INSTITUT FÜR
ENERGIETECHNIK UND
THERMODYNAMIK
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# CSP-Systems based on sCO2-Power Cycles and Particle based Heat Storage

1st European Seminar on Supercritical CO2 (sCO2) Power Systems
29.-30. September 2016 - Vienna - Austria

29.09.2016

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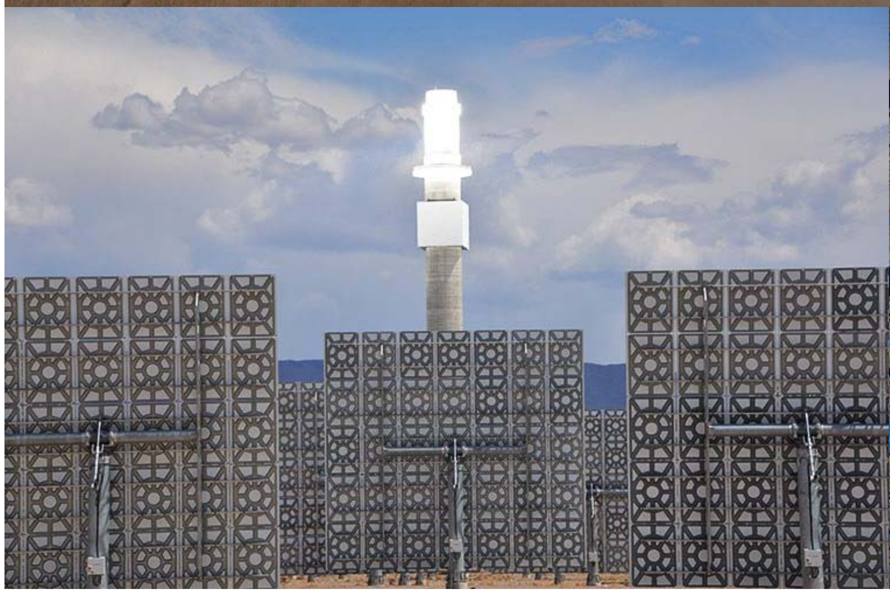
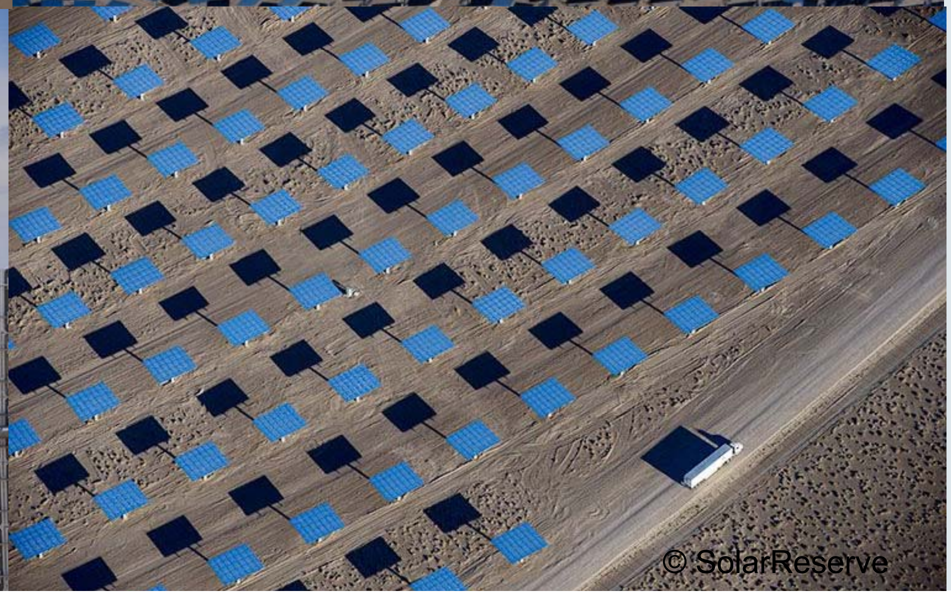
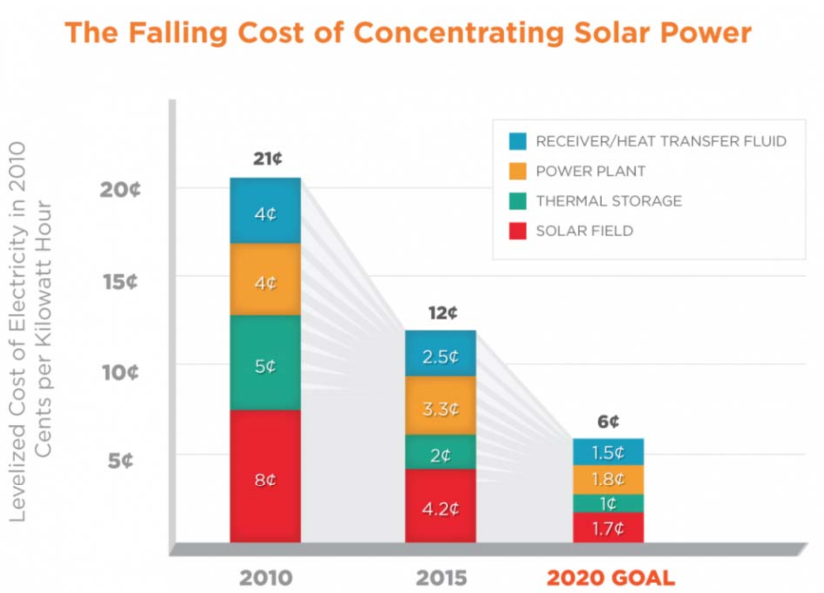
# CSP Plants - Crescent Dunes



