SunShot
U.S. Department of Energy

Gen 3 CSP Technology Development

Mark Lausten, CSP Technology Manager

Agenda

- Gen 3 CSP Technology Motivation
- Technology Pathways
- Background R&D
- Development Course - Outcomes
- Cross-Cut Research and Analysis
- Capabilities Partnerships and Coordination
- Facilities and Integrated Validation

Gen 3 Technology Motive

Motivation: CSP technology with Thermal Energy Storage has the potential to provide low cost solar energy on demand, improving grid stability, increasing the delivered value of other renewable power sources, and hedging against fuel price increases for conventional power plants

Challenge: Current CSP systems do not have a roadmap to reach the low costs necessary for significant market adoption. They are limited by the temperature range (currently 565^{o}C) of materials that capture, store and transfer thermal energy. Significant cost reductions are possible by overcoming material barriers to operate at higher temperatures (> 700^{o}C).

Objective: Develop new high temperature CSP technology and retire risk to enable larger-scale demonstrations by operating under representative conditions.

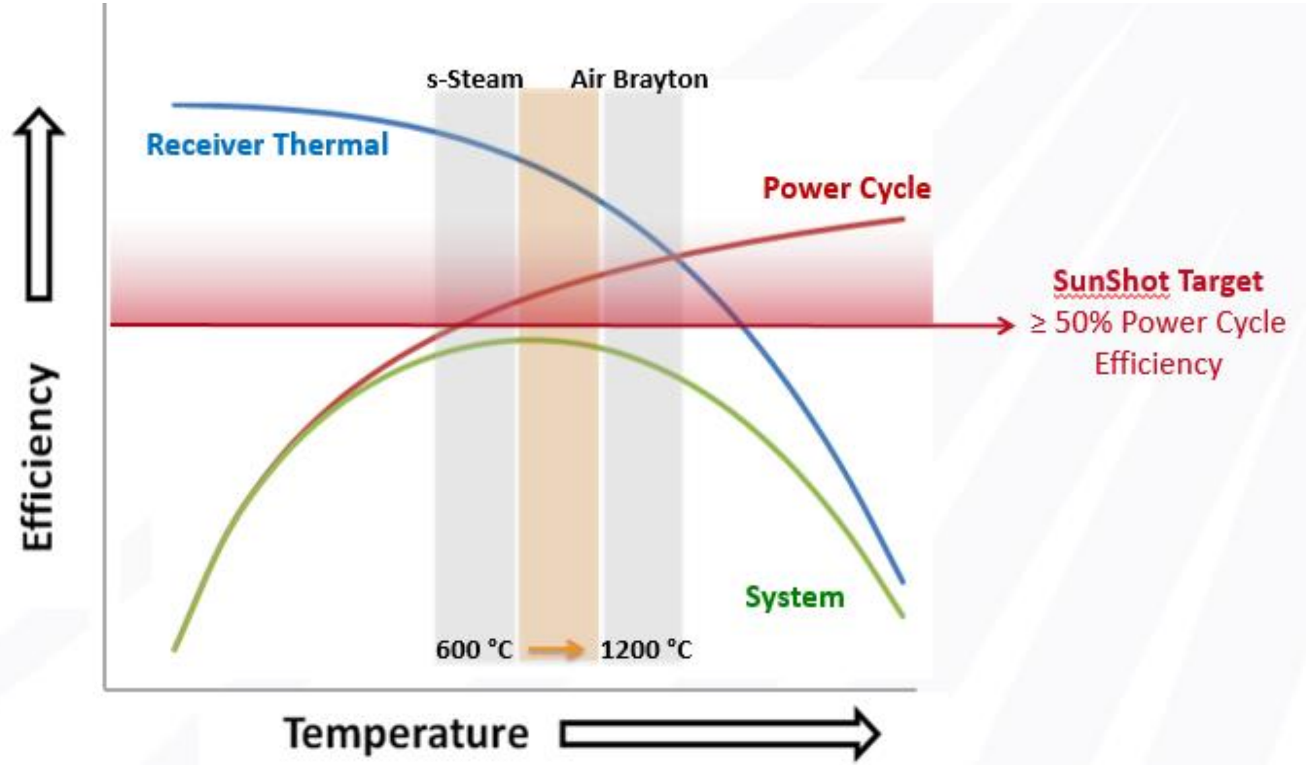
Third Generation CSP Power Cycle: 700°C +

