Sandia National Laboratories

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GEN 3 PARTICLE PILOT PLANT

Project Overview and Opportunities

Jeremy Sment (PI), Presentor

Concentrating Solar Technologies (8923)

Contributors: Clifford Ho, Brantley Mills, Matthew Sandlin, Hendrick Laubscher, Luke McLaughlin, Nathan Schroeder, Luis Garcia Maldonado, Shaker Alaqel, Kristina Ji, Madeline Hwang, Madeline Finale, Aaron Overacker, Ansel Blumenthal, Andrea Ambrosini, Evan Bush, Daniel Ray, Kevin Good, Roger Buck, Robert Crandel Francisco Alvarez, Kevin J. Albrecht, Logan Rapp, Mathew Carlson, Margaret Gordon, Jennifer Braid, Josh Stein, Logan Rapp, Abraham Ellis, Robert Lealand

U.S. DEPARTMENT OF ENERGY · NNSA National Nuclear Security Administration · SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department of Energy

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SAND2024-14815PE

AGENDA

October 29, 2024

10:00-10:40 Presentation

10:40-10:55 Q&A

Please log questions during presentation in chat.

Gen 3 CSP Program

Particle Pathway

G3P3 Overview

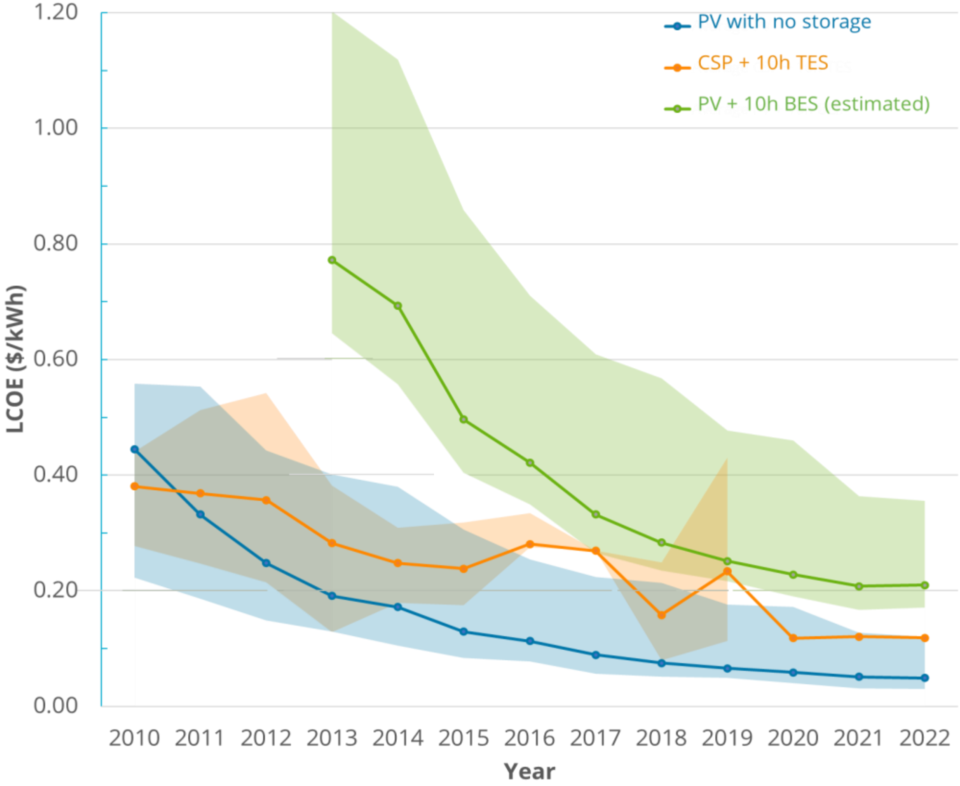
G3P3 Next Steps

Commercialization Pathways

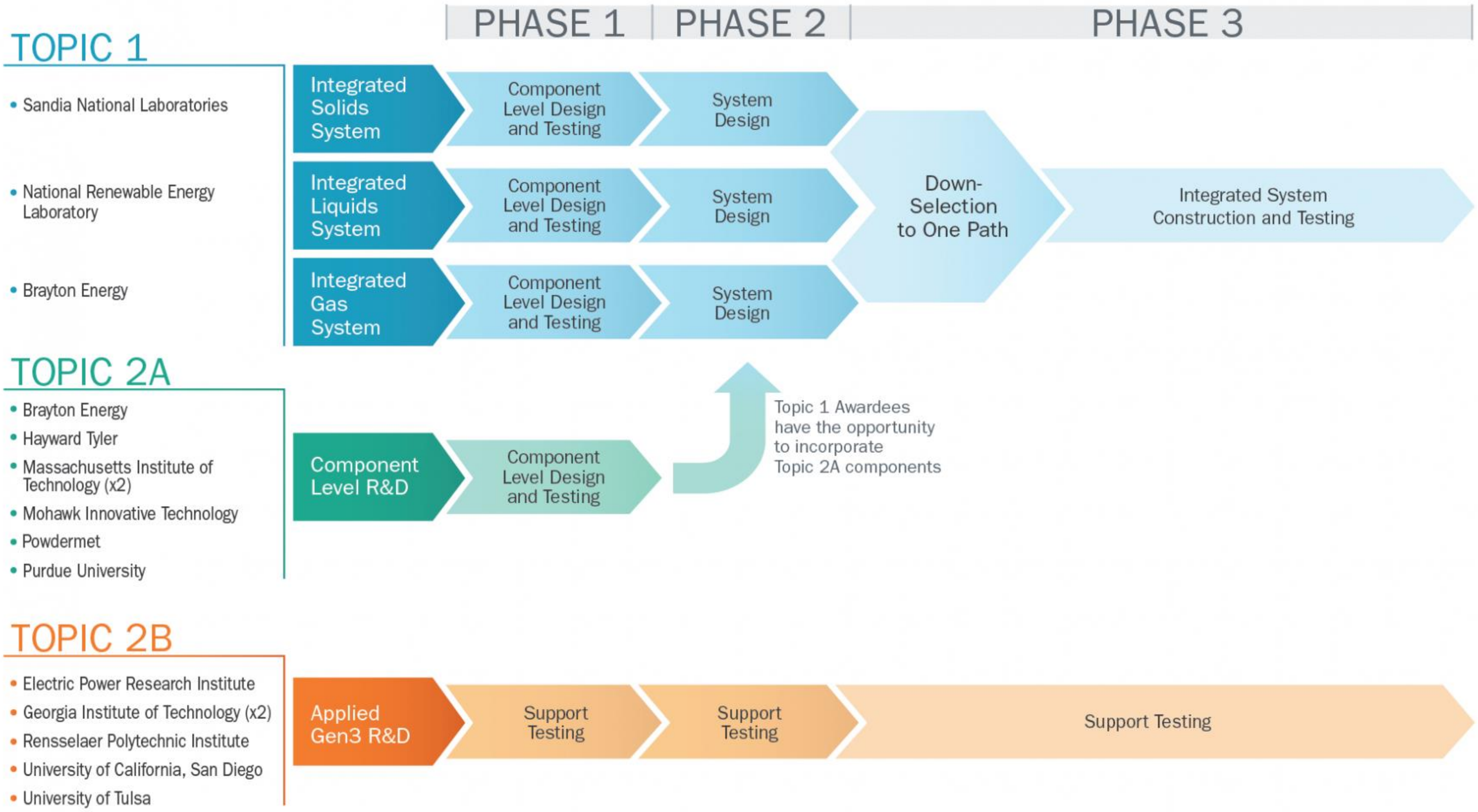
Market Opportunities

GEN 3 CSP PROGRAM

GEN 3 CSP PROGRAM OBJECTIVE



PROJECT OVERVIEW

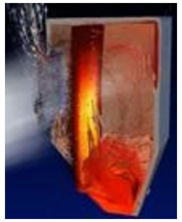


G3P3 ORGANIZATION AND TASK STRUCTURE

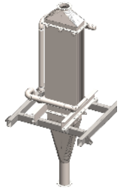
(ORGANIZED BY PHASE 3 DOWNSELECTION CRITERIA)

G3P3 Phases 1 and 2

- Technical Advisory Committee (E, SD)
- 1. Risk Reduction R&D
  - Receiver (S, CS, AN, AD, CN, D, GT, K)

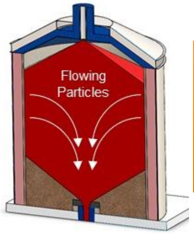


  - Heat Exchanger (S, SO, V, K)



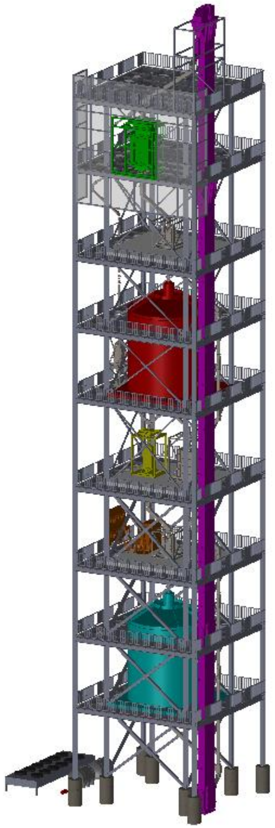
  - Particles (S, K, T)

  - Storage (S, AL, M, K)



  - Lift (S, GT, F, MH, K)

- 2. Phase 3 Management, Design, and Construction Basis (S, BP, BH, K, SEC)
- 3. Technoeconomic Analyses and Market Adoption Study (S, AN, E, SD)
- 4. Phase 3 Test Matrix and Risk Reduction (S, SD, K, SEC)
- 5. Risks of Scaling-Up to 100 MW_e (S, SO, V, AL, M, K, SEC)

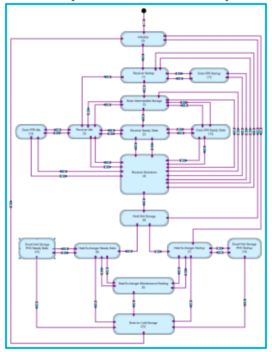


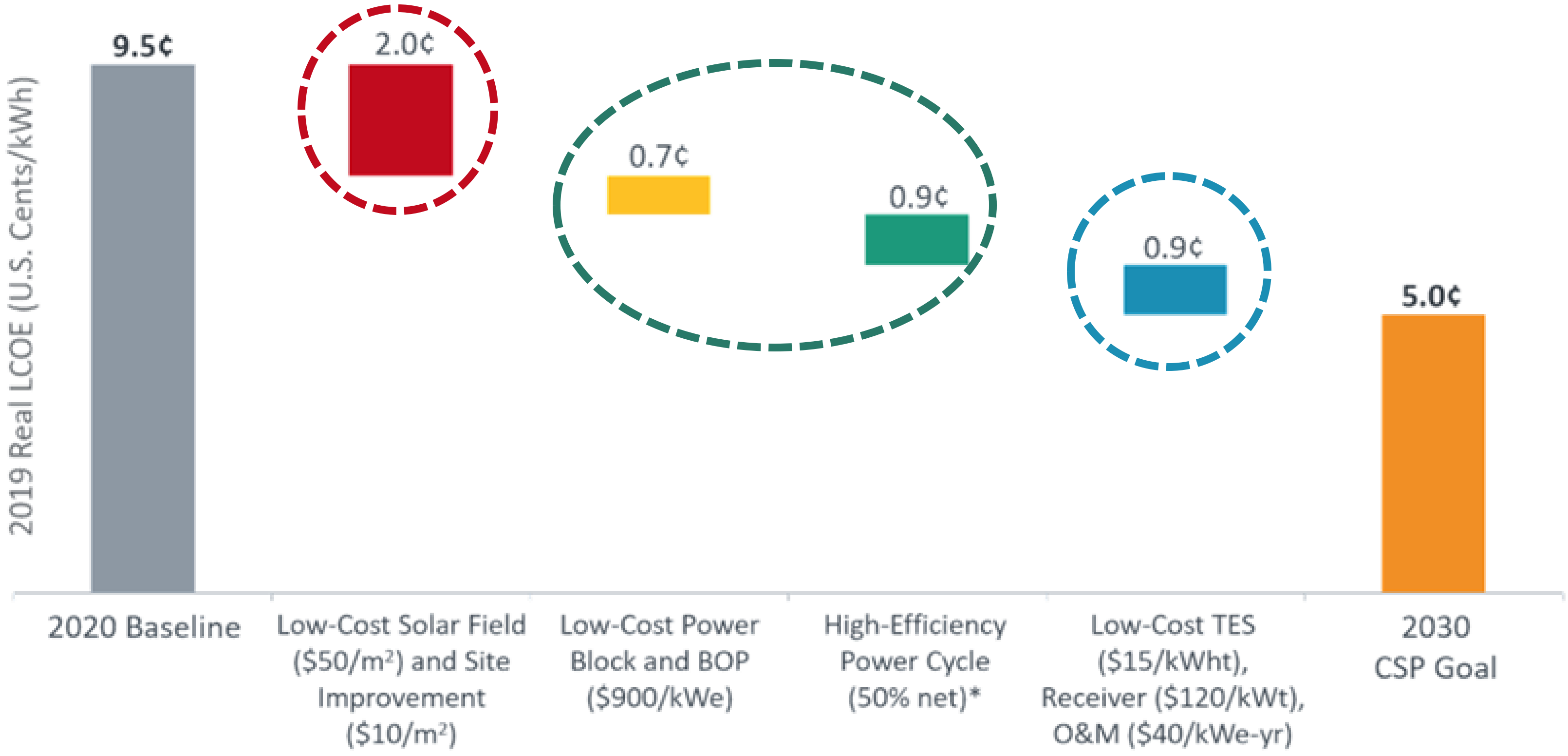
AD = Adelaide
AL = Allied Mineral Products
AN = ANU
BH = Bohanan Huston
BP = Bridgers & Paxton
C = Carbo Ceramics
CN = CNRS-PROMES
CS = CSIRO
D = DLR
E = EPRI
F = FLSmidth
GT = Georgia Tech
K = KSU
M = Matrix PDM
S = Sandia
SD = SolarDynamics
SEC = Saudi Electricity Co.
SO = Solex
T = Tulsa University
V = VPE

