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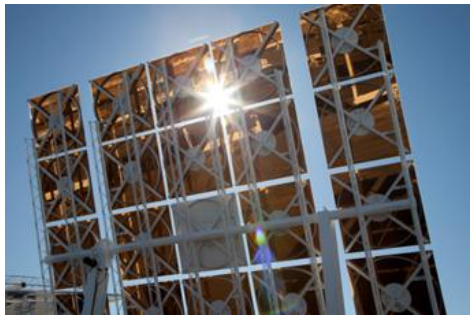

Trends in CSP Technology: Thermal Receivers

Solar PACES 2014
Chuck Andraka
September 19, 2014

U.S. DEPARTMENT OF ENERGY
National Nuclear Security Administration

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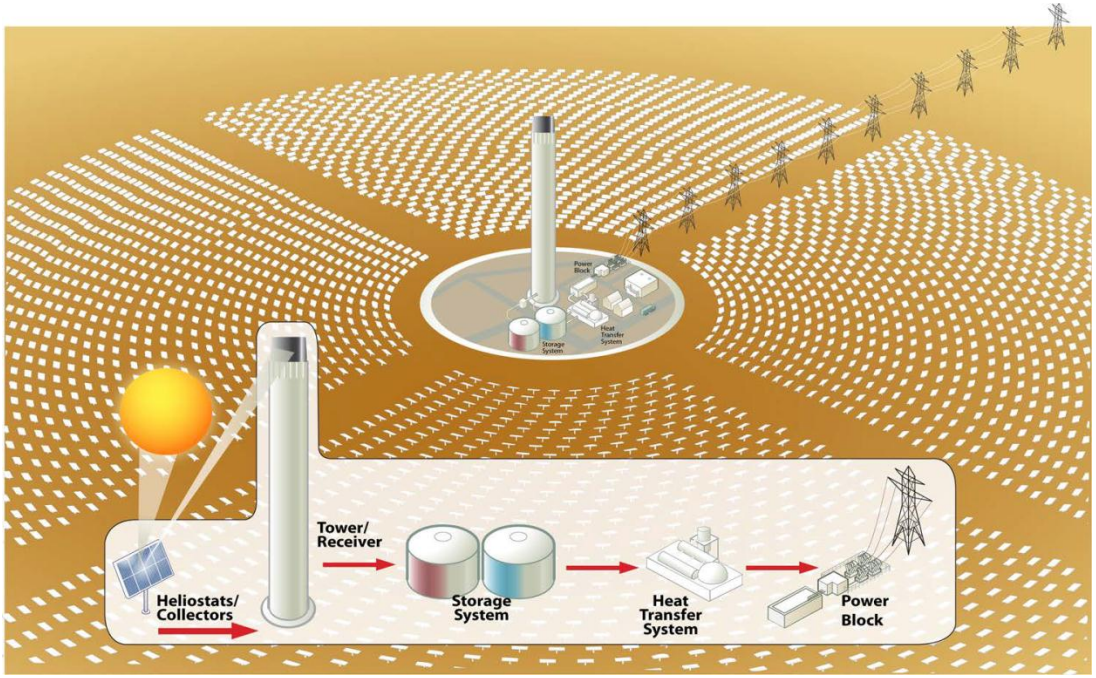
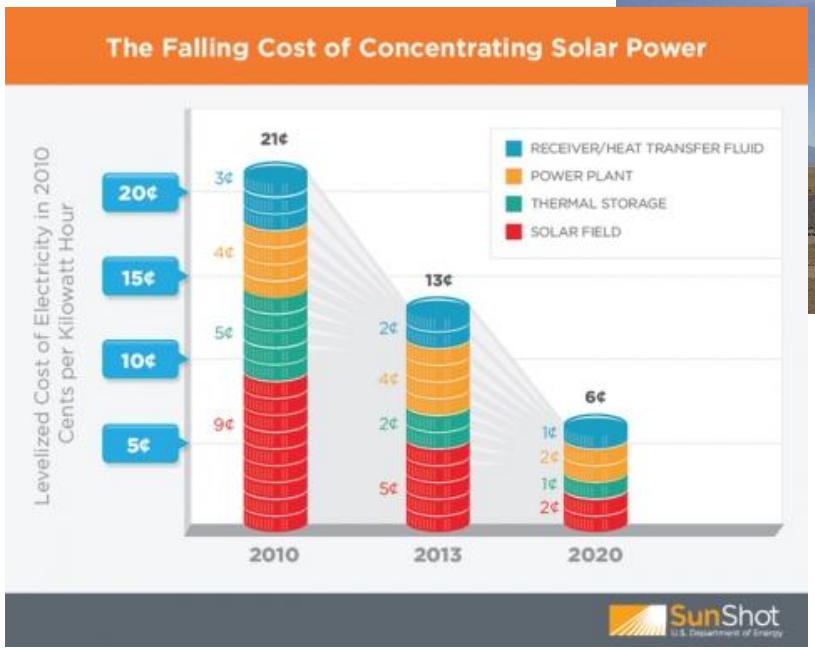
Receivers

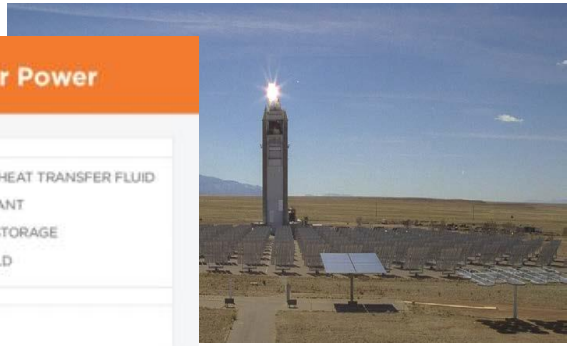
- Key interface
  - Concentrated sunlight
  - Environment (losses)
  - Heat transfer Fluid
- Key parameters
  - Cost
  - Flux levels
  - Losses
  - Compatibility



