U.S. Department of Energy
HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

Heliostat Field Optimization for Power Tower Solar Industrial Process Heat Applications

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Heliostat Consortium Task 8: Technoeconomic Analysis (TEA)

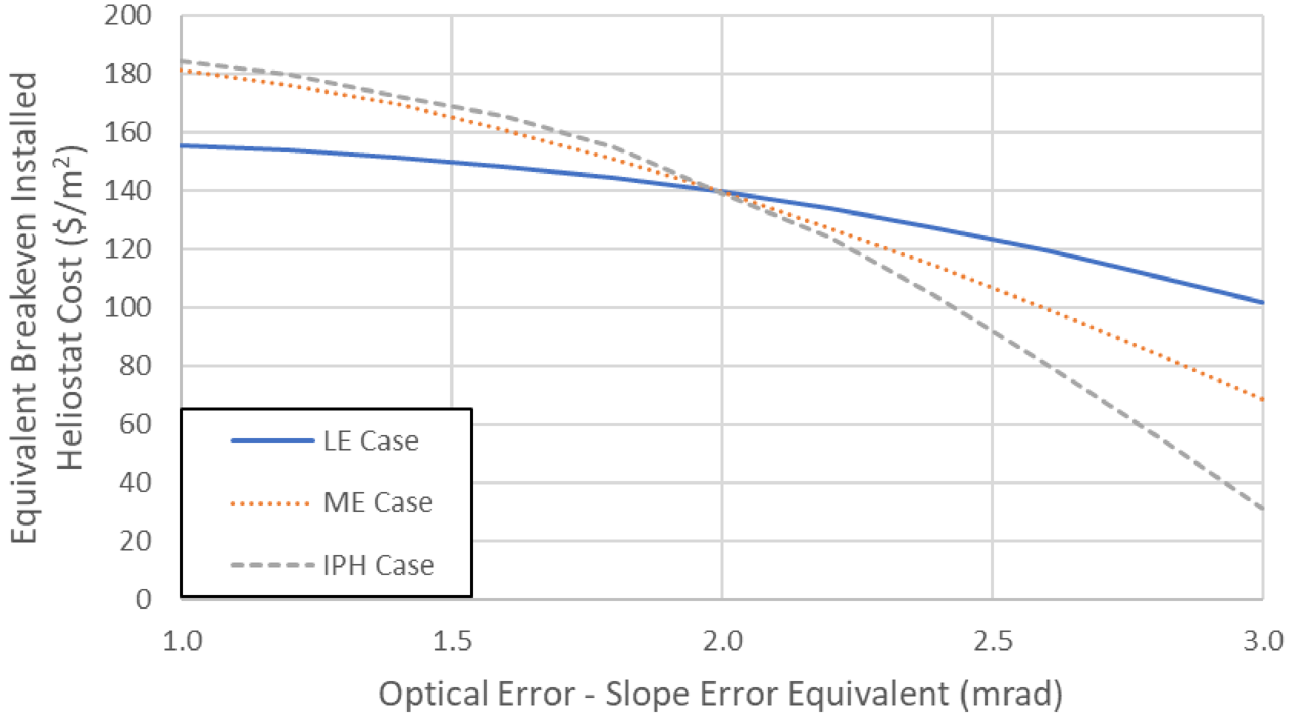
Objective: Develop techno-economic models to support the assessment and development of new heliostat concepts

- Develop capabilities to:
  - Model economic viability of new heliostat designs
  - Perform analysis on fundamental problems that would promote heliostat economics in general
  - Provide analysis and support to guide HelioCon R&D directions and portfolio
- Quantify tradeoffs and interactions of heliostat design, manufacturing, and operation to illustrate R&D benefits on a "total system" level

HelioCon Task 8: Technoeconomic Analysis

FY2022

- Developed baseline heliostat fields and benchmarked existing heliostat/CSP costs
  - Large Electric Field case (LE)
  - Modular Electric Field case (ME)
  - Industrial Process Heat case (IPH)
- Assessed R&D ideas from other topics for potential CSP cost reductions (i.e., is it worth studying?)

