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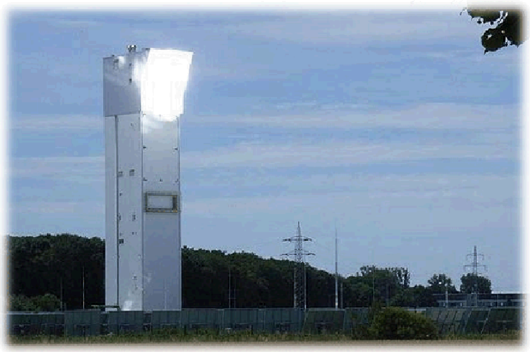

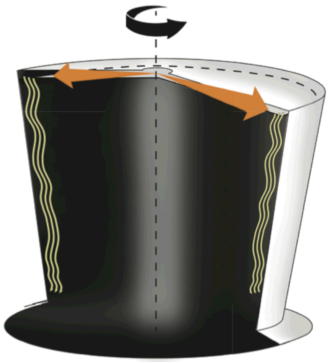

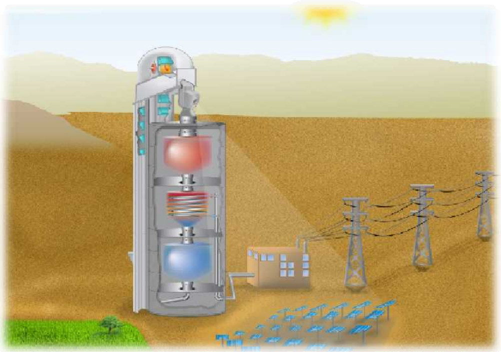

Review of Central Receiver Designs for High-Temperature Power Cycles

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Introduction

- Higher-efficiency, higher-temperature power cycles are being pursued
  - US DOE SunShot goal of $0.06/kWh (with storage)
- Need high efficiency, high-temperature receivers
  - $T_{HTF,out} \geq 650^{\circ}C$
  - $\eta_{annual} \geq 90\%$
  - Lifetime ≥ 10,000 thermal cycles
  - Cost ≤ \$150/kW_{th}

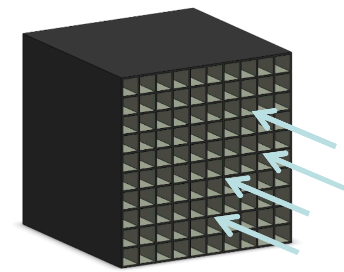
Objective

- Review central receiver designs for DOE SunShot goals
  - General principle
  - Review of tests and analyses
  - Outlet temperature and thermal efficiency
  - Benefits, challenges, and needs

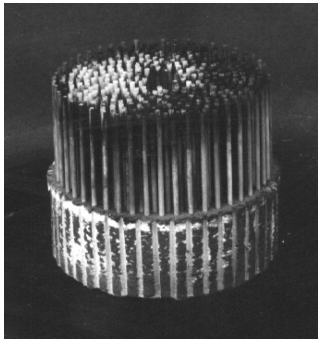
- Gas-Based Central Receivers
- Liquid-Based Central Receivers
- Solid-Particle Central Receivers

Gas-Based Central Receivers

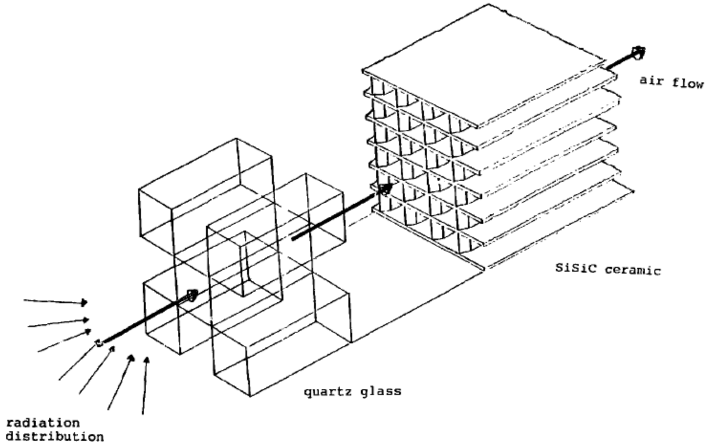
- Volumetric Air Receivers
  - Benefits
    - T > 700 °C
    - Demonstrated technology
  - Challenges
    - Flow instabilities
    - Material durability
    - Low efficiency (50 – 60%)
    - Heat storage and heat exchange



Airflow and Irradiance



“Porcupine”
(Karni et al., 1998)

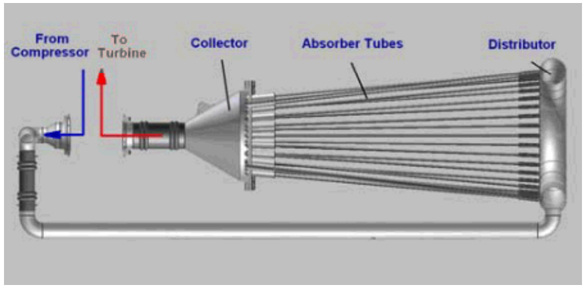


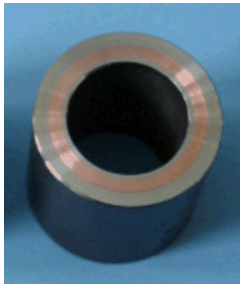
Selective volumetric receivers

- (Left image) Pitz-Paal et al. (1991)
- Menigault et al. (1991)