The Road to SunShot

- Higher performance
- Higher Temperatures
  - Materials
  - Compatibility
- Reduce losses
  - Smaller size
  - Higher flux
  - Modified surfaces
- Alternate working fluids
  - Solids
  - PCM's
  - HTF's
  - SCO_2
  - Air

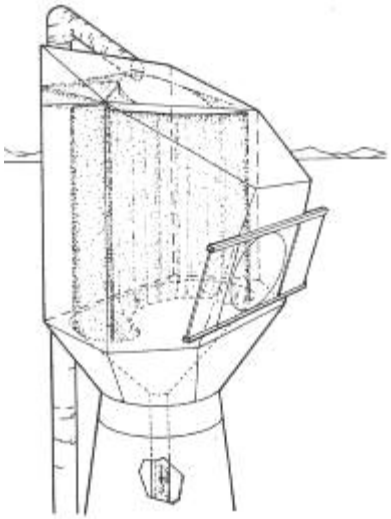


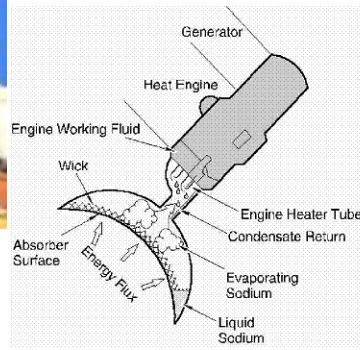


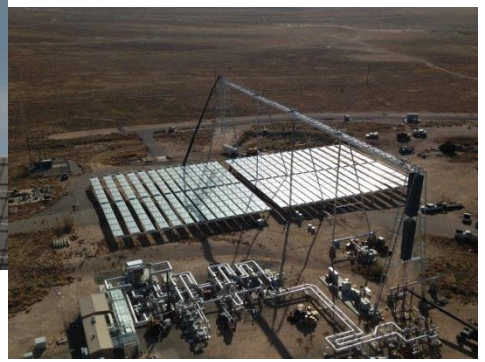
- **Heat transfer fluid exit temperature from the receiver > 650°C**
- **Thermal efficiency > 90%**
- **Lifetime > 10,000 cycles**
- **Cost < $150/kW$_{th}$**

Receivers for CSP Technologies

- Towers
  - Conventional tubes
    - Surround
    - Cavities
  - Air matrix
  - Particles
  - Beam down
  - Novel Approaches
- Linear Focus
  - Evacuated tubes
  - Advanced concepts (DSG, Salt)
- Dish systems
  - Cavity design optimization
  - Stirling, Brayton, Steam







Receiver Papers

- 43 total papers
  - 23 Oral
  - 20 Posters
- Tower emphasis consistent with SunShot
  - 15 Tower (+9 poster)
  - 5 Trough (+10)
  - 3 Dish (+4)

Geographic Trends

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Geographic Trends

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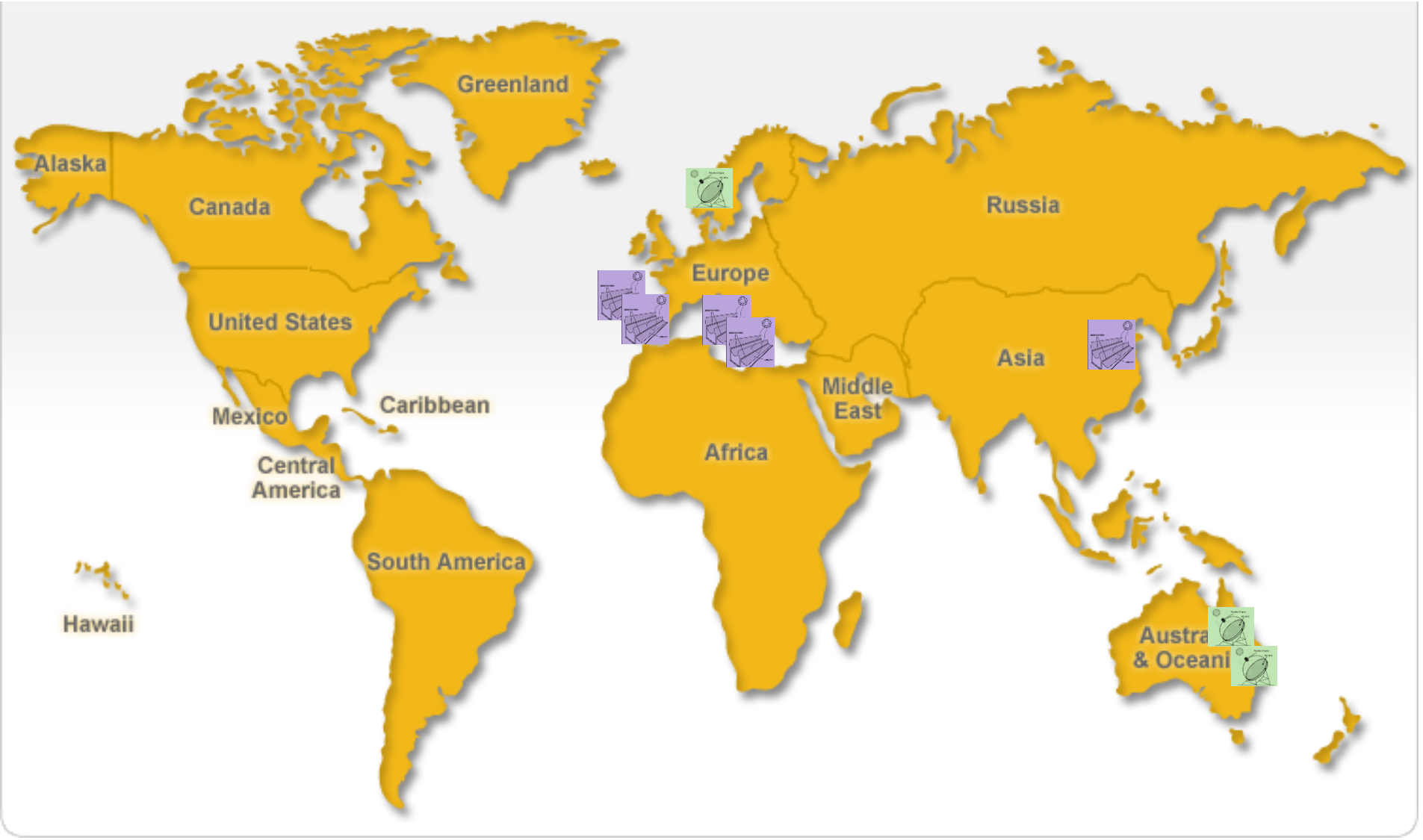