GEN 3 CSP PROGRAM OBJECTIVE AND ACCOMPLISHMENTS

SuNLaMP, sCO2 Loop, STEP, TESTBED

(8923, 1514)





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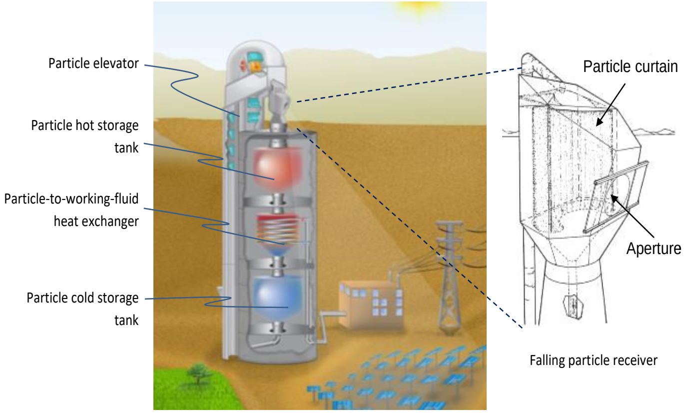
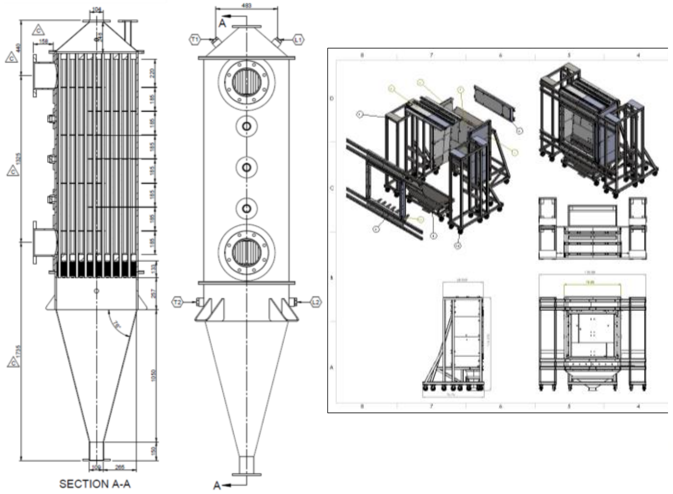
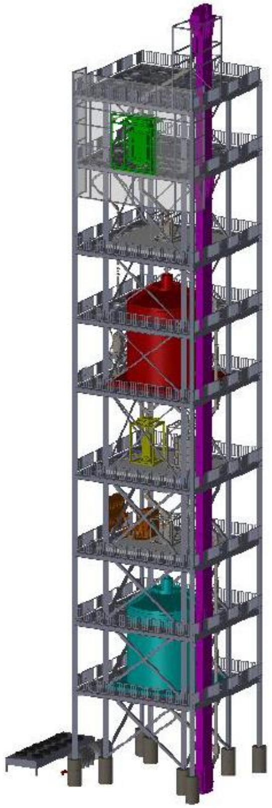
G3P3 FROM CONCEPT TO ACTUALIZATION



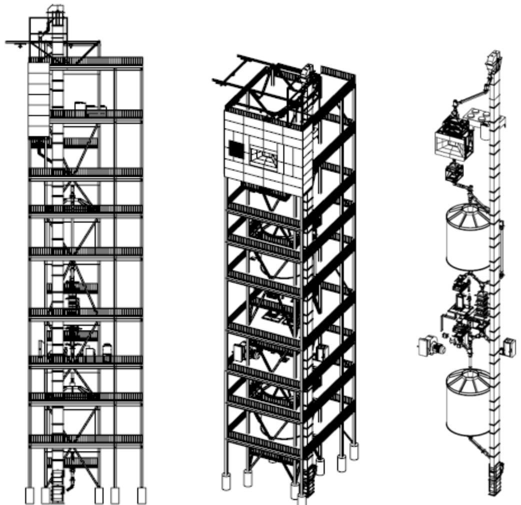
Conceptualization
Gen 3 CSP, 2017



Component Design and
Modeling 2018-2019



System Design and
Commercialization Plan
2020



SETO Awards Phase 3 to
Particle Pathway, 2021

Breaking Ground
February 2023

Top-out
February 2024

Tower Complete
Solar Equipment Loaded
Commissioning underway
Today

EXTERNAL AND INTERNAL PARTNERSHIPS

Role	Team Members		
PI / Management	• 8923 Concentrating Solar Technologies • 8925 Solar Thermal Testing and Demo • 4833 Project Management	• 4643 Isleta Liaison • 4643 NEPA • 11010 SFO	• 4623 Safety Engineering • 8518 ES&H • 10245 Supply Chain
R&D / Engineering	• Sandia National Laboratories • King Saud University • Georgia Institute of Technology • German Aerospace Center • University of Michigan	• CSIRO • U. Adelaide • Australian National University • CNRS-PROMES • University of Texas at Austin	
Integrators / EPC	• EPRI • Bridgers & Paxton • Bohannan Huston • Summit Construction	• JT Thorpe • Jon Balis • H+P3/Crane Services • TribalCo rescue and safety	
CSP Developers	• SolarDynamics	• Heliogen	
Component Developers / Industry	• Carbo Ceramics • Solex Thermal Science • Vacuum Process Engineering • FLSmidth	• Materials Handling Equipment • Allied Mineral Products • Matrix PDM • SSI	• Magaldi • Babcock & Wilcox • Albina Co. • Flowserve
Utility	• Saudi Electric Company	• Chugach Electric, Alaska	

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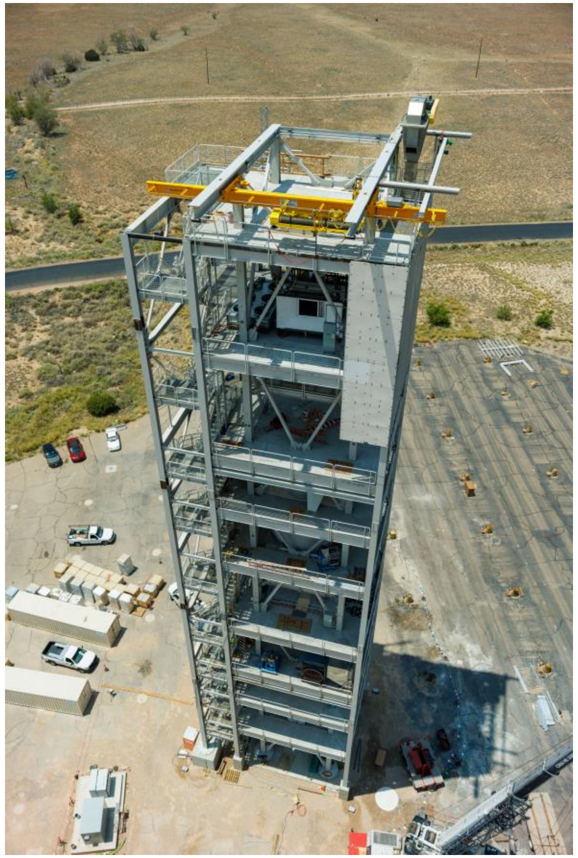
G3P3-USA Construction Timeline

- **March 2021** – Phase 3 awarded
- **May 2022** – Re-issued NEPA complete/Re-baselined schedule
- **September 2022** – Tower construction began
  - **January 2023** – Broke ground
  - **February 2024** – Steel top out
  - **June 2024** – Bridge crane/elevators installed
  - Expected tower completion is **October 2024**
- **June 2024** – CARBO particles delivered
- **July 2024** – CSP equipment lift
  - PHX from VPE has been delayed until late **August 2024**
- **July 2024** – Plan B PHX executed
- **December 2024** – Completion of particle loop assembly
- **January 2025** – Commissioning of the G3P3 System



Near complete G3P3 tower with the existing NSTTF Tower

System Components

System Overview

Parameter	G3P3-USA
Receiver thermal power	~2 MW_t
Solar multiple	~2
Particles	CARBO HSP 40/70 ceramic beads
Receiver	Falling particles with SNOUT and StAIR; single slide gate
Heat exchanger	1 MW_t duty; Moving packed bed; particle flow in shell; 20-25 MPa sCO_2 flow in plates
Particle Lift	Bucket elevator
Power block	~1 MW_t sCO_2 flow loop
Tower structure	Open

Tower Construction

- The G3P3 tower is in the final stages of construction

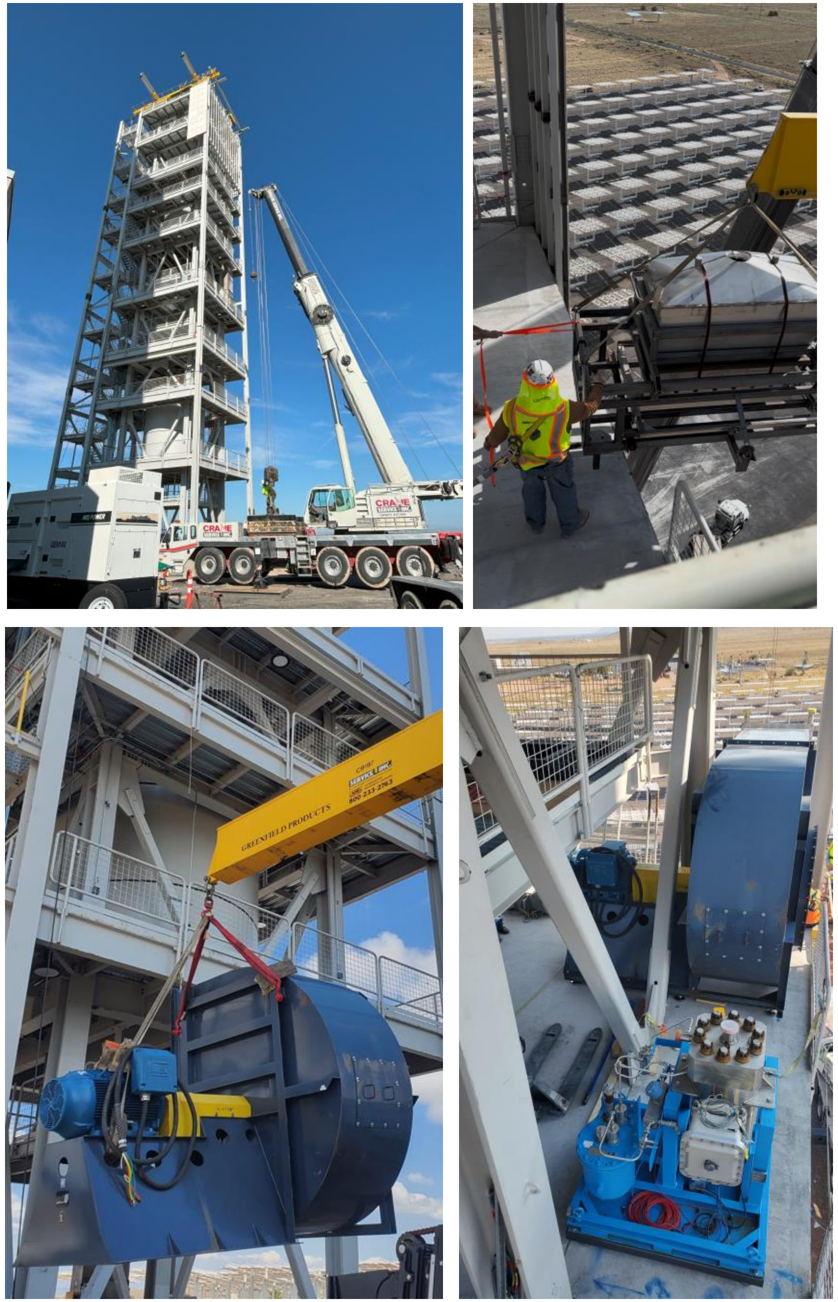
Poured and cured drilled piers and pier caps

