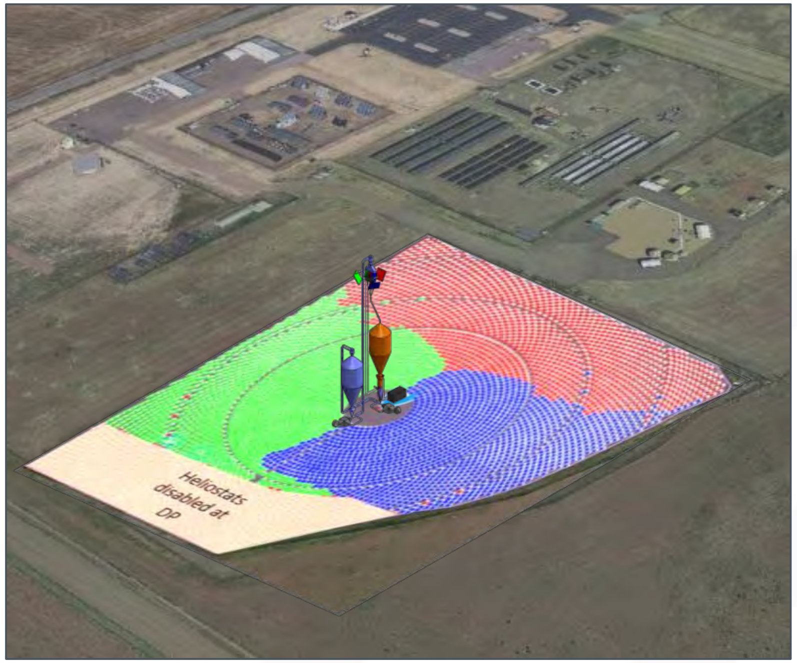
Progress Toward Commercial Deployment of sCO2 Brayton Power Cycles

SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

BraytonEnergy

Quarterly Report

Gen3 Gas Phase System Development & Demonstration



Principal Investigator: Shaun Sullivan

Other Contributors: NREL National Renewable Energy Laboratory, BrightSource, Worley energy | chemicals | resources, Advisian Worley Group, DLR, Echogen power systems, Heliogen, EPRI, Greg Mehos, Ph.D., P.E., SolarDynamics

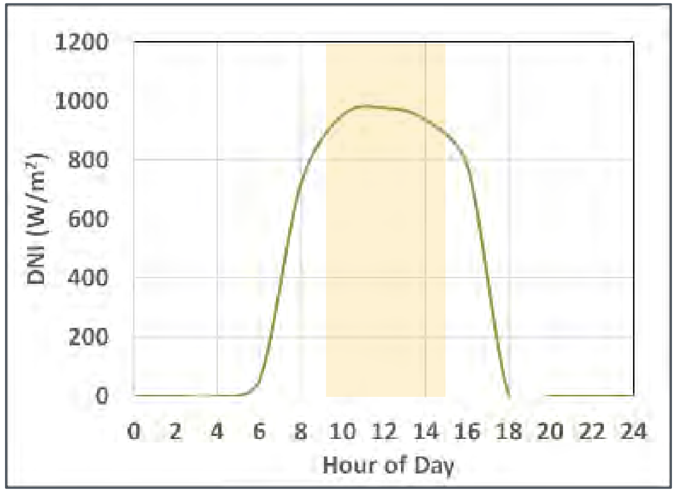
BraytonEnergy

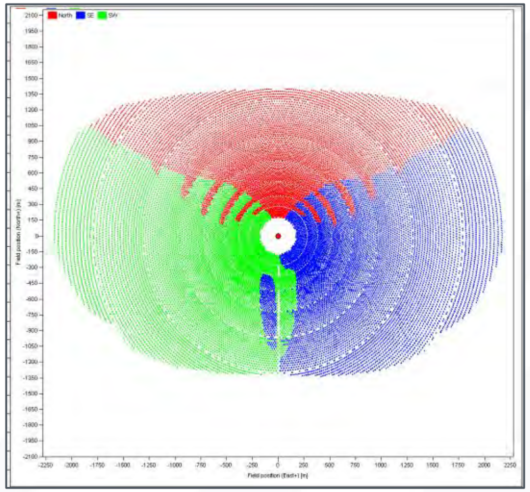
Award # DE-EE0008368

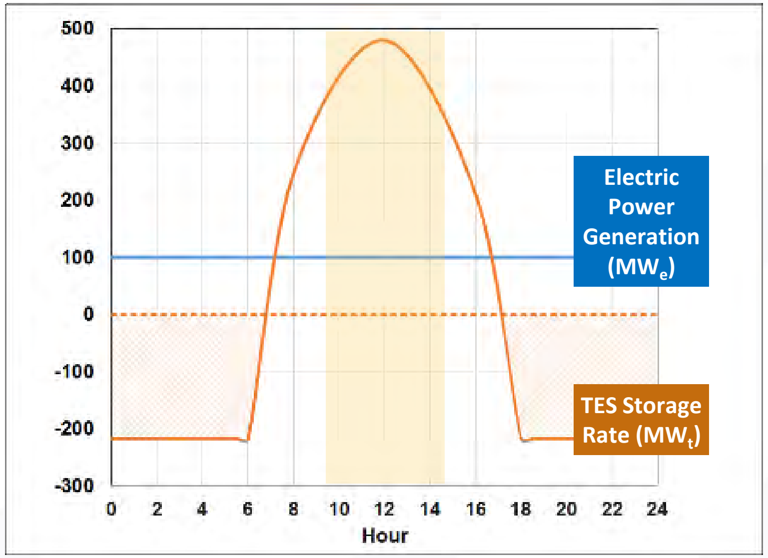
SolarTAC Technology Acceleration Center, SOLEX Thermal Science, Wisconsin University of Wisconsin-Madison