Geographic Trends

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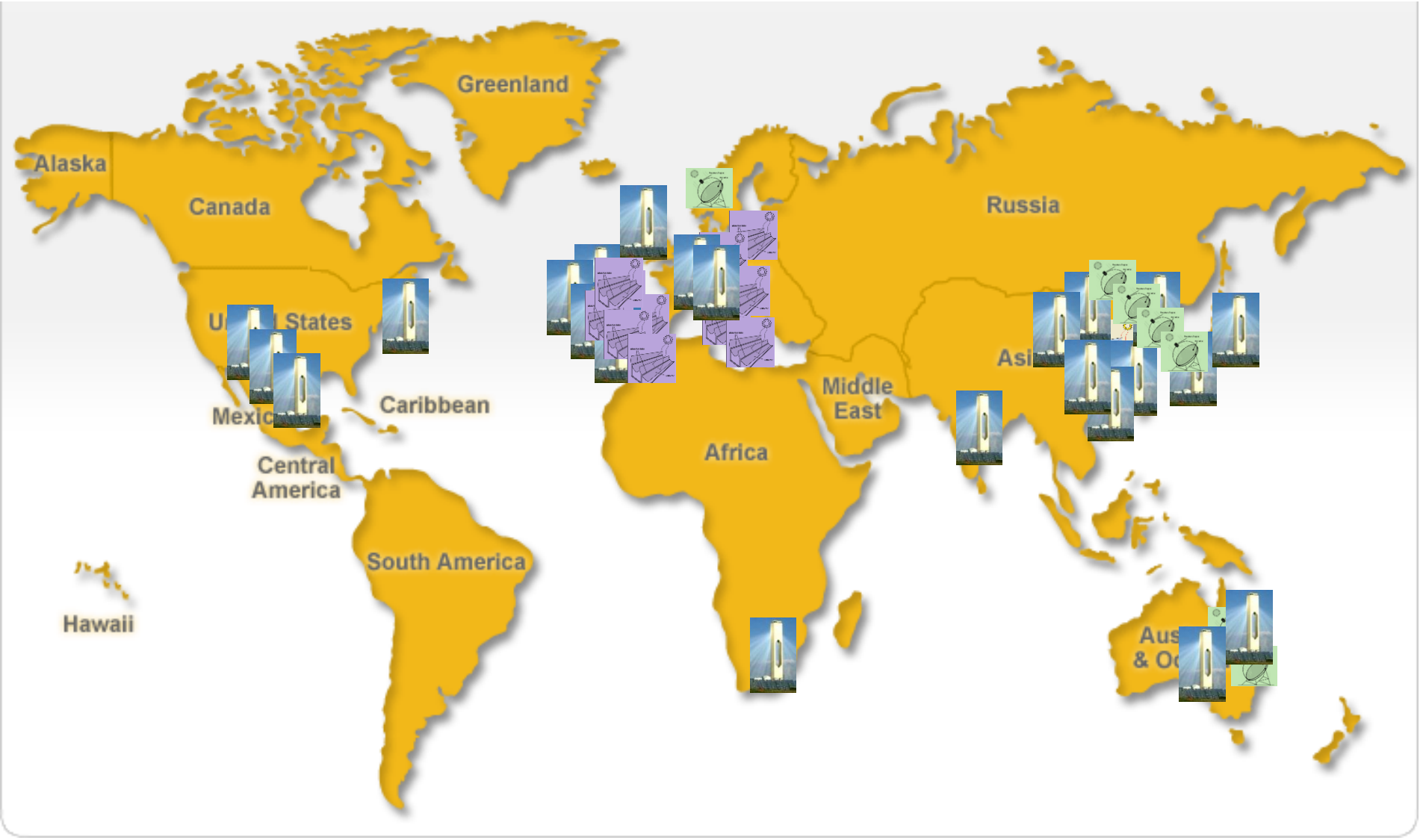