Gas-Based Central Receivers

- Tubular gas receivers
  - Benefits
    - T > 700 °C
    - Can heat working fluid directly (e.g., Brayton cycles)
  - Challenges
    - Heat transfer to gas
    - Material durability
    - Low efficiency (50 – 60%)
    - Heat storage





Copper in between Inconel to increase heat transfer

Segmented glass to form window to reduce heat losses

Amsbeck et al. (2009, 2010), Heller et al. (2009)

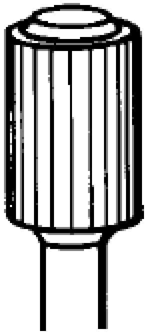
Gas-Based Central Receivers

- Small Particle Air Receiver
  - Hunt (1978, 1983)
  - Miller and Koenigsdorff (1991)

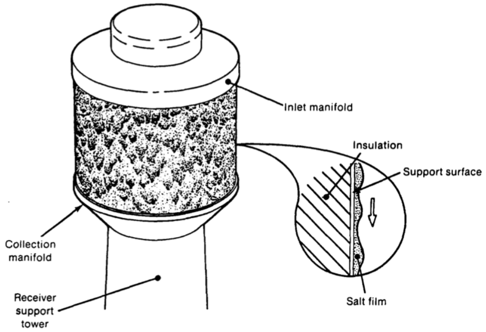
Liquid-Based Central Receivers

- Tubular liquid receivers
  - Benefits
    - Good efficiency (up to 90%)
    - Storage (molten salt)
  - Challenges
    - Limited temperature with existing nitrate salts (T < 650 °C)
    - Material durability

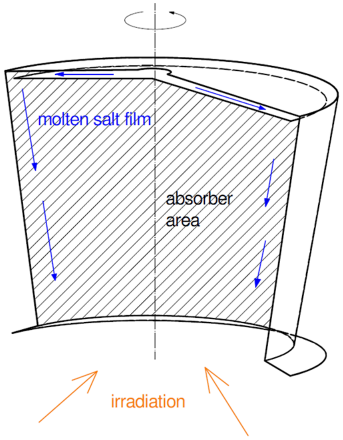
Solar Two Molten Salt Receiver (Pacheco, 2002)



Liquid sodium (Falcone, 1986) or fluoride salt receiver (Forsberg et al., 2007)



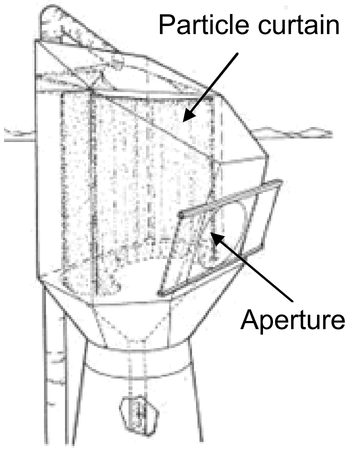
External direct absorption falling film (Bohn & Green, 1989)



Internal direct absorption falling film (Wu et al., 2011)

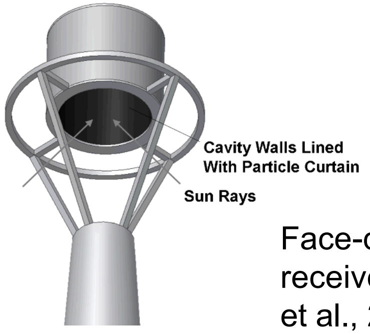
Solid Particle Central Receivers

- Falling Particle Receivers
  - Benefits
    - High temperatures (T > 700 °C)
    - Storage
    - Increased flux capability
  - Challenges
    - Need to increase thermal efficiency (prototype 50%)
    - Particle attrition
    - Particle/fluid heat exchange

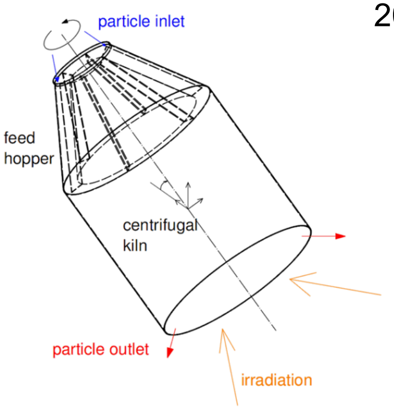


Falling particle receiver (Falcone et al., 1985)

On-sun prototype test and analysis (Siegel and Kolb, 2008; Ho et al., 2009)



Face-down falling particle receiver with recirculation (Roger et al., 2011; Khalsa et al., 2011)



Falling particle rotating kiln (Wu et al., 2011)

Summary

- Gas-Based Central Receivers
  - Volumetric
  - Tubular
  - Small particle
- Liquid-Based Central Receivers
  - Tubular
  - Falling film
- Solid-Particle Central Receivers
  - Recirculation
  - Rotating