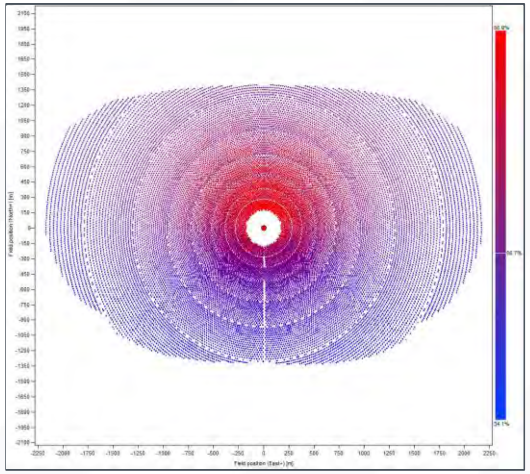
energy.gov/solar-office

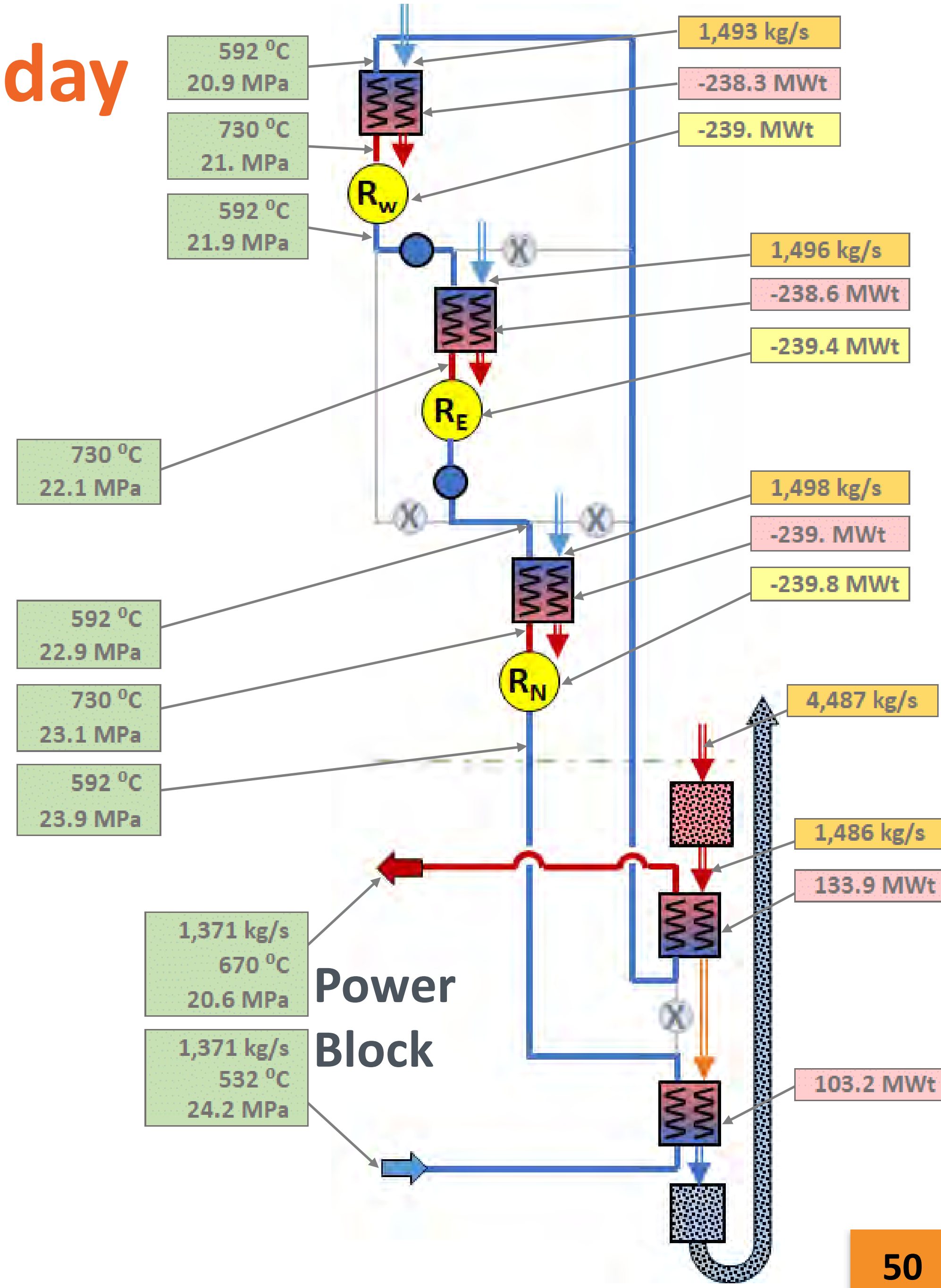
Commercial Baseload Operation: Midday







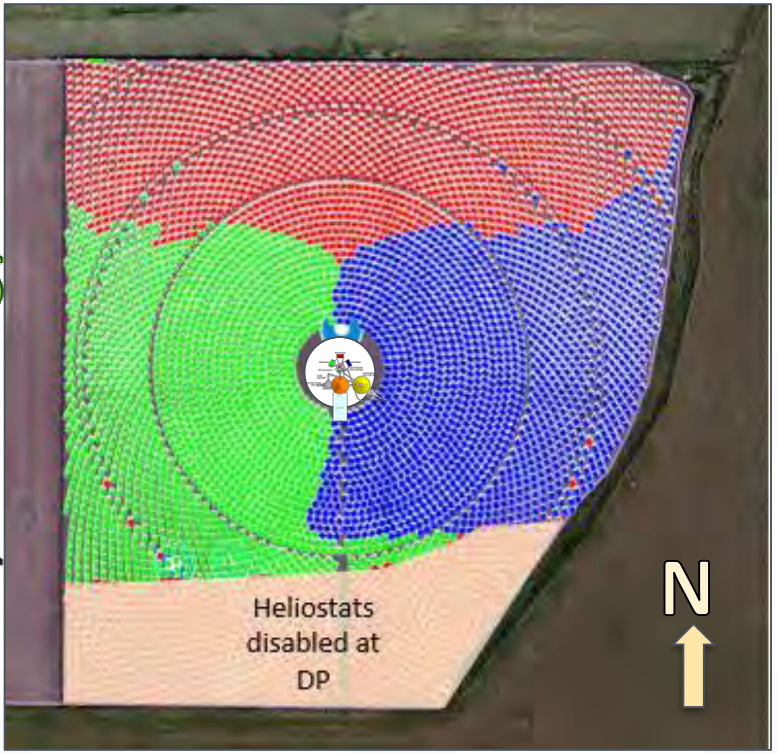


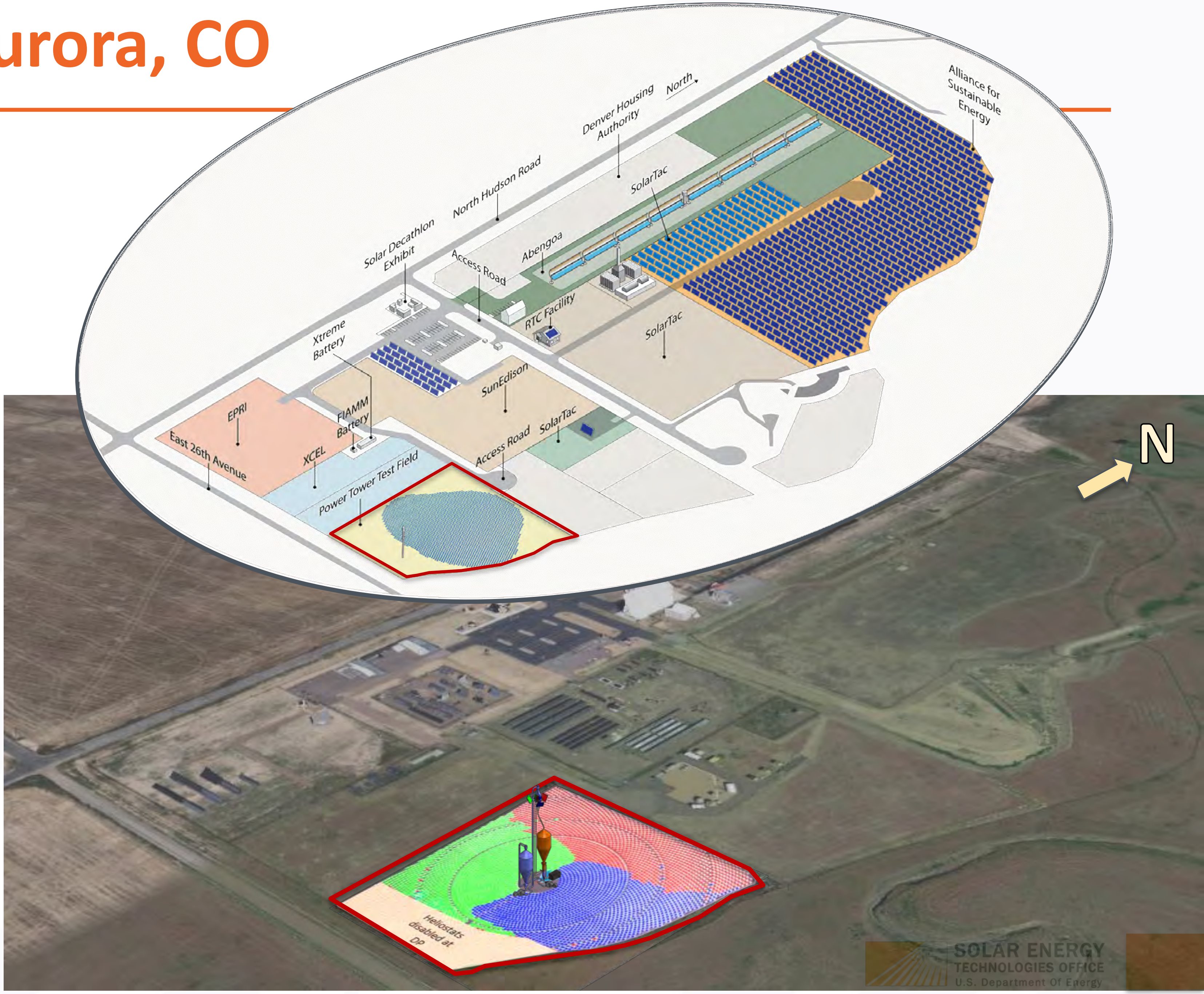


BraytonEnergy

Phase 3 Testing: Aurora, CO

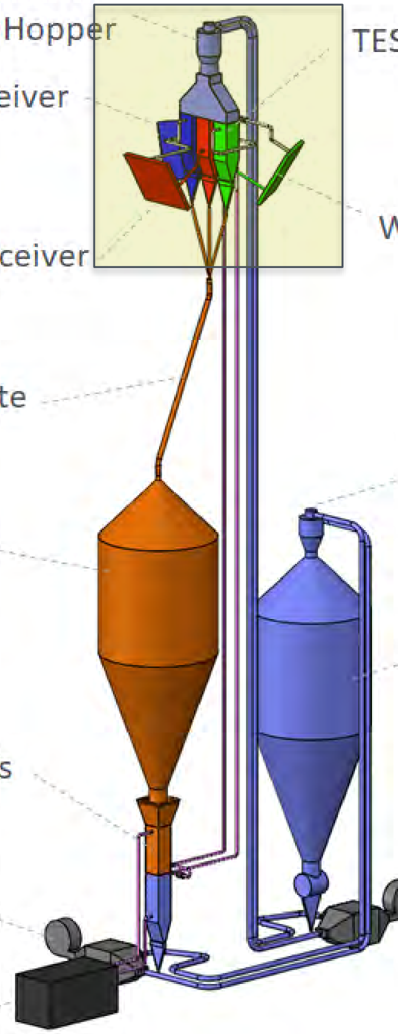
- 3 MW_t System
- 1 MW_t “Power Block”
- Fully representative operation

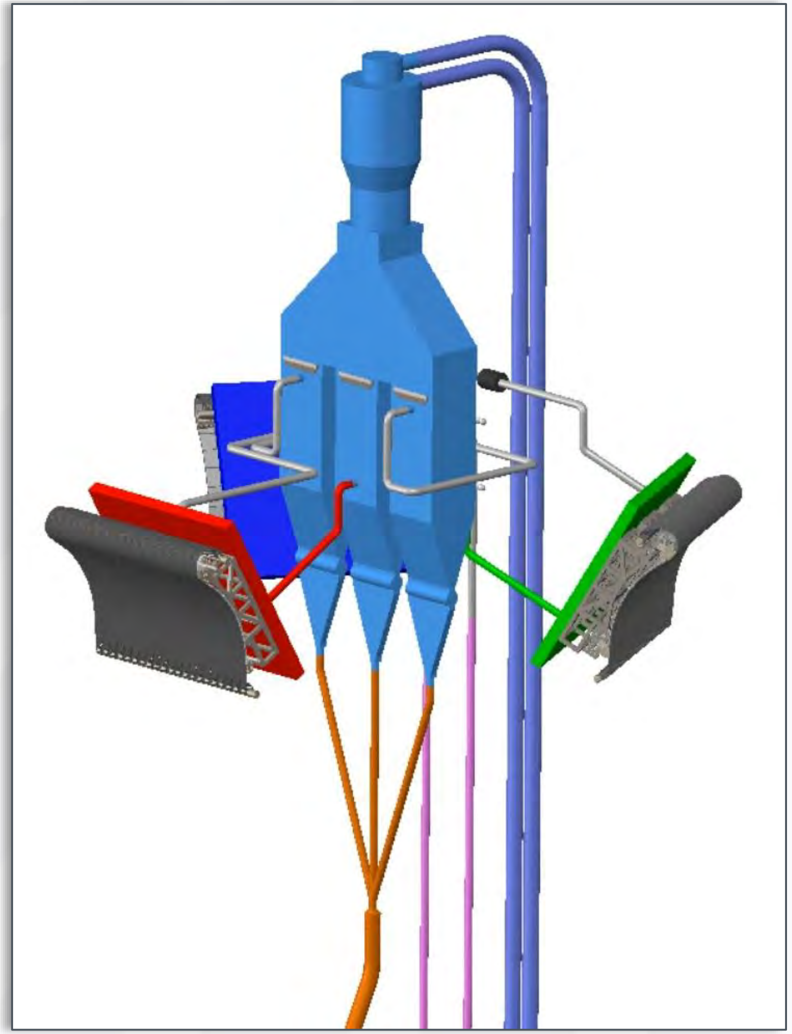




BraytonEnergy

Phase 3 Layout



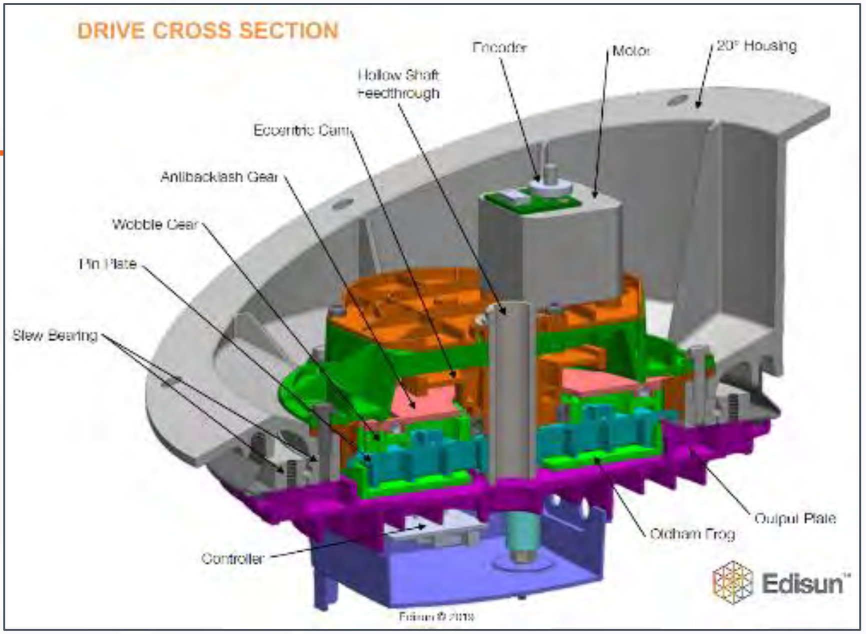


BraytonEnergy

Edisun Heliostats

Heliogen Heliostat

- ~1.5 m^2 Mirrored Area each
  - approaching \$100/m^2, targeting \$75/m^2
- 1 mrad slope error
- 1 mrad aiming error
- Closed loop control