Overall Trends

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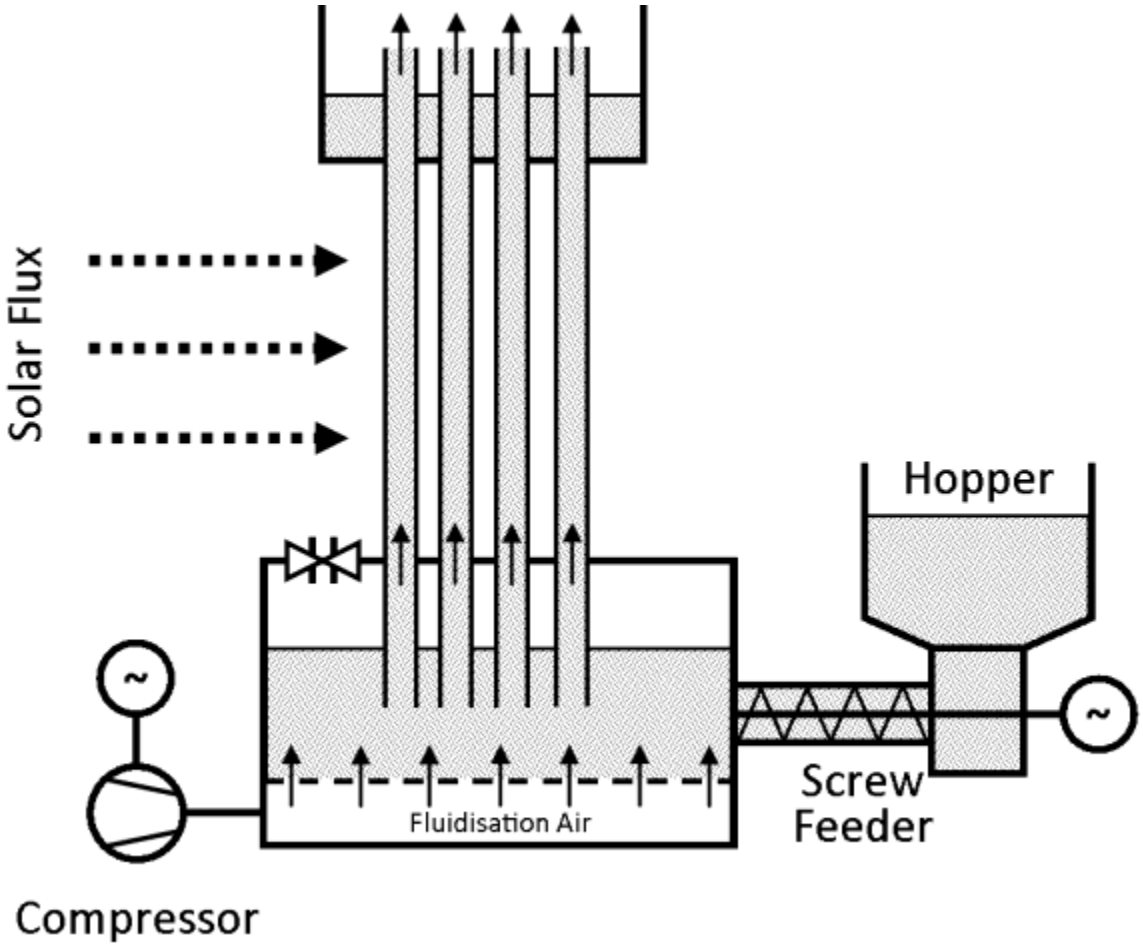
	Oral	Poster
Paper Approach		
Modeling/analysis	13	10
Lab experimental	7	3
Full scale hardware	3	4
Design	3	4
Literature survey	1	0
Technology		
Air receivers	11	3
Cavity receivers	6	3
Particle receivers	4	1
Selective absorbers	3	0
Higher temperature fluids	3, not air	0
Other	3	9

