Direct s-CO2 Receiver Development

NREL
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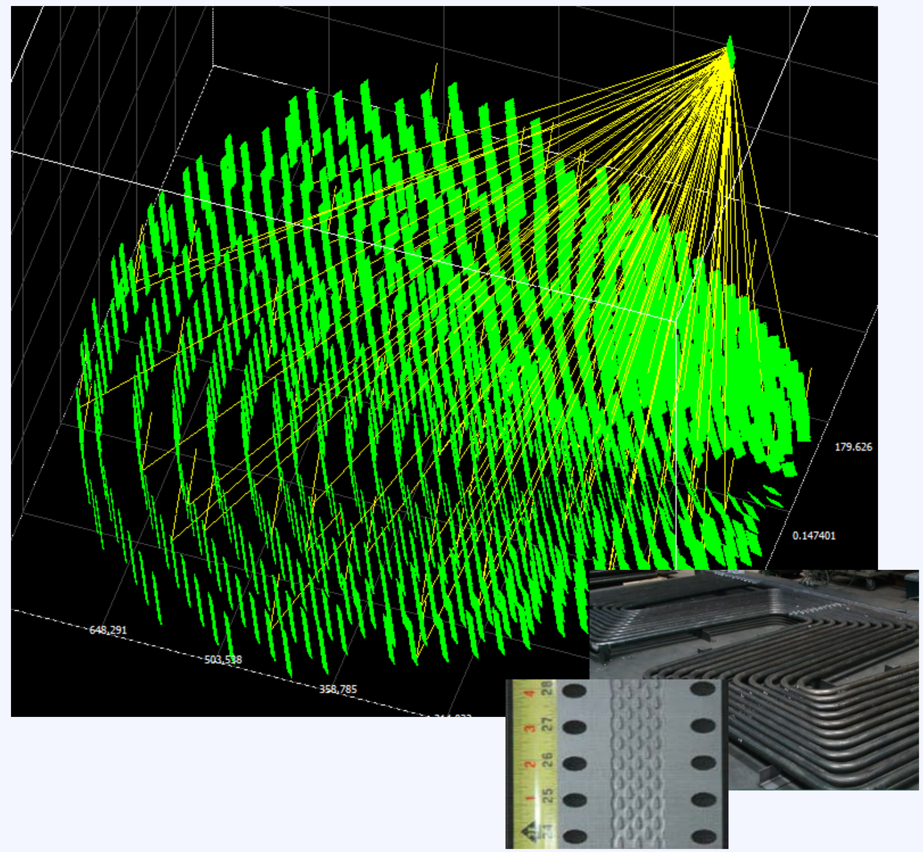


Principal Investigator:

Michael Wagner

Start Date:
October 1, 2012

Outline

- Purpose of developing the s-CO2 receiver
- Technology context
- Innovative aspects
- Tools and methodology for predictive performance modeling
- Results to date
- Lessons learned and future challenges
- Next steps

Project seeks development of power tower receiver to directly heat s-CO2

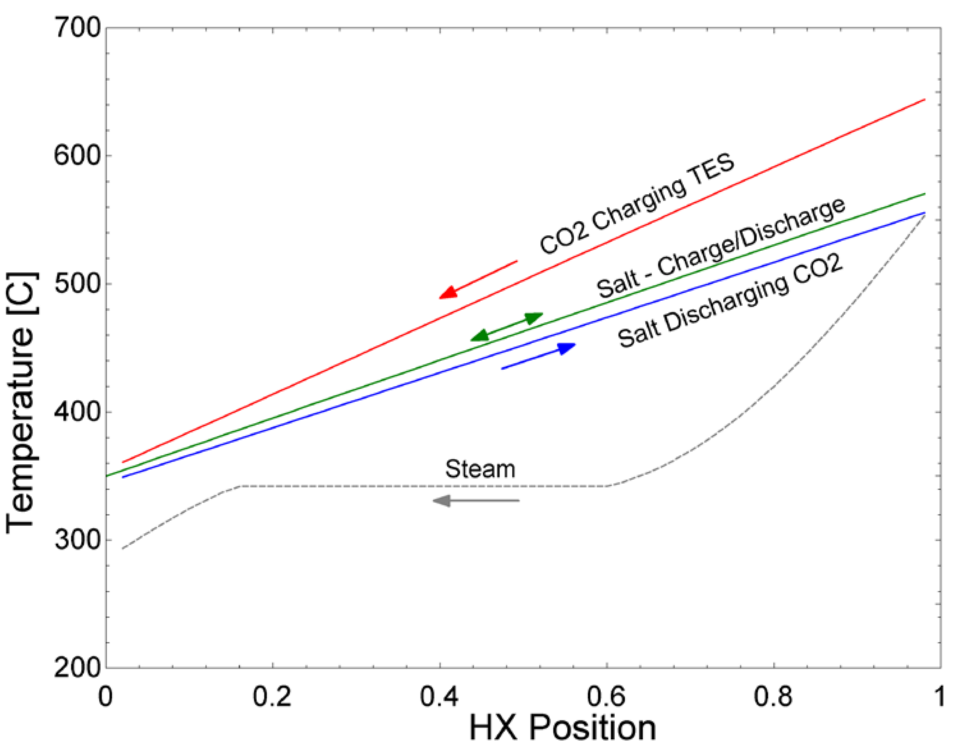
Specific goals:

- Develop power tower receiver technology that directly heats s-CO_2, enabling advanced power cycle
- Investigating Tubular Panel and PCHE absorbers
- Use novel receiver geometry approach to:
  - Deliver fluid to power cycle at 650C
  - Achieve >90% thermal efficiency
  - Withstand 10,000 thermal cycles (equiv.)
- Focus on smaller "modular" systems
- Build on related NREL work
  - Heliostats, coatings, analysis, particle receiver

Receiver technology driven by larger system design

Driving factors:

1. Integration of receiver with power cycle, thermal storage
   - Direct heating of working fluid eliminates intermediate heat exchanger
   - Sensible heating matches well with molten salt thermal storage; HX required



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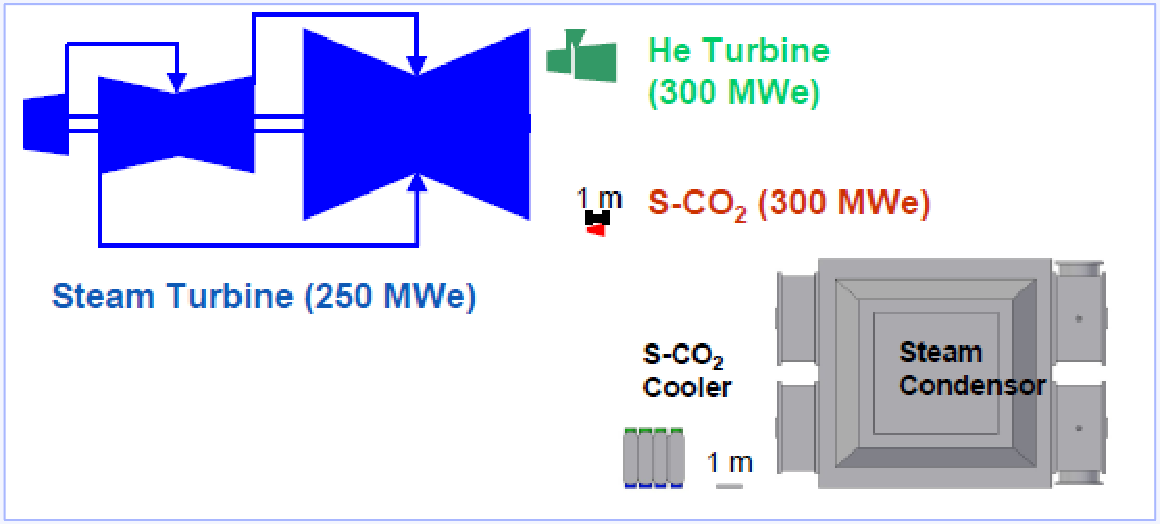
Receiver technology driven by larger system design

Driving factors:

2. Concept requires high flux concentrations at aperture
   - Small and/or focused heliostats
3. High-pressure fluid limits length of transport piping
   - Integration of s-CO_2 power cycle in tower
   - Turbomachinery is compact
   - Heat rejection and thermal storage on the ground



Receiver technology driven by larger system design

Driving factors:

4. Must out-perform alternative systems
   - Increased perceived risk with novelty of s-CO_2 cycle pairing
   - Molten salt, other liquid HTF could offer superior performance; but fluid stability an issue at 650C
   - Steam receiver systems proven, but integrate with traditional cycles, undergo phase change, have lower power density than s-CO_2