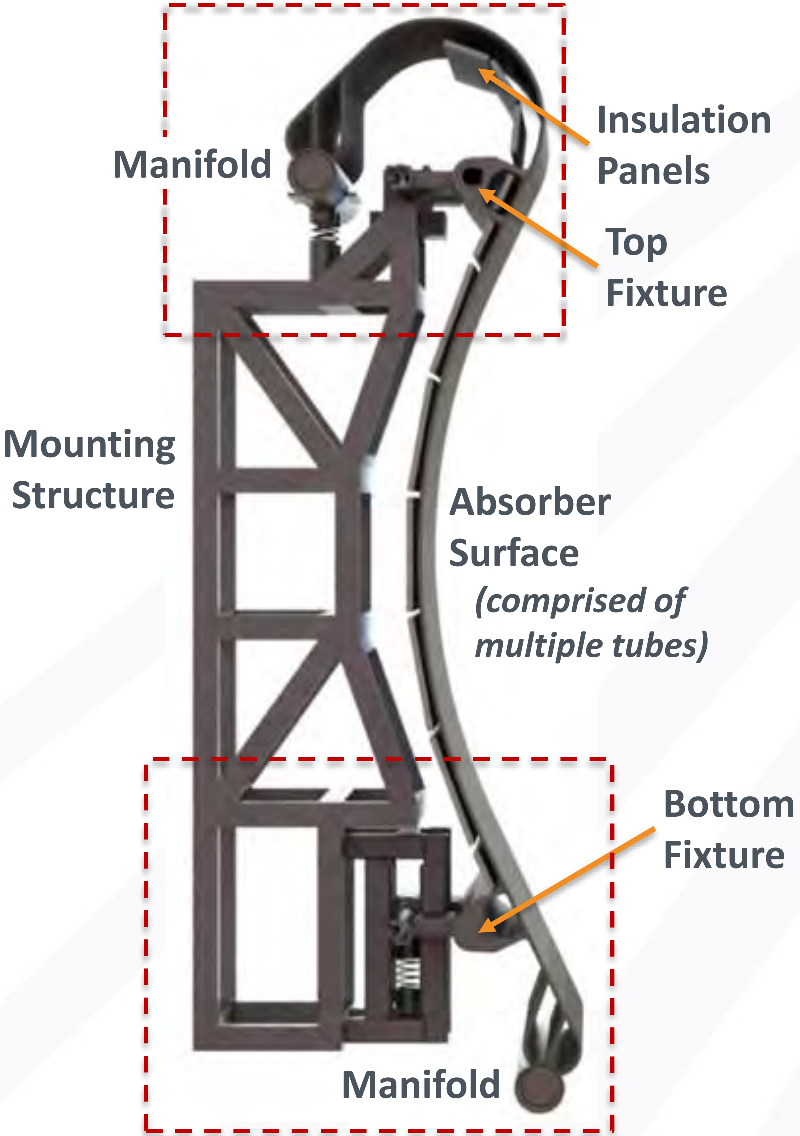


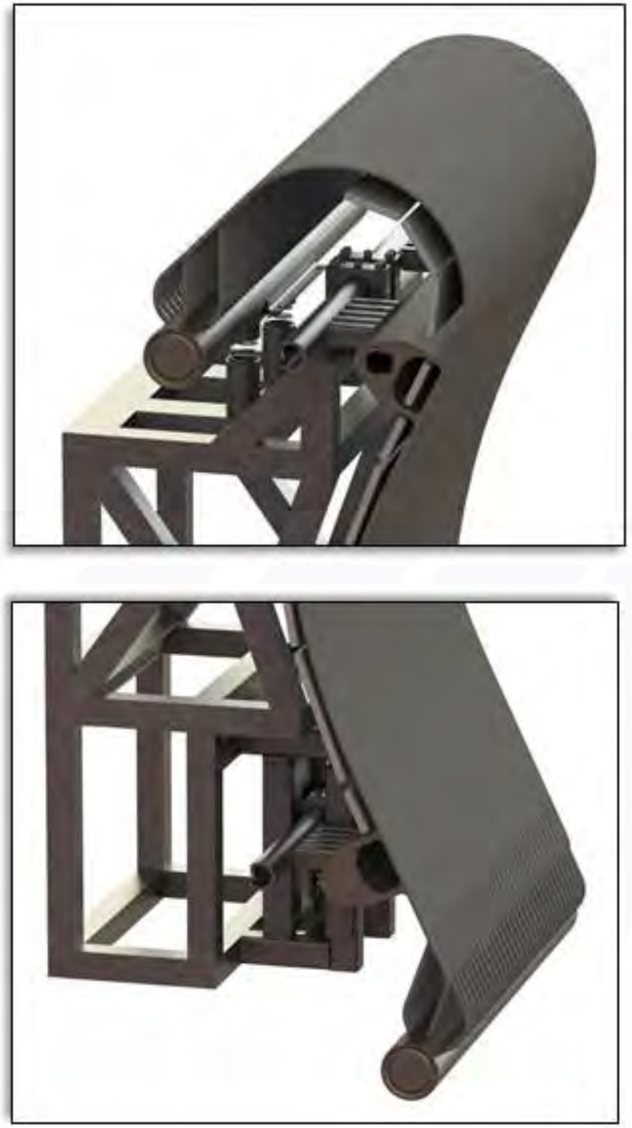
Heliogen Test Facility in Lancaster, CA

BraytonEnergy

Receiver Layout: Commercial Panel

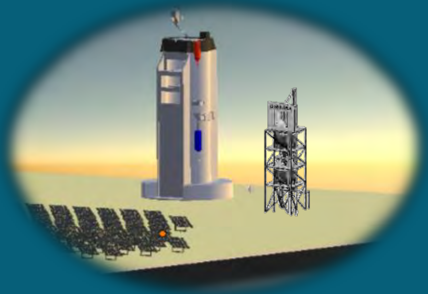
- Each modular absorber panel is factory built
- Each receiver is comprised of multiple panels





BraytonEnergy

Overview and Design Basis for the Gen 3 Particle Pilot Plant (G3P3)



SolarPACES 2019, October 1 – 4, 2019, Daegu, South Korea

SAND2019-11615 C

Clifford K. Ho, Kevin J. Albrecht, Lindsey Yue, Brantley Mills, Jeremy Sment, Joshua Christian, and Matthew Carlson

Concentrating Solar Technologies
Sandia National Laboratories, Albuquerque, New Mexico, USA

Contributors: Georgia Tech, King Saud University, DLR, CSIRO, U. Adelaide, Australian National University, CNRS-PROMES, EPRI, Bridgers & Paxton, Bohannan Huston, Solar Dynamics, CARBO Ceramics, Solex Thermal Science, Vacuum Process Engineering, Allied Mineral Products, Matrix PDM, Saudi Electricity Company

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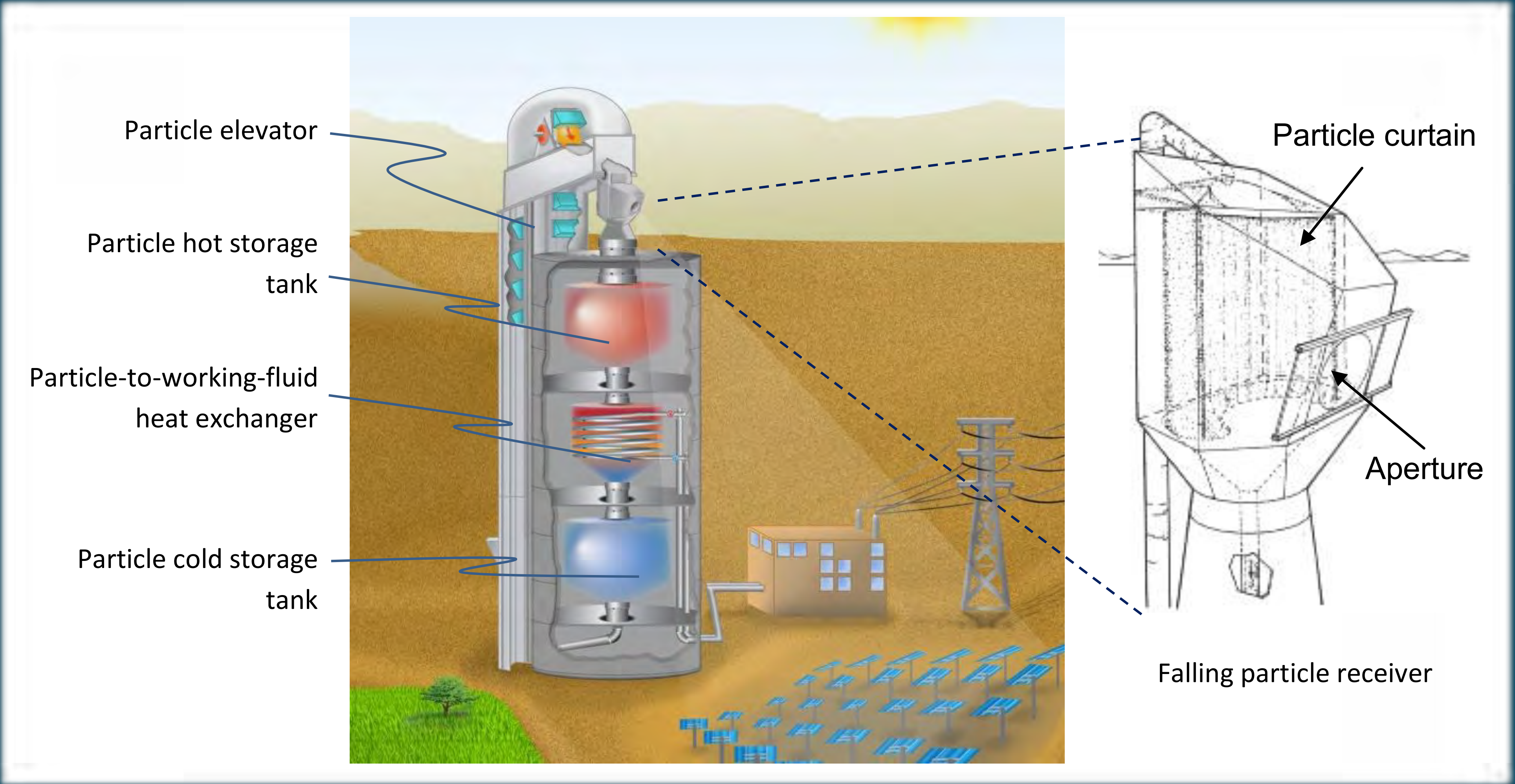
Large International Team

Role	Team Members	
PI / Management	• Sandia National Laboratories	
R&D / Engineering	• Sandia National Laboratories • Georgia Institute of Technology* • King Saud University** • German Aerospace Center (DLR)**	• CSIRO** • U. Adelaide** • Australian National University** • CNRS-PROMES**
Integrators / EPC	• EPRI* • Bridgers & Paxton* / Bohannan Huston	
CSP Industry	• SolarDynamics*	
Component Developers / Industry	• Carbo Ceramics • Solex Thermal Science** • Vacuum Process Engineering* • FLSmidth	• Materials Handling Equipment • Allied Mineral Products* • Matrix PDM*
Utility	• Saudi Electricity Company**	

*15 subcontracts (**8 international)

High-Temperature Falling Particle Receiver

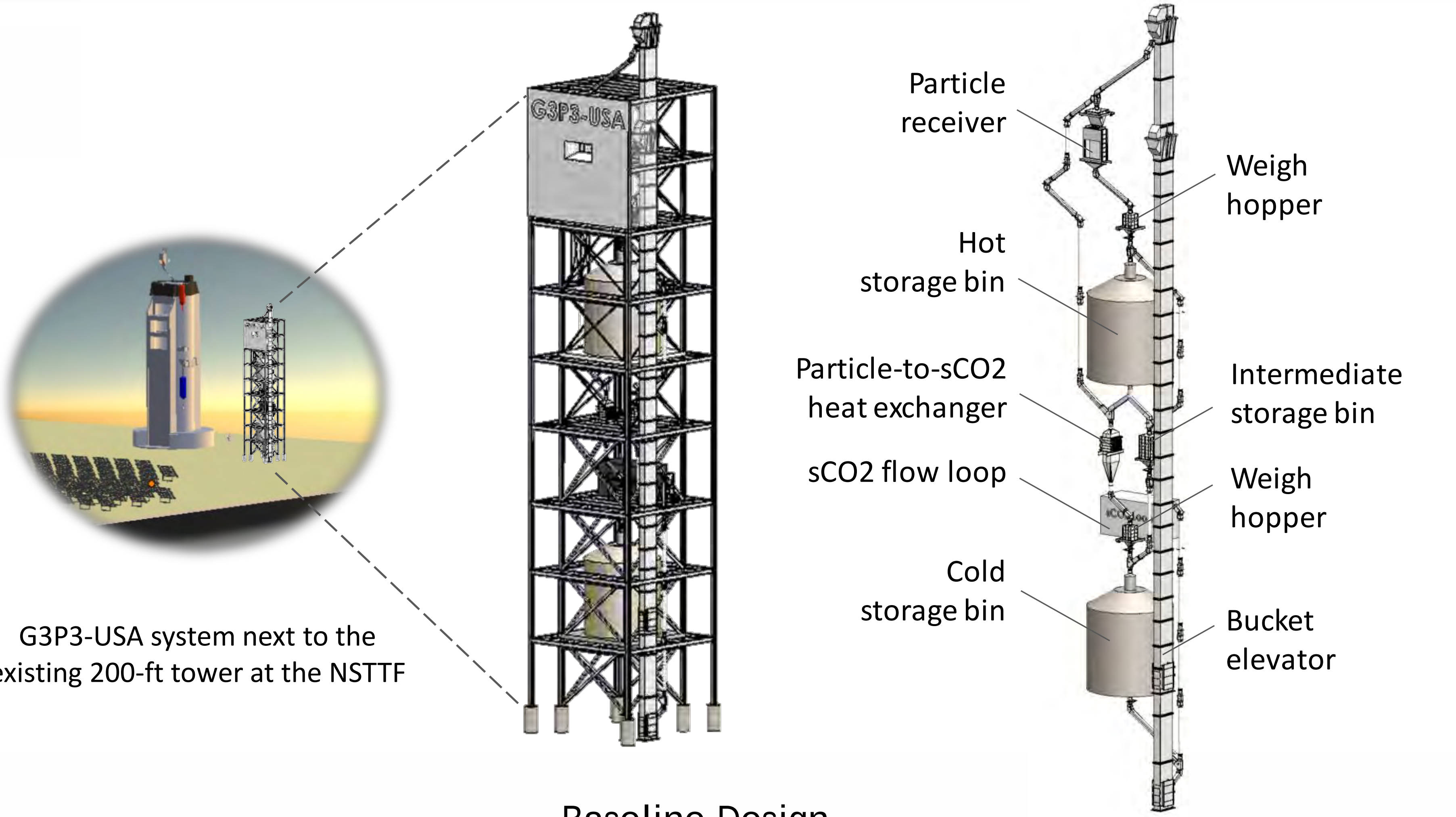


Falling particle receiver

Goal: Achieve higher temperatures, higher efficiencies, and lower costs

Gen 3 Particle Pilot Plant (G3P3)