Installing “cold” storage bin

Completed first structural steel splice

Tower top out

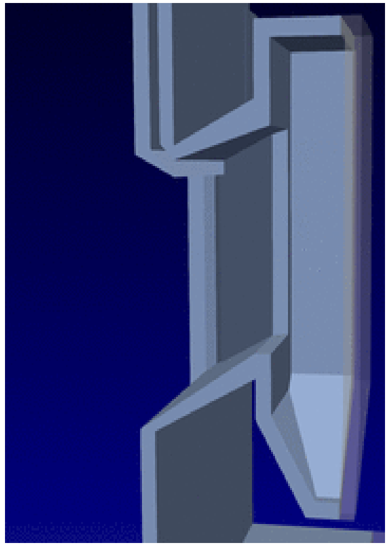
Completed installation of hot storage bin



Early installation of CSP components (July 2024)

CAPABILITIES

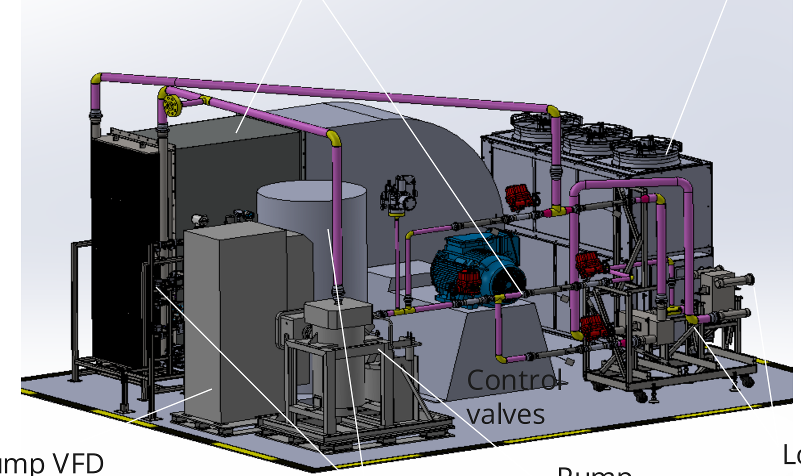
High-Performance Computing tools for computational particle flow modeling, B. Mills 1514



Design and Engineering

Cooling fan and motor

Water chiller for pump lubricant (sCO2)



Pump VFD

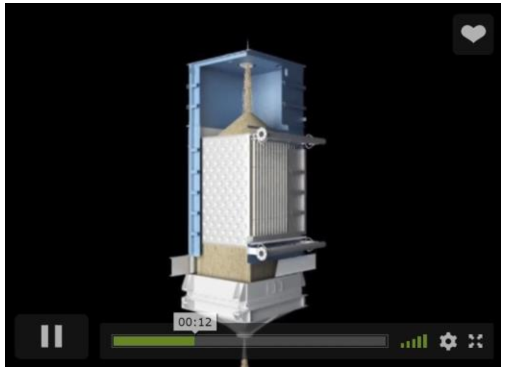
Pump

Low- and high-temperature recuperators

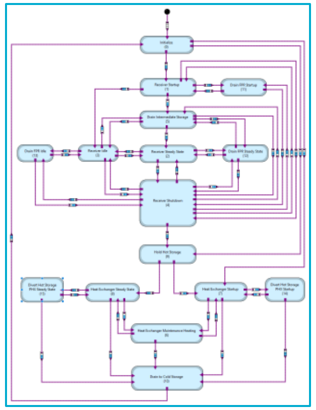
Dewar and inventory system (needs to be on ground level)

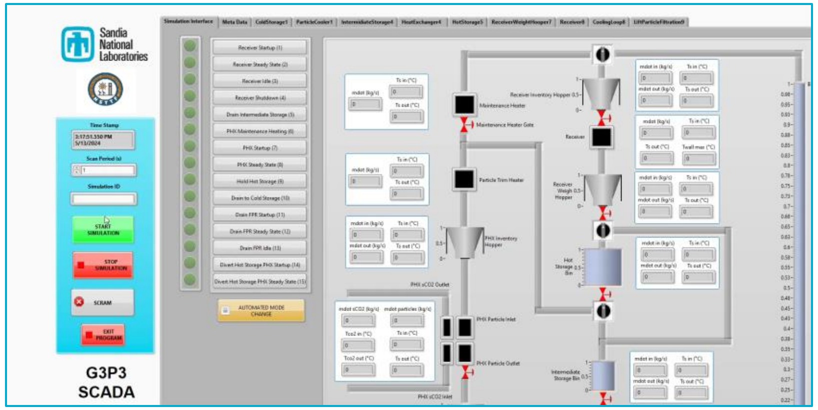
Unique World Class Test Facilities

Advanced manufacturing and materials, Solex



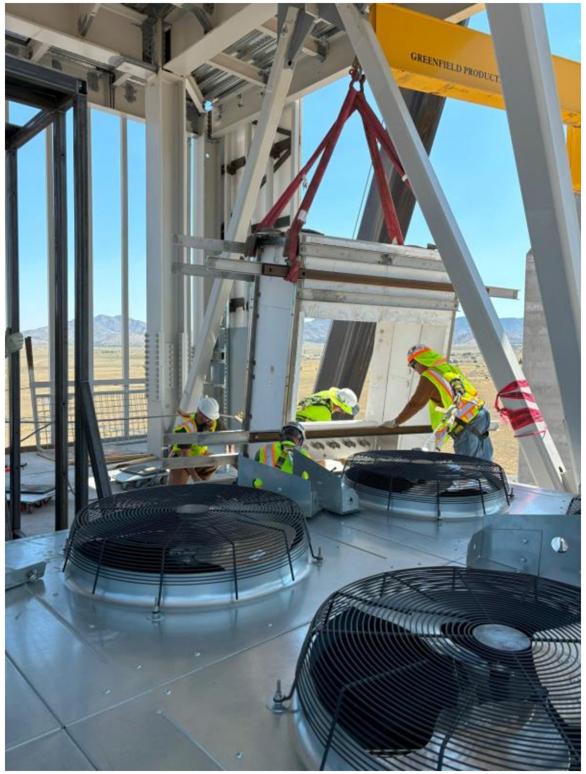
Physics-based control systems with engineered safety



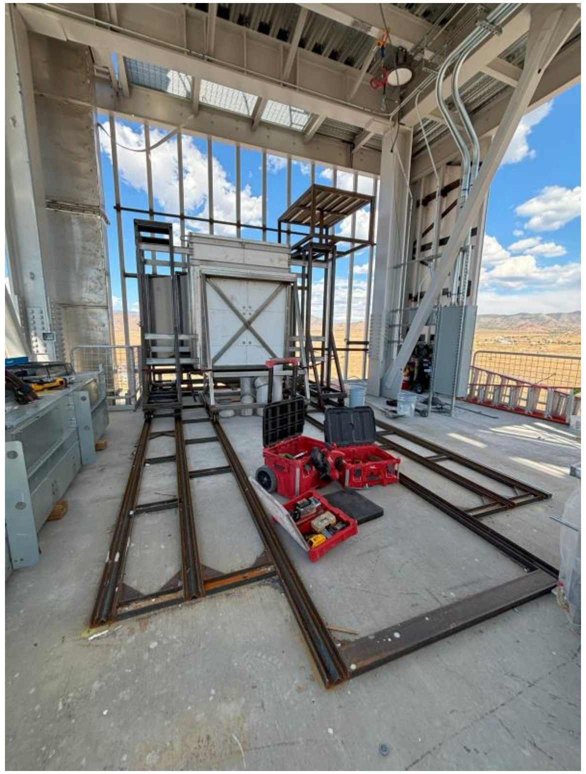


RECEIVER INSTALLATION

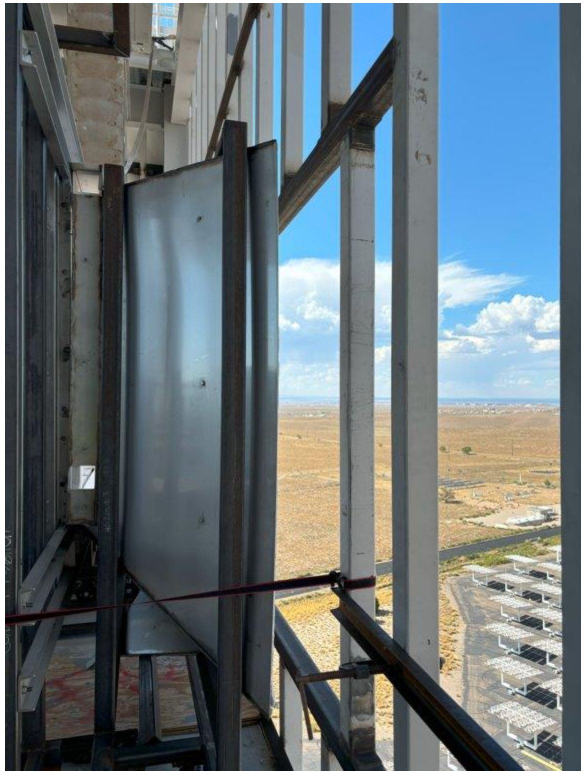
- The receiver system has been installed within the tower
  - Receiver installation is ongoing focusing on interconnection with the ducting



Receiver cavity being lifted into the tower



Receiver cavity mounted on a rail system

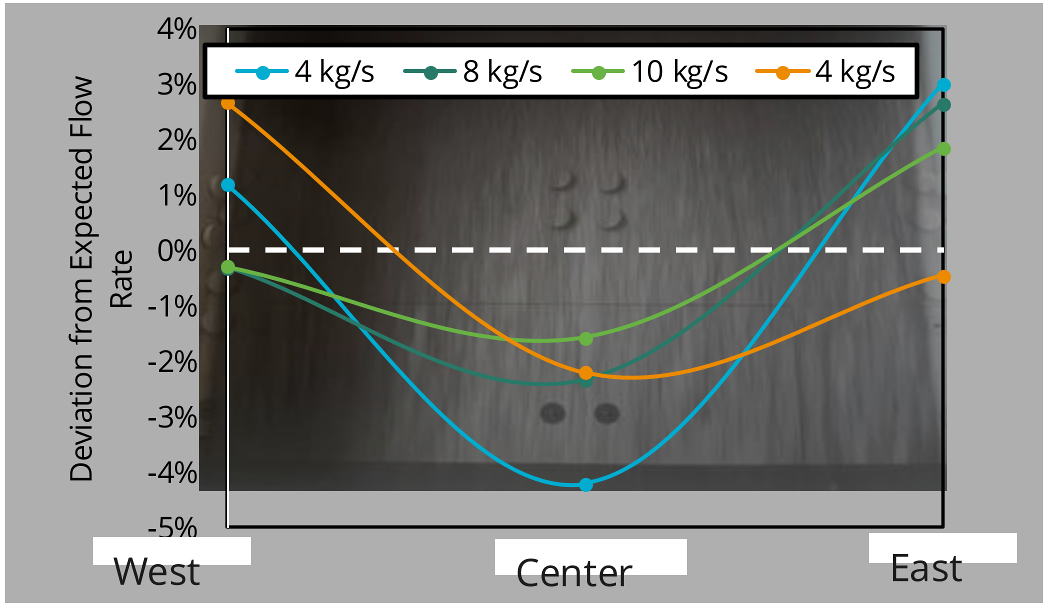


SNOUT interface with spillage board rails

Gravimetric receiver weigh hopper below the receiver cavity

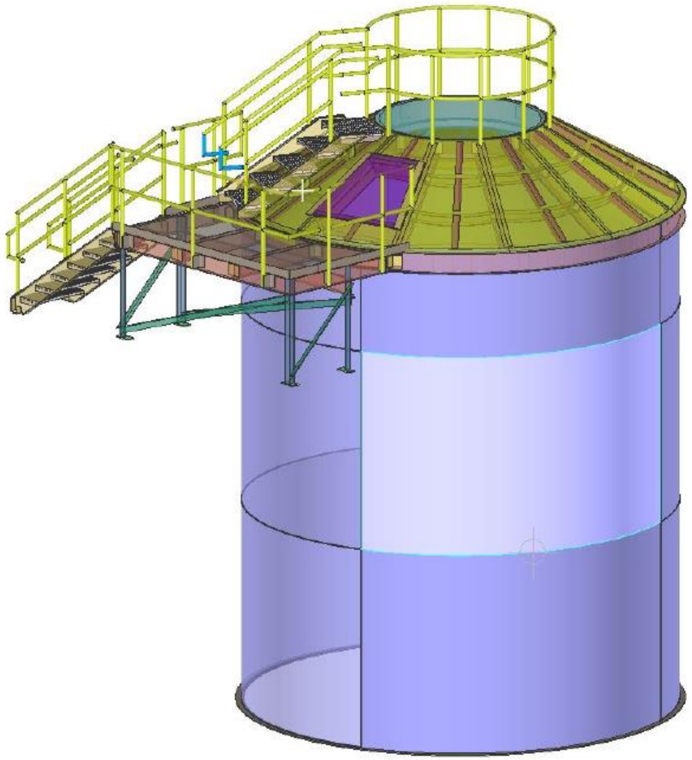
RECEIVER GROUND TEST

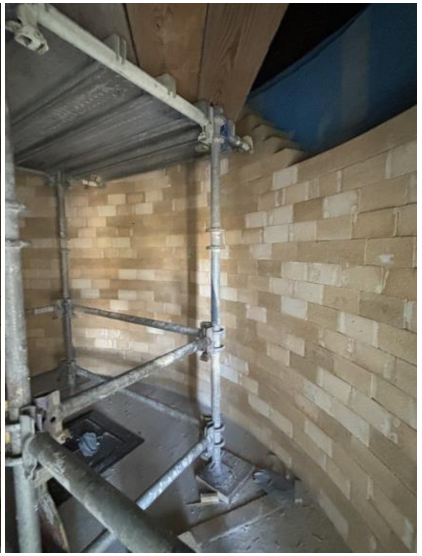
- Achieved minimum and maximum flow rates (3-12 kg/s)
  - Maximum flow rates (20 kg/s) did not eject particles through the aperture
- Particles flowed through the cavity as expected
- Confirmed SCADA integration with receiver hardware
- Some mass flow rate deviation was observed across the curtain
  - Caused by stock material tolerances
  - Corrections have been made before the installation into the tower
  - PCGV valves may also be integrated as an alternative solution