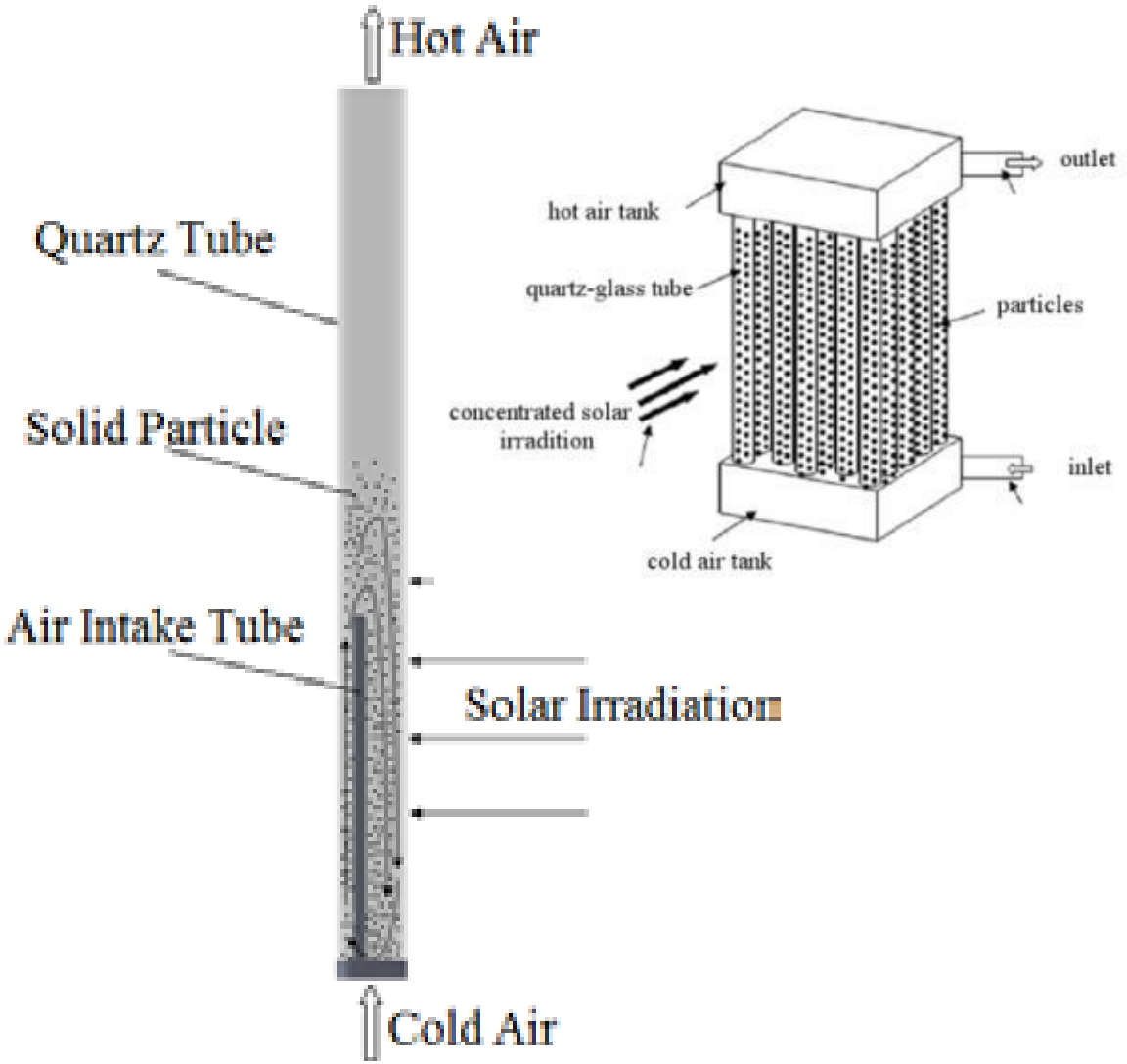
Particle Receivers: Upflow

- Galloa (Spain): Dense particle suspension
  - 100 kW prototype for 10MW design
  - Sensible heat to particles entrained in air
  - Control residence time
  - Particles are HTF replacement
  - 81.3% efficient (70% target)



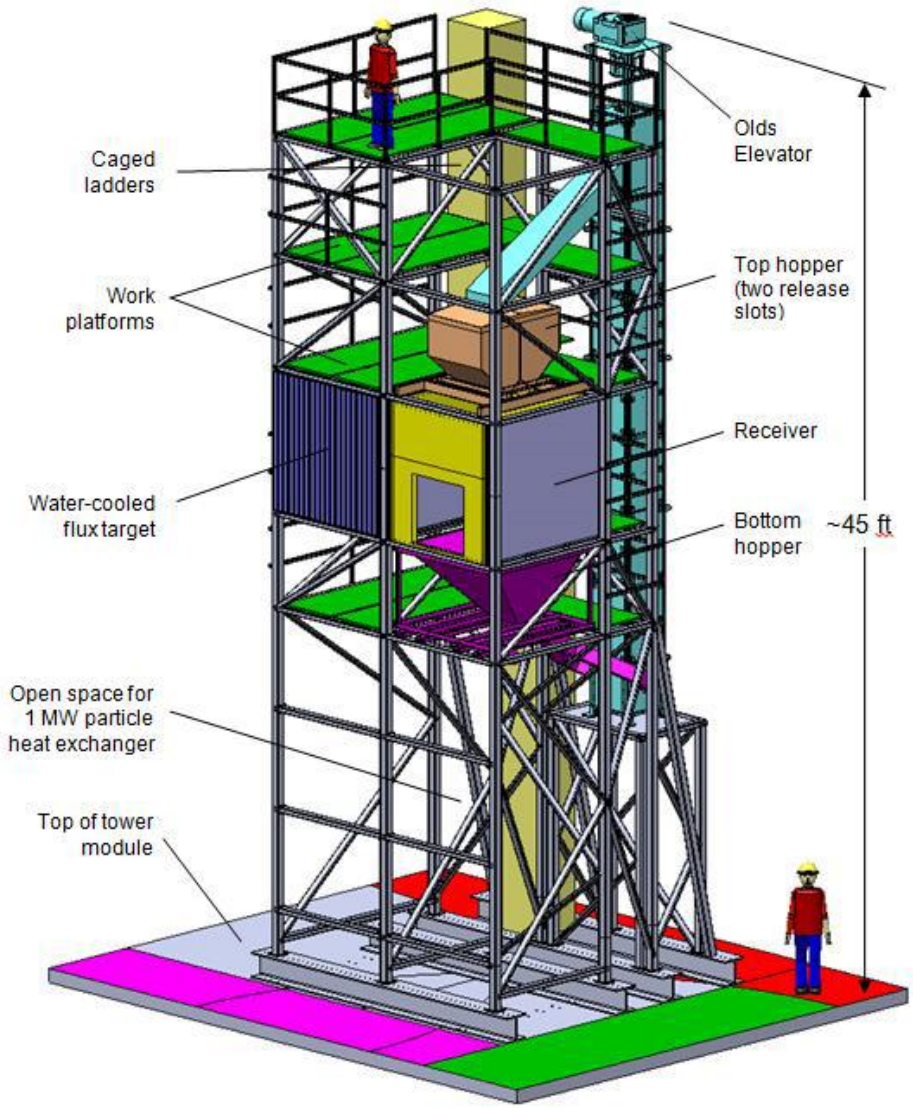
Particle Receivers: Upflow

- Zhang (China): Volumetric Air Receiver
  - Stationary fluidized bed of particles in upflow air
  - Quartz tube containment
  - Vary particle fractional load
  - Overcomes the need for beamdown
  - Experimental results as well as modeling



