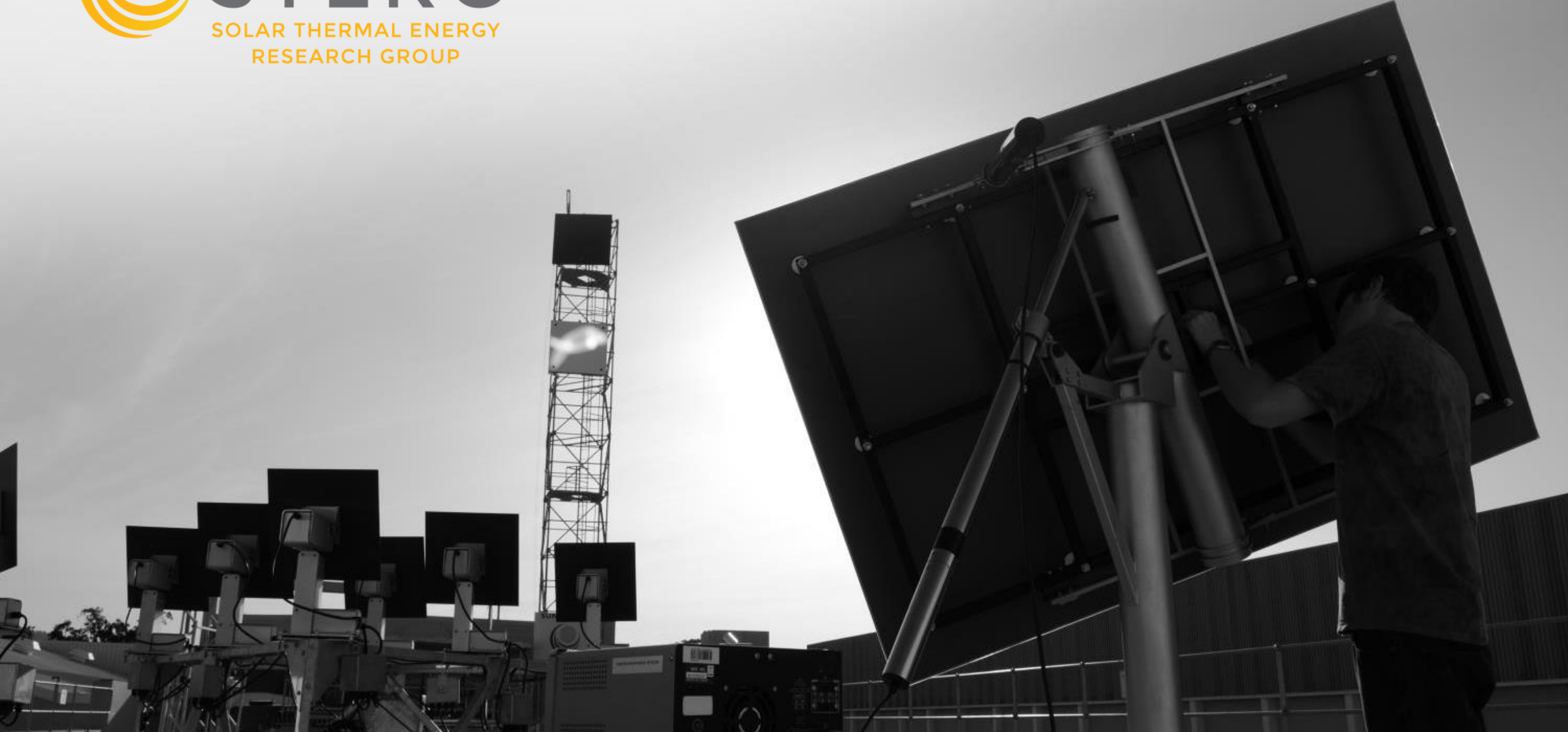
STERG

SOLAR THERMAL ENERGY
RESEARCH GROUP



Integrating Supercritical Carbon Dioxide Brayton Cycles into Concentrating Solar Power Plants