STORAGE INSULATION INSTRUMENTATION

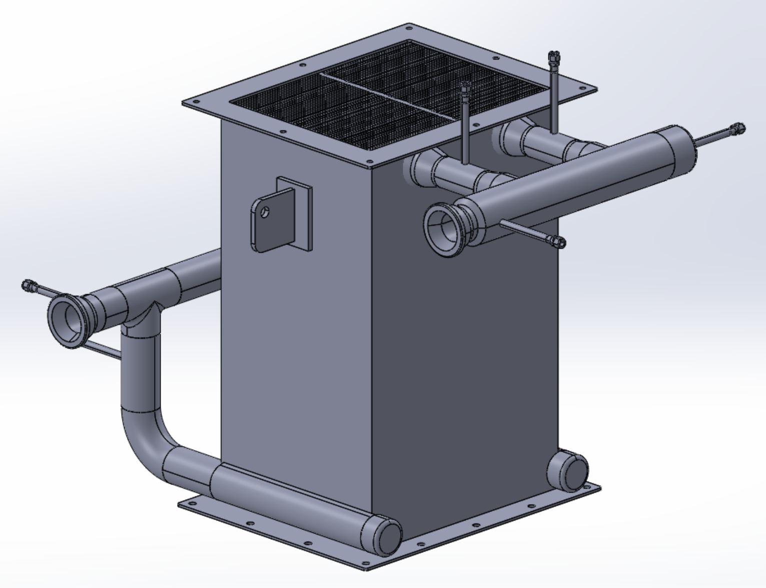
- 6 MWh two-tank thermal energy storage
- 122 metric-tons of CARBO HSP 40/70 particles
- Flat bottom tanks with particle riser
- Tanks installed bottom-up with structure construction
- Insulation installation on-going: Planned completion Oct. 2024





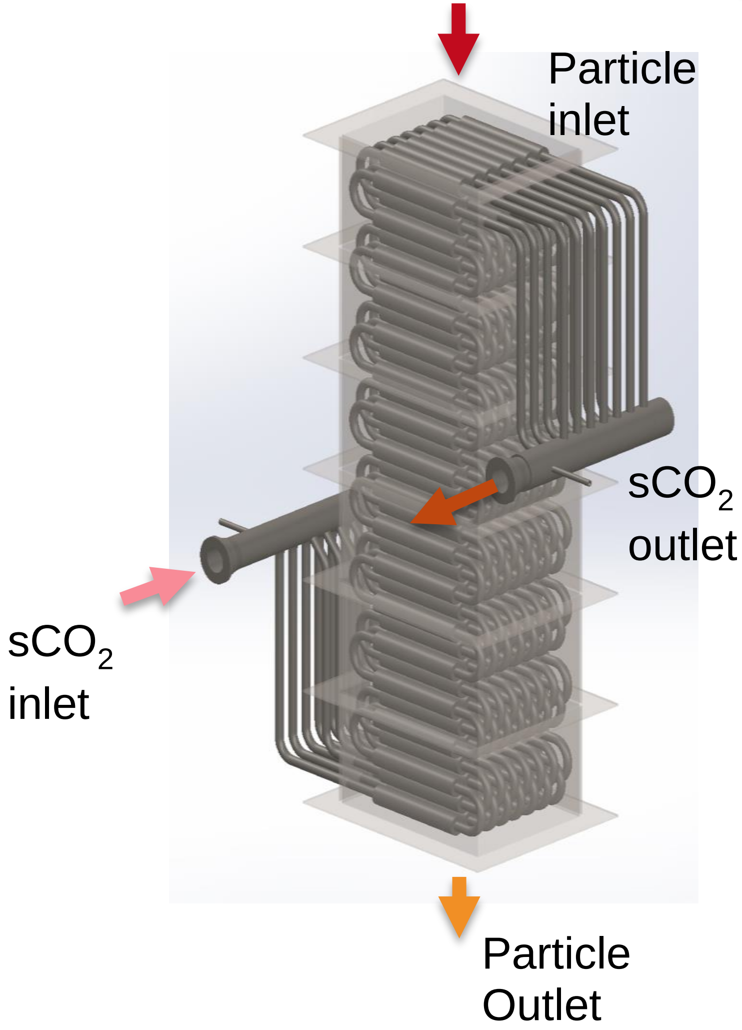
PRIMARY HEAT EXCHANGER

- G3P3-USA is awaiting delivery of two heat exchanger concepts
  - Parallel plate design (Inconel 625) (primary concept)
    - Currently experiencing fabrication delays
  - Shell and tube design (Inconel 625) (backup concept)



Parallel plate PHX core rendering

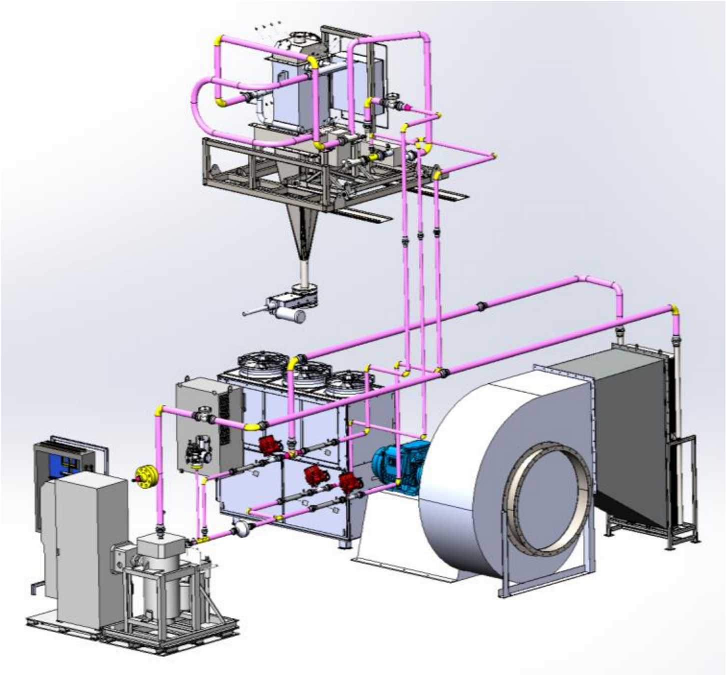
Shim assemblies prior to furnace loading (diffusion bonding)



Shell and Tube PHX rendering

SCO2 LOOP DESIGN UPDATE

- 1 MWt sCO2 heat rejection loop
- Serves as the heat rejection step in the gen3 CSP cycle – future augmentation to power cycle
- 5 kg/s flow rate, targeted 715 C maximum T_{sCO2}



sCO_2 loop CAD rendering

sCO_2 blower (right) and air cooler HX (left)

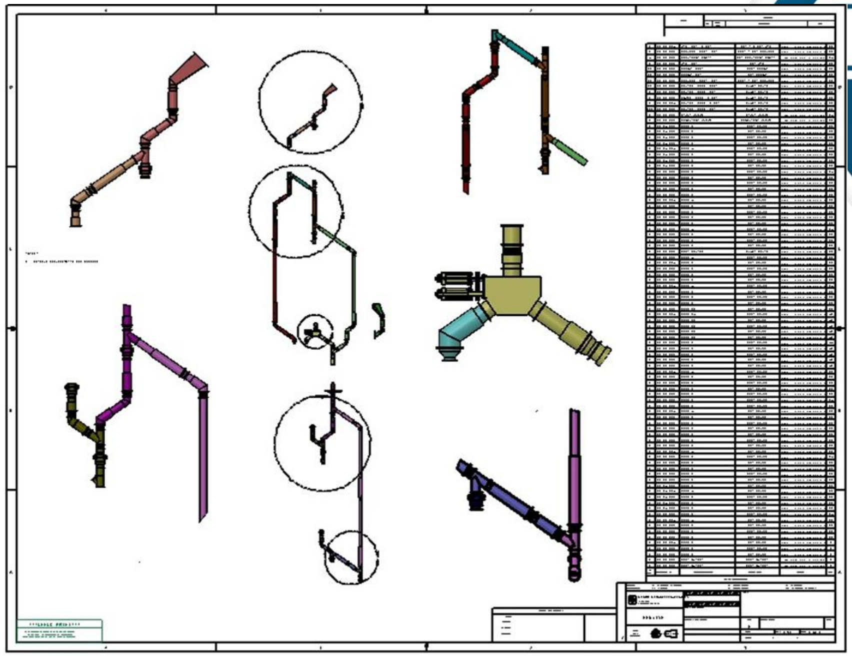
sCO_2 blower (heat rejection) (top) and sCO_2 pump (bottom)

DUCTING AND VALVES

- Circular ducting design chosen over square system
  - Minimizes the number of unique parts and fabrication
  - Simplifies design for thermal expansion
  - Simplifying mounting strategy – utilization of off the shelf hardware
- Ducting fabrication is underway

Dual actuation valve below hot storage

Testing of particle flow within the isolation valve

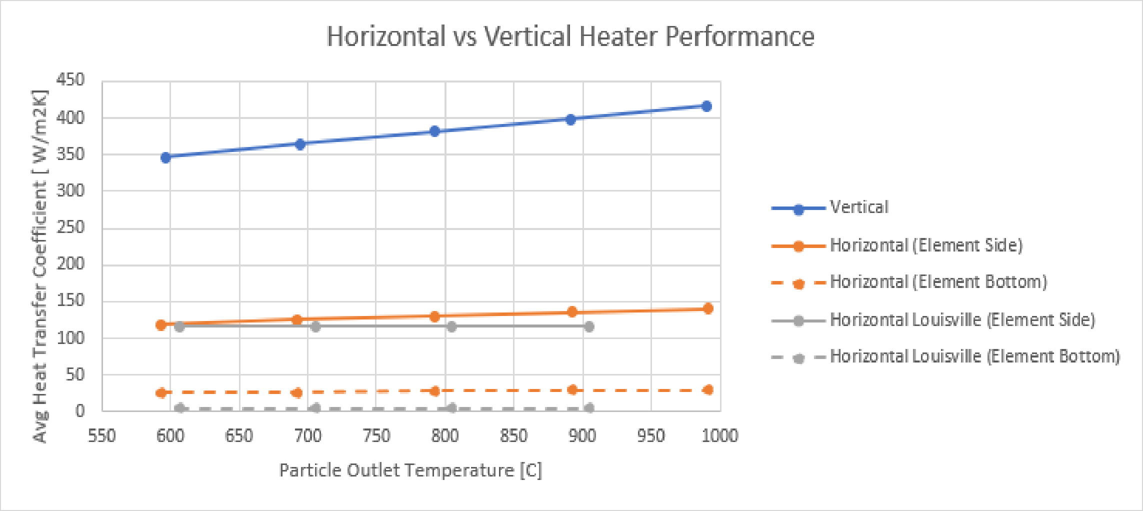


Completed interconnections

In-house construction of the ducting system

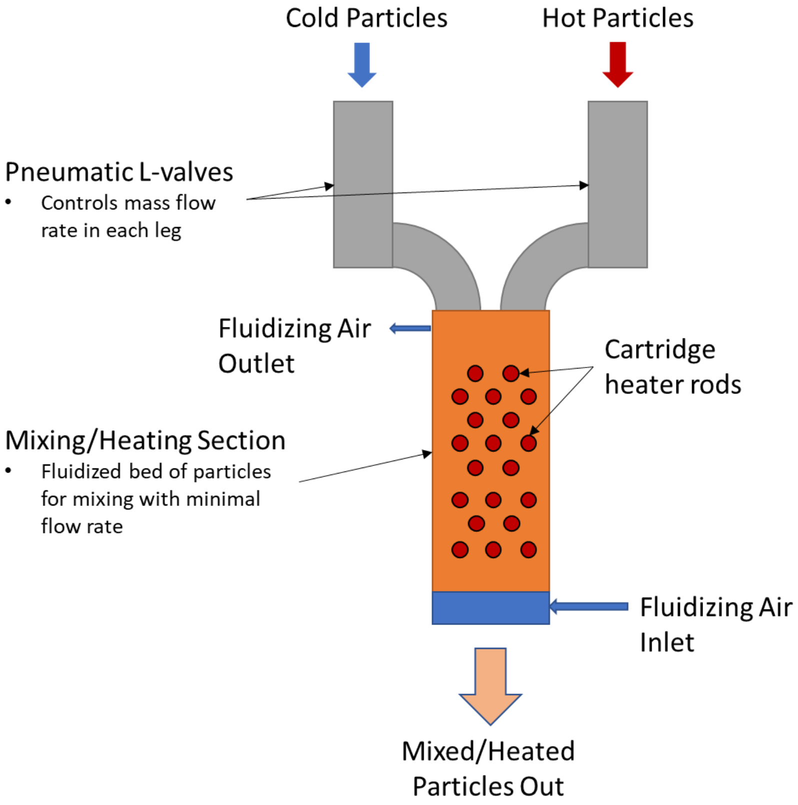
ELECTRIC HEATING

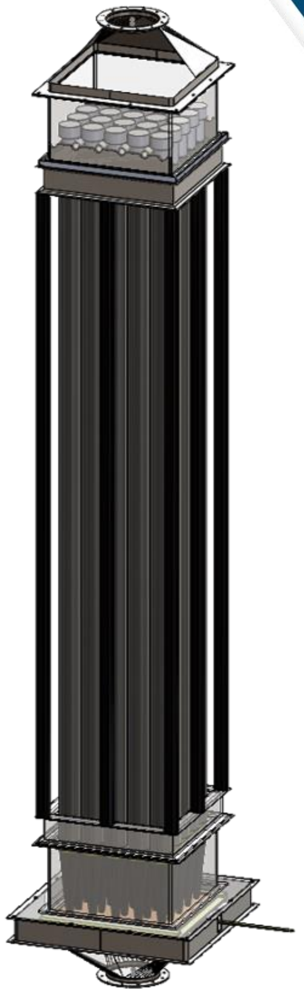
- Utilized for system pre-heating and particle temperature control
- 400 kW packed bed and 200 kW fluidized bed designs
- Designs completed and fabrication/procurement underway