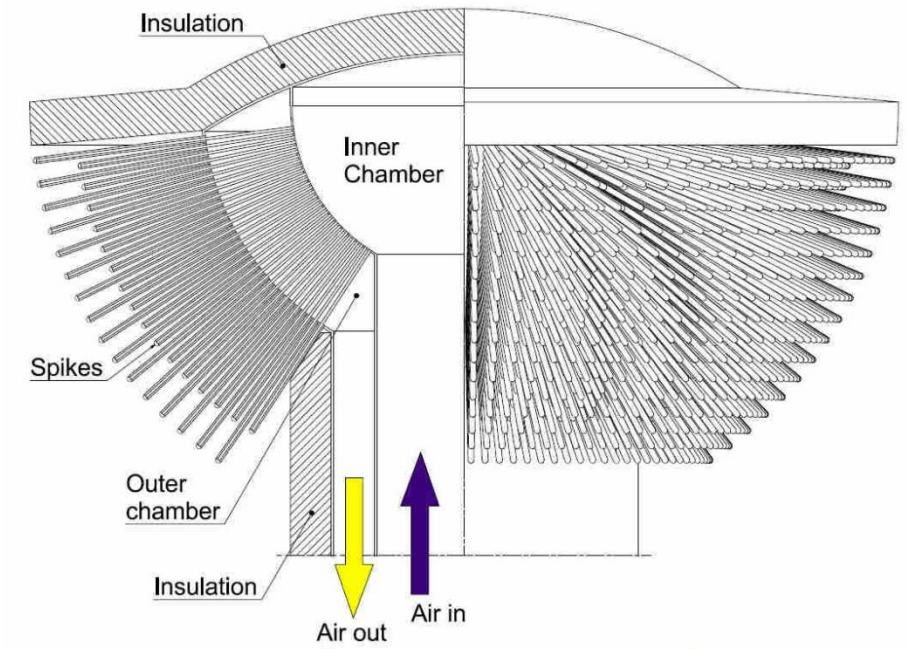
Falling Particle

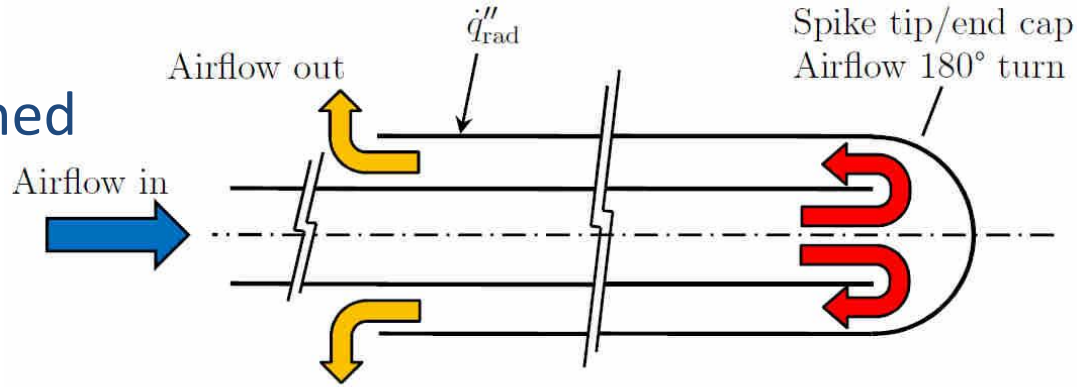
- Ho (USA): Multi-pass falling particle system design
  - Large test hardware
  - First test of a multi-pass receiver
  - Hot particle elevator to accomplish sufficient residence time
  - Testing planned this fall



Air Receivers: Pressurized

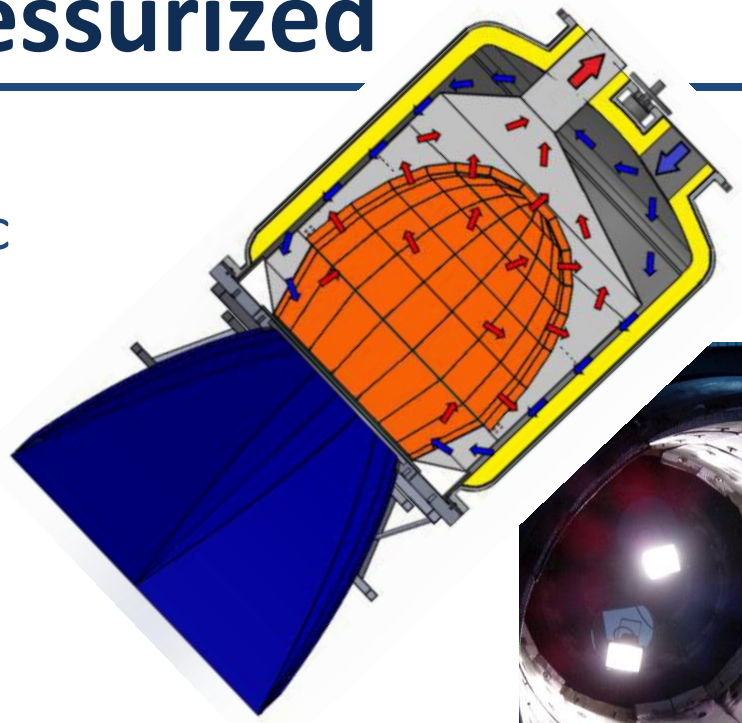
- Lubkoll (Aus): “SCRAP” porcupine receiver (Spiky Central Receiver Air Preheater)
- Novel approach for an exposed volumetric receiver
- Flow path puts hot section at root
- For high pressure combined cycle plant
- No window needed