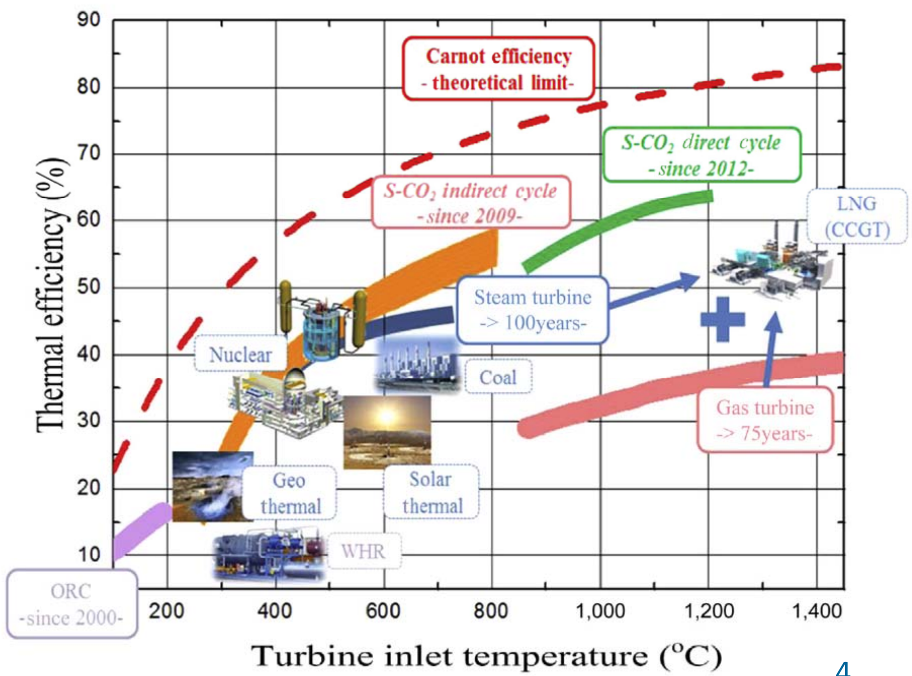


## Introduction

- Concentrated Solar Power (CSP) as dispatchable alternative for Photovoltaics
- Imperative to lower the Levelized Cost of Electricity (LCOE)
- Approach: Enhancing efficiencies of CSP plants (e.g. SunShot Initiative)
  - Increasing plant temperatures (max. ~560 °C at the moment)
  - Novel plant concepts