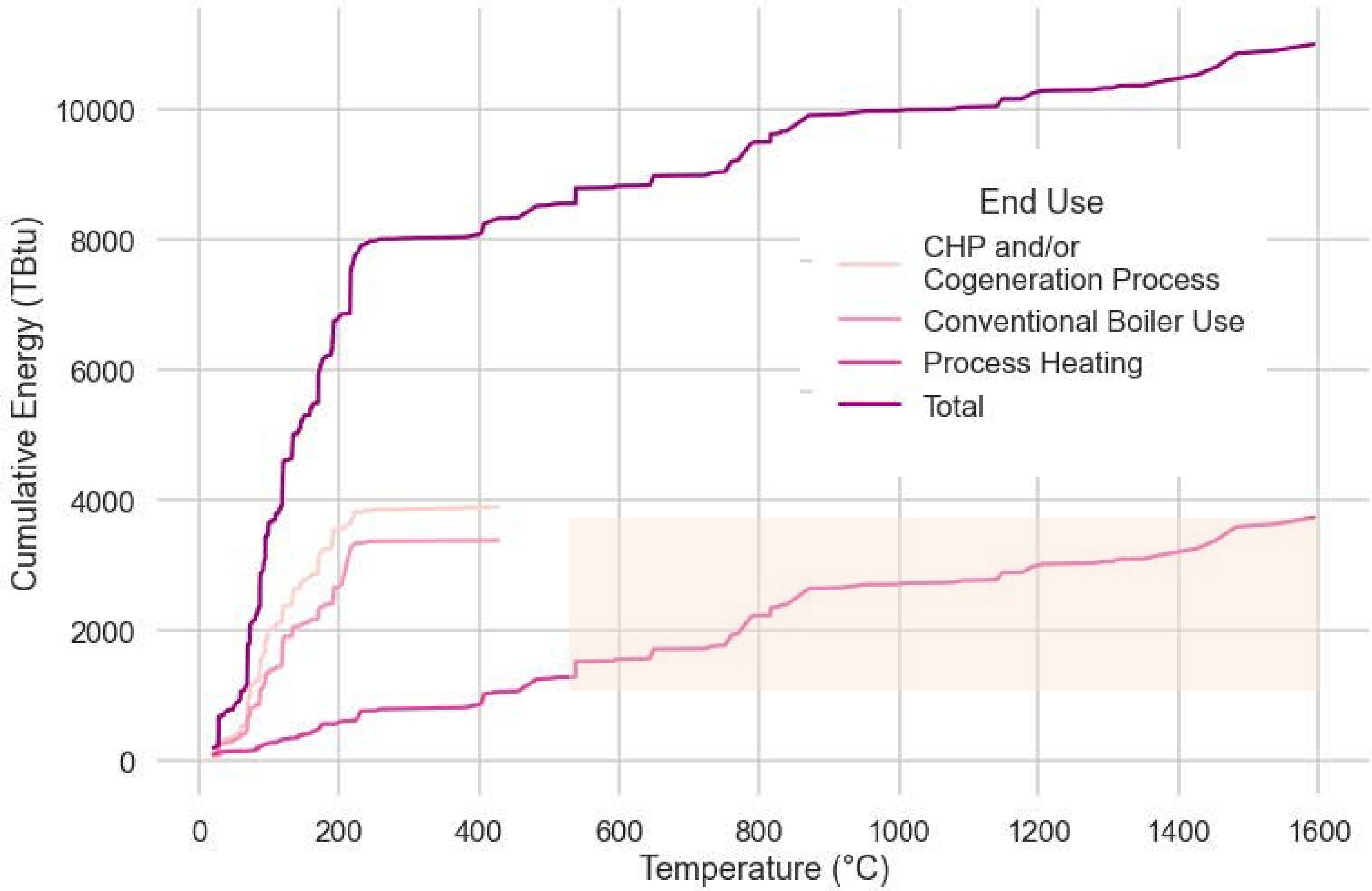


Zolan A, Augustine C, Armijo K. *Equivalent Breakeven Installed Cost: A Tradeoff-Informed Measure for Technoeconomic Analysis of Candidate Heliostat Improvements*. Pressented at SolarPACES 2023 Conference. National Renewable Energy Laboratory; 2023. https://www.nrel.gov/docs/fy23osti/84002.pdf

Zolan A, Augustine C, Armijo K. "Case Studies and Parametric Analysis of Heliostat Performance with a Tradeoff-informed Technoeconomic Analysis Metric" *J. Sol. Energy Eng*. November 2013, 135(4): 040301.

HelioCon Task 8: Technoeconomic Analysis

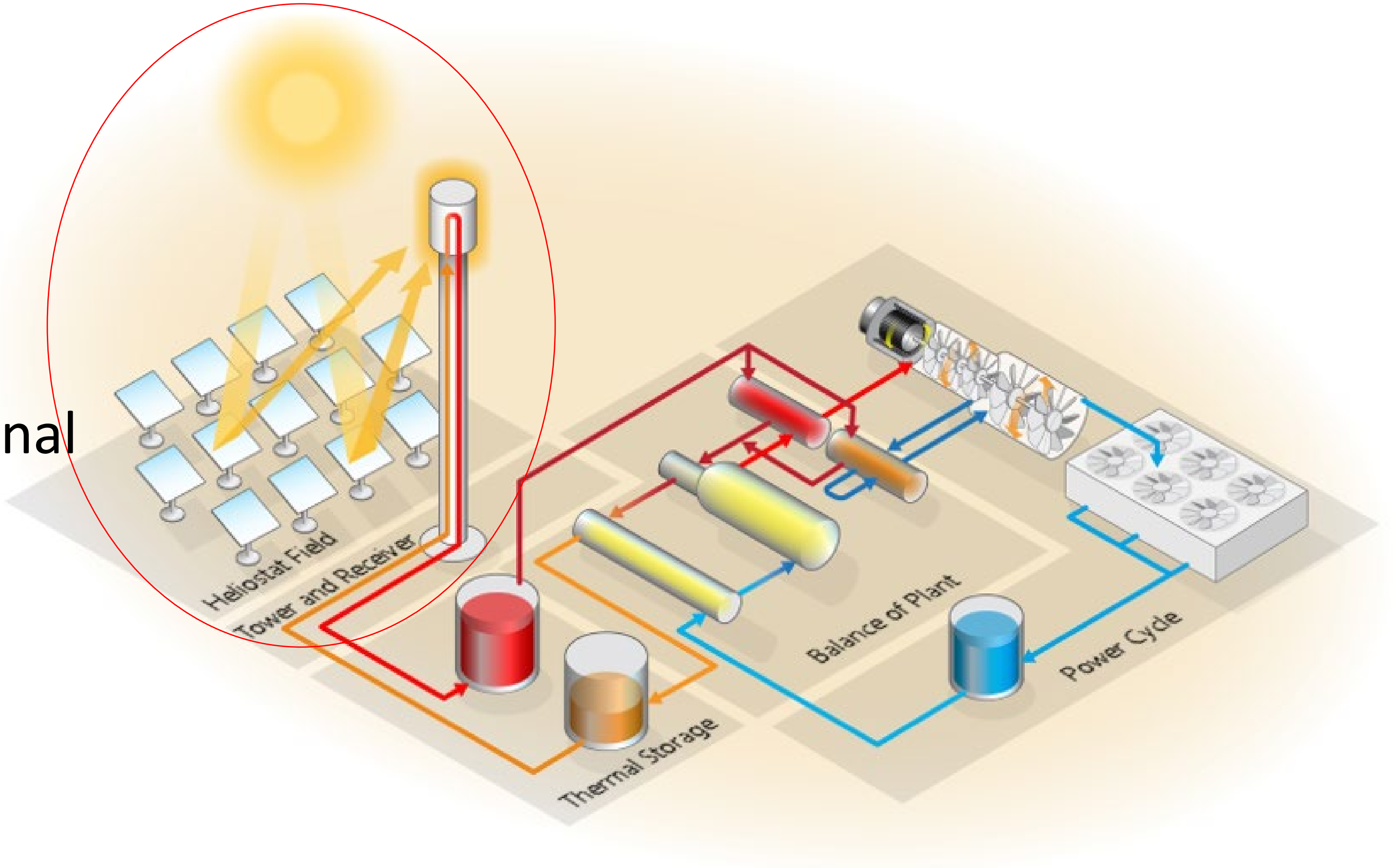
- FY2023 Goal: Characterize concentrating solar power tower fields for solar industrial process heat (SIPH) as a function of temperature
- Motivation:
    - Decarbonization of industrial sector will require substitute for burning fuels to generate high-temperature process heat
    - CSP power tower is only renewable energy tech with high temperature thermal energy (>500+ °C) as its initial output