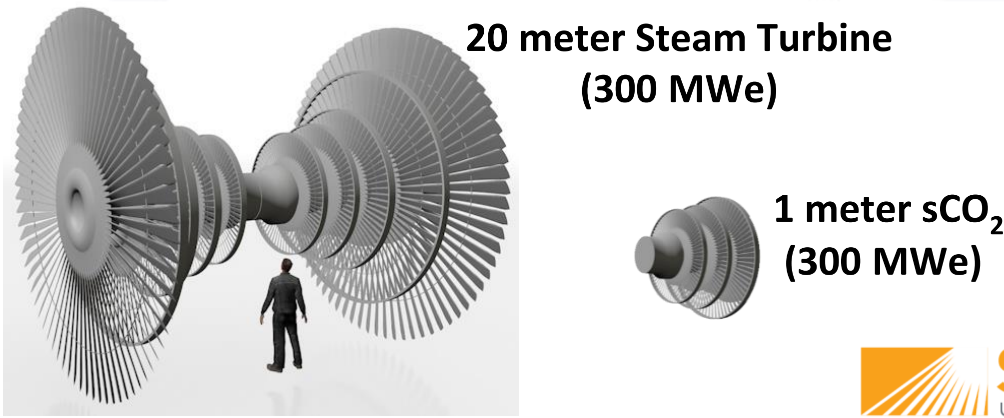
Science Principles

- Carnot vs. radiation optimum: 650 – 750°C
- Power Cycle Isothermal heat input higher η
- CSP most suitable for Power Blocks <150 MW
- Increased efficiency critical to lower CSP costs

sCO_2 Power Cycles

- Can achieve η > 50% operating at >700°C
- Scale from 50-500 MW and can scale to 10 MW with modest η decrease
- Suitable for dry cooling