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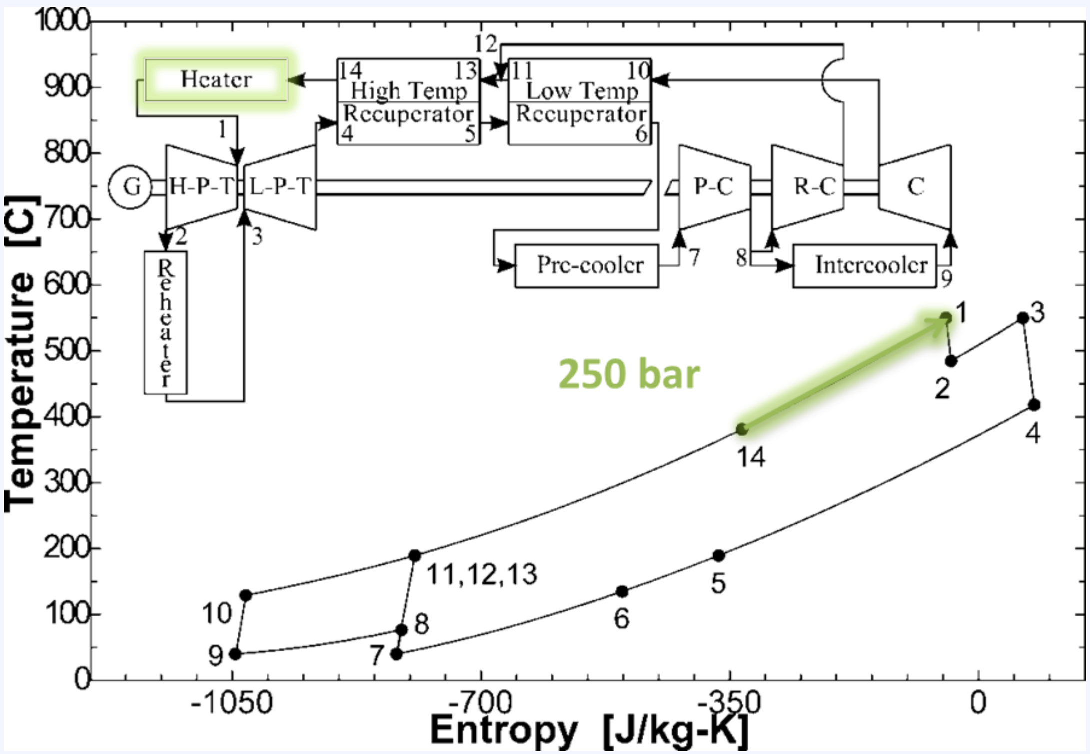
Aspects of innovation – Fluid, Flux & Form

Receiver Parameters	Value	Units
Design thermal power	100	MWt
Inlet temperature	470	C
Outlet temperature	650	C
Operating pressure	25	MPa