McMillan CA, Schoeneberger CA, Zhang J, et al. *Opportunities for Solar Industrial Process Heat in the United States*. National Renewable Energy Laboratory; 2021. https://www.nrel.gov/docs/fy21osti/77760.pdf

SIPH Field Layout Methodology

1. Choose SIPH process temperatures for analysis
2. Develop base case field layout for each process temperature
   - SolarPILOT is our modeling tool
   - Collaborating with Australia National University, using SolarTherm
3. Screen results
4. Add cost estimates
5. Parametric and optimization studies



SIPH Field Layout – Selected Temperatures

- Temperatures selected after literature review
- Selections chosen to cover a wide range of temperatures and a number of key high-temperature industrial processes
- We are concerned with heliostat field layout – actual process is not considered.
  - Assume heat delivered to off-sun process or storage

Calcination (cement)

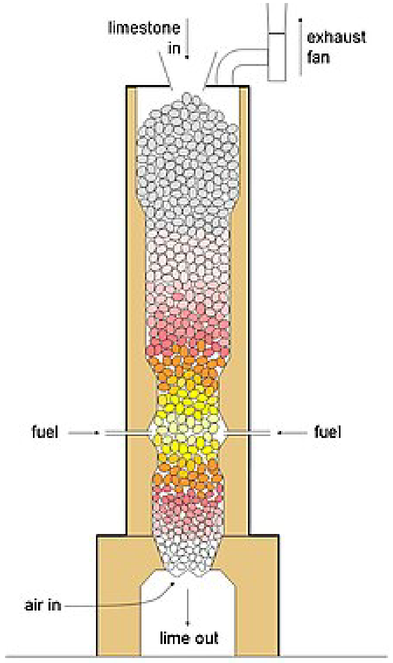
- 900 °C

Solar Fuels (ex., hydrogen production)