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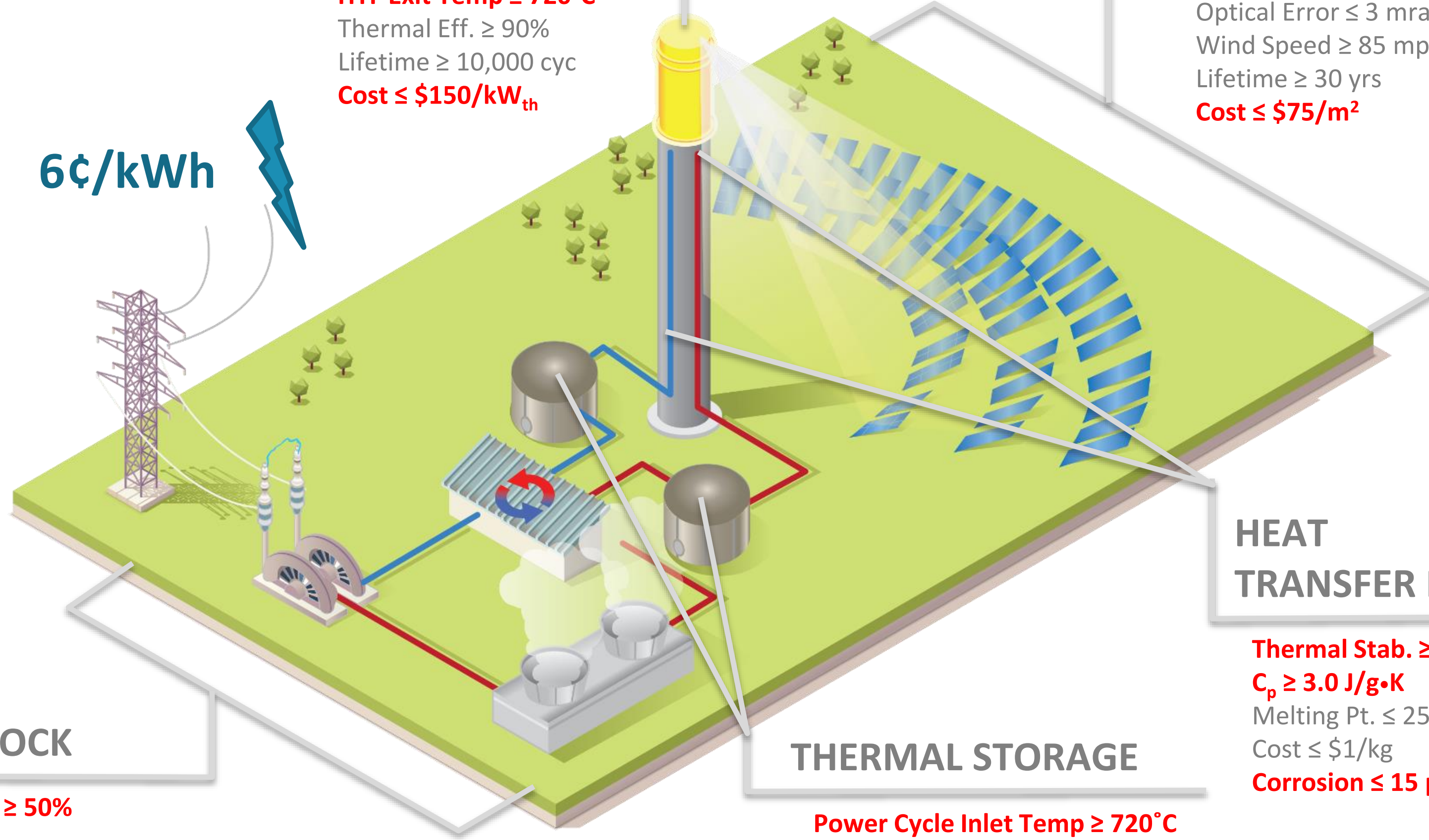
CSP Program Technical Targets



RECEIVER

HTF Exit Temp ≥ 720˚C
Thermal Eff. ≥ 90%
Lifetime ≥ 10,000 cyc
Cost ≤ $\$150/kW_{th}$

SOLAR FIELD

Optical Error ≤ 3 mrad
Wind Speed ≥ 85 mph
Lifetime ≥ 30 yrs
Cost ≤ $\$75/m^2$

HEAT TRANSFER FLUID

Thermal Stab. ≥ 800˚C
C_p ≥ 3.0 J/g•K
Melting Pt. ≤ 250˚C
Cost ≤ $1/kg
Corrosion ≤ 15 µm/yr

POWER BLOCK

Net Cycle Eff. ≥ 50%
Dry Cooled
Cost ≤ $\$900/kW_e$

THERMAL STORAGE

Power Cycle Inlet Temp ≥ 720˚C
Energy Eff. ≥ 99%
Exergy Eff. ≥ 95%
Cost ≤ $\$15/kWh_{th}$

CSP Program Technical Targets

RECEIVER

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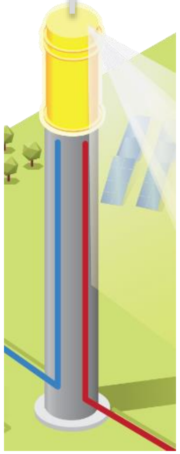
Lifetime ≥ 10,000 cyc
Cost ≤ $150/kW_{th}$