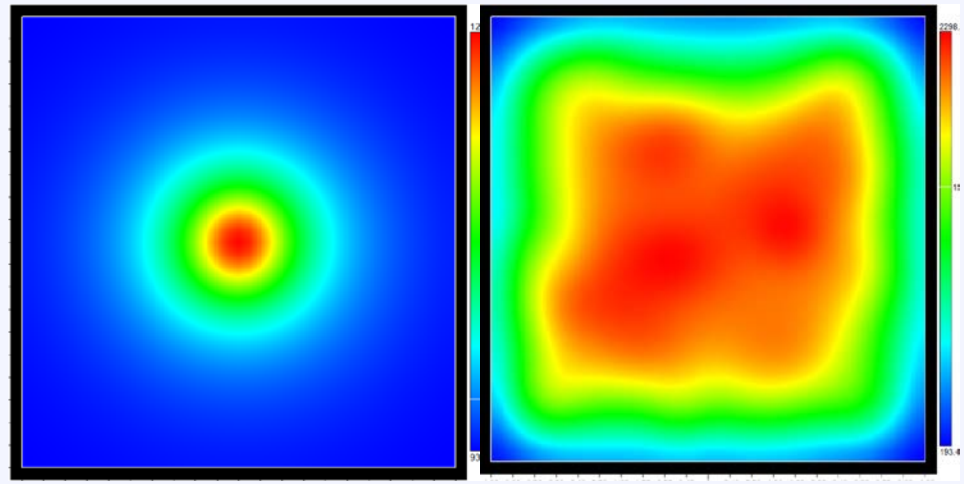
Direct s-CO_2 Fluid

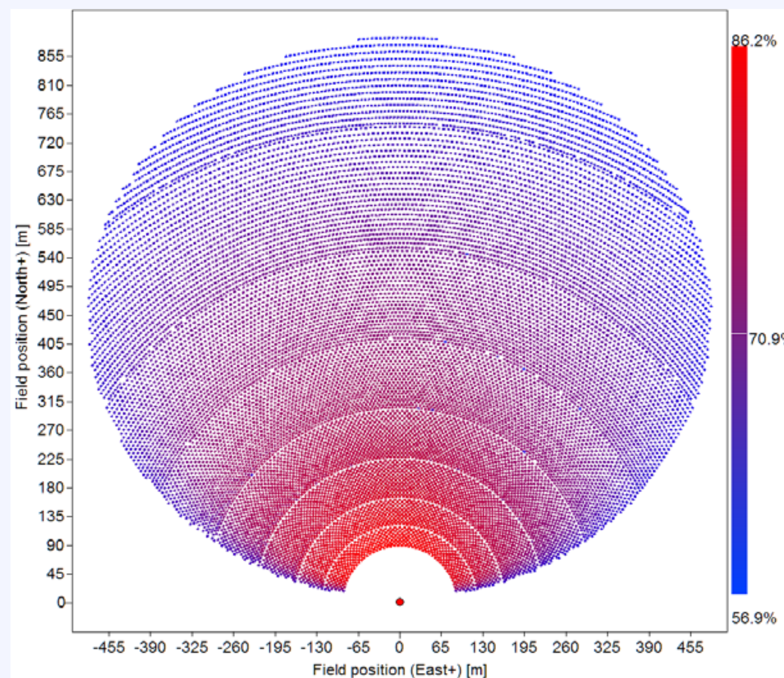
- Offers receiver solution for next-gen power cycle
  - Improved exergetic efficiency
  - Reduced component cost
- s-CO_2 stable over operating range

Aspects of innovation – Fluid, Flux & Form

Flux modeling

- Fully integrated solar field optical models
- Receiver is designed in the context of feasible solar fields
- Realistic flux profiles used to improve component design
- Development/extension of publicly available tools *SolarPILOT, SolTrace*