- 1,200 °C

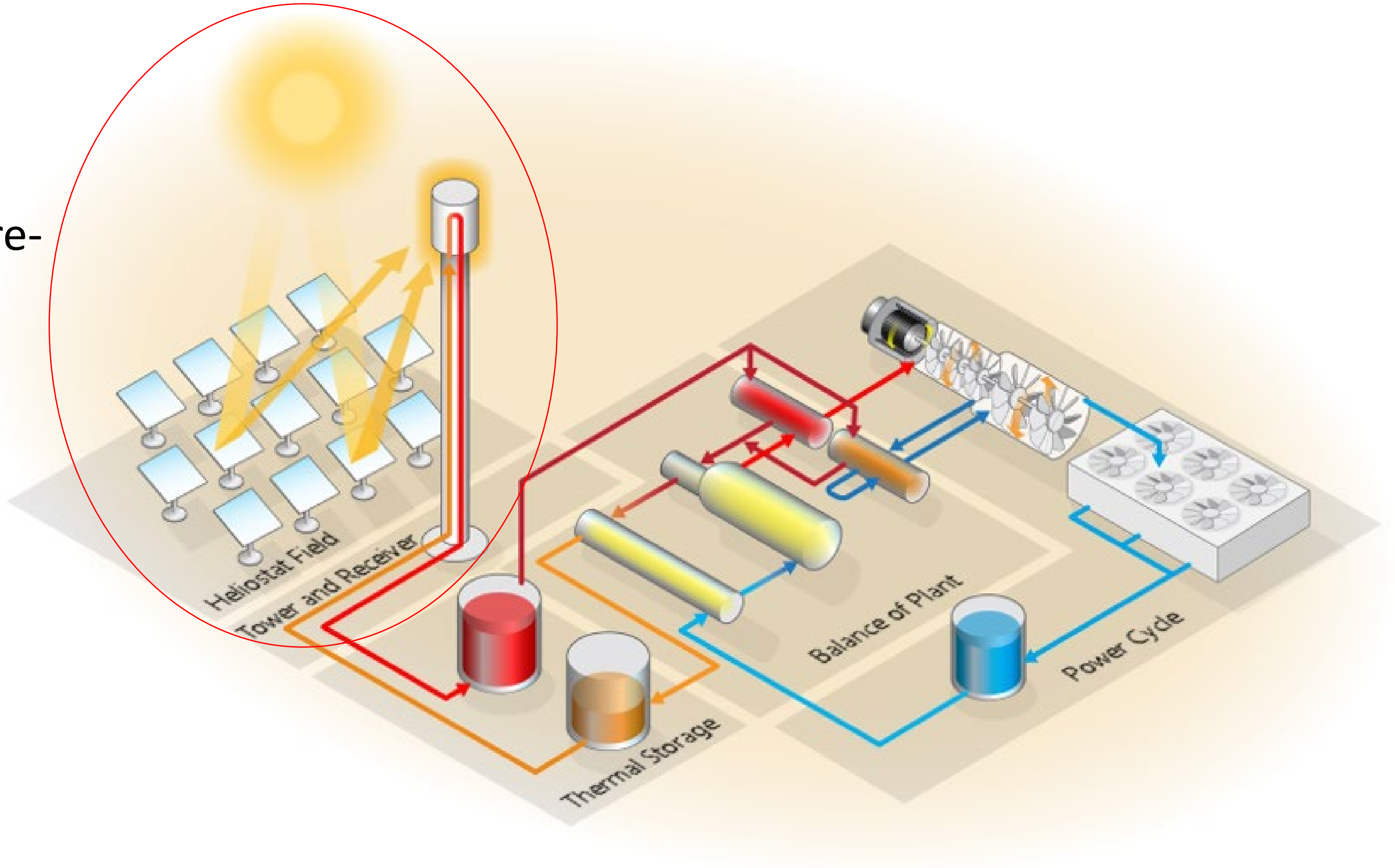
Clinker production (cement)