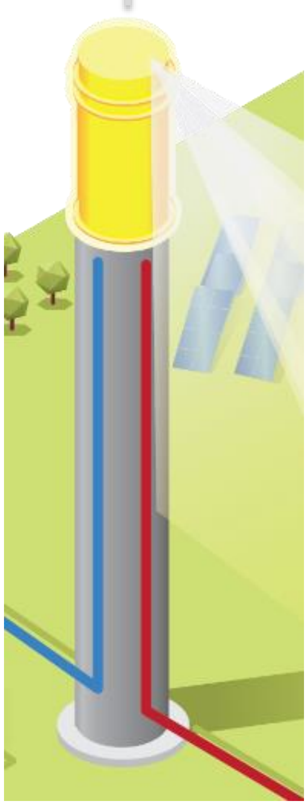
Gen 3 CSP Thermal Energy Sub-Systems

RECEIVER

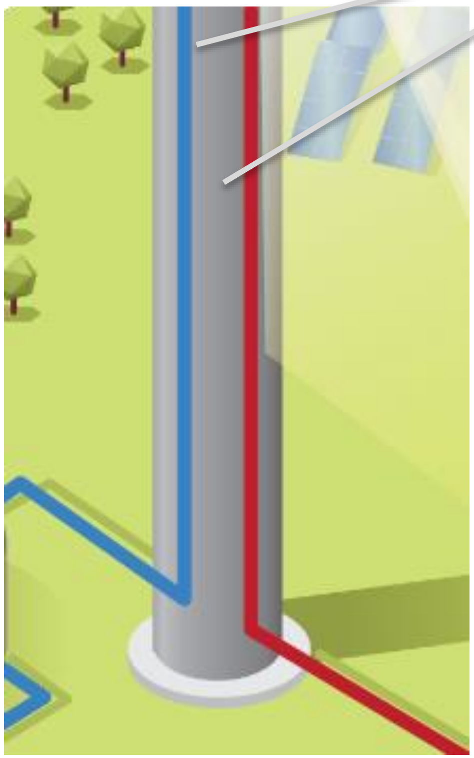
HTF Exit Temp ≥ 720˚C
Thermal Eff. ≥ 90%
Lifetime ≥ 10,000 cyc
Cost ≤ $150/kW$_{th}$

Some Key Challenges

Inert Gas	High temp / pressure stress / fatigue	Absorptivity and thermal loss
Liquid	High Temp Stability / Low Freeze Point	Corrosion Allowance vs. Thin Tube Wall
Solid Media	Challenging to get high efficiency	Media Flow Control or Heat Transfer



Gen 3 CSP Thermal Energy Sub-Systems



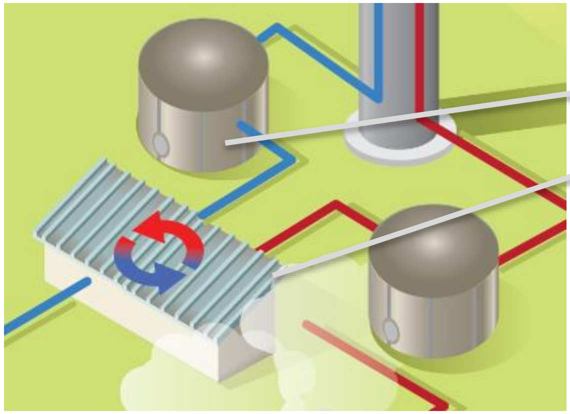
HEAT TRANSFER FLUID

Thermal Stab. ≥ 800˚C
C_p ≥ 3.0 J/g•K
Melting Pt. ≤ 250˚C
Cost ≤ $1/kg
Corrosion ≤ 15 µm/yr

Some Key Challenges

Inert Gas	Corrosion risk retirement	Minimize pressure drop / Parasitic Load
Liquid	Potential materials identified but best not determined	Corrosion concerns dominate
Solid Media	High Temperature Material handling	Particle attrition