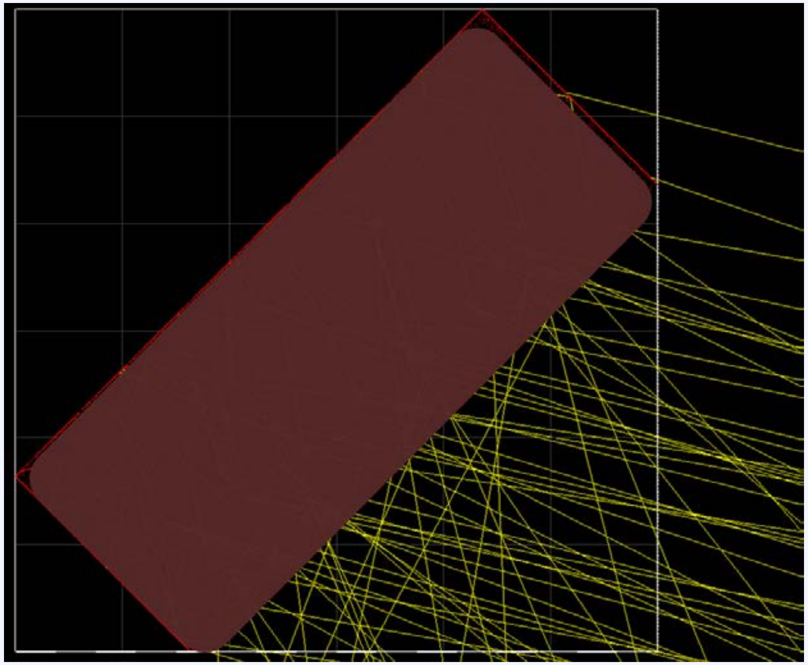




Aspects of innovation – Fluid, Flux & Form

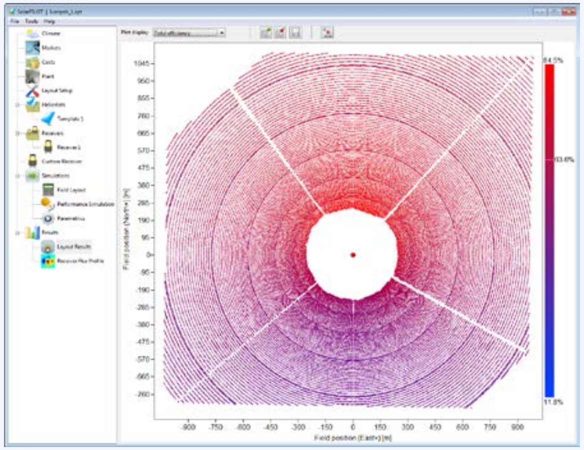
Receiver geometrical design

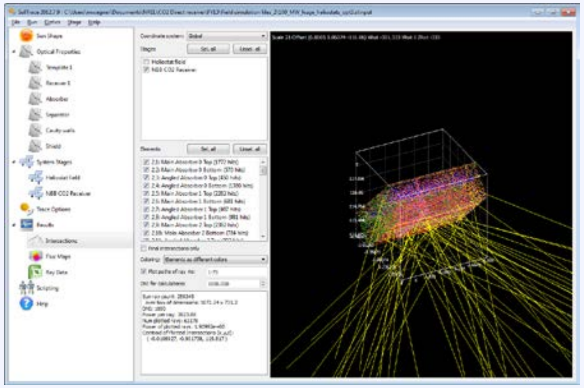
- Form accounts for actual flux profile provide by solar field
  - Distribution intensity
  - Directionality
- Designed to "trap" incoming radiation
  - Improve effective absorptance
  - Limit emission loss through improved radiation view factors
  - Reduce convection loss by isolating hottest surfaces



Design tools and methodology

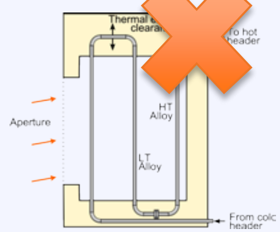
- Using combination of in-house & vendor tools
- Absorber mechanics modeling
  - In-house optimization tool w/ ASME B&PV code
  - ANSYS Mechanical
  - SolidWorks
- Solar flux modeling
  - SolarPILOT (NREL) solar field simulation tool
  - SolTrace (NREL)
    - ~2,000,000 rays per data point
- Thermal loss modeling
  - ANSYS Fluent
    - $k - \omega$ standard turbulence model
    - Specified surface temperature boundary conditions
    - S2S radiosity model for emissive loss