Integrated System



G3P3-USA system next to the existing 200-ft tower at the NSTTF

Baseline Design

Particles

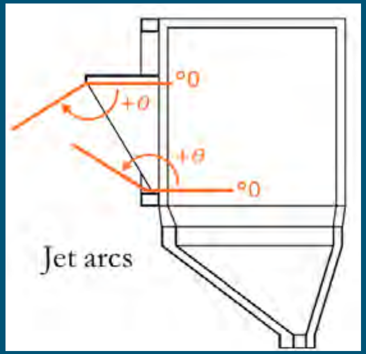
- Cost
  - ≤ $1/kg
- Durability
  - Low wear/attrition
- Optical properties
  - High solar absorptance
- Flowability, low erosion
- Inhalation hazards (e.g., silica, PM2.5)

CARBO HSP 40/70

Other Receiver Innovations

High-Performance CFD modeling
Brantley Mills, Sandia National Laboratories

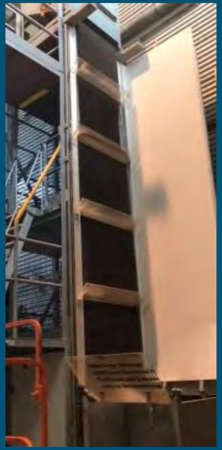
Quartz aperture covers
(SNL, DLR; Yue et al., 2019)

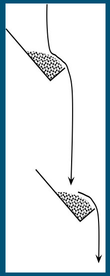


Active airflow (SNL, ANU, Adelaide; Yue et al., 2019)

Free Falling

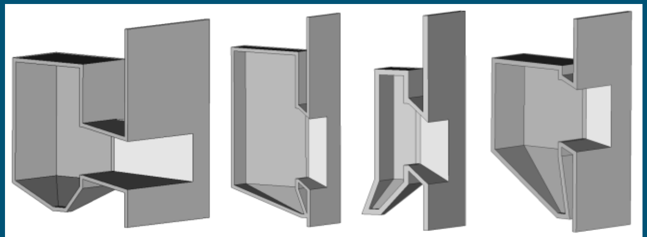
Catch-and-Release

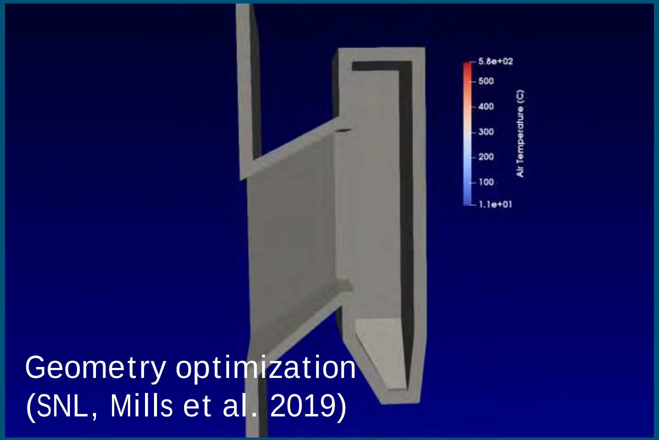




Multi-stage release
(CSIRO, SNL, Adelaide, ANU; Kim et al., 2019)

Videos from Jin-Soo Kim (CSIRO)

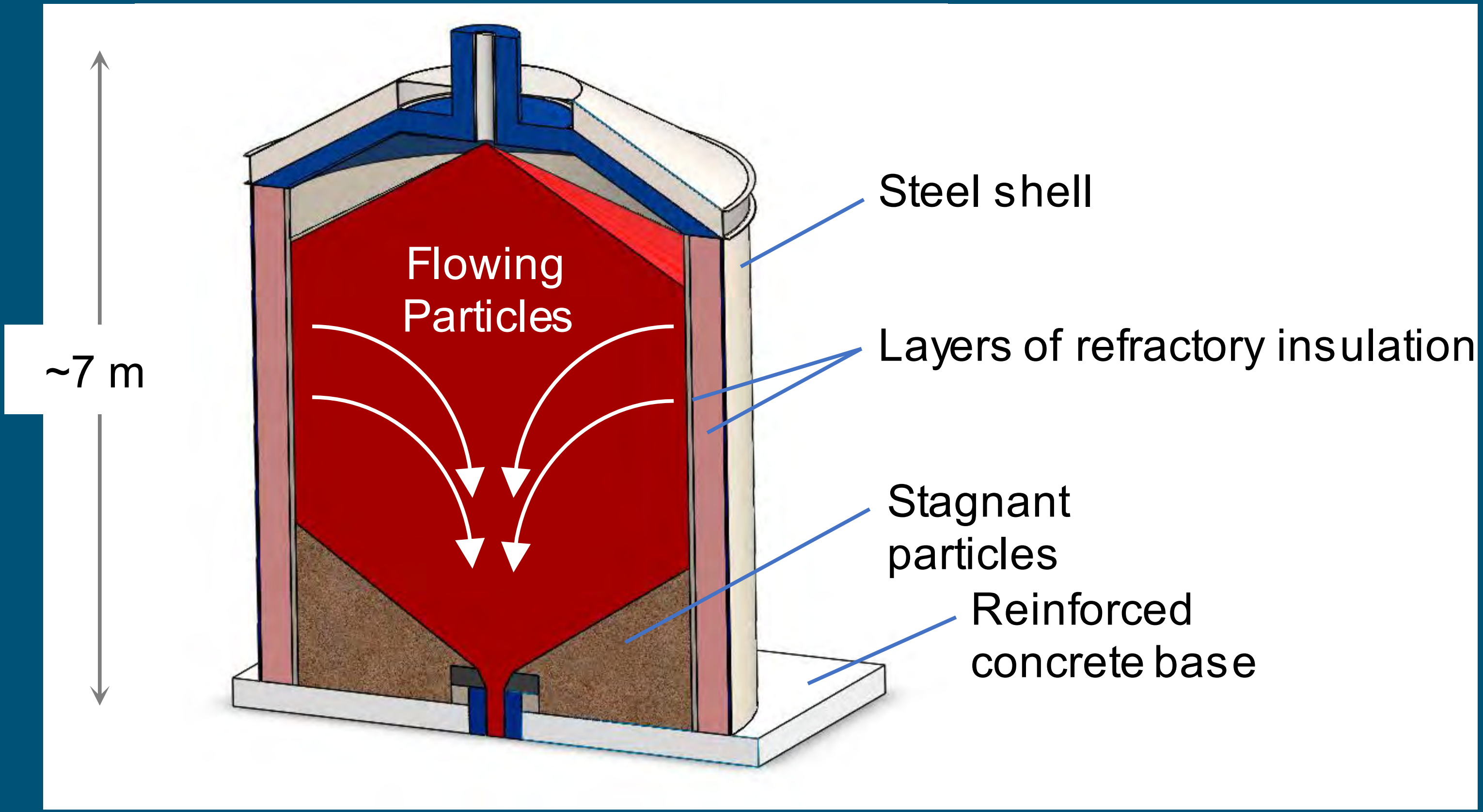




Geometry optimization
(SNL, Mills et al. 2019)

G3P3 Storage Tank Design

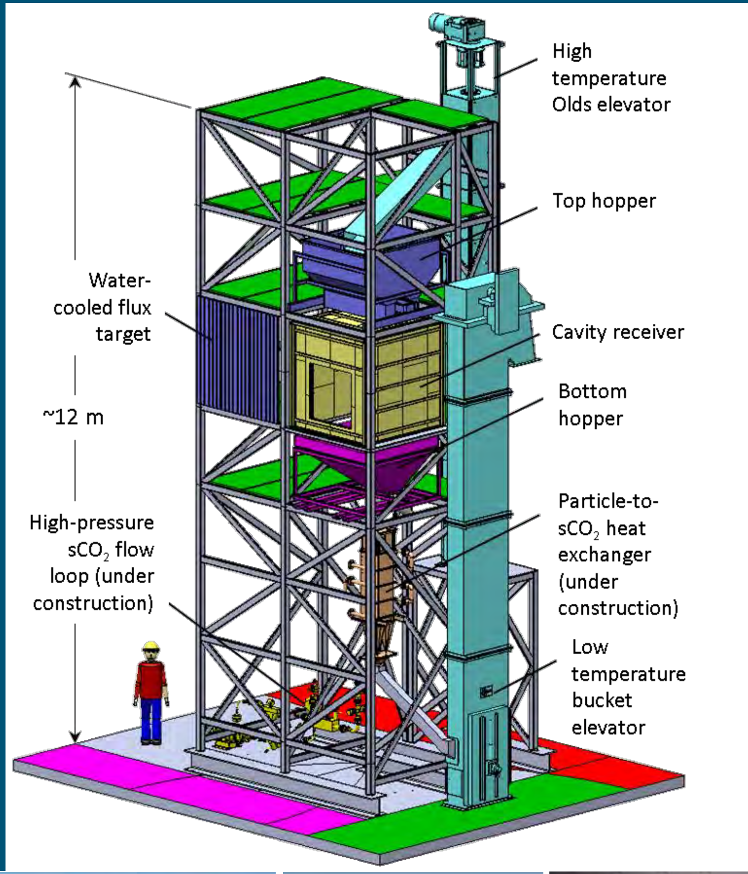
- 160,000 kg of particles
  - 40,000 kg stagnant
  - ~80 m^3 volume
- Goal is < 10 °C temperature drop over 10 hours



Design intended to reduce heat losses, minimize wall erosion, and reduce costs

G3P3 Summary

- Significant advantages
  - Direct heating of particles
    - Wide temperature range (sub-zero to >1000 °C)
    - Inexpensive, durable, non-corrosive, inert
  - Demonstrated ability to achieve >700 °C on-sun with hundreds of hours of operation
- Gaps and risks being addressed
  - Heat loss (receiver, storage, heat exchanger, lift)
  - Particle-to-working-fluid heat transfer
  - Particle attrition and wear
  - Thermomechanical stresses and erosion in heat exchanger and storage tanks
  - Scale-up to commercial applications



On-sun testing of the falling particle receiver at Sandia National Laboratories

Molten Chloride Salts for Thermal Energy Storage

Heat Storage for Gen IV Reactors for Variable Electrify from Base-Load Reactors
Idaho Falls, ID
July 23-24, 2019

Craig Turchi, PhD
Thermal Sciences Group
National Renewable Energy Laboratory
craig.turchi@nrel.gov


Crescent Dunes Solar Energy Facility, USA

Gen3 Liquid-Phase Pathway to SunShot

Project Summary

Evaluate two heat-transfer fluid (HTF) options for >700°C CSP:

1. ternary molten-chloride salt and
2. liquid sodium metal

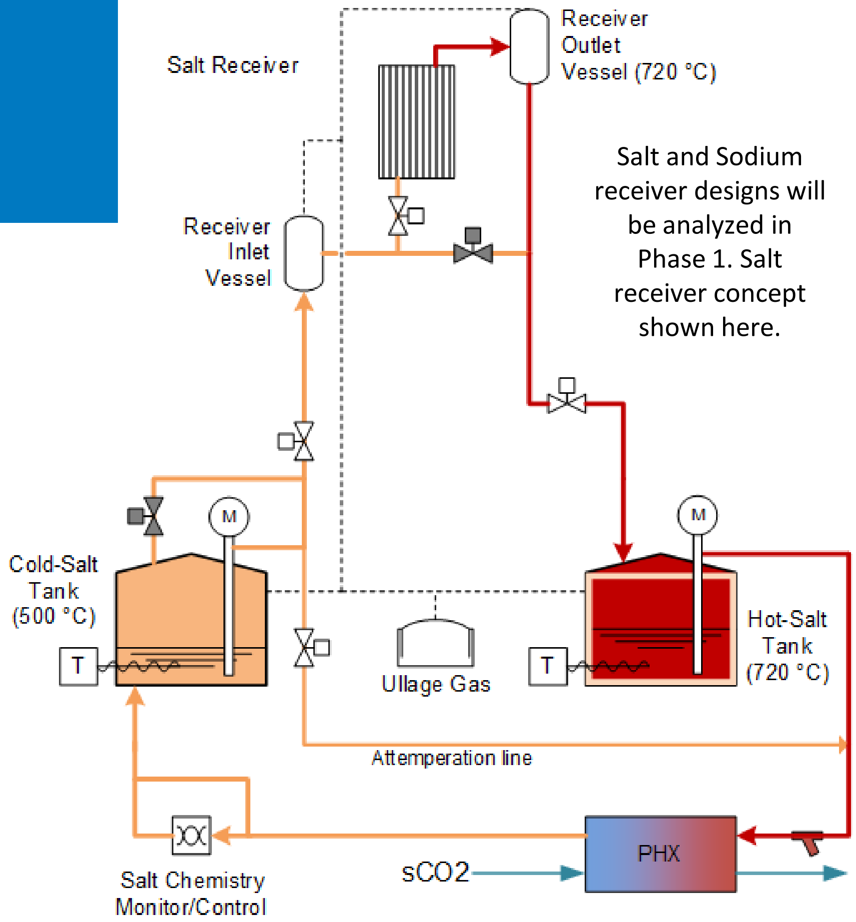
Design, develop, test, and validate a pilot-scale, 720°C CSP system encompassing the thermal-energy collection and transport system