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- S-CO_2 Brayton Cycles
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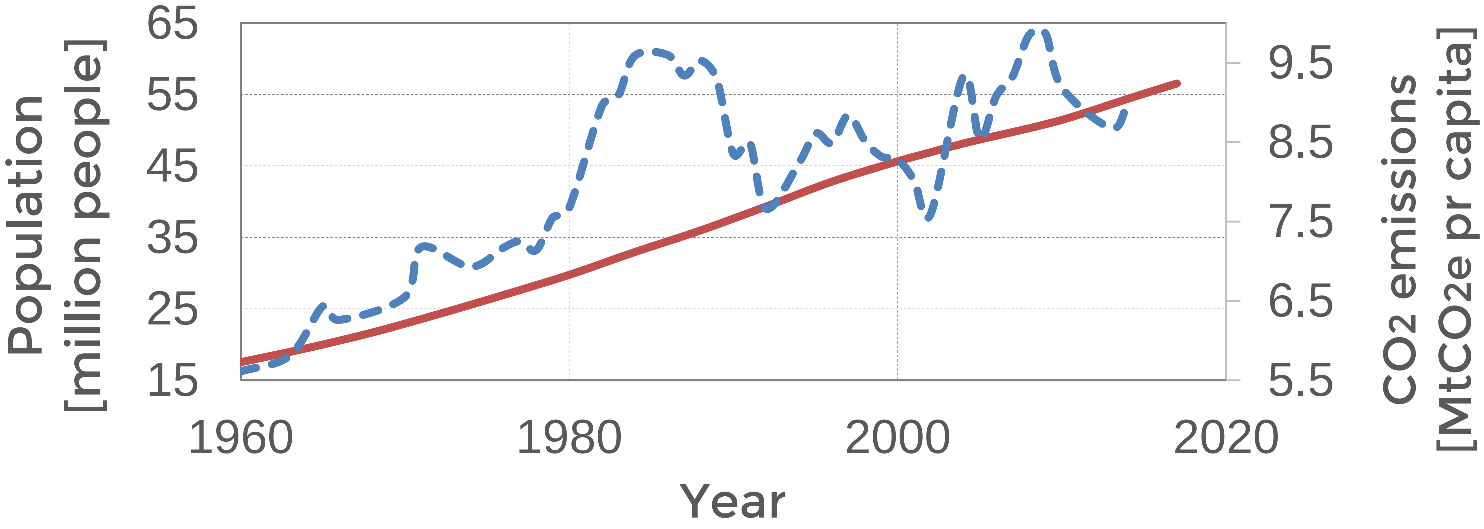
Introduction

Greenhouse Gas Emissions

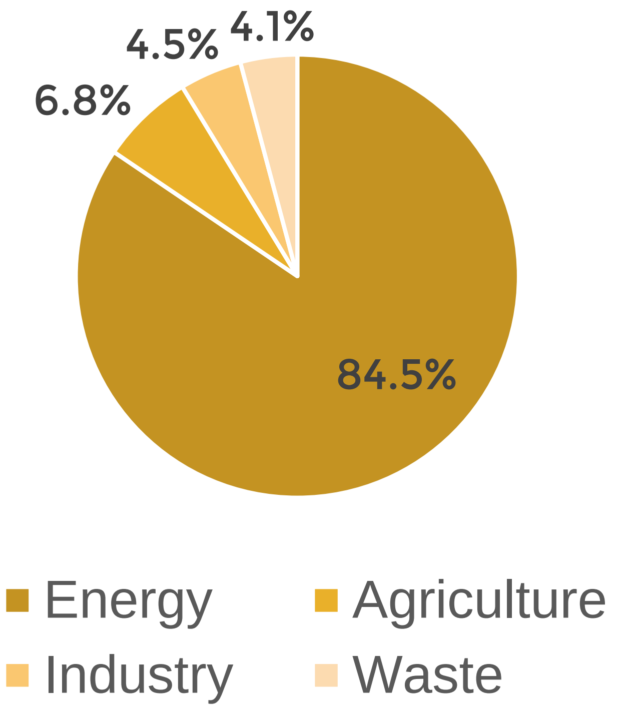


Google Public Data, 2018, World Development Indicators: Environment. Available at https://www.google.com/publicdata/explore?ds=d5bncppjof8f9_ [Accessed 29/08/18]