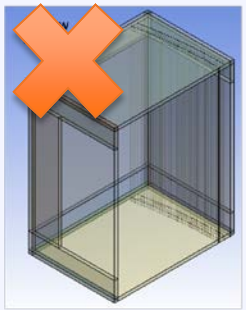


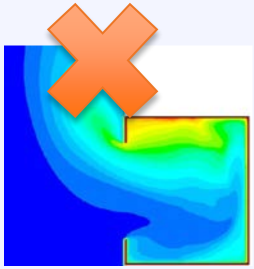


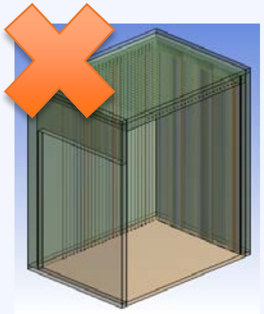
Key Technical Results

Lessons learned improve the receiver design





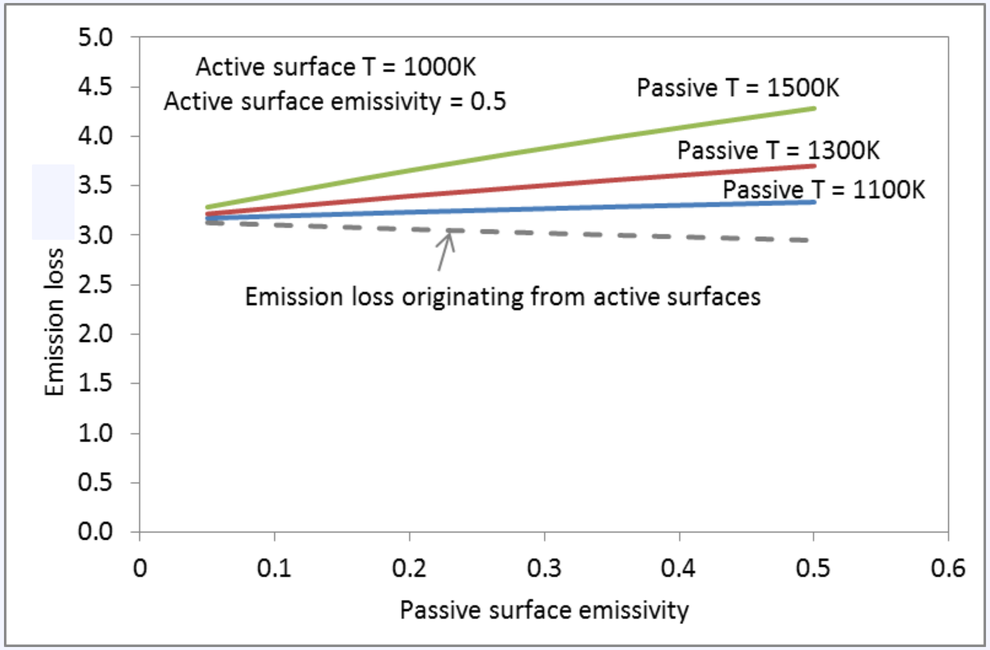




Lesson	Design change
Passive surfaces penalize performance	Eliminate most passive surfaces, using only where required
Uneven circumferential flux drives thermal strain	Illuminate absorbers directly around the circumference
Peak flux too high for material constraints	Reduce flux intensity through the cosine effect
Tube strain driven by peak surface temperature	Cold flow path arranged in highest-flux regions
Convective loss induced along vertical walls	Limit length of continuous vertical surfaces
Pressure drop proportional to tube length	Reduce tube length by changing tube orientation
Reflection and radiation most significant losses	Reduce view factor between absorber surfaces and aperture; take advantage of multiple reflections

Design-point efficiency above 90% is possible

Parameter	Value (%)
Thermal loss due to reflection	0.9- 2.7
Thermal loss due to convection	0.7 - 1.2
Thermal loss due to emission	3.2 - 3.6
Thermal efficiency	92.5 - 95.2



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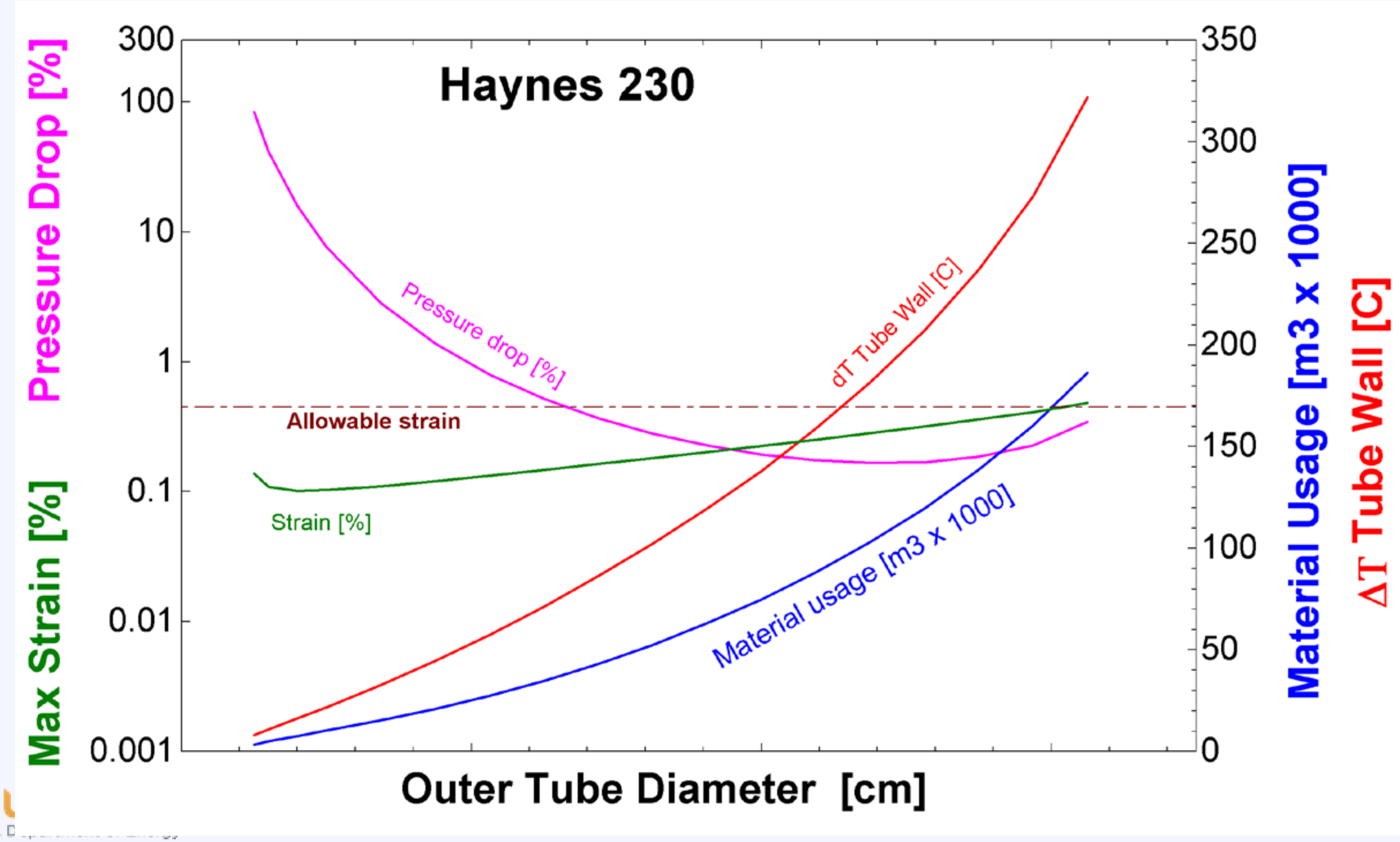
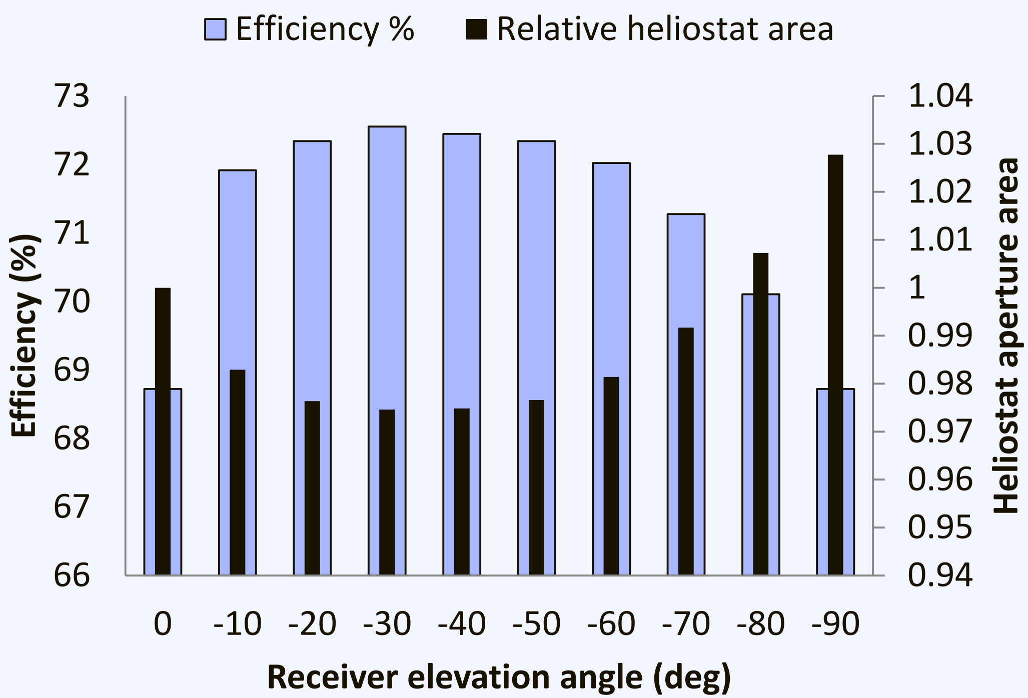
Absorber design balances material strain, pressure loss