Improved packed bed heater performance targets

Fluidized heater concept



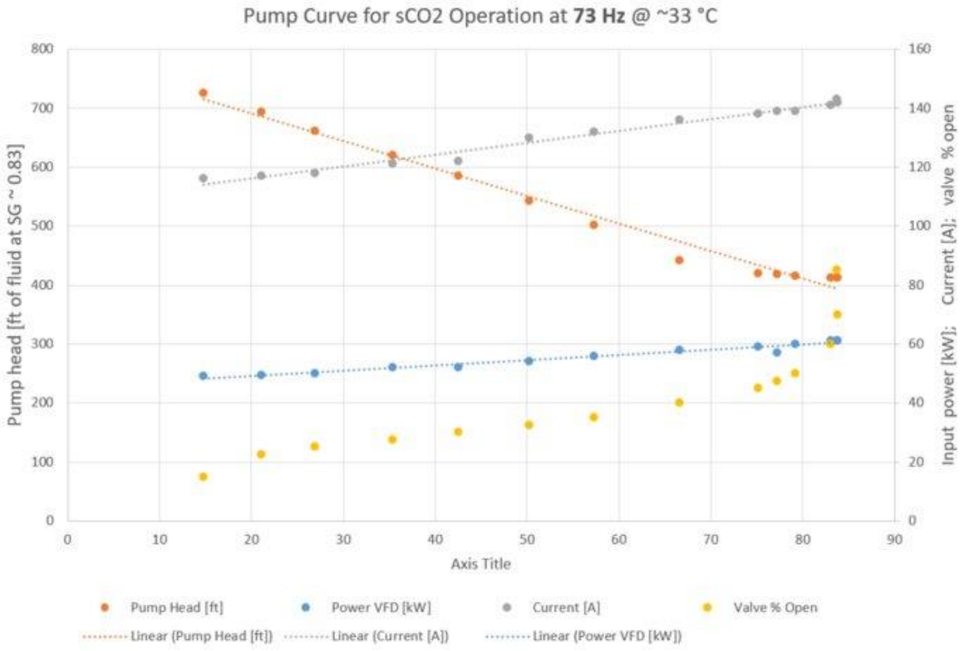


400 kW heater CAD

SCO2 LOOP GROUND TESTING

- sCO2 loop “cold” commissioned on ground prior to installation in G3P3 tower
- System pump and sensors characterized
    - Pump curve produced
    - Sensor ranges assessed
- Lessons learned
    - Venturi flow meter unsatisfactory – need for Coriolis flow meter
    - Pressure sensor differential measurement range too low – upgraded instruments needed
- Improved equipment procured
- Equipment installed in G3P3 tower

sCO_2 ground loop assembly during testing



LESSONS LEARNED

- NEPA (ask for everything you might need, changes can take years)
- Slope of decks for standard construction vs. equipment positions
- Crane design should be led by design team to ensure proper range of motion
- Storage assembly and materials
- Formal review of construction drawings and architect understanding of use (cutouts for ducts)
- SCADA (IT) was a much larger than anticipated
- Ductwork, valves, and pressure system merits dedicated design team
- Management reserve budget was critical

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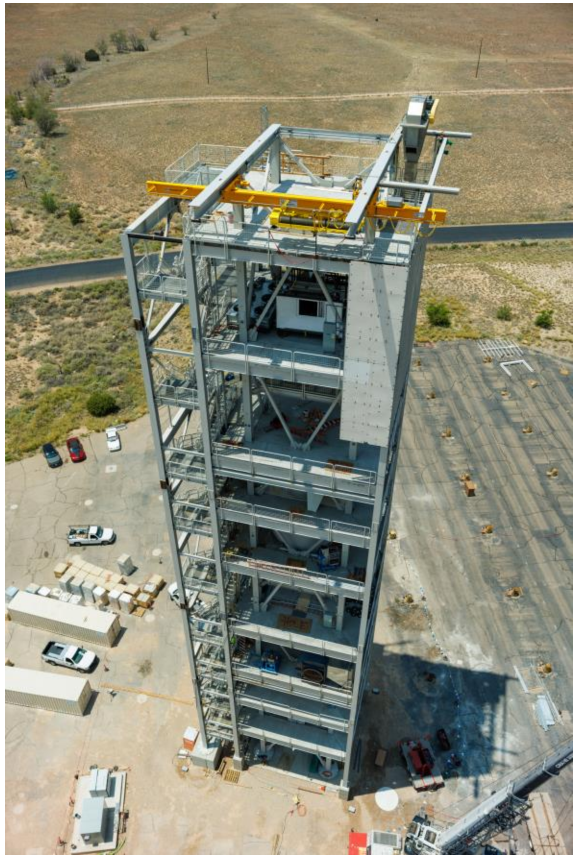
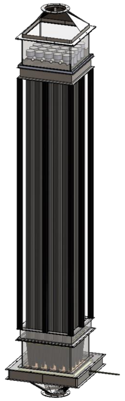
NEXT STEPS

What's Next?

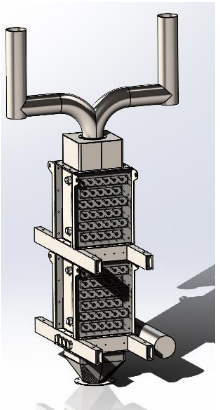
- Complete ducting/insulation installation
- Install heat exchanger and complete sCO_2 loop
- Setup SCADA system & calibrate valves/sensors
- Cold flow particles
- Gradually add heat to the system



MEETING THE CLIMATE CHALLENGE: IMPACT/OPPORTUNITIES



Electric particle heaters
Hybrid PV/CSP demo
RE grid storage



Particle-air heater
Industrial processes

Sand enables:
- Higher power efficiency
- Smaller Lower Cost Receiver
- Abundant sourcing
- Low material cost \$0.58/kW$_e$
- LCOS 160 \$/kWh$_e$
- 3.7x lower $CO_{2\text{-eq}}$ than Li+
- Higher temperatures

Electricity generation

Brantley Mills, SNL

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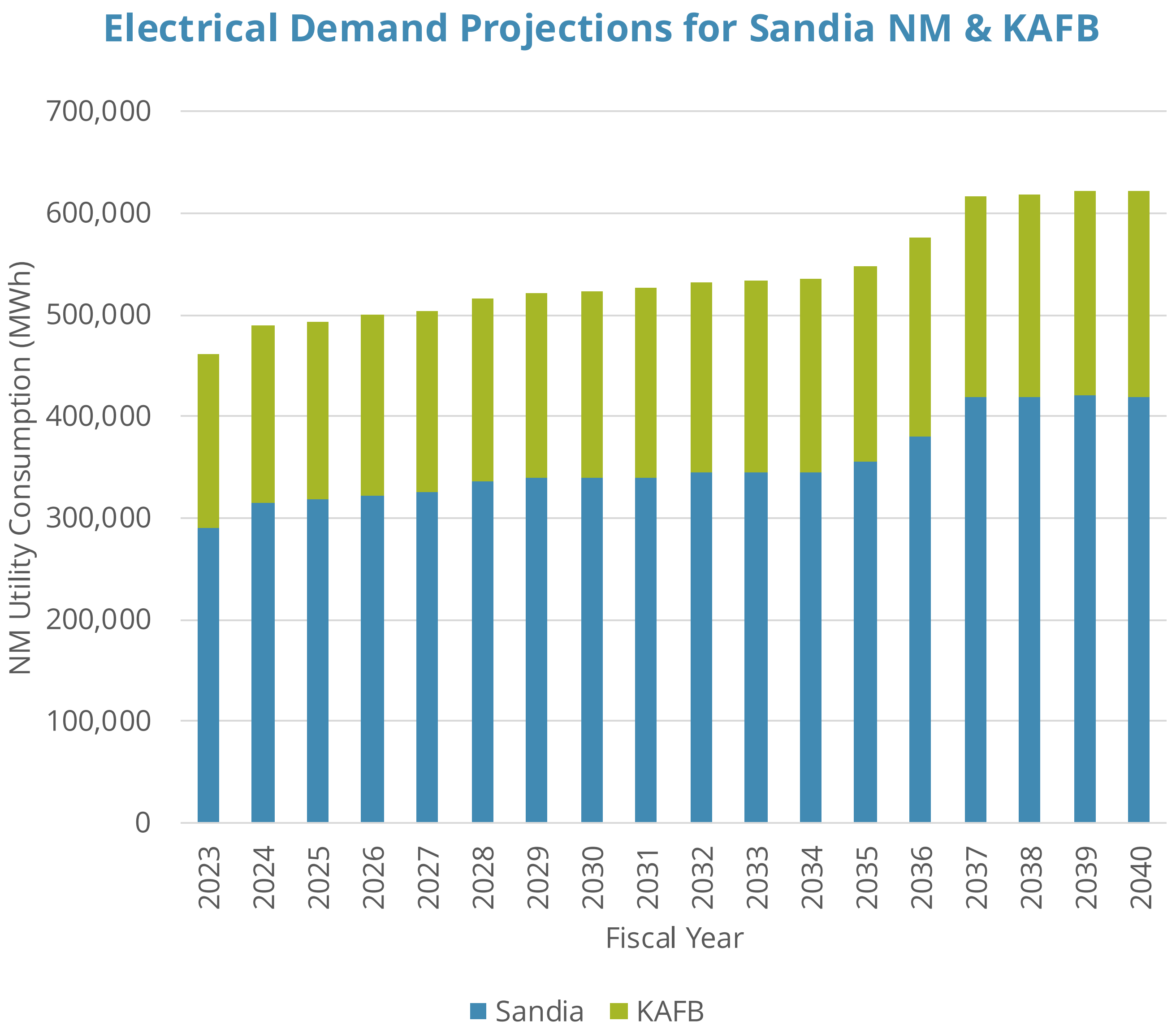
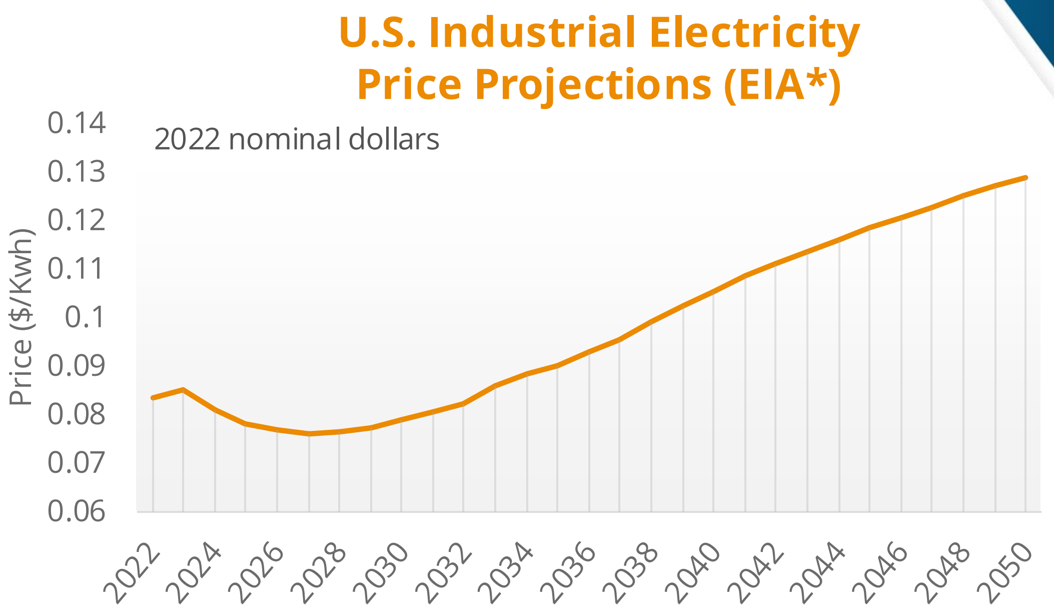
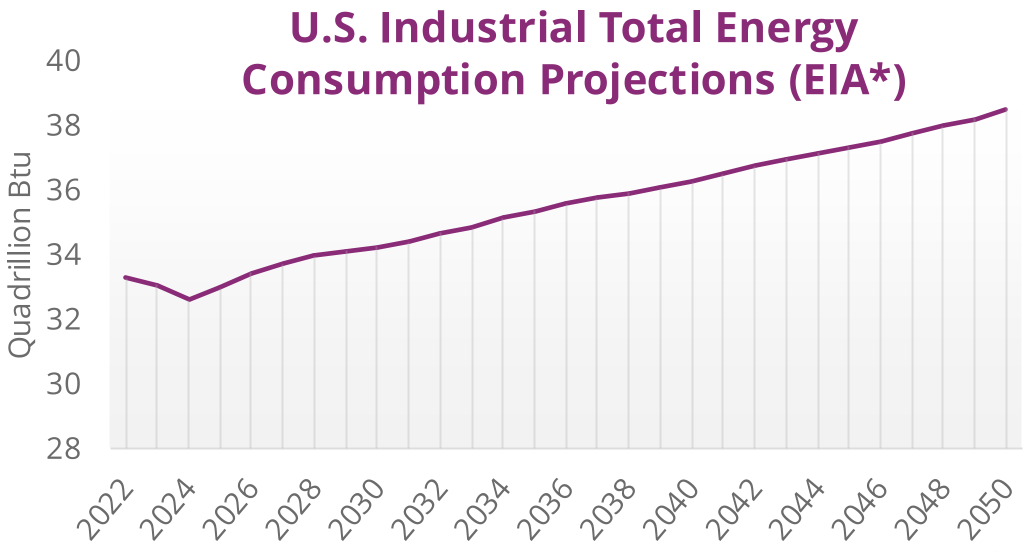
PROJECTED ELECTRICAL DEMAND FOR SANDIA NM AND KAFB