Introduction

Electricity Production

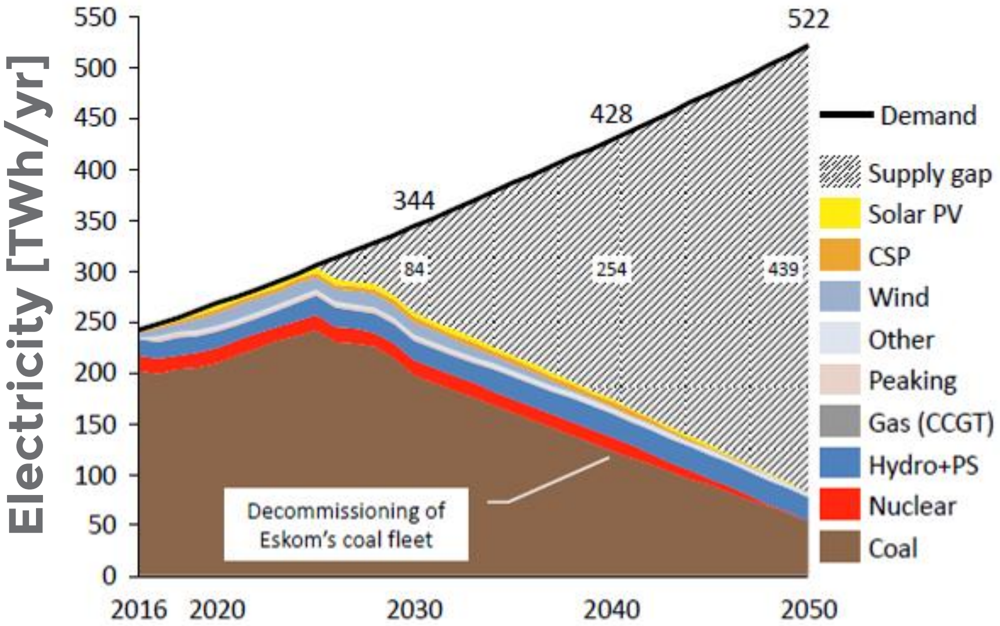
- The energy sector is the largest contributor to GHG emissions: 84.5%
- 94% of electricity in South Africa produced from coal



Source: USAID, 2016, GHG Emissions in SA

Introduction

Mitigation target



Bischof-Niemz, 2017, Energy Modelling for South Africa, Latest Approaches & Results in a Rapidly Changing Energy Environment

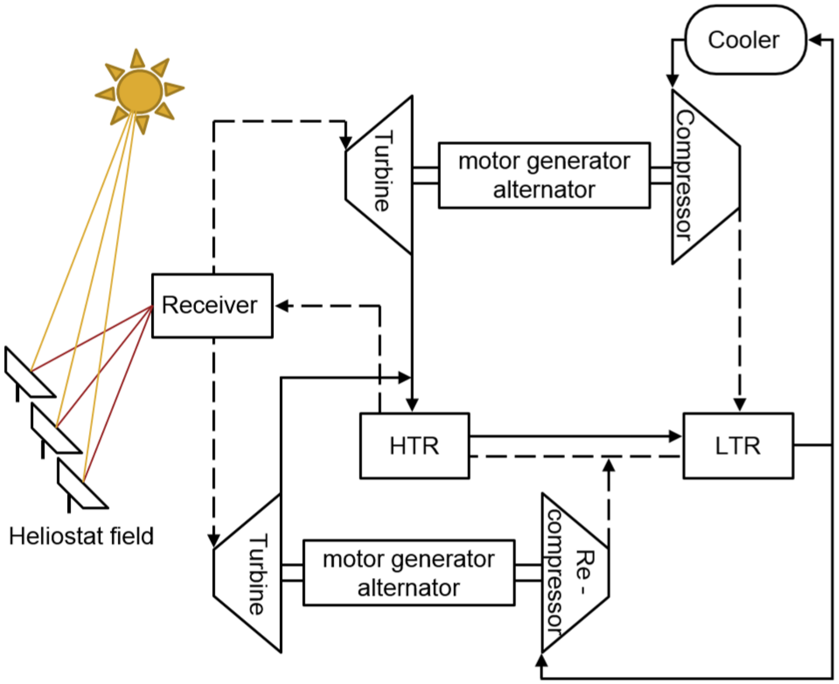
The s-CO_2 Brayton Cycle

Improved efficiency

- Large amounts of solar resource
- The most effective way to improve the CSP plant's efficiency is through improvements to the power cycle
- Efficiencies of over 50% possible in central receiver tower type CSP systems