- 1,550 °C



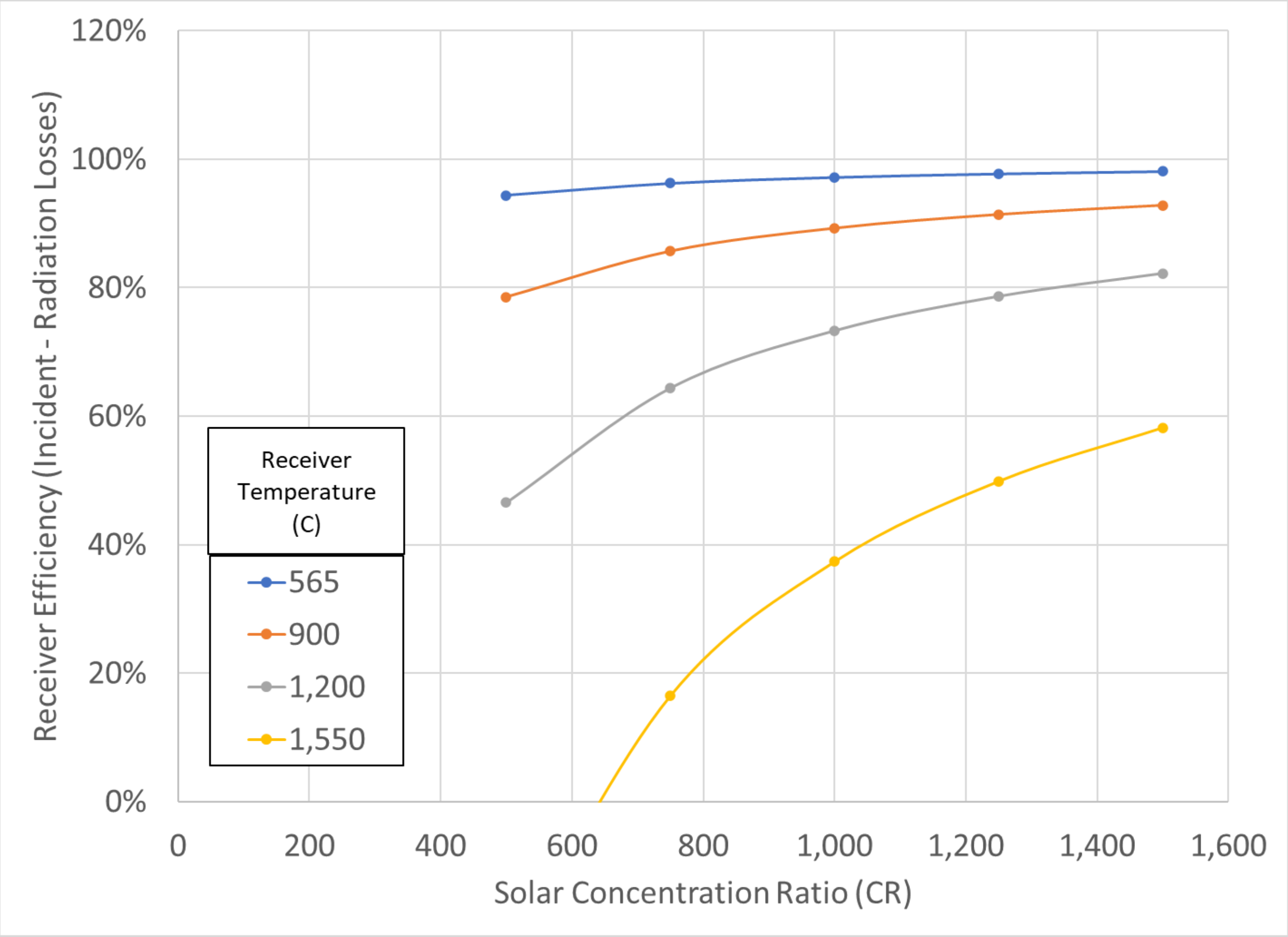
SIPH Field Layout Assumptions

1. Limit analysis to field, receiver, and tower
2. Assume polar field and cavity receiver are needed
   - Li L, Wang B, Pye J, Lipiński W. Temperature-based optical design, optimization and economics of solar polar-field central receiver systems with an optional compound parabolic concentrator. Solar Energy. 2020. https://doi.org/10.1016/j.solener.2020.05.088.
3. Assume blackbody radiation for heat loss from cavity receiver
   - [Li et al. 2020]
4. Fixed heliostat-receiver height ratio across runs (~0.7)
   - Attempt to keep spillage consistent across search



SIPH Field Layout Assumptions – Black Body Radiation

- Radiation losses increase significantly with temperature
  - Stefan-Boltzmann's law: radiation directly proportional to the 4th power of temperature (losses ~ T^4)
- Receiver efficiency a strong function of CR as temperature increases

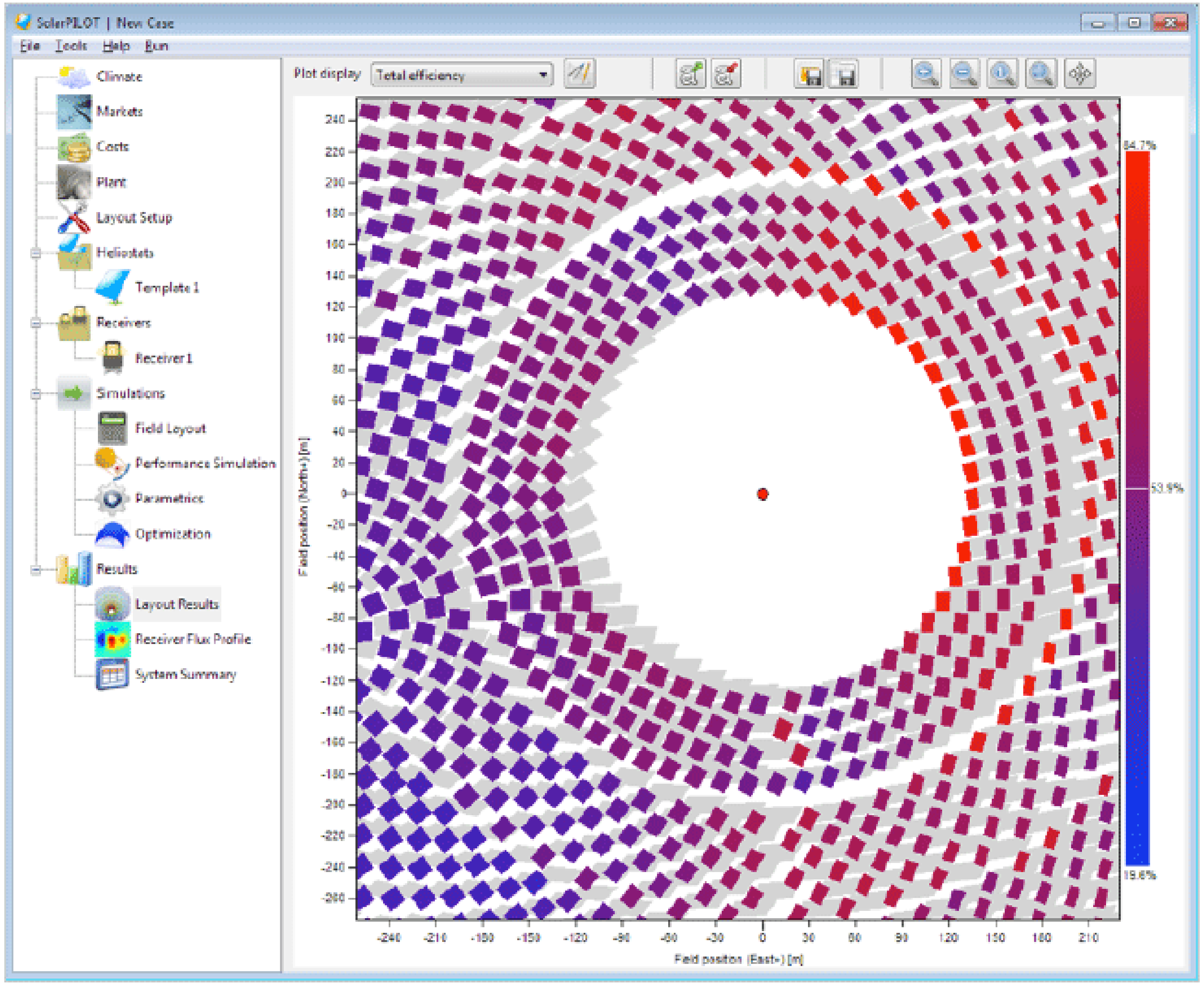


SolarPILOT

"Overview of NREL's SolarPilot(TM) and SolTrace Open-source Software"
https://www.youtube.com/watch?v=wiYV2VLqr_k