Gen 3 CSP Thermal Energy Sub-Systems



THERMAL STORAGE

Power Cycle Inlet Temp ≥ 720˚C

Energy Eff. ≥ 99%

Exergy Eff. ≥ 95%

Cost ≤ \$15/kWh$_{th}$

Some Key Challenges

Inert Gas	Indirect storage PCM, TCES, Sensible	Multi Heat Exchange Match Temp and Power with Cycle
Liquid	Containment Material Cost	Corrosion allowance and high pressure working fluids
Solid Media	Engineered Systems for reliability, cost and efficiency	Heat transfer solid particle to fluid

Gen 3 CSP Systems Targets and Challenges

Collector Field

- Cost < $75/m2
- Concentration Ratio > 50
- Operable in 35 mph winds
- Optical error <3.0 mrad
- 30 year lifetime

	Receiver *Cost < $150/kW$_{th}$* *Thermal eff. > 90%* *Exit Temp > 720°C* *10,000 cycle life*	**Material & Transport** *Cost < $1/kg* *Operable range from 250°C to > 800°C*	**Thermal Storage** *Cost < $15/kWh* *99% energetic eff.* *95% exergetic eff.*	**HTF to sc-CO_2 Heat Exchanger**
Inert Gas	• High pressure fatigue challenges mitigated • Absorptivity control and thermal loss management	• Minimize pressure drop • Corrosion risk retirement	• Indirect storage required • Cost includes fluid to storage thermal exchange	• Cost includes fluid to storage thermal exchange
Liquid	• Similarities to prior demonstrations • Allowance for corrosive attack required	• Potentially chloride salt, best material not yet determined • Corrosion concerns dominate	• Direct or indirect storage may be superior	• Challenging to simultaneously handle corrosive attack and high pressure working fluids
Solid Particle	• Most challenging to achieve high thermal efficiency	• High Temperature Material handling reliability and attrition	• Particles likely double as efficient sensible thermal storage	• Challenging heat transfer rate through solid particle • Cost and efficiency concerns dominate

Super Critical CO_2 Brayton Cycle

- Net thermal to electric efficiency > 50%
- Power cycle system cost <$900/kW$_e$
- Dry cooled heat sink at 40°C ambient
- Turbine inlet temperature near 720°C

Background R&D and Analysis

B&V Concept Design and Estimate Study

- Concepts based on 1990's Solar I and Solar II 10 MWe demo
- Evaluated the cost to demonstrate new high temperature systems considering Molten Salt and Solid Particle Pathways.
- Key Findings: Cost to build 10 MW demonstration >$200 M
- Technology readiness of Sub-Systems premature for 10MW Integrated Tests

CSP System Integration Workshop April 2016:

- Over 100 CSP program R&D community, utilities and industrial manufacturers.
- Technology Breakouts: experts discussed state of the high temperature CSP

Gen 3 Roadmap:

- Multi-team effort to analyze known Technology pathways and key barriers
- Identify R&D priorities to advance Gen 3 to be prepped for 10 MW demo

Key Activities for Gen 3 Development

Gen3 CSP Systems Integration:

- Champions of Complete Gen 3 System Concepts Lead Development and Sub-System Integration
- Requires parallel development of individual components and sub-systems

Components or sub-systems development:

- Industrial Manufacturers or Sub-System Developers
- Requires Close Integrated Exchange of System Requirements and Component Capabilities

Integrated System Testing and Operation:

- Components and Sub-Systems Testing under **Representative Conditions**
- Scale and duration of testing to retire risk for adoption to a pilot demonstration

Goal: Integrated Operation at industrial relevant scales

Solar Energy Collection →Storage → Transfer to sCO2 at +700°C 250 bar

Cross Cut and Adjacent Activity

Materials Corrosion and Properties:

- Alloys, corrosion and fundamental heat transfer

Solar Field and sCO2 Power Cycle Integration and Analysis:

- Cross-cut Analysis to inform the entire field of development

Near Term Adoption of New High Temperature Systems:

- Adoption of Materials and Concepts to Advance Systems Deployed in the next 5-10 years e.g. with steam turbines at lower temperatures

Manufacturing with High Temperature Materials:

- Joining, ASME qualification, additive manufacturing

Integration Engineering and Grid Integration Analysis:

- Looking ahead to the construction and Grid Integration of Gen 3
- Feedback into current development requirements

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Thank you!