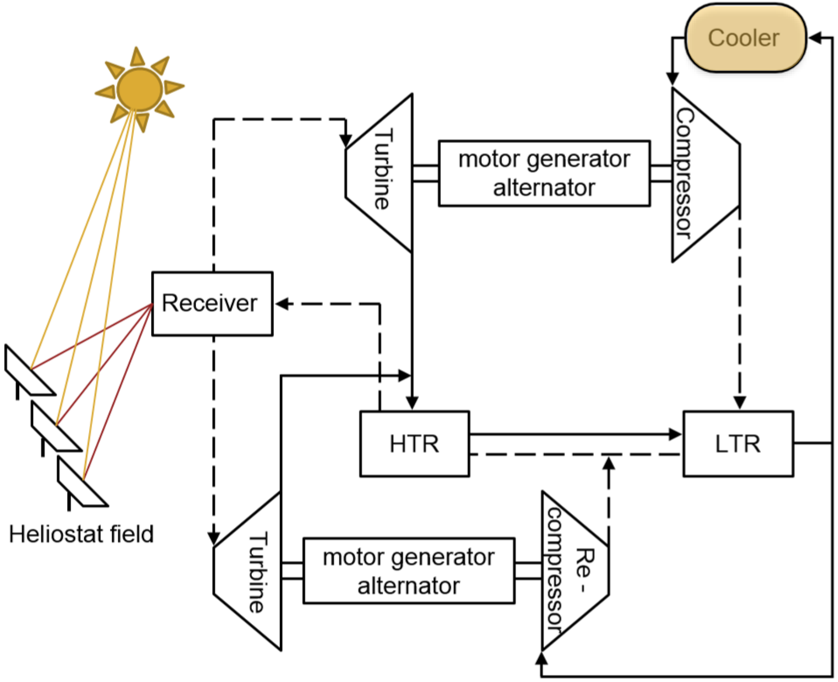
The s-CO$_2$ Brayton Cycle

Recuperated Recompression Cycle



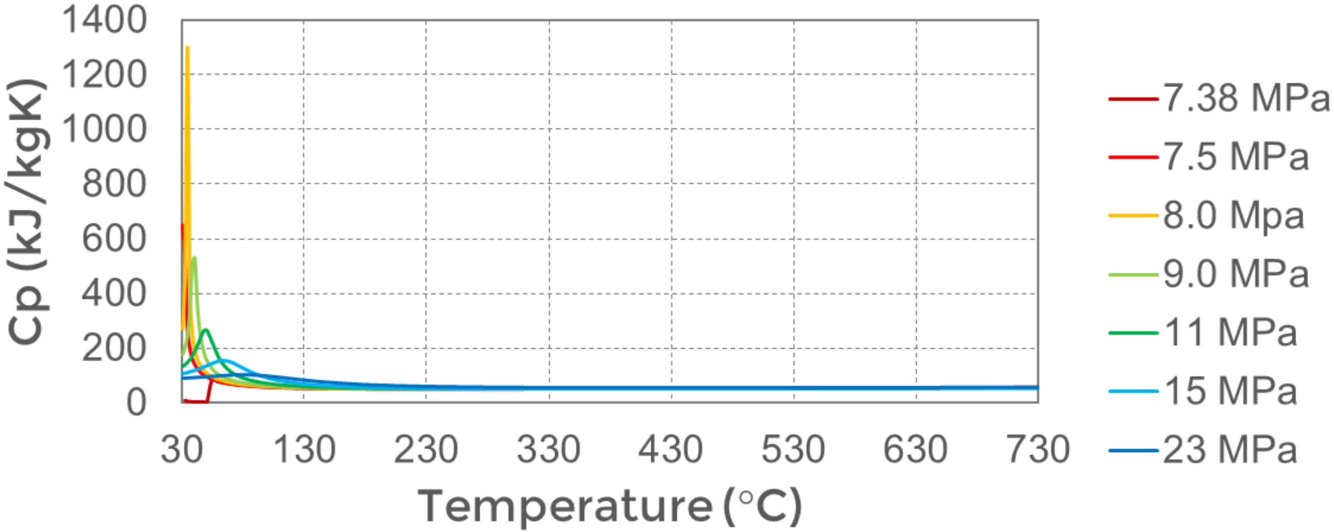
The s-CO$_2$ Brayton Cycle