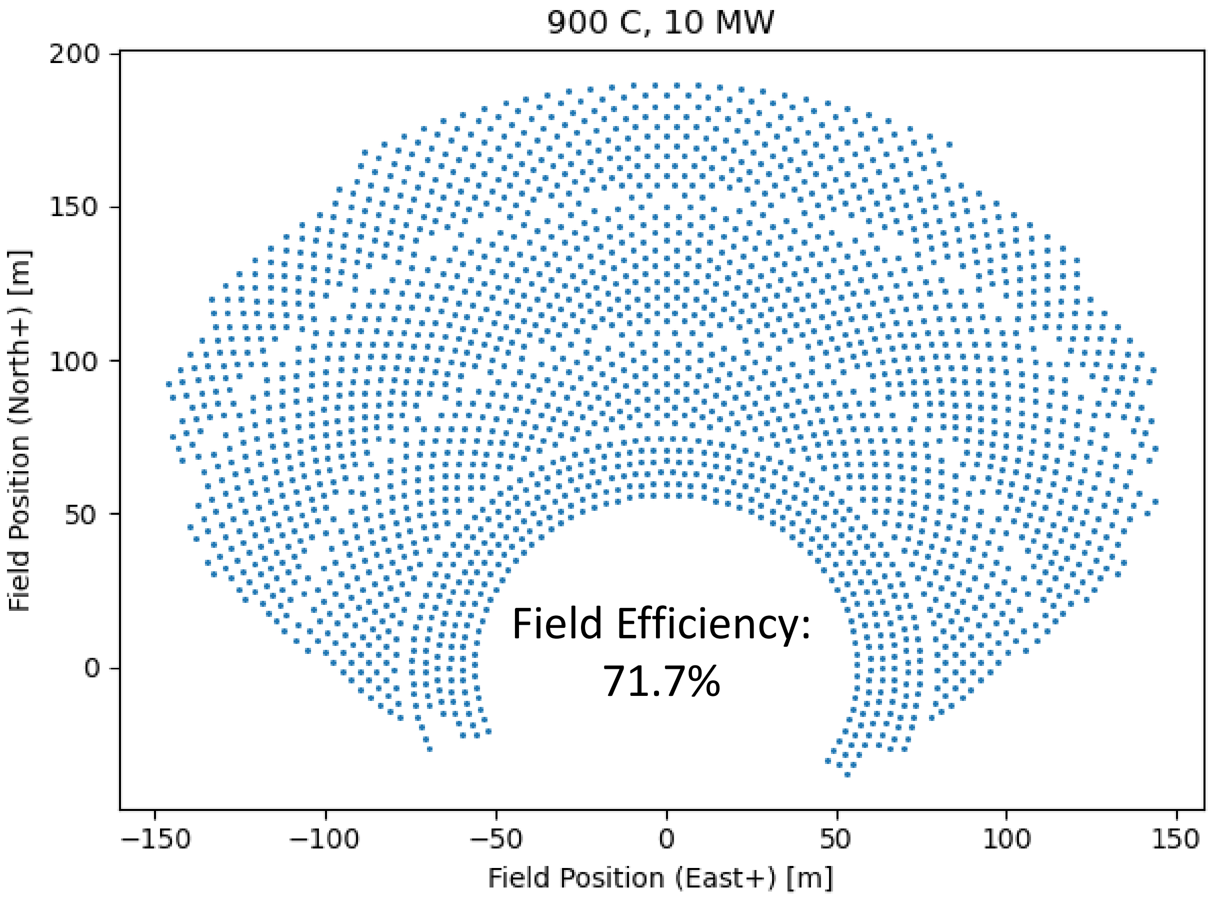
Solar Power Tower Integrated Layout and Optimization Tool (SolarPILOT)

- Create heliostat layouts
- Simulate receiver flux profiles
- Optimize tower, receiver, and layout configurations
- Integrated SolTRACE ray-tracing engine
- Accessible by external programs
- Open source



SIPH Base Case Heliostat Field Layouts

- Assumed a 10 MWth receiver for each temperature
- Generated polar heliostat field optimized for tower height and elevation angle
  - Field layout similar across cases
  - Since receiver power is 10 MWth for each, higher temperatures result in a smaller receiver
  - Smaller receiver = smaller heliostat (fixed ratio)