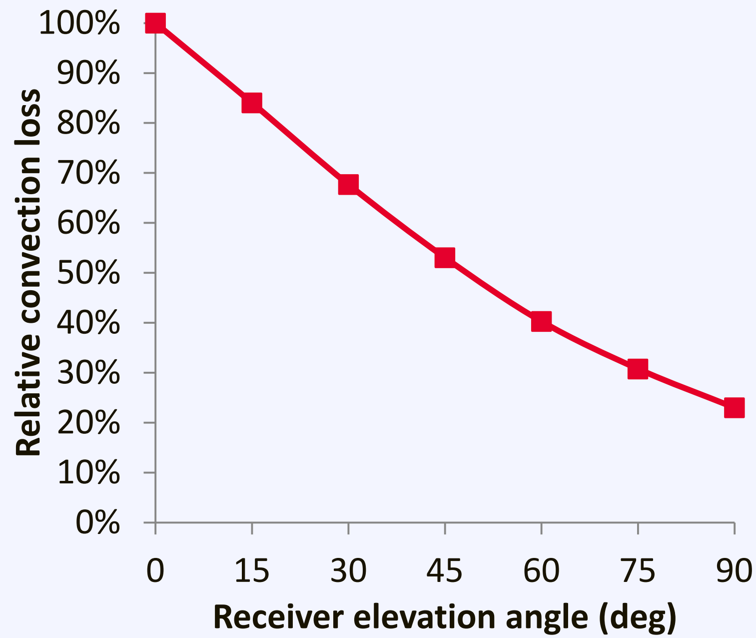
- Nickel alloys can provide suitable design window for 650C operation