Energy Information Administration

SOLAR ENERGY OPTIONS – WHY A HYBRID SYSTEM MAKES SENSE

Model results for a generic system without KAFB constraints

- **LCOE: 5 ¢/kWh**
- No storage

Least cost daytime energy

No energy storage

- **LCOE: 13 ¢/kWh**
- Storage: 12 hrs

Expensive option to add long duration energy storage

- **LCOE: 9 ¢/kWh**
- Storage: 12 hrs

Significantly lower cost with long-duration energy storage

- **LCOE: 8 ¢/kWh**
- Storage: 12 hrs

Combines least cost daytime energy with lowest cost long-duration energy storage

Modeling Assumptions:

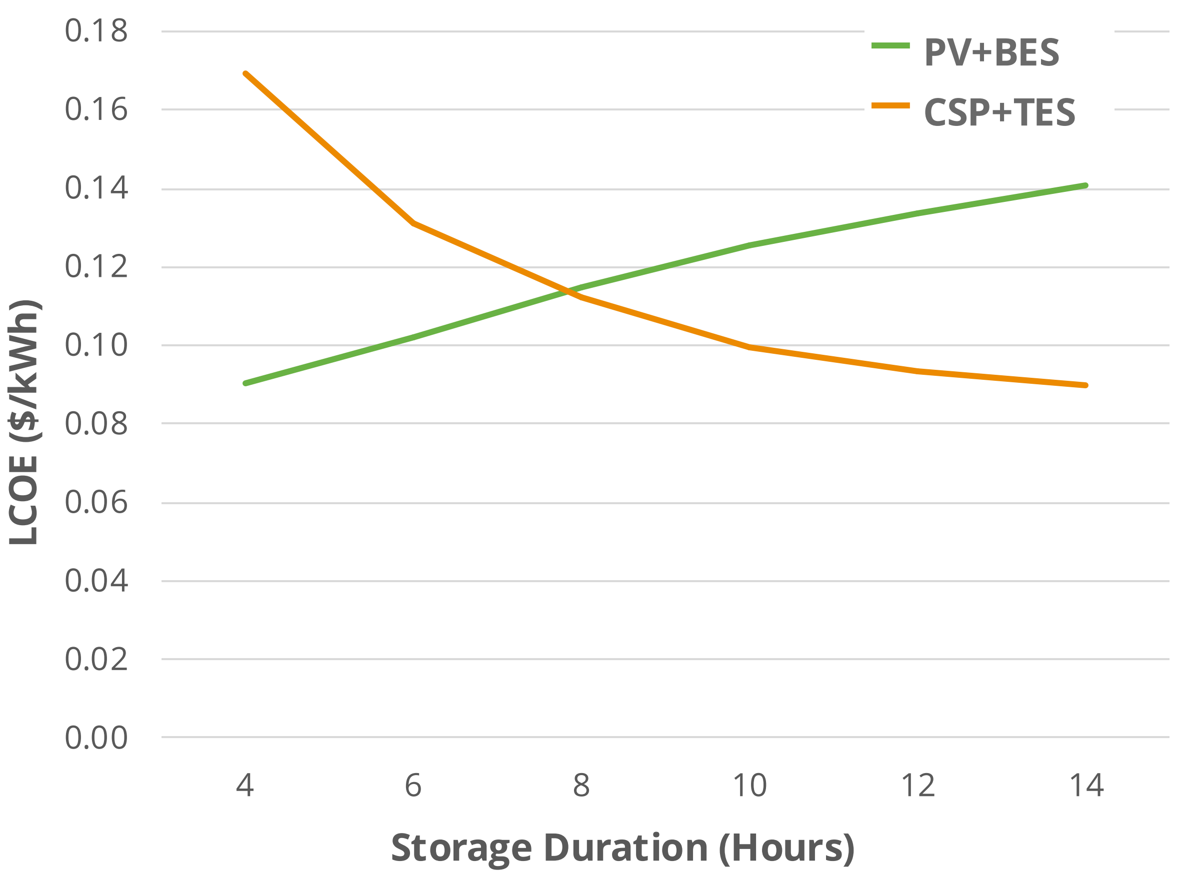
- Calculations for generic system with 12 hours of storage, 100 MW overnight output capacity
- No operational or land area constraints
- 30% investment tax credit, 30-year operational lifetime

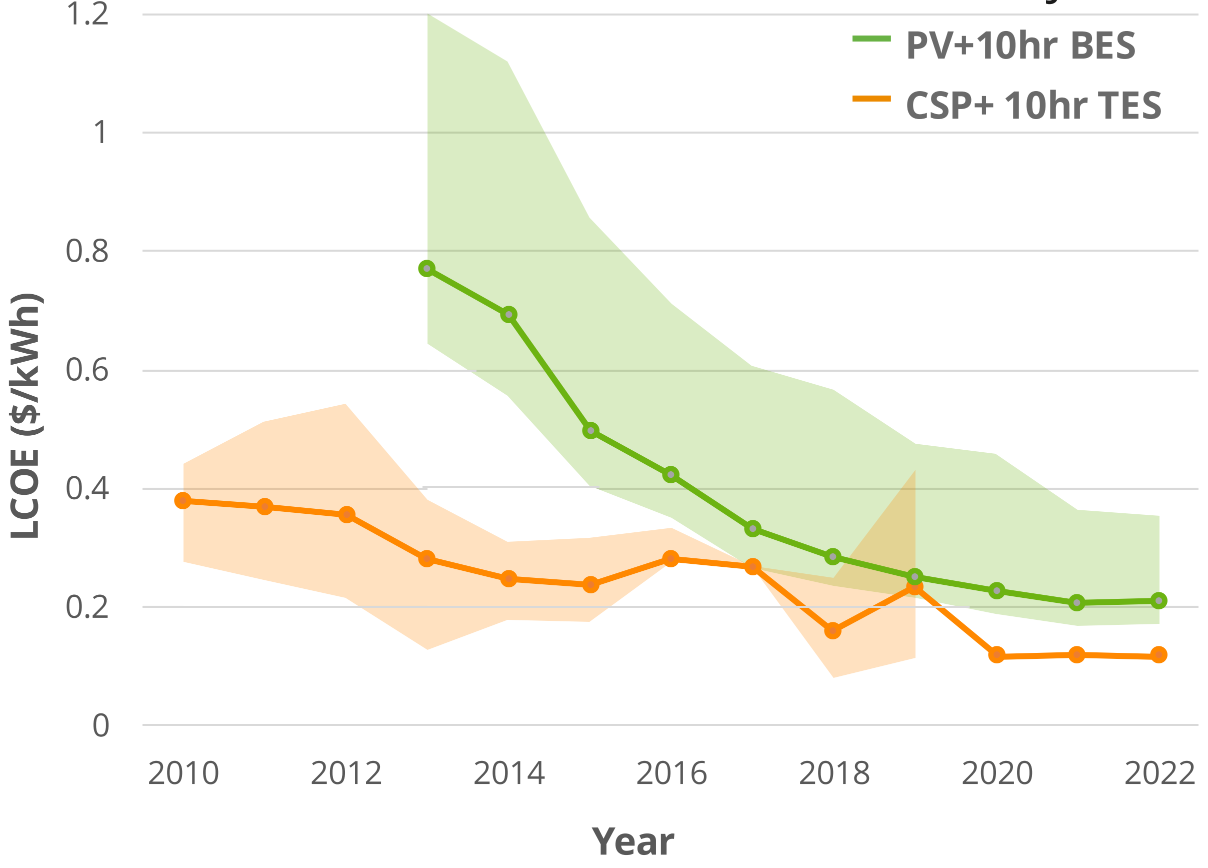
Content: L. McLaughlin

COMPARING PV AND CSP SYSTEMS COST

When long duration storage needed, CSP+TES is more cost-effective

Content: J. Braid



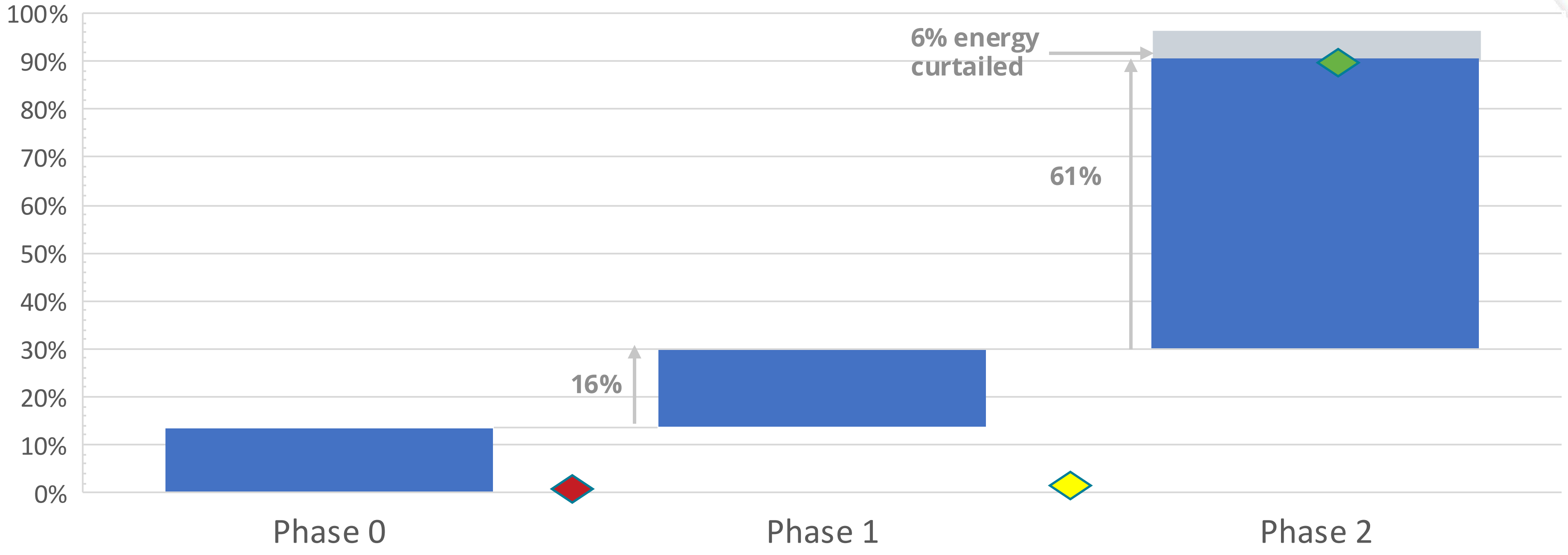


- Model results for generic solar + storage system with a 100 MW of overnight output capacity
- LCOE = Levelized Cost of Energy