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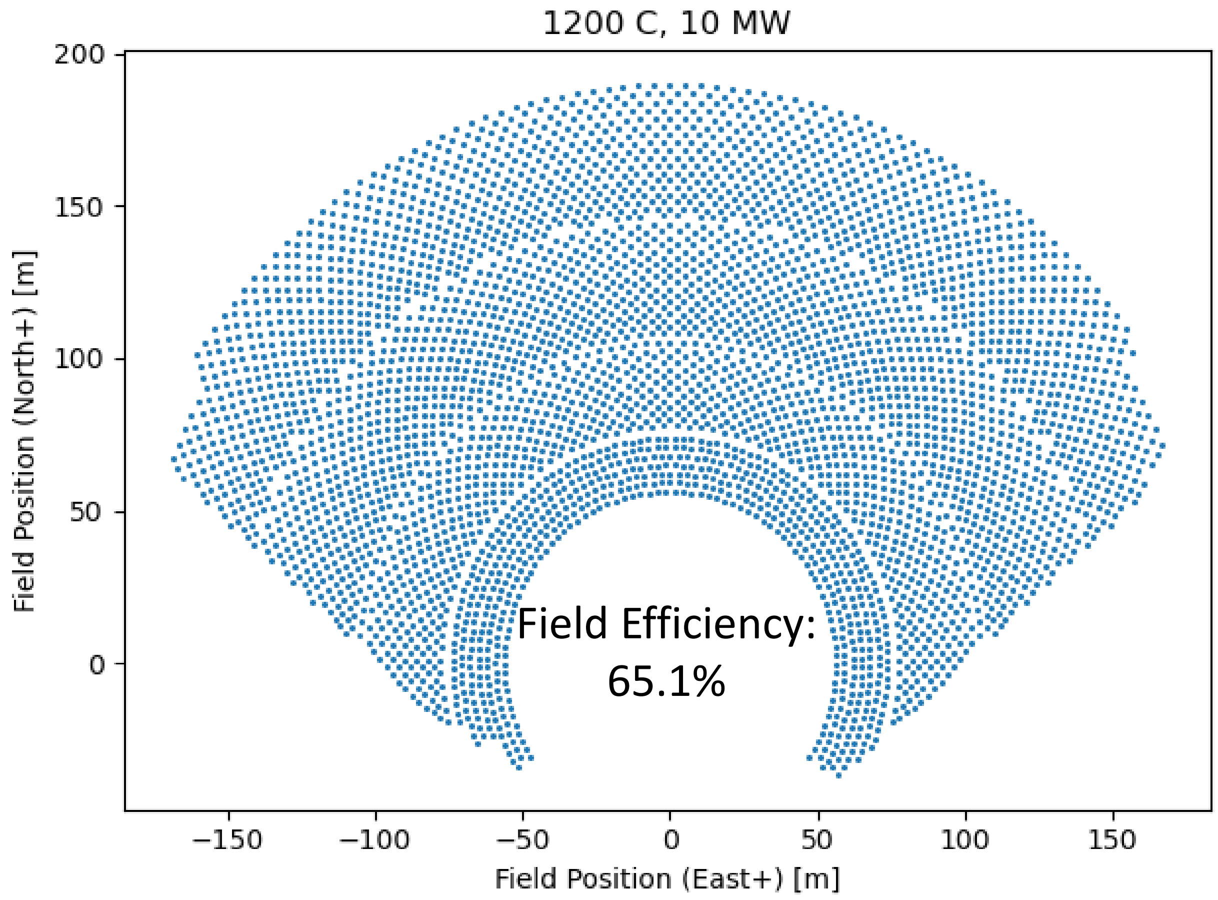