Award

- Gen3 Integration FOA Topic 1 award

Project Objectives

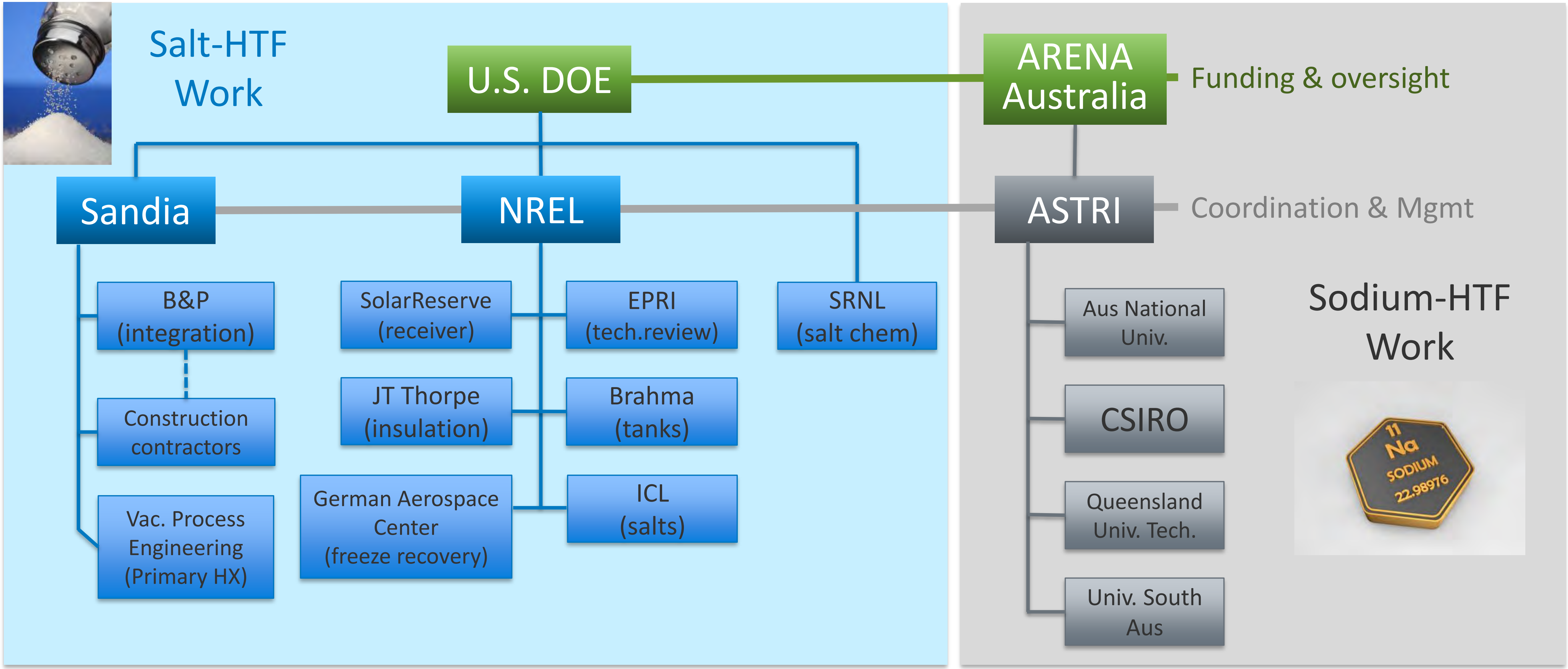
- Control salt chemistry to minimize corrosion and allow use of affordable containment metals.
- Create a stable, insulating liner to protect the walls of the hot-salt tank.
- Validate the efficiency and performance of the solar receiver and primary heat exchanger (PHX) with a liquid heat-transfer fluid (HTF).
- Map the path to full-scale commercialization through system simulation and industry collaboration.



Salt and Sodium receiver designs will be analyzed in Phase 1. Salt receiver concept shown here.

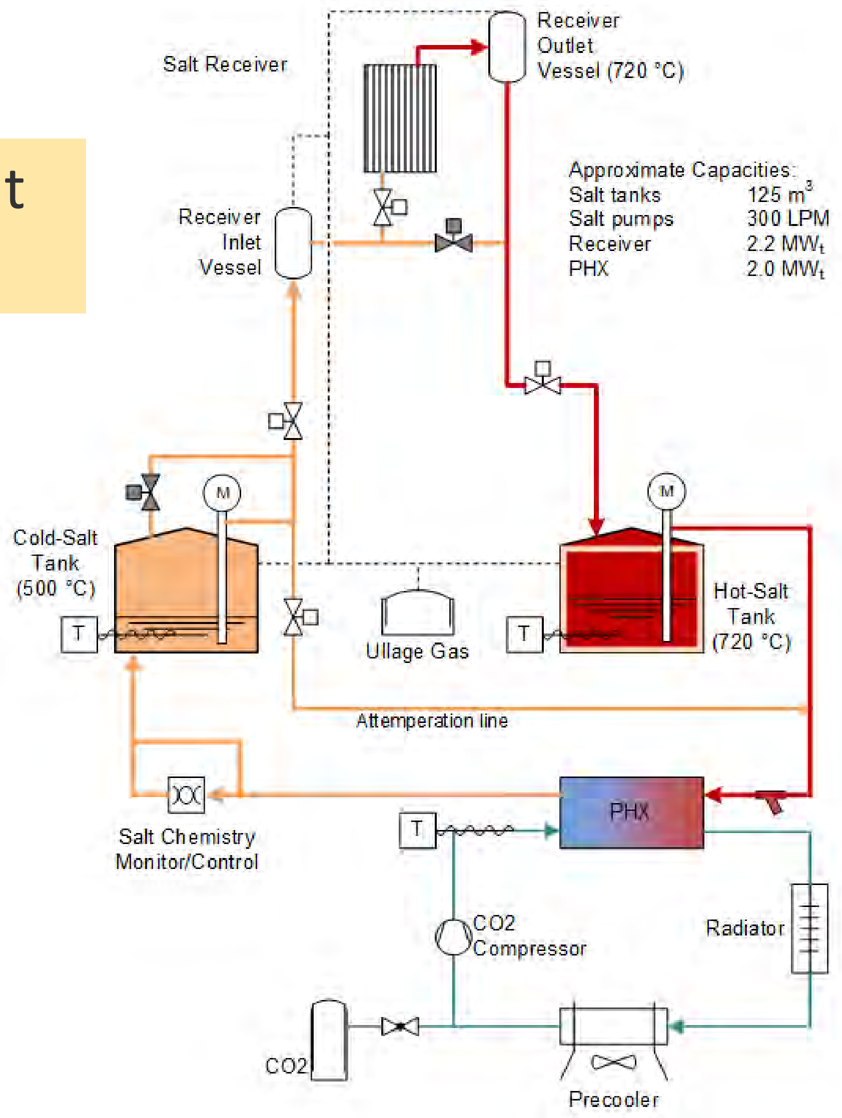
Phase 3 testing would occur at Sandia National Labs