http://energy.gov/eere/sunshot/concentrating-solar-power




Y. Ahn et al.: Review of supercritical CO2 Power Cycle Technology and current Status of Research and Development

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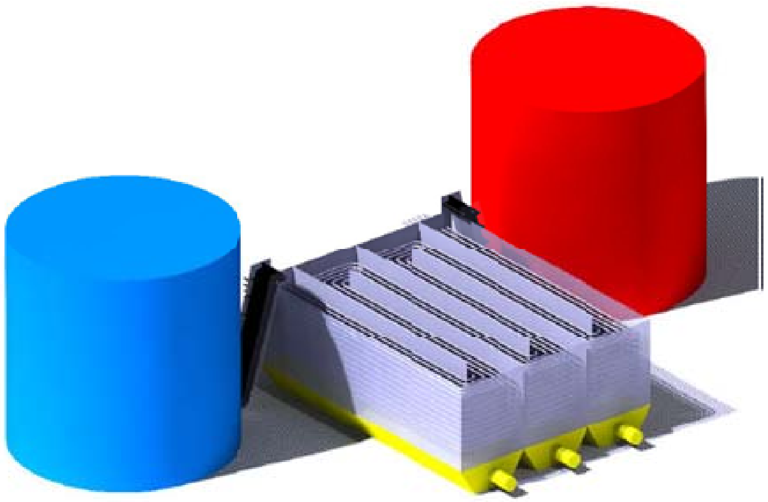
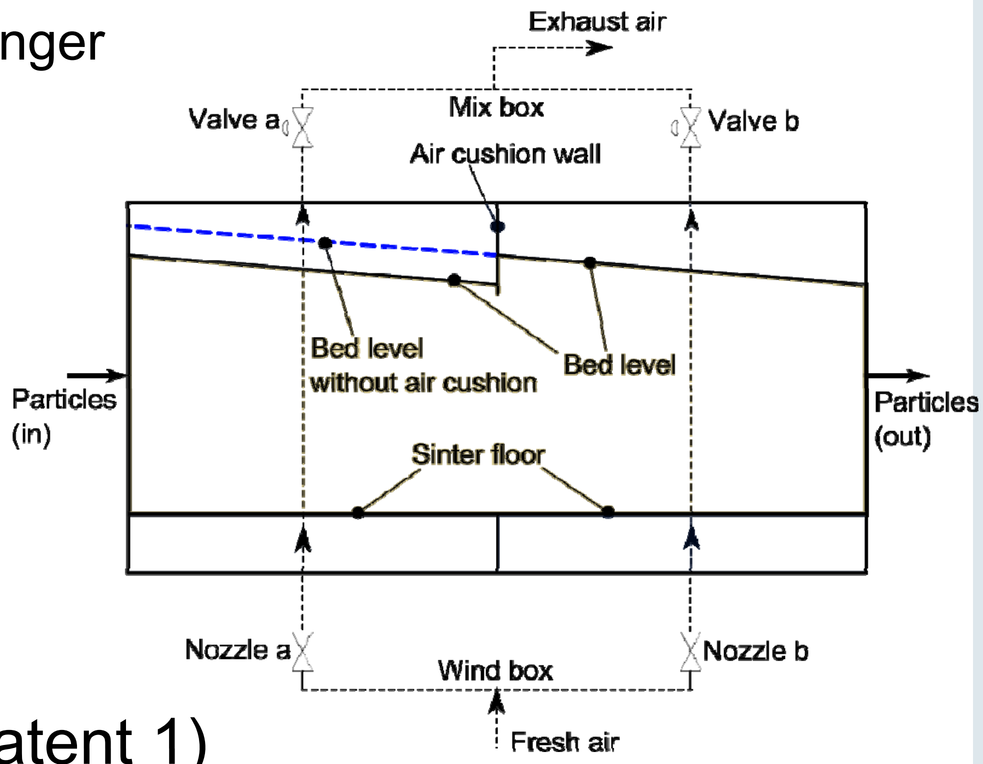
# SandTES – High Temperature Thermal Energy Storage