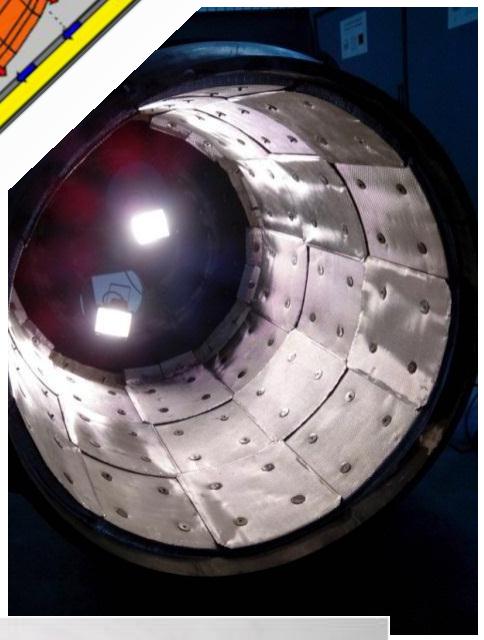




Air Receivers: Pressurized

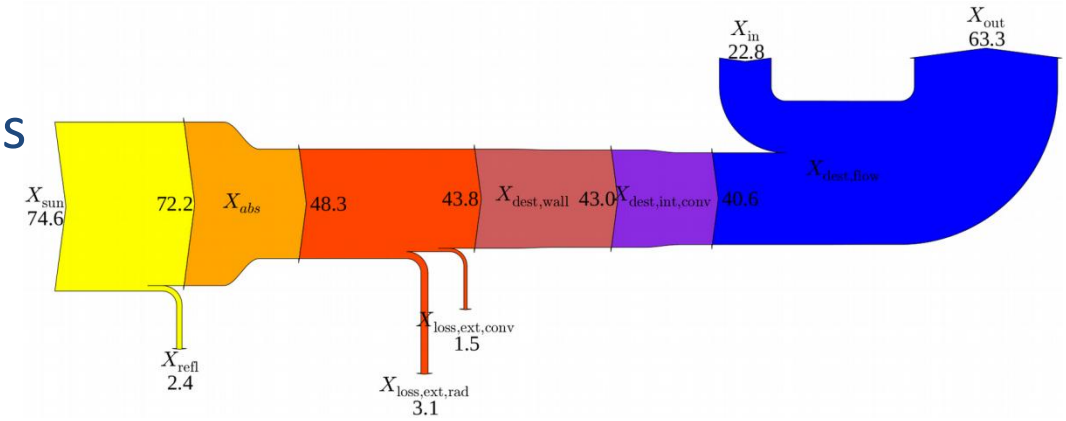
- Del Rio (Spain): Volumetric air receiver
  - Brayton system (SOLTREC)
  - Hardware testing
  - Up to 1000^{o}C
- Uhlig (Germany): Air receiver with corrugated tubes
  - Optimization with experiments
  - More tubes = slower flow
  - Corrugations to recover some heat transfer



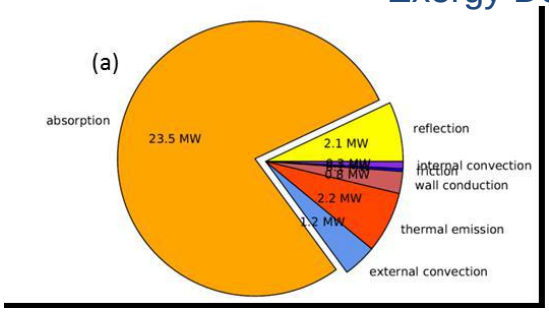


High Temperature Fluids

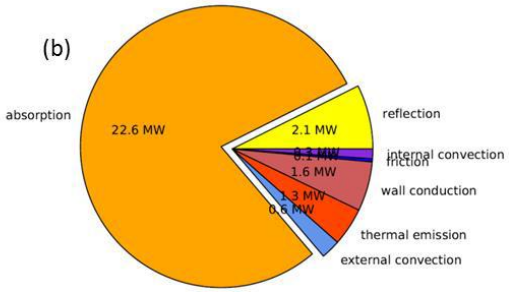
- Pye (Aus): Exergy analysis
  - Various HT fluids
  - Optimized for higher temperature operations
  - Sodium a clear winner
- Coventry
  - Review of past sodium experimental work
  - Proposes phase change HTF for large tower systems