Cooling



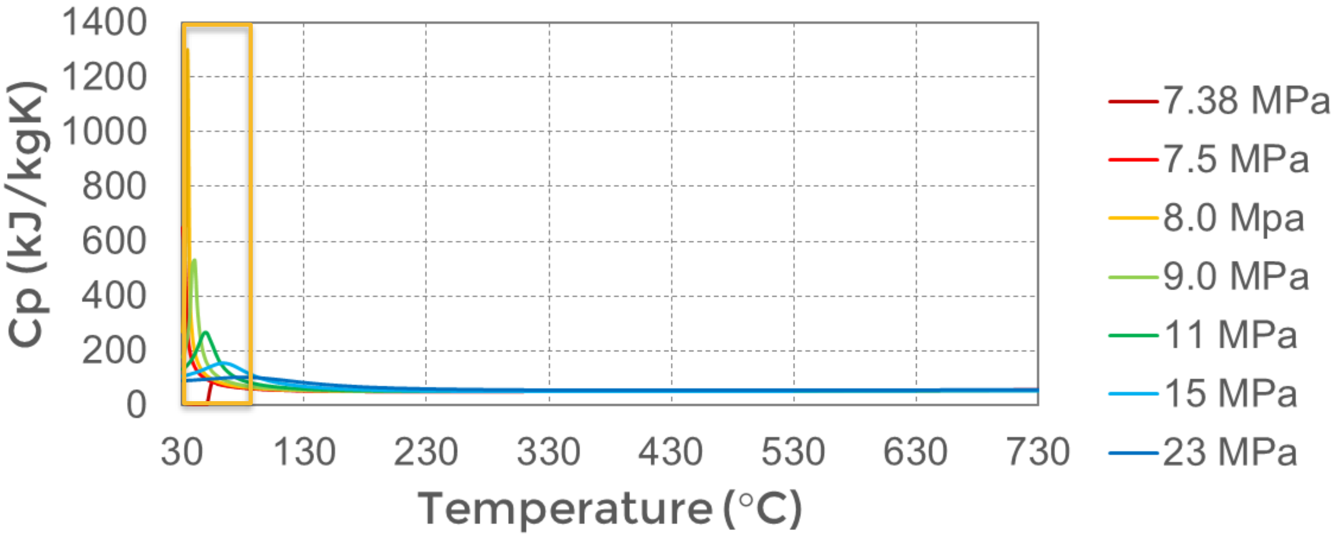
The Properties of s-CO_2

Specific Heat



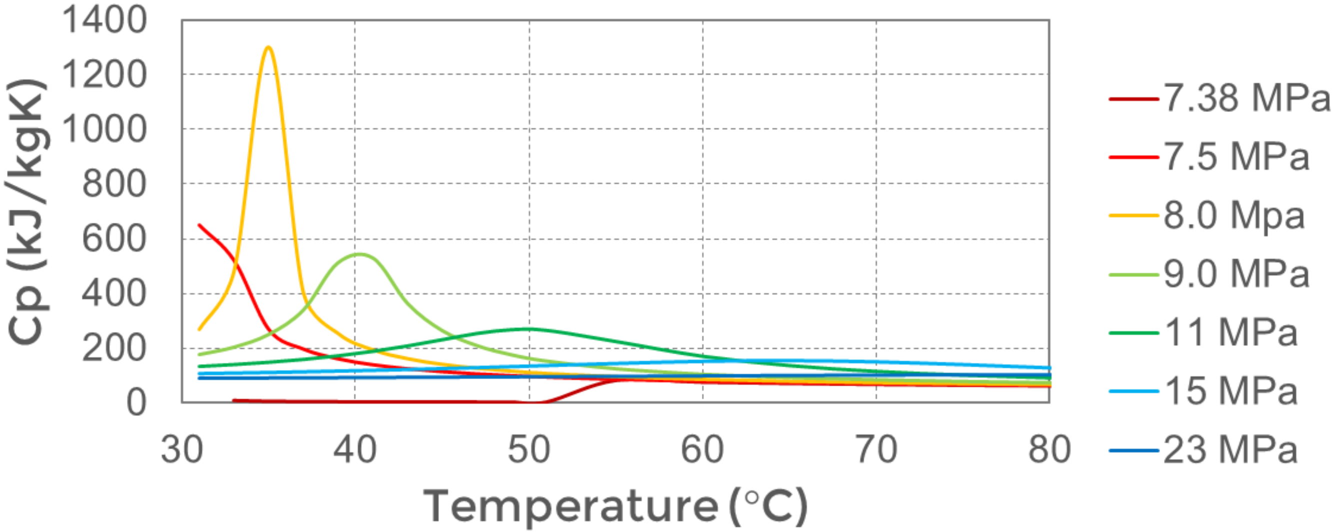
The Properties of s-CO_2

Specific Heat