- Solids (Particle diameter ~80 microns) as Storage Media
  - Quartz sand ($SiO_2$), Corundum ($Al_2O_3$) or Siliconcarbide (SiC)
- Cheap materials (huge cost impact)
- Temperatures up to 1000 °C
- Resulting in high energy densities



# SandTES – Technology

- Novel fluidized bed heat exchanger
- Plug flow
- Counter current
- Scalable




➢ Nozzle distributor floor (Patent 1)

- Stable fluidization near the minimum fluidization velocity

➢ Air cussion technology (Patent 2)

- Controll of the particle flow

# 280 $kW_{th}$ Pilot plant

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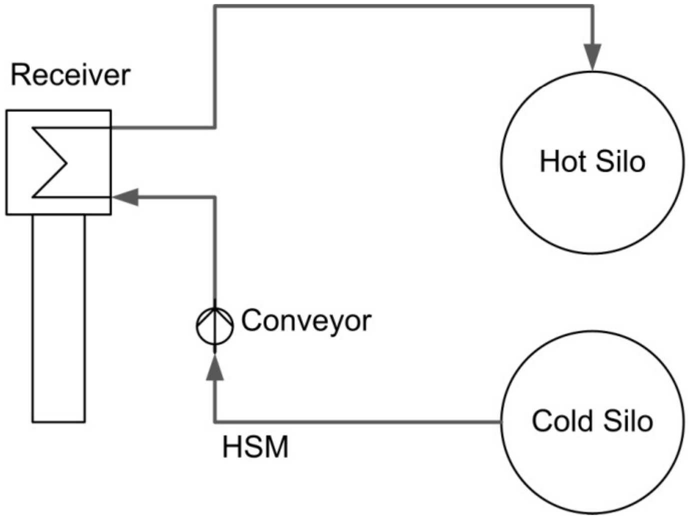
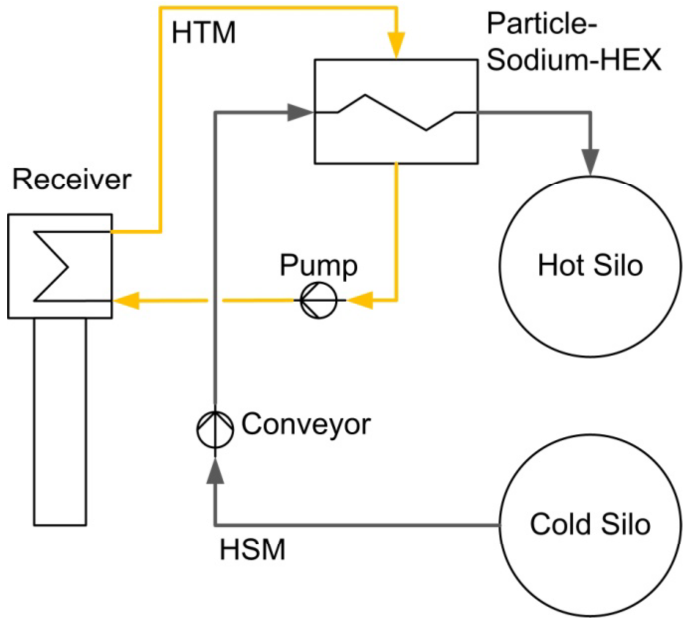
# Storage Cycles