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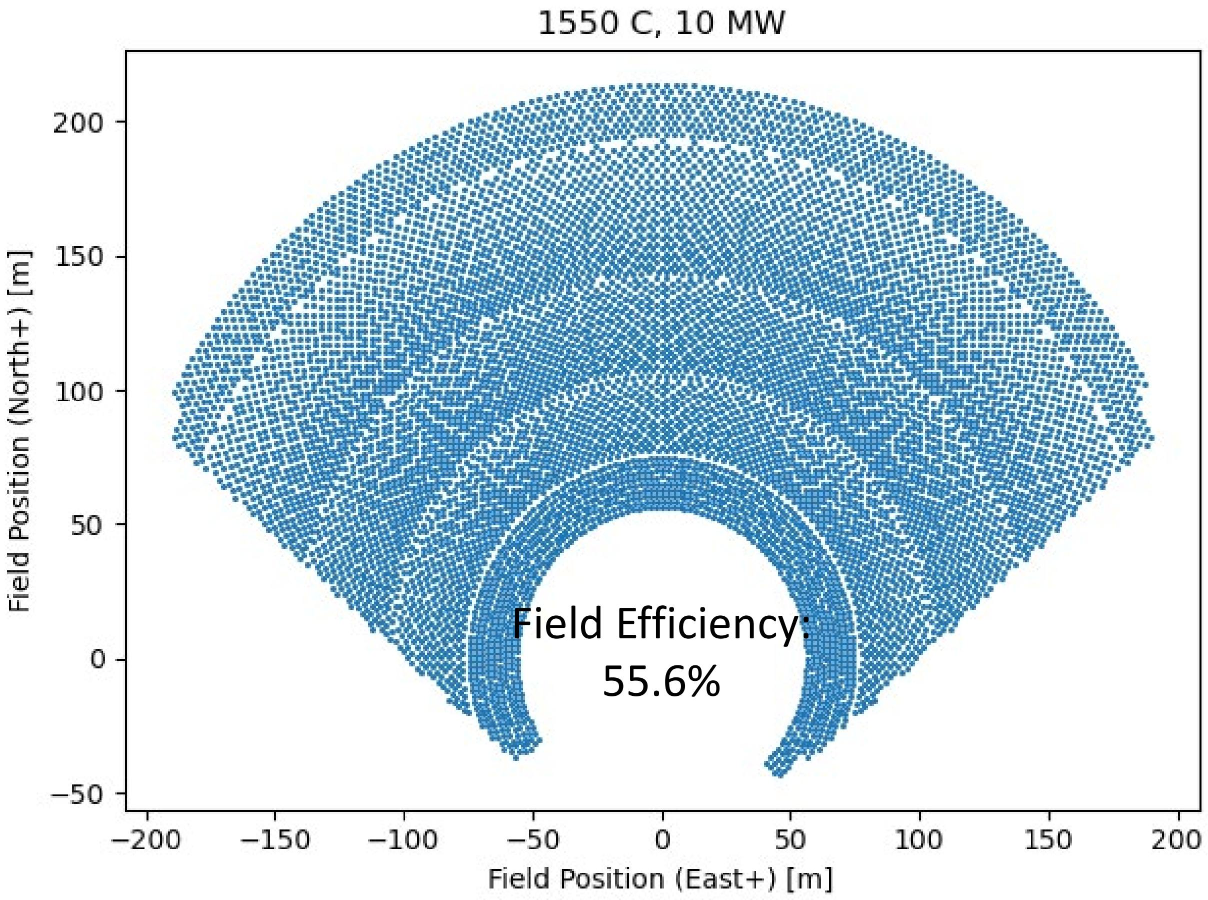
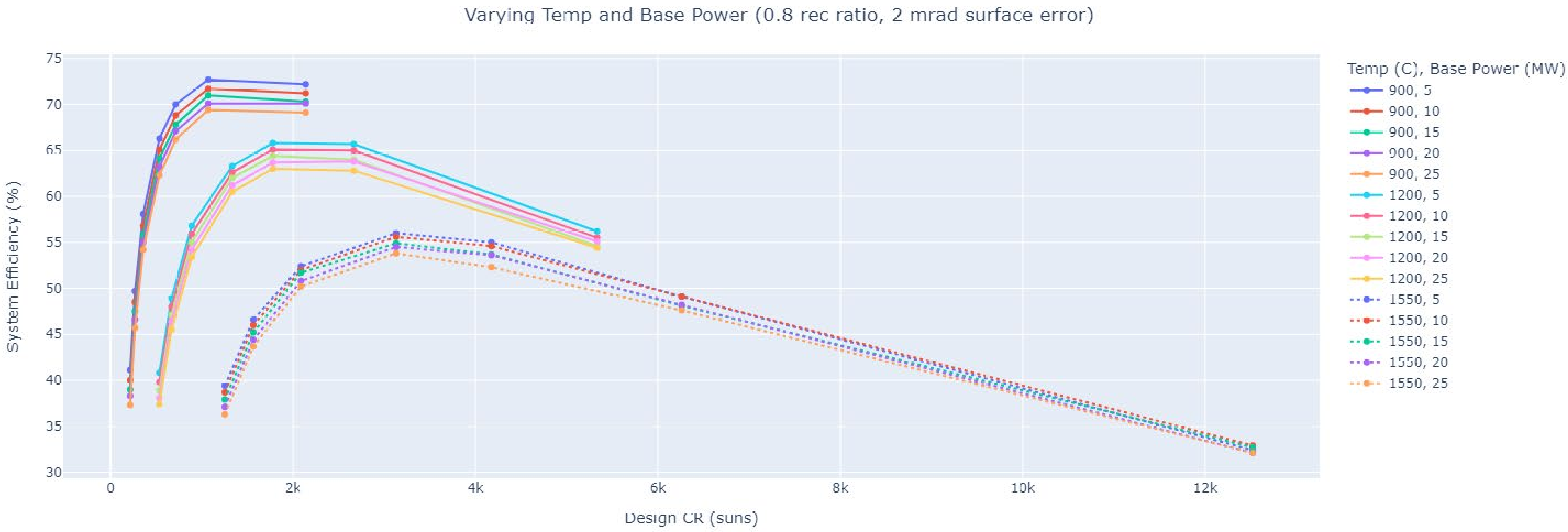


SIPH Heliostat Field Optimization



SIPH Heliostat Field Optimization

SIPH Heliostat Field Optimization – Status

Discrepancy between concentration ratio (CR) and average flux:

- CR = actual flux/reference flux
  - (reference = 1,000 W/m^2)
- CR is input to our simulations
  - We give it design receiver thermal power capacity (MW) and receiver area (m^2) as the CR being studied
- Average flux output from model is much lower than what would be expected from CR
  - Troubleshooting what the error might be
  - Will also compare with Australia National University results when available

SIPH Heliostat Field Optimization – Next Steps

1. Troubleshoot SolarPILOT scripts to fix CR/heat flux discrepancy
2. Study efficiency as function of process temperature and receiver load
3. Add in screens for realistic effects
   - Practical maximum heat flux limitations
   - Mirror and receiver size check
   - Blackbody radiation vs. cavity receiver performance
4. Add in cost estimates
5. Optimize levelized cost of heat (LCOH) as a function of heliostat, tower, and receiver costs

HelioCon Task 8: TEA

Application of Results to Industry

- Implications for heliostat design – likely to be smaller, more accurate for SIPH systems
- Implications for decarbonization of industry – many small towers rather than large central towers
  - Tradeoff in field size vs. capacity factor for supplying a thermal load over the year
- Impact of receiver design and performance on field layouts
  - Impact of receiver flux limitations on field size
  - Impact of heliostat costs
- Goal is to identify most likely field and tower/receiver configurations to be used for SIPH and key parameters to focus RD&D on to lower costs. Encourage industry and investors to use results to focus on standard design concepts and economy of scale for SIPH systems.

Thanks!

Questions?

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