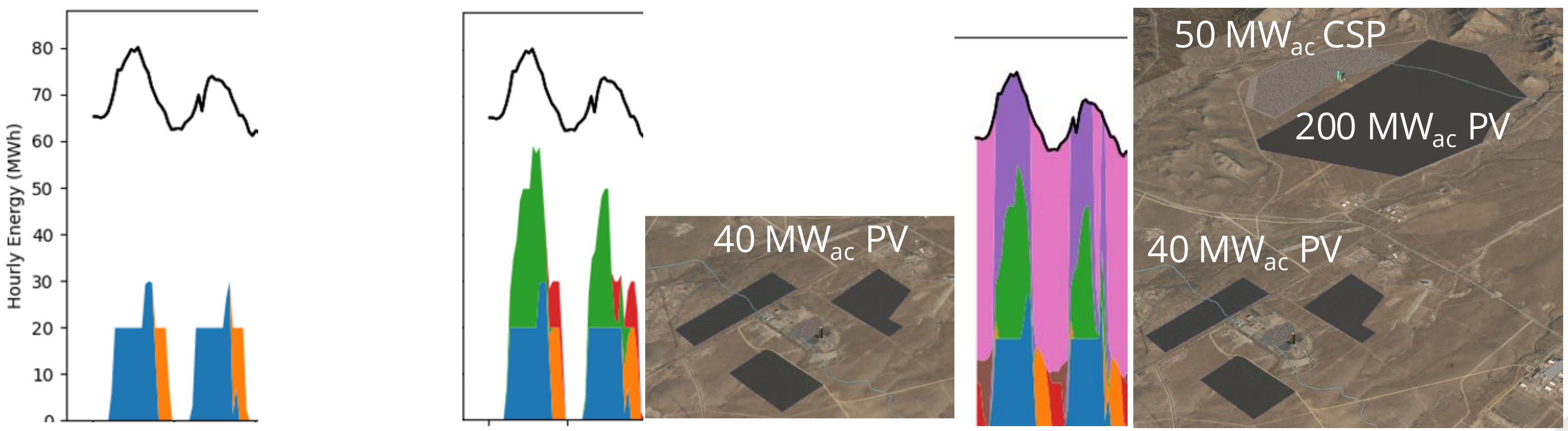
- PV and CSP costs are from historical data
- PV + 10 hrs BES derived from historical PV and BES data

PHASED BUILDOUT

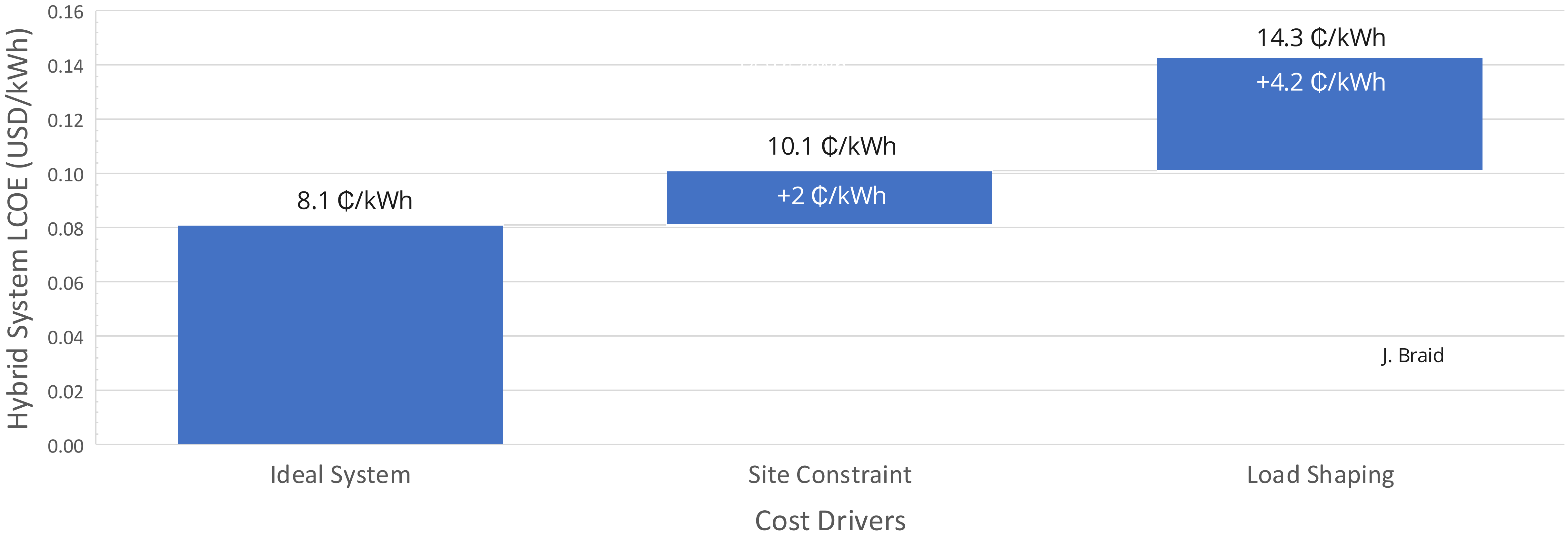
Contribution to Net Zero and Resilience Goals (J. Braid)



	Phase 0 – PV to Load
	Phase 0– BES to Load
	Phase 1 – PV to Load
	Phase 1 – BES to Load
	Phase 2 – PV to Load
	Phase 2 – BES to Load
	Phase 2 – TES to Load
	Grid to Load
—	KAFB/SNL Nominal Load (2033)

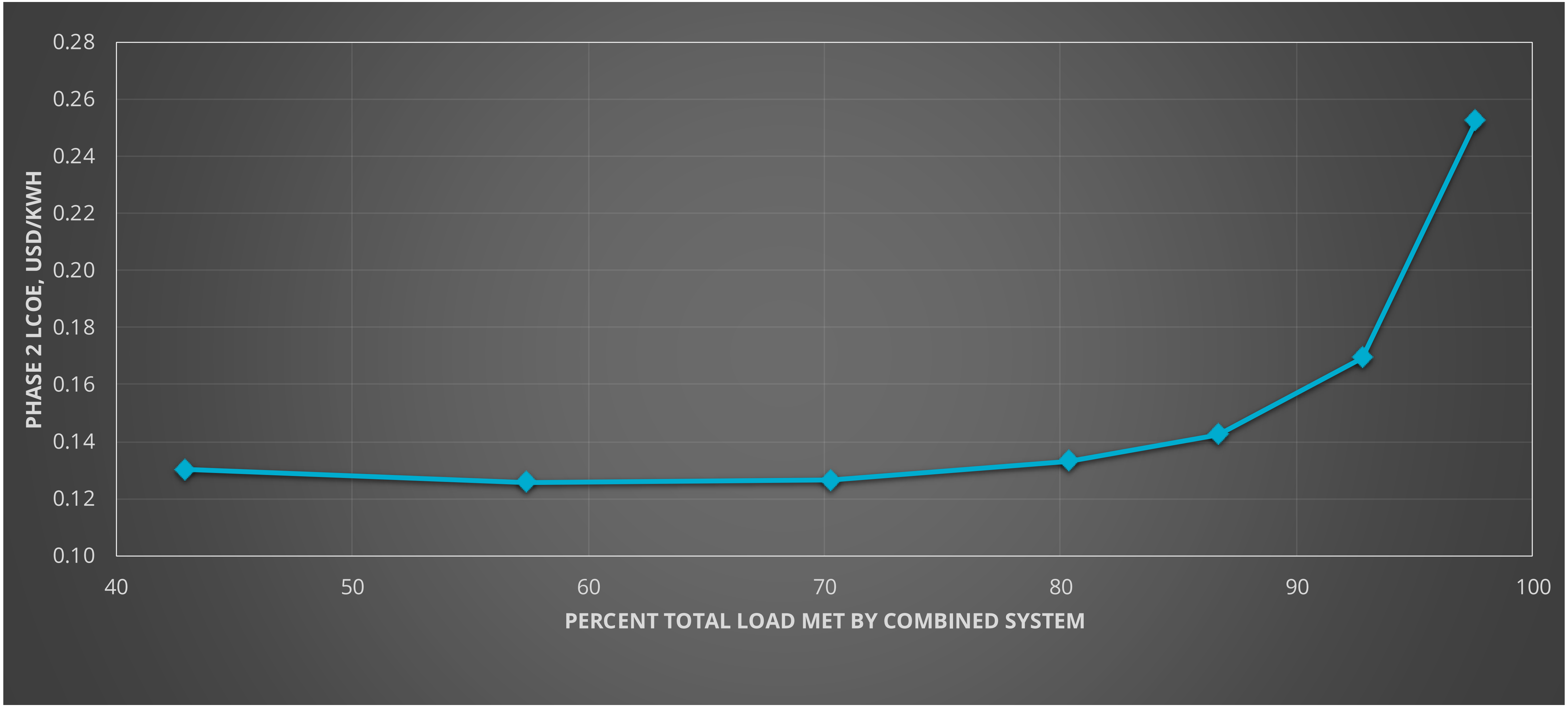


HYBRID SYSTEM COST DRIVERS



- Constraints on the hybrid system imposed by KAFB load, site, and policies increase real costs
- Load shaping includes curtailment and thermal storage efficiency losses for PV

COST VERSUS LOAD SATISFACTION CURVE, FOR PHASE 2

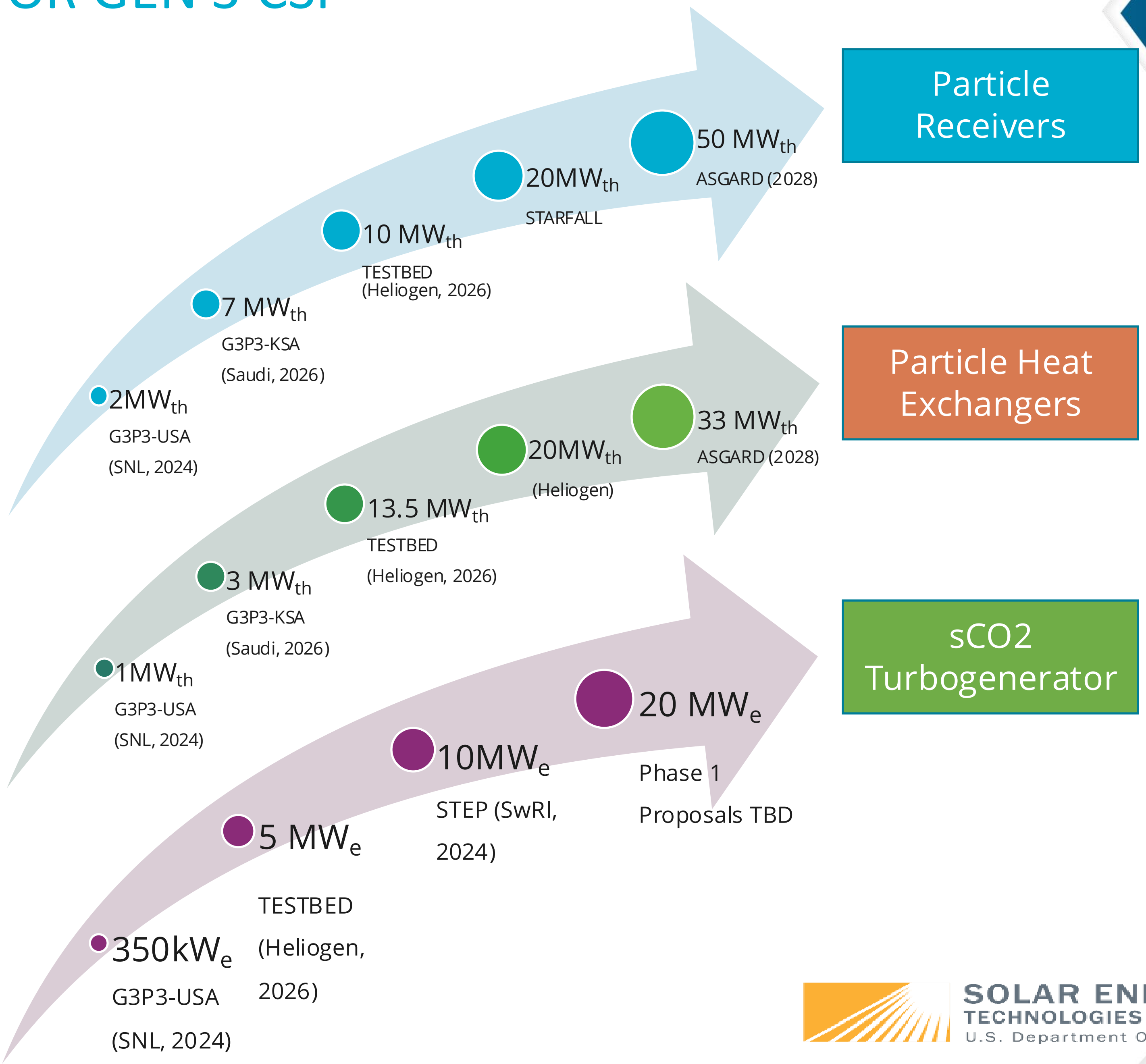


J. Braid

COMMERCIAL TRAJECTORY FOR GEN 3 CSP

Particle-based Tower Projects
- G3P3-USA – Commissioning
- G3P3-KSA – Pre-construction
- Capella - Pre-construction

Economic Sector Opportunities
- Energy production
- Industrial Process Heat
- Solar Thermochemical Fuels