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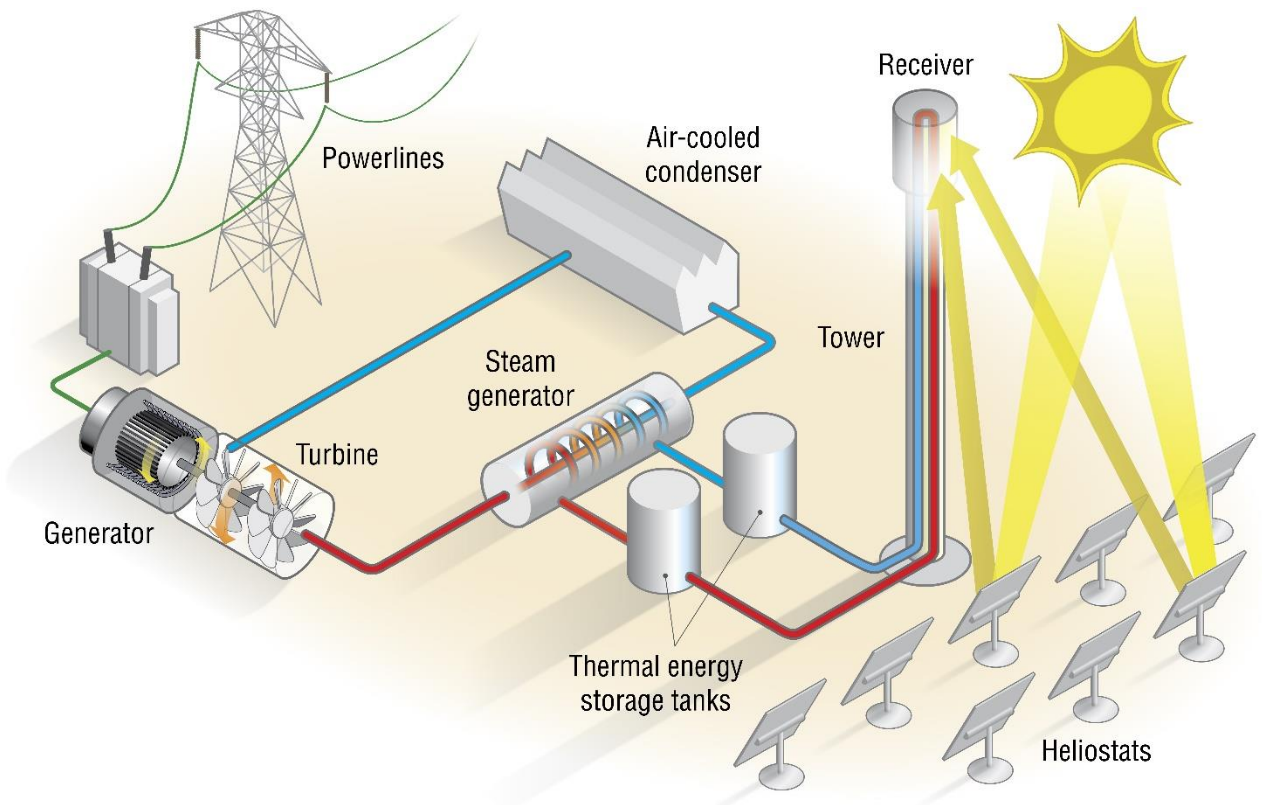
Liquid System Concept