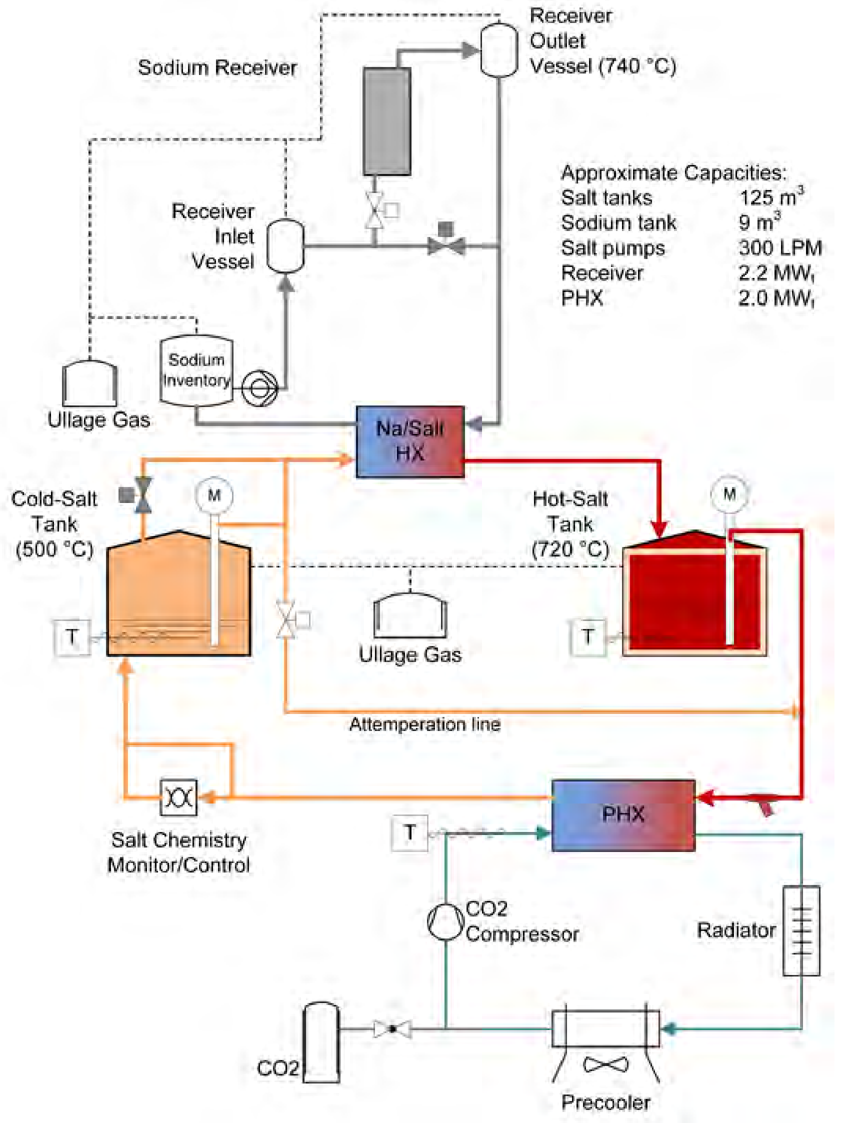
Liquid Pathway Team



Liquid-HTF Pilot System Alternatives

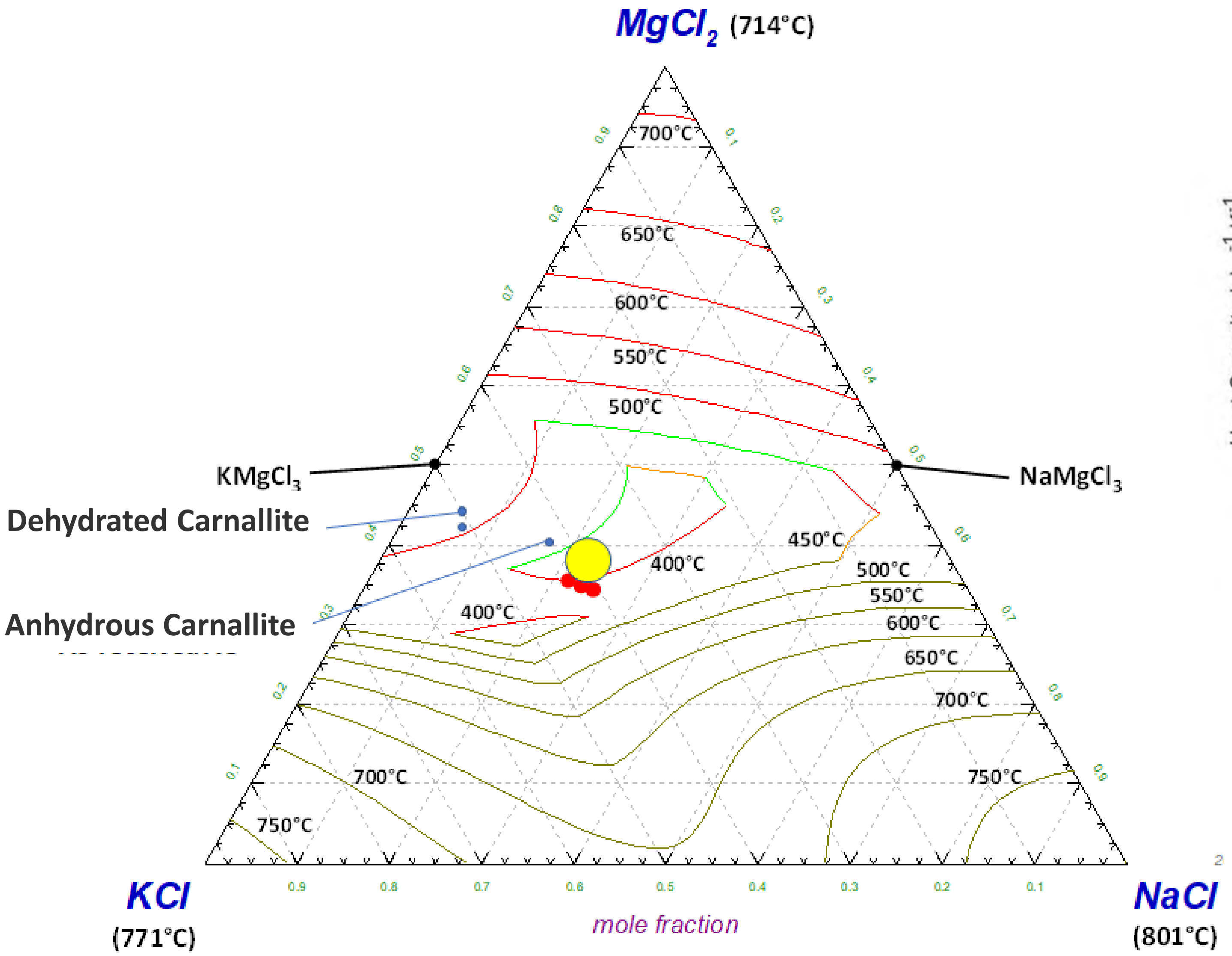
Cl-Salt HTF

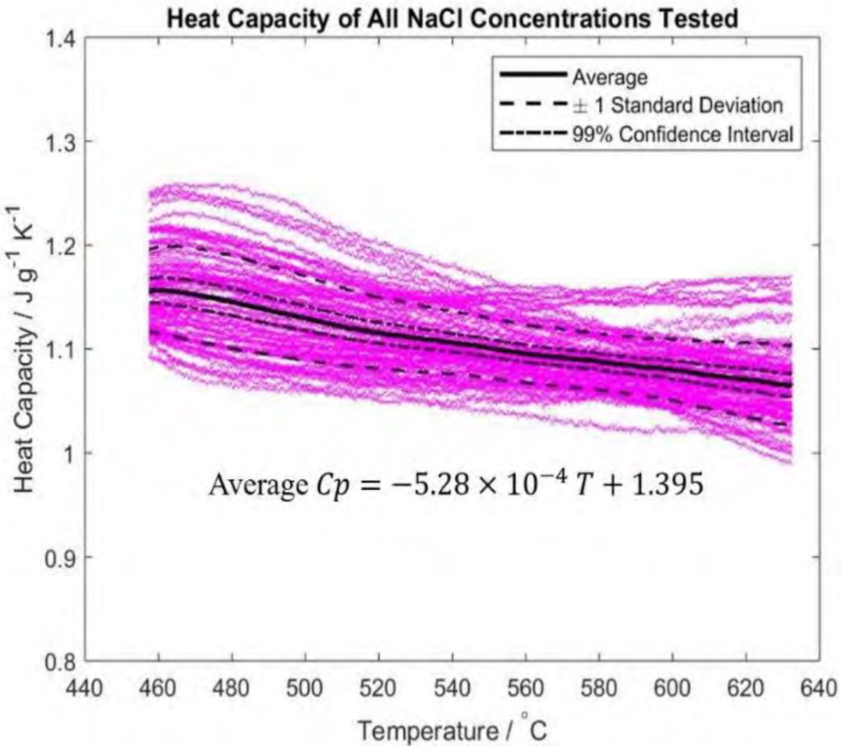




Sodium HTF

Optimizing Chloride-Salt Formulation



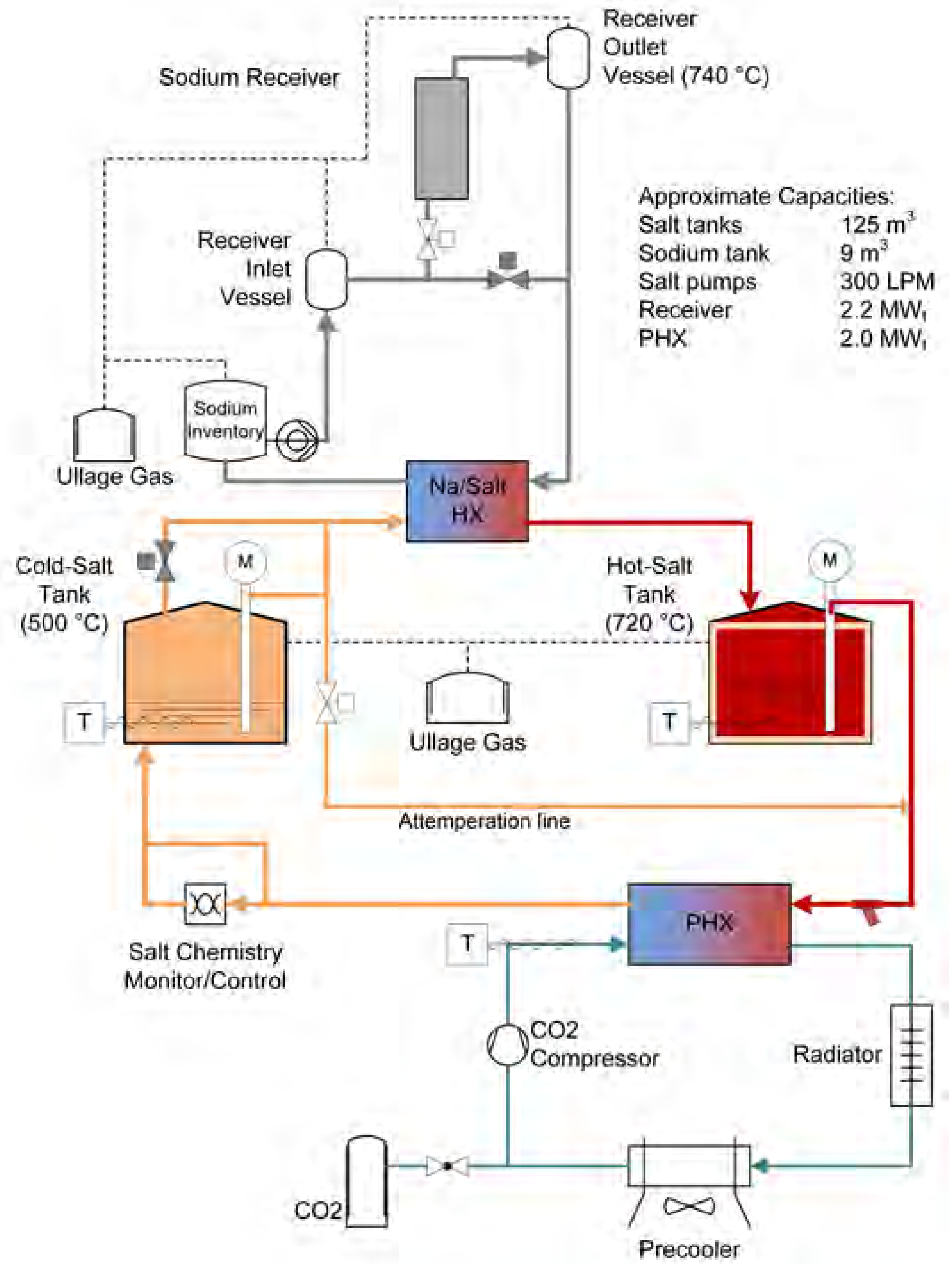


Phase diagram of Na/K/Mg–Chloride modeled with FactSage [Mohan et al., Energy Conversion and Management 167 (2018).

The Case for Sodium

CSP considering the use of liquid sodium for the solar receiver:

- >100x higher thermal conductivity
- T_{mp} = 98 °C vs. 420 °C for salt
- Lower corrosivity



Optics and autonomy

Progress Toward Commercial Deployment of sCO_2 Brayton Power Cycles

New autonomous in-situ optics tools

Sandia National Laboratories

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Near-Field Target (UFACET)	Far-Field Target (NIO)
Develop algorithm to measure: - Canting error at multiple points - Slope error at multiple lines	Develop algorithm to measure: - Slope error over the surface - Canting errors relative to a reference mirror facet - Tracking error of heliostats

Validate both methods on slope error and canting error.

Integrated Application Steps

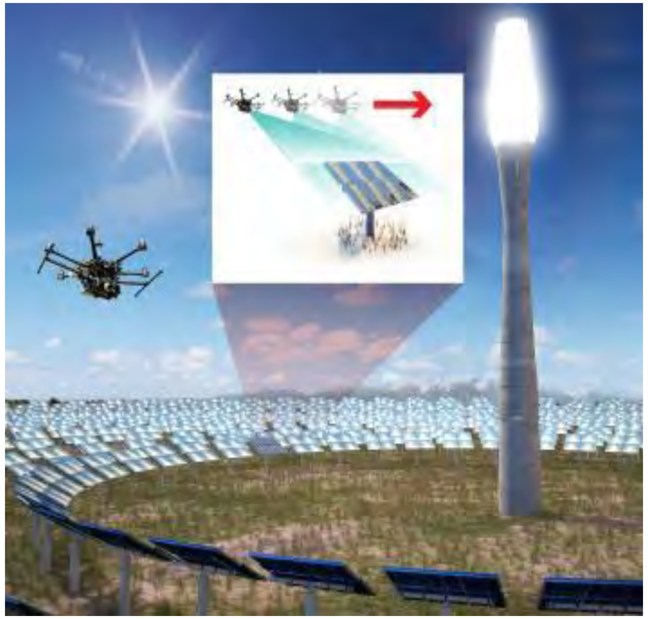
Near-Field Target (UFACET)	Far-Field Target (NIO)
	1. Survey over the field - Slope error, canting error 2. Ensure design conditions of neighboring heliostats and derive best canting strategy
3. Perform canting correction on the identified heliostats in the field.	
	4. Survey over the field for tracking error

5. Validate and monitor solar field performance

6. Investigate temporal effects of heliostat optical errors, due to installation errors, temperature, partial illumination, gravity, wind, etc.

Non-Intrusive Optical (NIO) Method

- Use a drone-driven camera to collect reflection images.
- Use photogrammetry and image-processing (coupled with machine learning) techniques to calculate
  - mirror slope error,
  - mirror-facet canting error
  - heliostat tracking error.