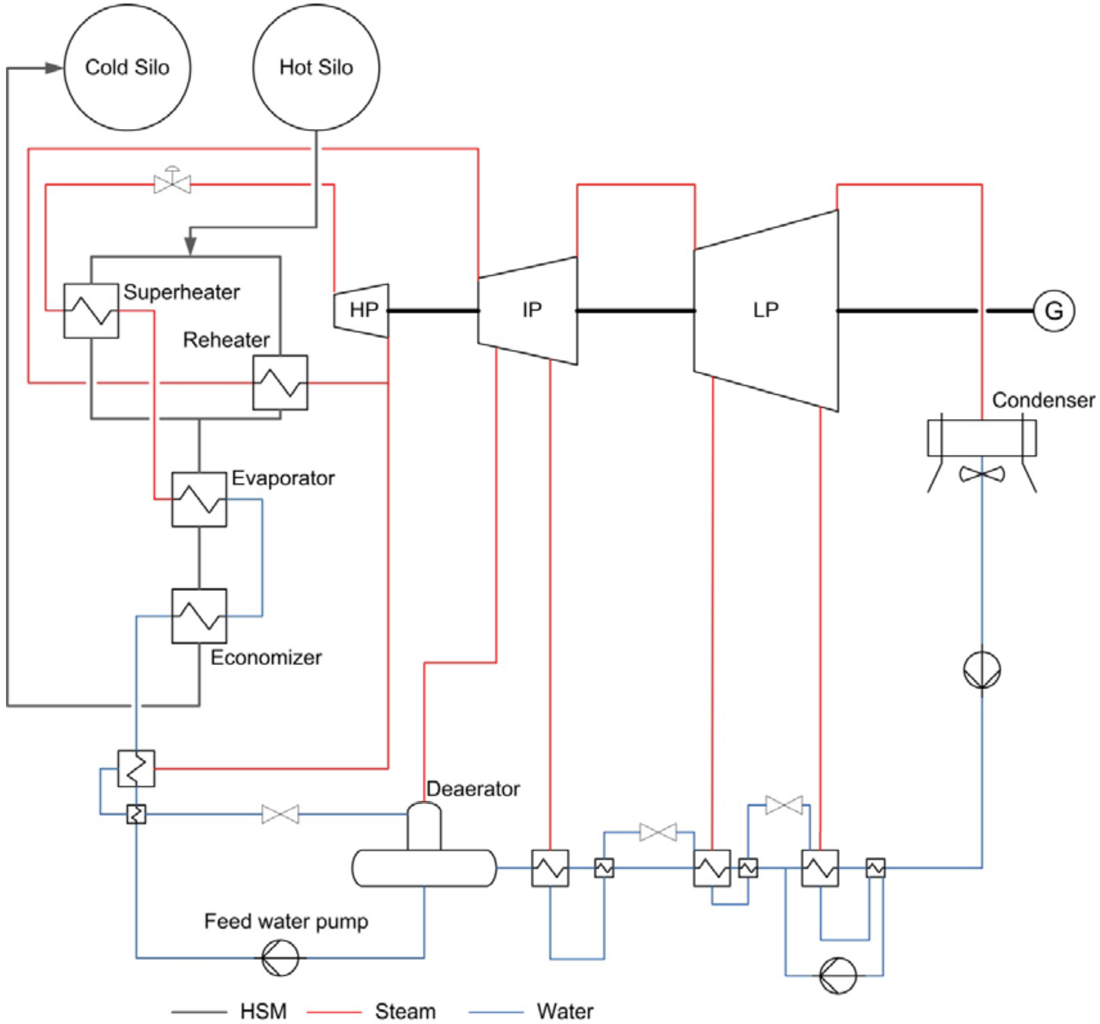



Direct Storage Cycle



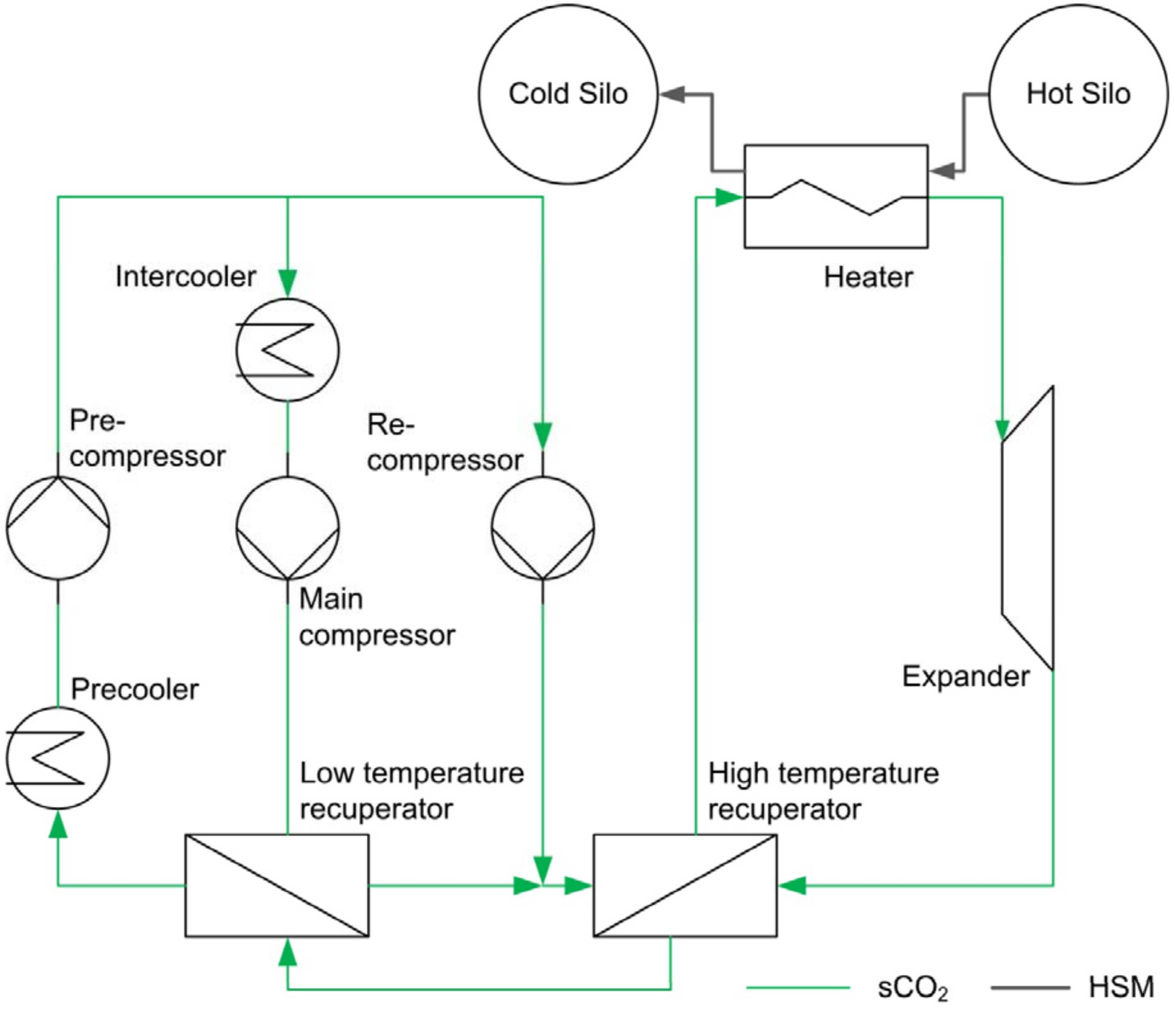

Indirect Storage Cycle

# Power Cycles – Rankine