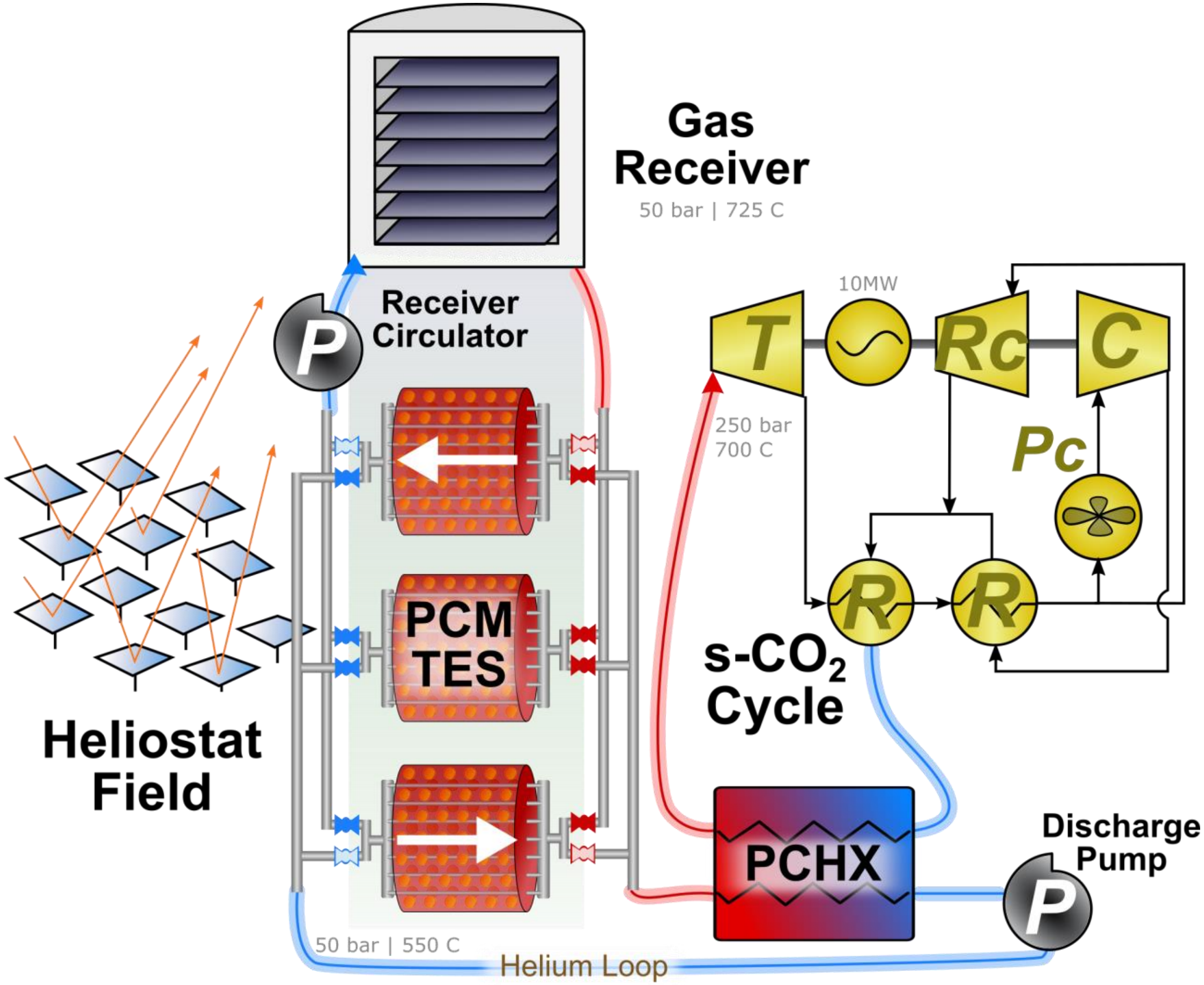
Liquid Systems:

- One Fluid for receiver and thermal energy storage (TES).
- Sensible heat TES heats sCO_2