Downward orientation for cavity receiver advantageous optically & thermally

- Heliostat field optical efficiency improved by aperture orientation
- Convective loss for cavity receivers can be reduced by creation of "stagnation" zones





Optimization of receiver thermal size includes system, optical requirements

- Receiver thermal size depends on choice of heliostat

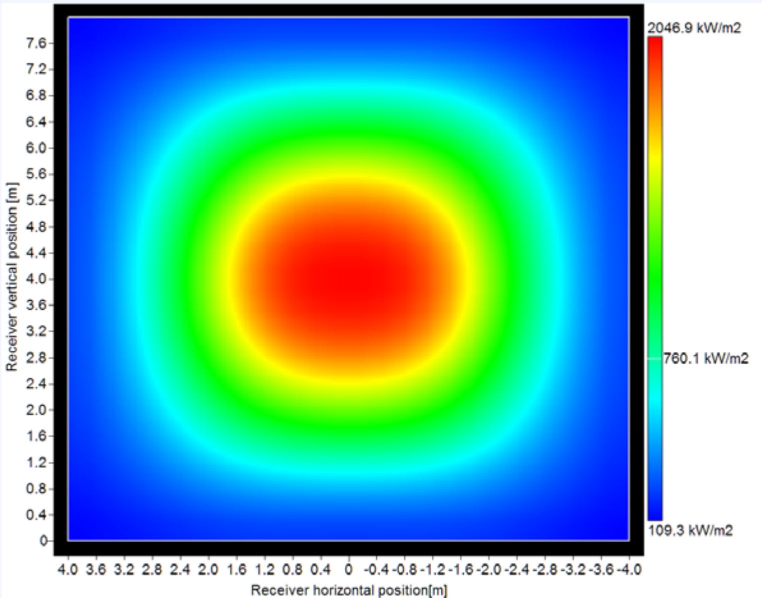
Example:

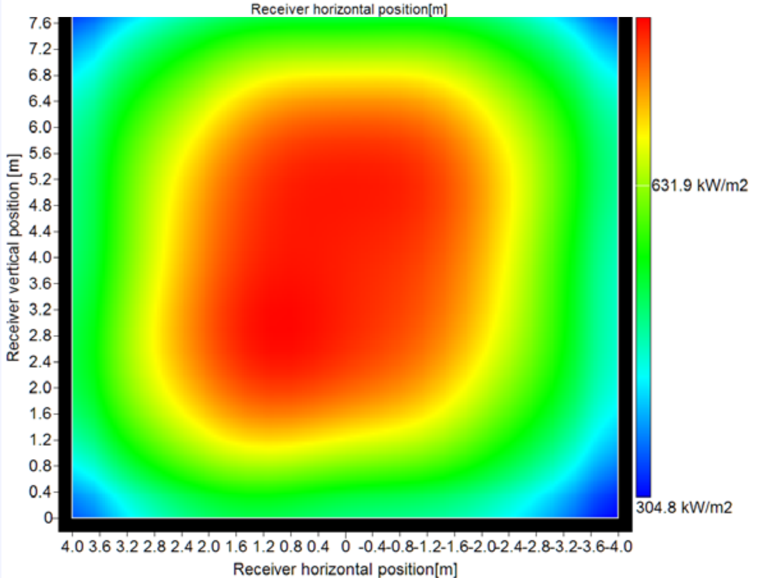
- Smaller 4m x 4m heliostats, non-focusing
- 50 MWt plant size
- Target <850 kWt/m2

- Simple aiming (top)
  - 96.1% intercept
  - 2047 kW/m2 peak flux

- Aiming algorithm (bottom) limiting peak flux
  - 79.8% intercept
  - 808 kW/m2 peak flux

➢ Indicates heliostats must focus or be smaller, or receiver design thermal size must increase





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Design Challenges

- Ensuring parallel flow paths receive equal power
- Tailoring optical properties of absorbers and passive walls to desired values
- Incorporating reheat stage
- Optimal system (revenue) may not be system with minimal LCOE
- Tremendous number of potential optimization variables complicates design process

Next Steps

- Multi-variable optimization study
- Complete cost analysis, estimate LCOE impact
- Detailed flow path analysis
- Off-design performance characterization
- Design and build prototype test system

Thank you!

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- Craig Turchi (NREL)
- Austin Fleming (Utah State University)