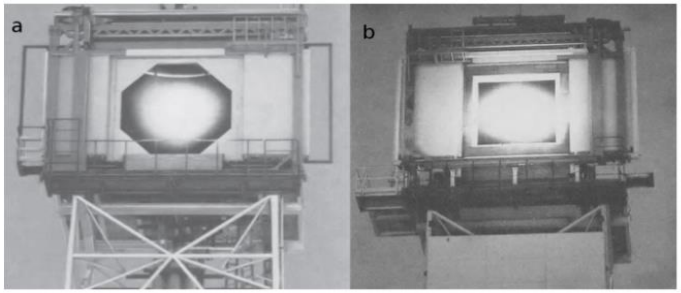
Exergy Destruction



700 kW/m²

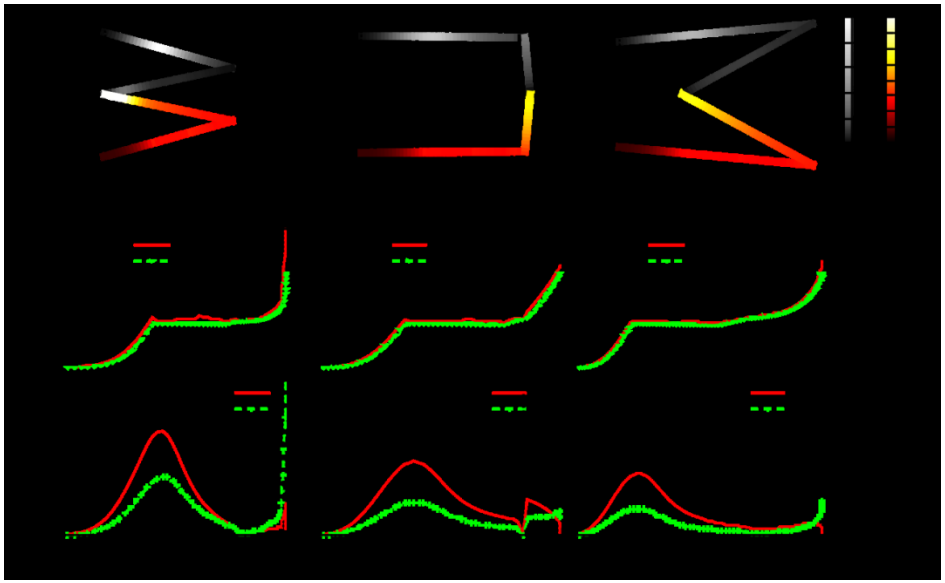


1400 kW/m²



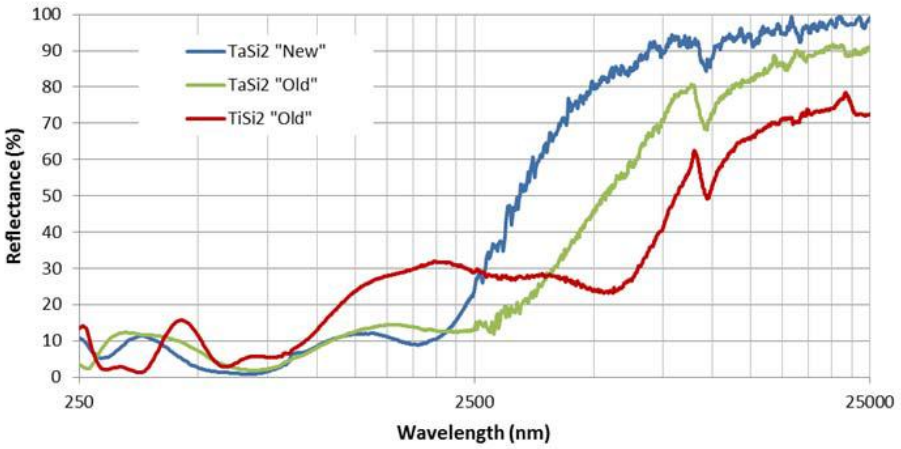
Cavity Receivers

- Dish and Tower systems
- Focus on cavity optimization
  - Detailed modeling
  - Transient models
  - Heat loss
    - Convection
    - Radiation
  - Flux profiles



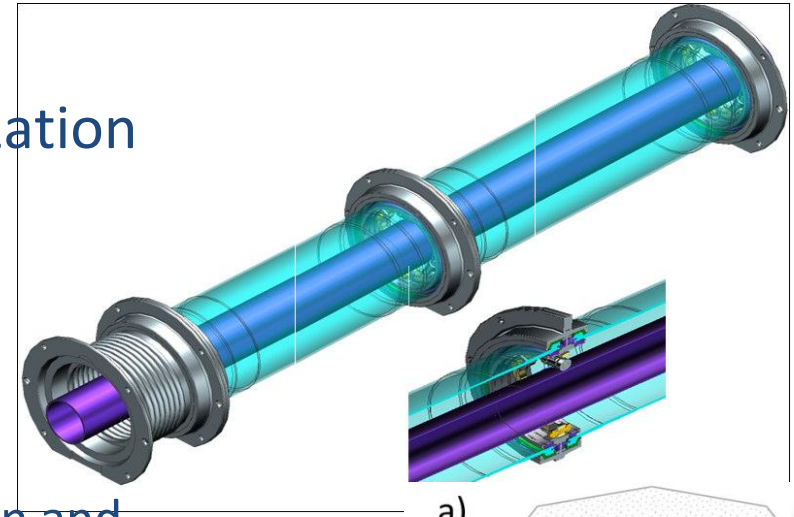
Selective Coatings

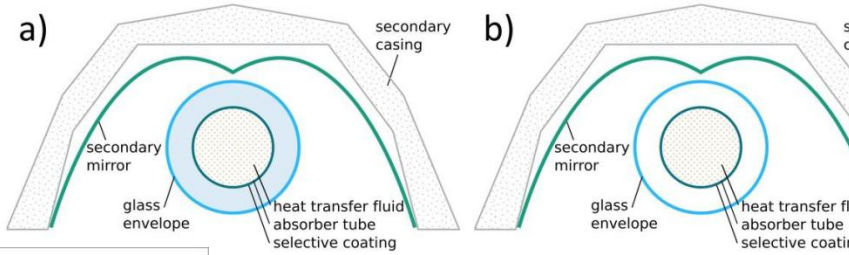
- Gray (USA): High temperature selective coatings
  - 1000°C
  - Refractory metal silicide binaries
  - Fabrication and characterization
- Ho (USA): LCOE impact of coatings (reapplication intervals)
- Cachafeiro (Spain): Aging impact on energy cost

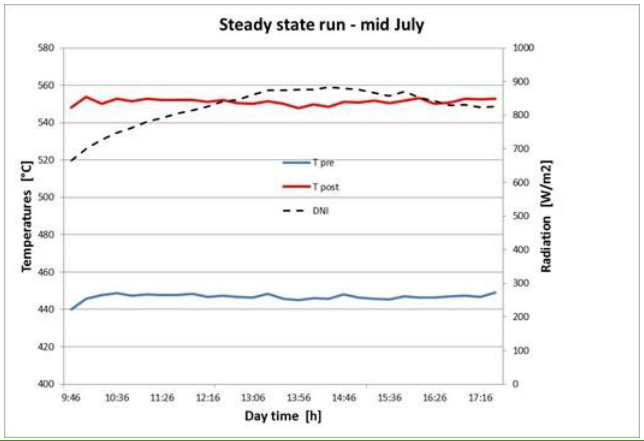


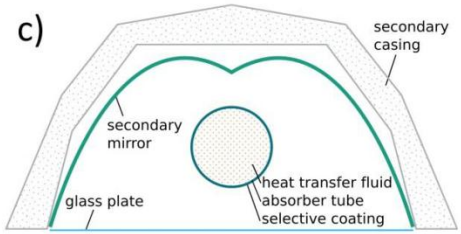
Linear Systems

- Focus on characterization (mostly Spain)
  - Test standards
  - Thermography
  - Abrasion
  - Receiver optimization and losses (Linear Fresnel)
- High temperature options (Italy)
  - DSG
  - Salt in field
- Representative of maturity









Consistent Challenges

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- Optimization
  - Low hanging fruit
  - Often funds cover a one-off point design
- Integrated system design
  - Important to consider collector characteristics
  - Storage imposes additional constraints
  - Higher performance cycles may impact receiver performance
- Materials
  - Fluid compatibility
  - Structural durability
  - Air side corrosion
- Cost must be contained
- Move to hardware