Cycle



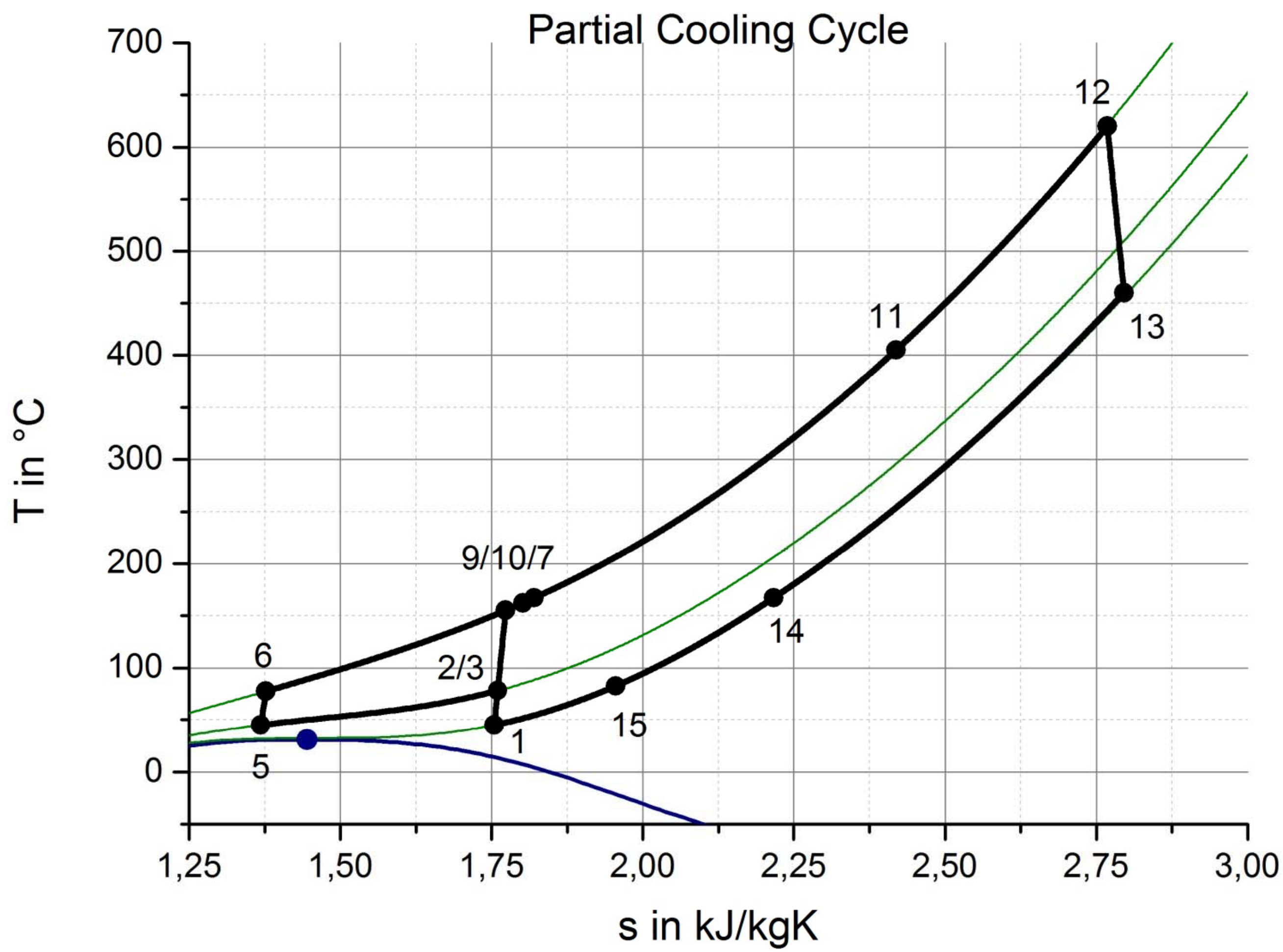

| Name | Unit | Value |
|---|---|---|
| $T_{SH}$ | °C | 600 |
| $T_{RH}$ | °C | 620 |
| HP | bar | 190 |
| IP | bar | 40 |
| LP | bar | 3 |
| $\eta_{s,Turbine}$ | - | 0.88 |
| $\eta_{s,Pump}$ | - | 0.80 |
| $T_{Silo,hot}$ | °C | 660 |
| $T_{Silo,cold}$ | °C | 330 |