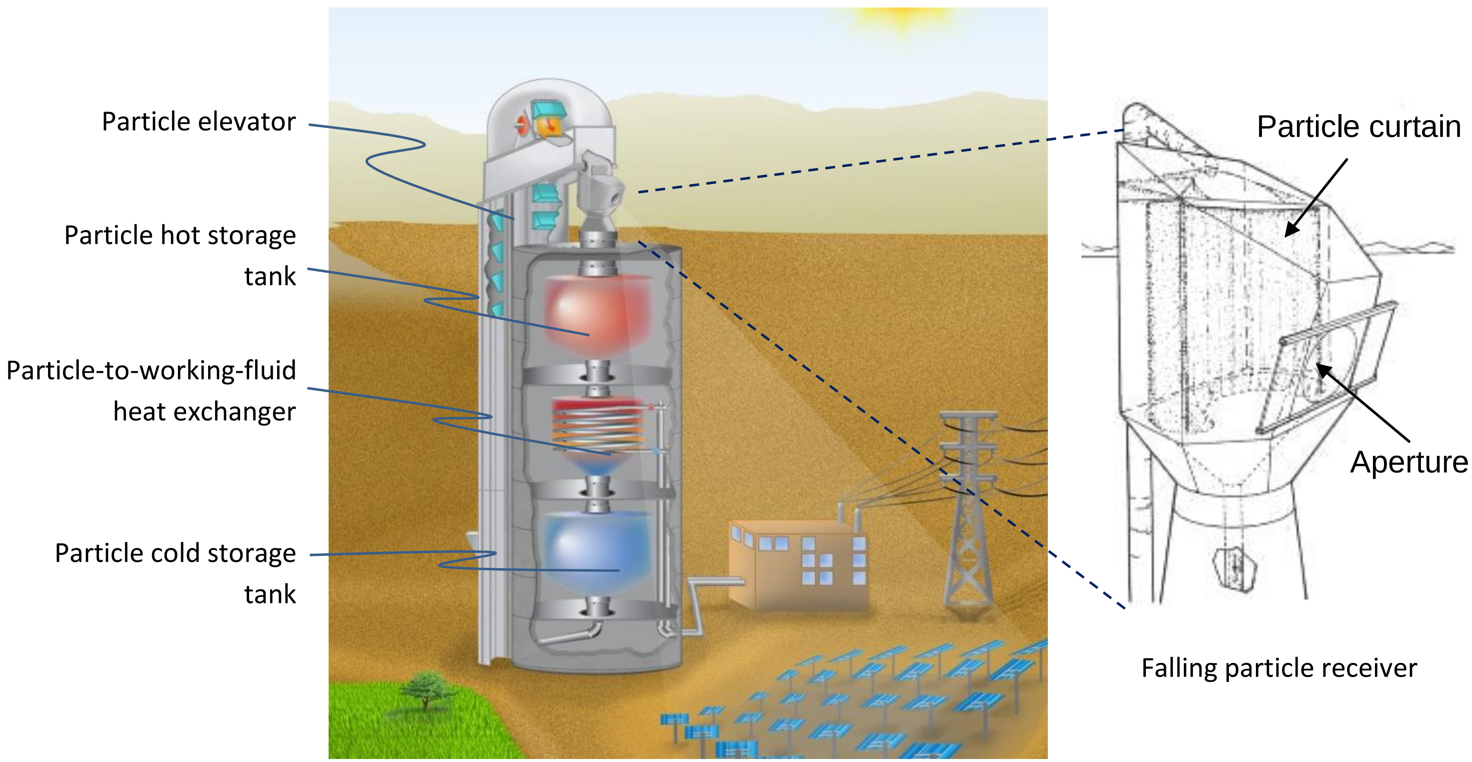
Inert Gas Receiver Concept

Gas Receiver System:

- Gas is circulated through receiver and transfers heat to thermal energy storage (TES)
- TES may be:
  - Phase Change
  - Sensible
  - Thermal Chemical Energy Storage



Falling Particle System Concept



Solid Particle Systems:

- Solid inert particle heated directly or indirectly and stored as TES.
- Particle to sCO_2 Hx.