Approach

Calculate camera position

↓

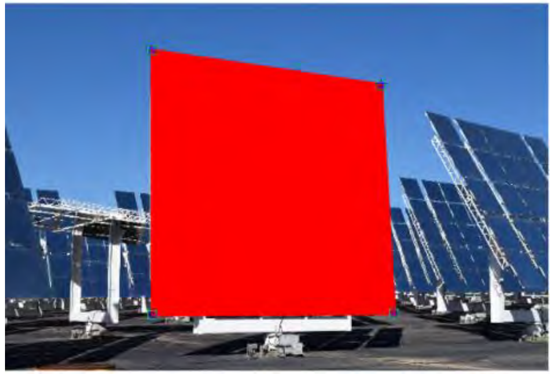
Calculate tower position → Calculate tracking error

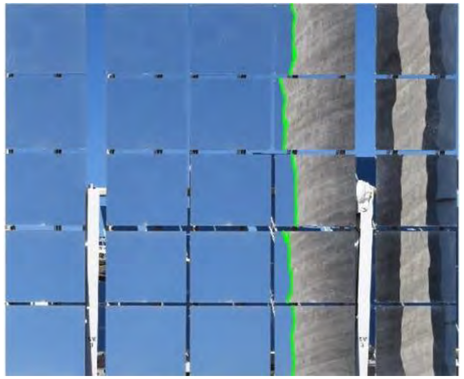
↓

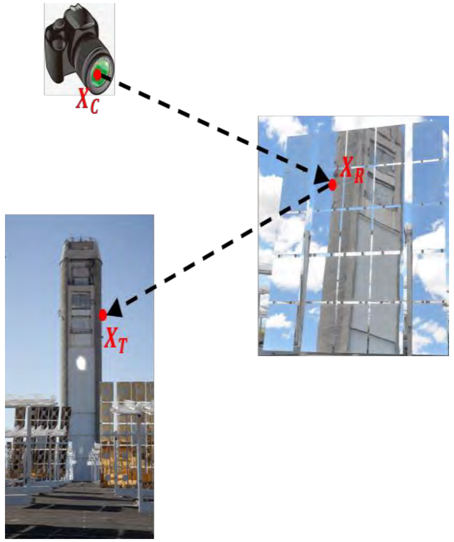
Calculate slope errors

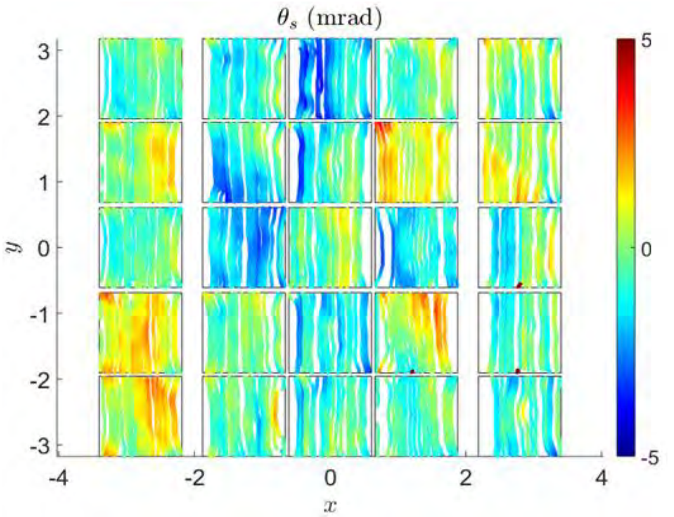
↓

Calculate Canting Errors

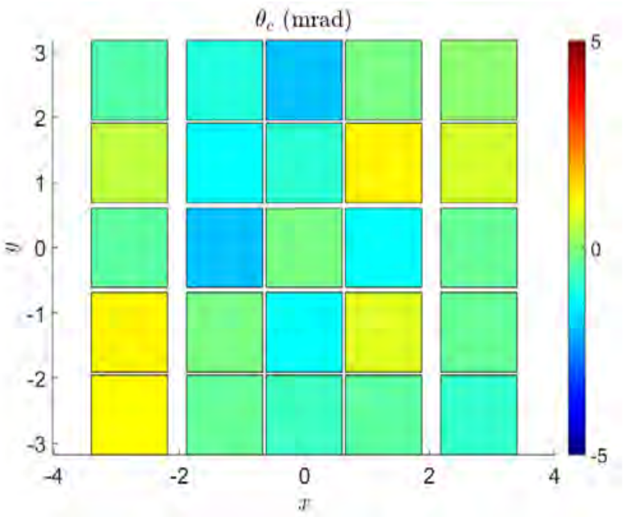








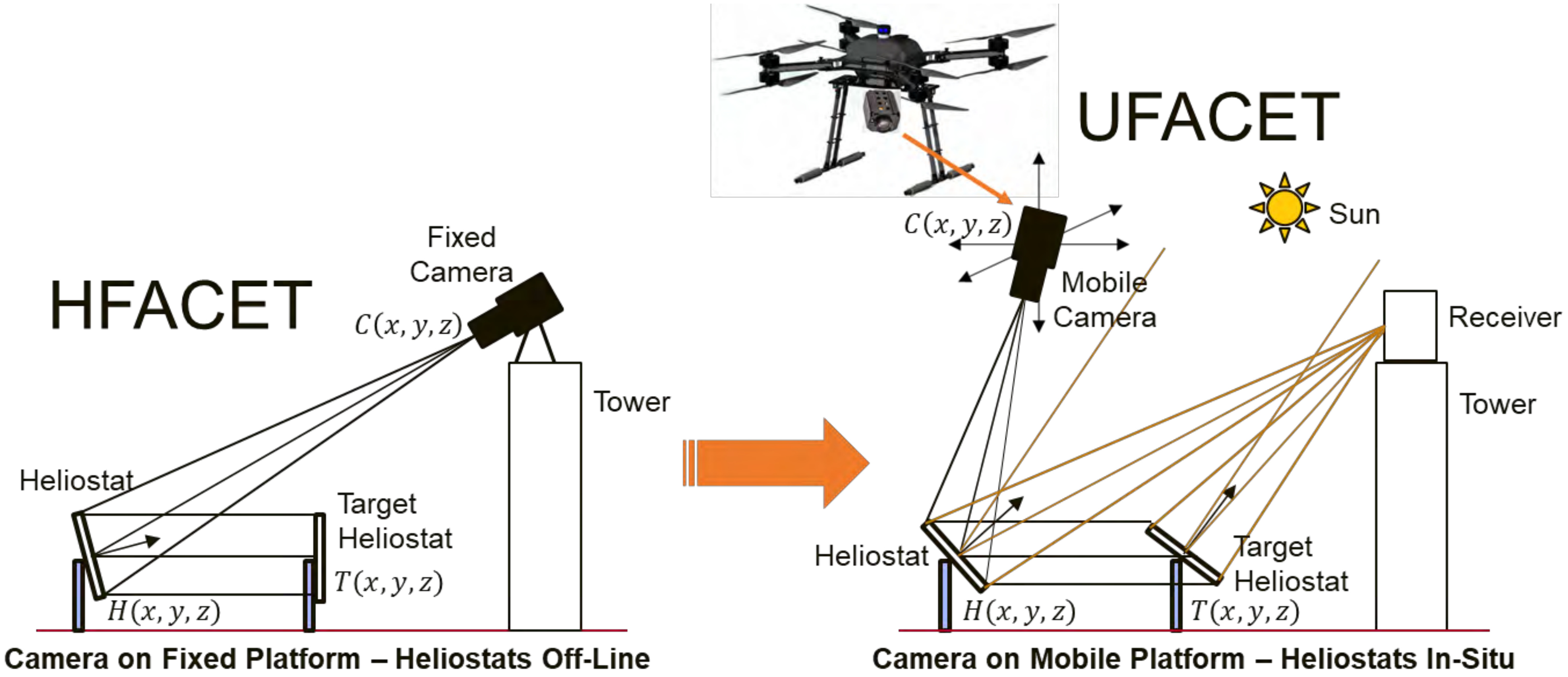
Slope Error Map



Canting Error Map

HFACET + UAS = UFACET

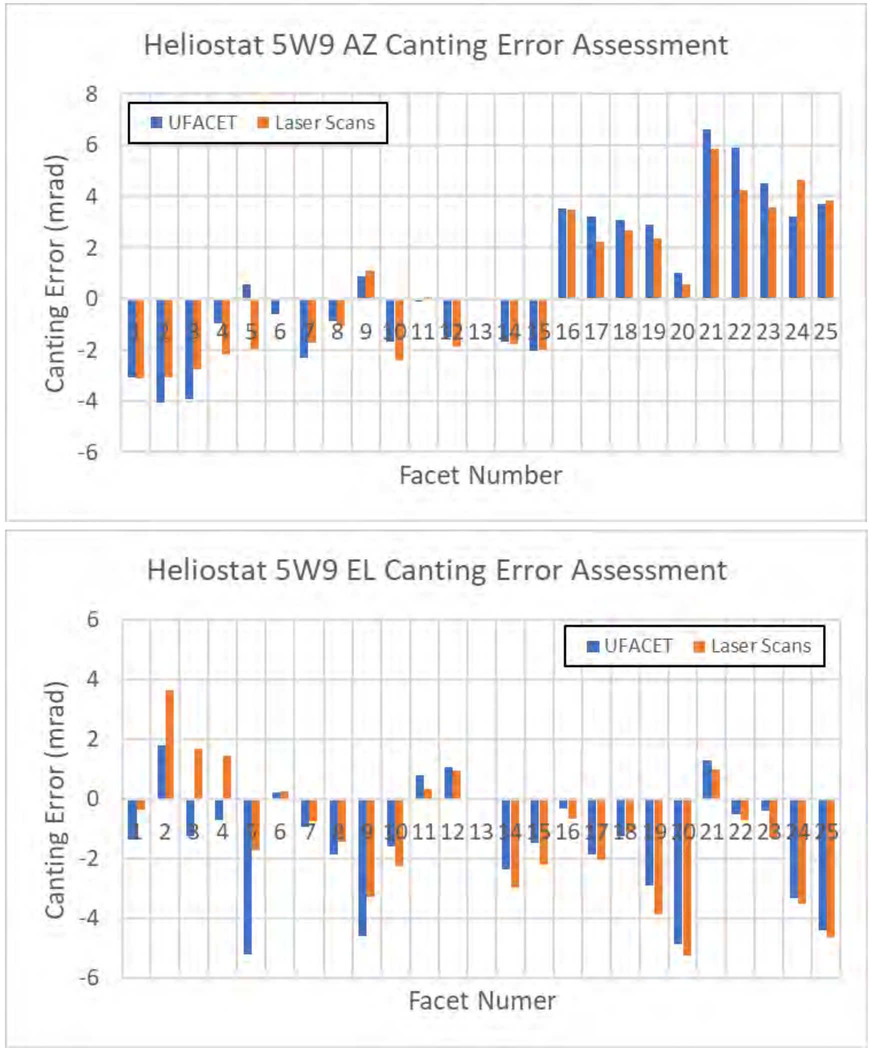
- **UFACET** builds on **HFACET**, which is a heliostat assessment tool that was developed at Sandia and successfully implemented at the NSTTF.
- New innovations include attaching the camera to a mobile platform (UAS), which can follow pre-determined paths to assess optical performance parameters of the field, and developing new methods to measure mirror reflectance and slope error on in-situ heliostats.