AGENDA

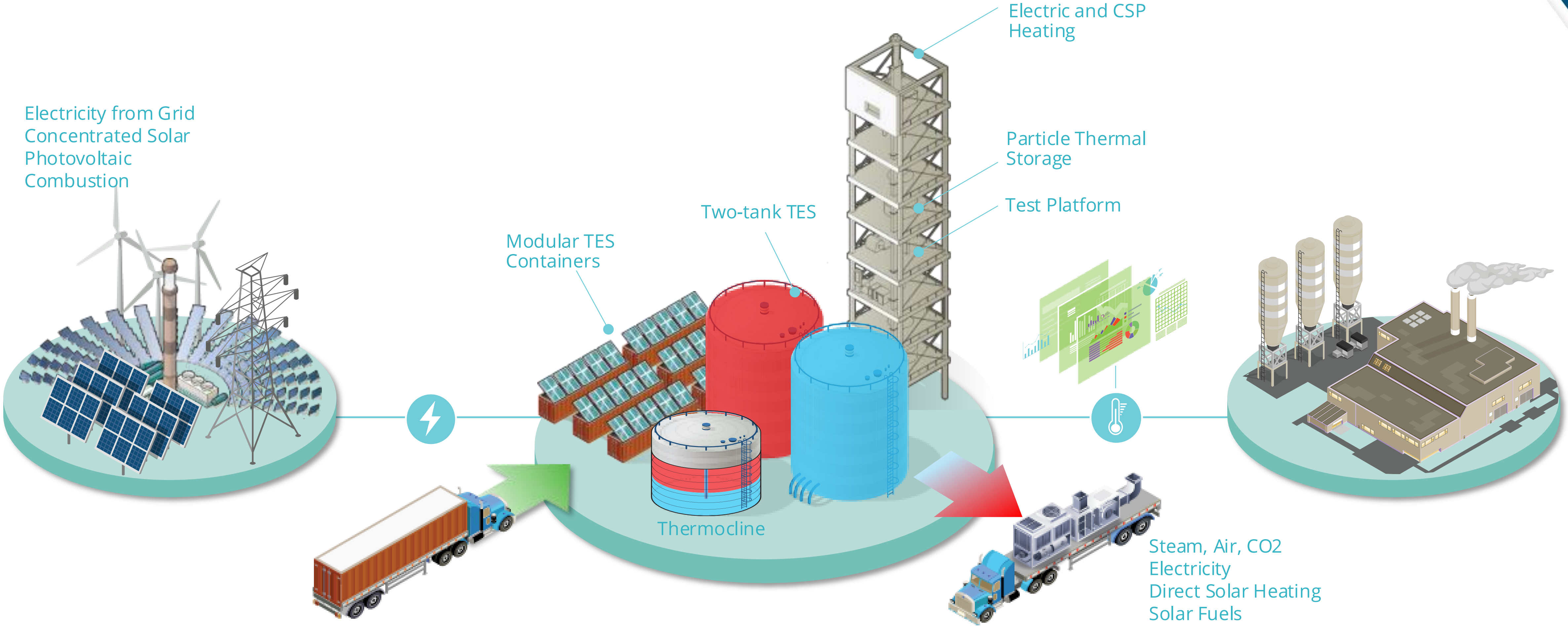
October 29, 2024

10:00-10:40 Presentation

10:40-10:55 Q&A

Please log questions during presentation in chat.

NSTTF THERMAL ENERGY STORAGE TESTBED

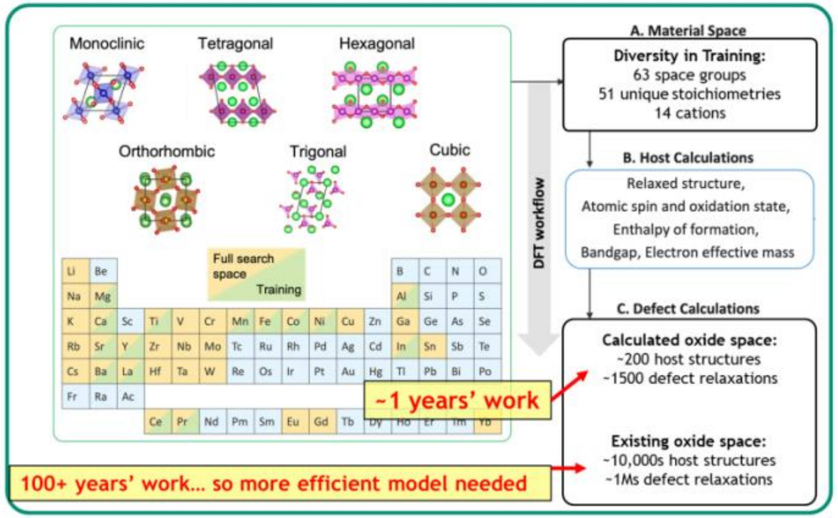


MULTIPLE SOURCES OF ENERGY INPUT

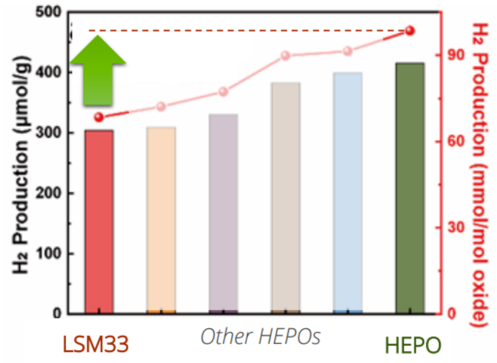
THERMAL ENERGY STORAGE DEMONSTRATIONS

INDUSTRIAL SCALE EQUIPMENT DEMONSTRATION

PARTICLE-BASED SOLAR THERMOCHEMISTRY



Discovery of new STCH materials using machine learning (M. Witman, 8341 Nanomaterials) Nature Computational Science (2023)



Discovery of new High-Entropy Perovskite Oxide Enhances H2 Production $La_{1/6}Pr_{1/6}Nd_{1/6}Gd_{1/6}Ba_{1/6}Sr_{1/6})MnO_{3-\delta}$ (S. Bishop, 1816 Material Physics) ECS Trans. (2023)

$$T_{red}=1300\text{-}1500°C$$

$$MO_x \rightarrow MO_{x-1} + \frac{1}{2}O_2$$

$$T_{ox}=800\text{-}1000°C$$

$$MO_{x-1} + H_2O \rightarrow MO_x + H_2$$

NSTTF CeO_2 particles heated with solar simulator to split water to produce H_2 (A. McDaniel, 8367 Hydrogen Materials Science) SAND2017-9334R

NSTTF: $SrFeO_3$ particles heated with solar simulator to isolate N_2 from air and then with Mo3Co3N particles and H_2 to make NH_3 (A. Ambrosini, E. Bush, 8923 CSP)

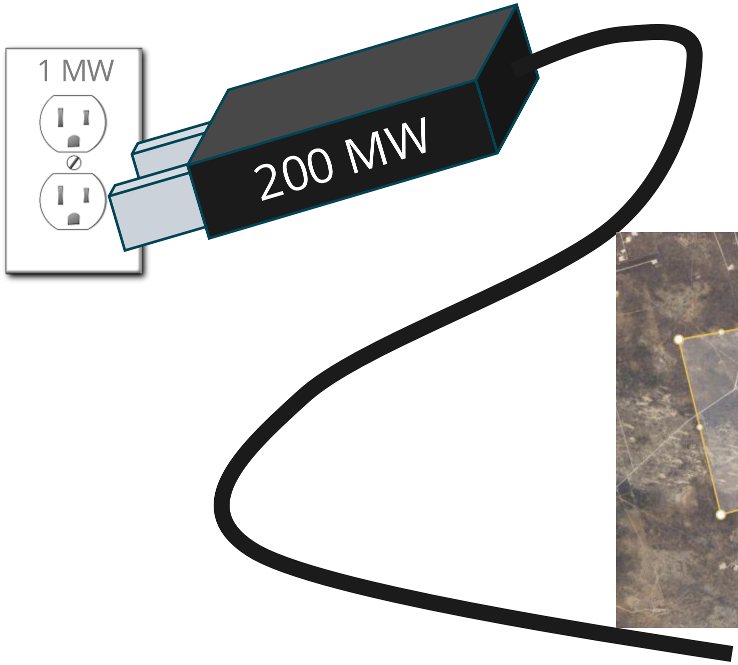
CONCENTRATING SOLAR HEAT FOR HYDROGEN PRODUCTION

CST could help accommodate Green Hydrogen production in a stretched grid infrastructure.

A green hydrogen hub that makes 100 tons/day requires a 200 MW_e 122 kV transmission line (assume 65% efficiency). High-voltage lines are hard to permit and may have to compete with other users.

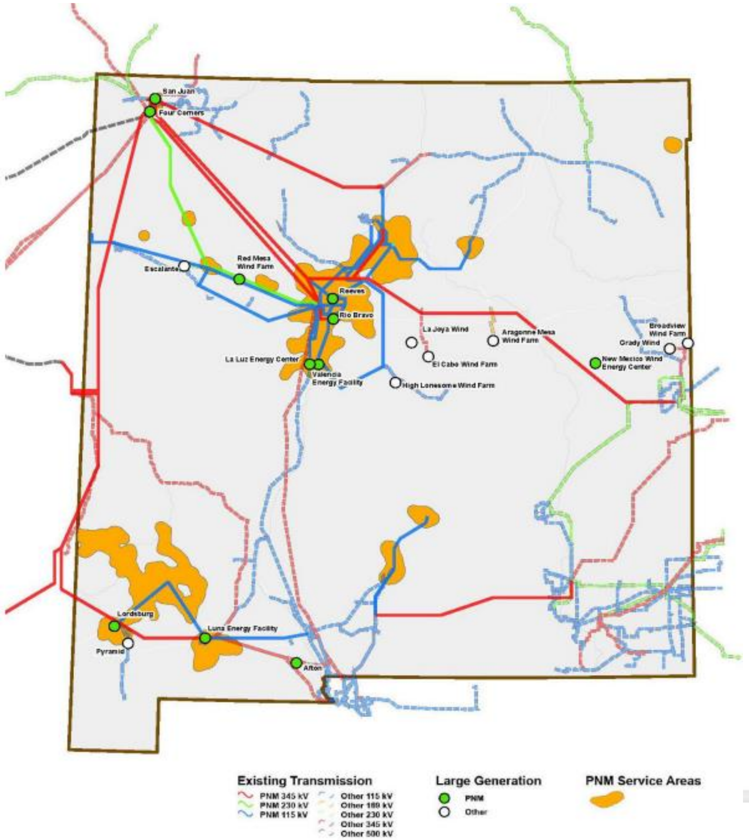
A CST hydrogen hub could be islanded away from high power transmission but would only make 15 tons/day of H_2 for a 200 MWt plant (Ma 2022). Land area improves by ~20%.

Scaling particle handling and hermetic receivers are the main barriers to be overcome.



PV array needed to power 100 ton/day H_2 plant

Overlay on Santa Fe map



Acknowledgements

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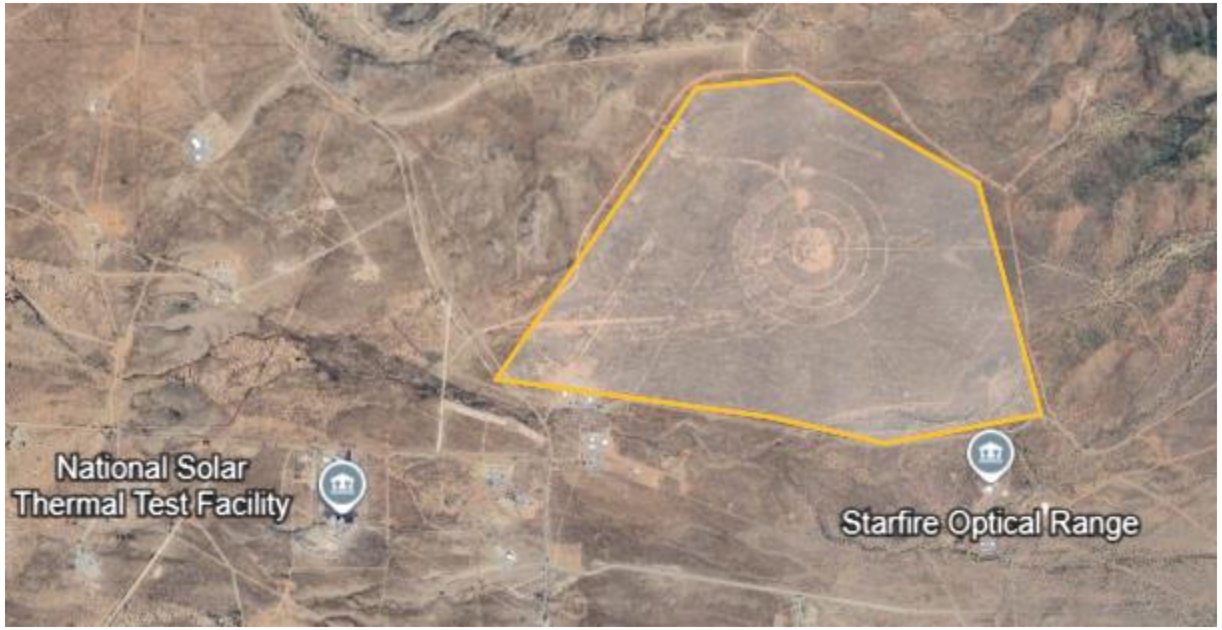
QUESTIONS?


National Solar Thermal Test Facility
Starfire Optical Range