# Power Cycles – sCO2 (Partial Cooling) Cycle




| Name | Unit | Value |
|---|---|---|
| $T_{Heater}$ | °C | 620 |
| $p_{Heater}$ | bar | 285 |
| $\eta_{s,Expander}$ | - | 0.93 |
| $\eta_{s,Compressor}$ | - | 0.89 |
| Split ratio | - | 0.4 |
| $P_1$ | - | 1.6 |
| $P_2$ | - | 2.5 |
| $\Delta T_R$ | °C | 5 |
| $\Delta p_{LTR,c/h}$ | bar | 0.5/1 |
| $\Delta p_{HTR,c/h}$ | bar | 0.2/1.2 |
| $\Delta p_{Cooler}$ | bar | 0.15 |
| $\Delta p_{Heater}$ | bar | 2.5 |
| $T_{Silo,hot}$ | °C | 660 |
| $T_{Silo,cold}$ | °C | 445 |

# Partial Cooling Cycle T-s-diagram



# Plant Concepts - Overview

| Description | Crescent Dunes | Rankine Cycle Plant | sCO2 Cycle Plant |
|---|---|---|---|
| Power Cycle | Rankine | Rankine | Partial Cooling |
| Storage Cycle | Direct | Indirect | Indirect |
| HSM | Molten Salt | Corundum | Corundum |
| HTM | - | Liquid Sodium | Liquid Sodium |
| $T_{HTM/HSM,max}$ | 565 °C | 700 °C | 700 °C |
| Number of Media | 2 | 3 | 3 |

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# Power Cycles – Comparison

| Parameter | Unit | CD | RC | sCO2 | *HT-sCO2* |
|---|---|---|---|---|---|
| $\dot{Q}_{Cycle}$ | $MW_{th}$ | 269 | 280 | 280 | *280* |
| $P_{Net}$ | $MW_{el}$ | 110 | 123 | 120 | *125* |
| $T_{max}$ | °C | 540 | 620 | 620 | *660* |
| $p_{max}$ | bar | 116 | 190 | 285 | *285* |
| $\dot{m}_{Cycle}$ | kg/s | 100 | 93 | 1032 | *995* |
| $\eta_{Net}$ | % | 40.6 | 43.8 | 42.7 | *44.5* |
| $\eta_{Gross}$ | % | 43.2 | 46.7 | 43.4 | *45.2* |
| $\dot{m}_{HTM}$ | kg/s | - | 1616 | 2482 | *2402* |
| $\dot{m}_{HSM,SC}$ | kg/s | 1530 | 1743 | 2635 | *2542* |
| $\dot{m}_{HSM,PC}$ | kg/s | 643 | 727 | 1097 | *1056* |
| $\Delta T_{HEX,min}$ | °C | 25 | 2x40 | 2x40 | 2x20 |
| $T_{HSM,max}$ | °C | 565 | 660 | 660 | *680* |
| $T_{HSM,min}$ | °C | 288 | 330 | 445 | *458* |
| $\Delta T_{HSM}$ | °C | 277 | 330 | 215 | 222 |

# Plant Concepts – Comparison

| Parameter | $\eta_{Receiver}$ | $\eta_{Net}$ | E | $V_{Silo,hot}$ | $A_{HEX,tot}$ |
|---|---|---|---|---|---|
| Unit | % | % | MJ/m³ | 10³ m³ | m² |
| CD | 90 | 41 | 880 | 11 | n. A. |
| RC | 93 | 44 | 578 | 17 | 40392 |
| sCO2 | 93 | 43 | 383 | 26 | 41805 |

## Content

## Conclusion

- Lowering the LCOE
- Increasing plant efficiencies by enhancing the plant temperatures (State of the art: ~560°C)
- Higher temperatures concern the entire plant
  - Storage cycle (Receiver, TES)
  - Power cycle
- More expensive materials needed (nickel-base alloys, ceramics)
- ISC (vs. CD):
  - \+ Lower costs for heat storage medium
  - \+ Higher efficiencies
  - \- Large intermediate HEX
  - \- Low energy density
- sCO2 cycle (vs. Rankine cycle):
  - \+ Higher efficiencies (above ~650 °C)
  - \+ Lower plant sizes and costs
  - \- Lower energy density

Thank you for your attention!