Canting Error Assessments on 5W9

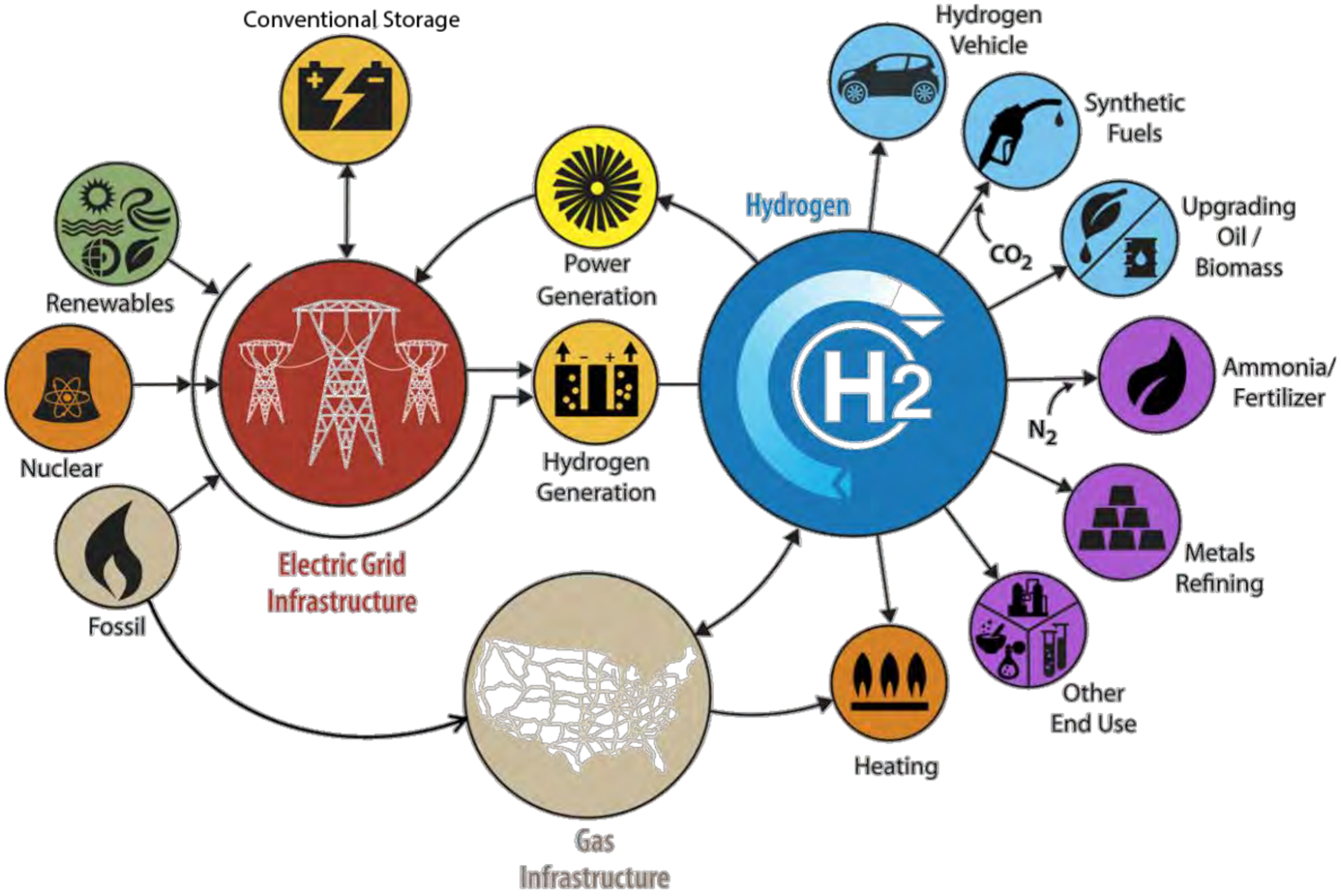
Differences between the theoretically mapped target features and the actual reflection images reveal canting errors.

Measured AZ and EL Canting Errors



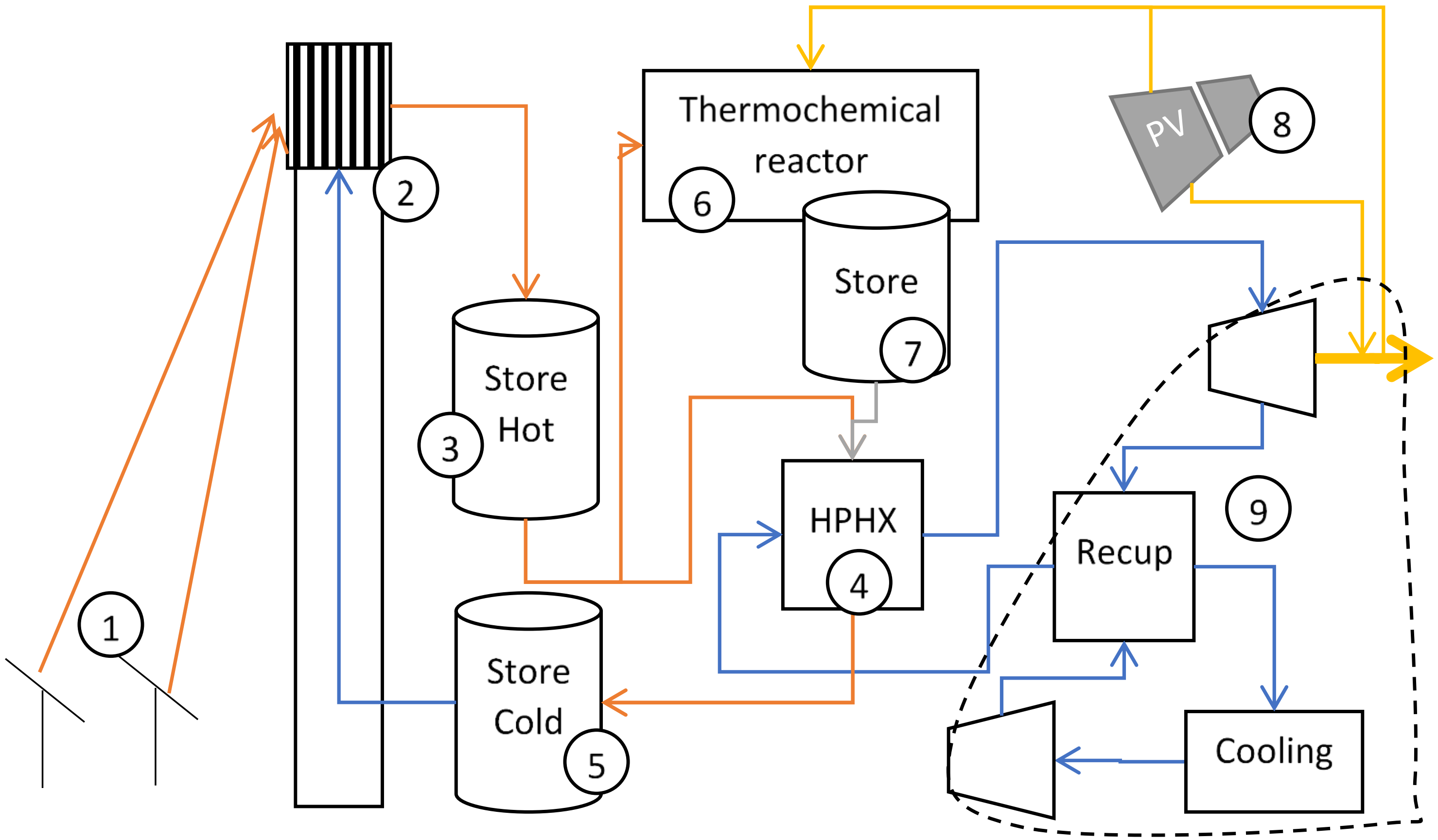
Fuels and long duration storage

H2@Scale and HydroGen

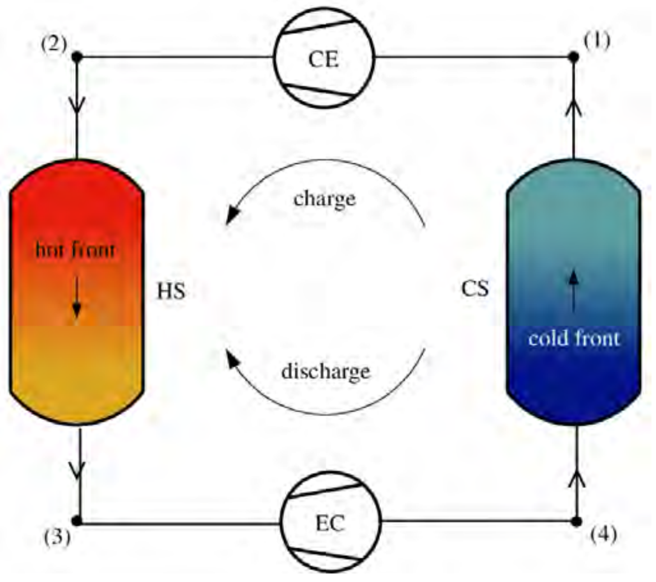


https://www.energy.gov/eere/fuelcells/h2scale

Dual storage concepts: Thermal + Solar Fuels



Integrated heat pump thermal storage and power cycle for CSP



Project Objective

Increase efficiency, dispatchability, and flexibility of CSP through integration with a novel storage system.

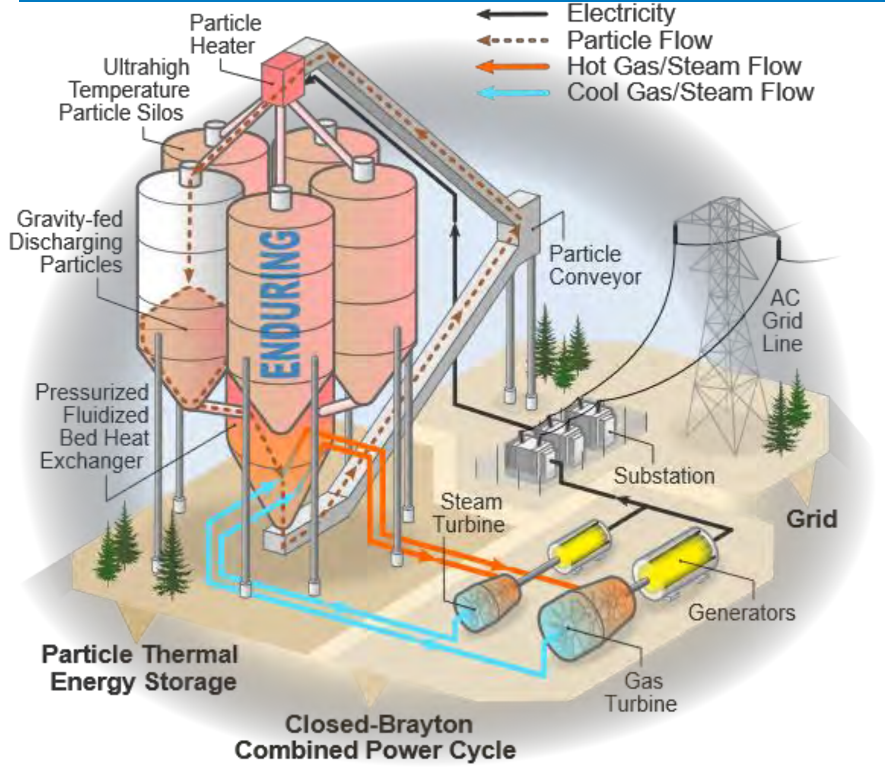
Award

- SETO Lab Call Award

Significance & Impact

- CSP is inherently intermittent and storage tanks may be under-utilized (especially in the winter).
- Heat pump charges store - *decouple* storage from solar availability.
- 'Sub-ambient heat rejection' to reduce effect of high ambient temperatures.
- Combine CSP power cycles with novel storage system – "Pumped Thermal Energy Storage".
- Develop transient thermodynamic and economic models, and assess 'value' with grid analysis tools.

Economic Long-Duration Electricity Storage by Using Low-Cost Thermal Energy Storage and High-Efficiency Power Cycle (ENDURING)



Award

- DOE ARPA-E DAYS

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Project Objectives:

1. Develop the ENDURING system and components for long-duration energy storage (LDES) to support grid resilience and security.
2. The ENDURING LDES system is designed to be deployed economically anywhere in the United States.

Project Team Members:

- General Electric Company
- Greenway Energy
- Allied Mineral Products, Inc.
- Purdue University
- Colorado School of Mines
- POWER Engineers

Significance & Impact

- The project team will develop the ENDURING system and verify the component designs to meet the cost and performance targets for demonstration and technology to market.
- The ENDURING LDES system addresses grid storage needs, provides power for several days by low-cost, high-performance storage cycle, allow integration of large amounts of renewable sources like wind and solar, and increase their value to the grid.

Acknowledgements

To **SASEC** for inviting me to present this summary of U.S. CSP R&D

Primary contributors to this presentation

- **Dr Avi Shultz**, DOE CSP Program Manager
- **Matthew D. Carlson**, Sandia National Laboratories
- **David Stapp**, CEO/CTO, Peregrine Turbine Technologies, LLC
- **Shaun Sullivan**, Principal Engineer, Renewable Energy R&D Program Mgr., Brayton Energy
- **Dr Clifford K. Ho**, Senior Scientist, Sandia National Laboratories
- **Dr Craig Turchi**, Principal Engineer, National Renewable Energy Laboratory
- **Dr Guangdong Zhu**, Sr Researcher, National Renewable Energy Laboratory
- **Dr Julius Yellowhair**, Principal Engineer, Sandia National Laboratories
- **Mark Mehos**, Group Manager, Thermal Systems R&D, National Renewable Energy Laboratory

Thank you and visit us in 2020!

Paul Gauche pgauche@sandia.gov csp.sandia.gov

2020 SolarPACES Conference

29 September – 2 October 2020,
Albuquerque, New Mexico, USA

SolarPACES
Solar Power & Chemical Energy Systems