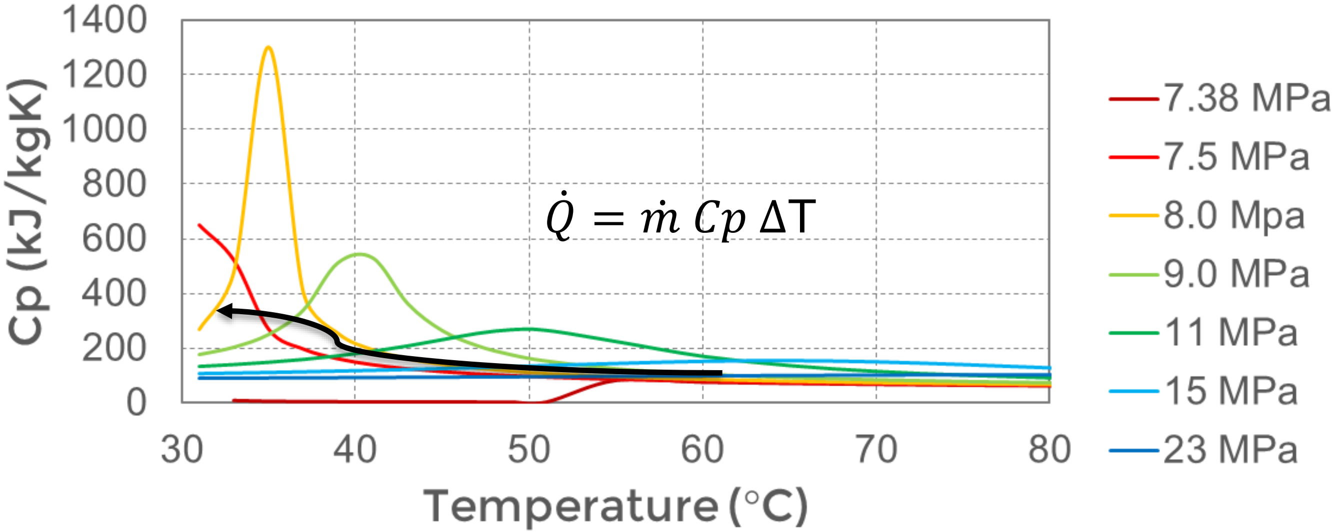
The Properties of s-CO₂

Cooling process



The Properties of s-CO_2

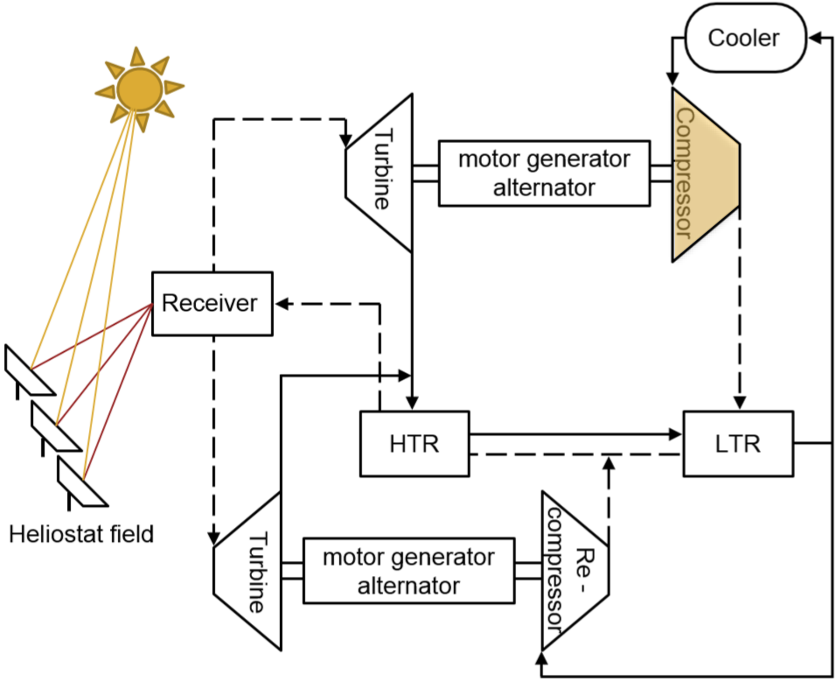
Cooling process



$$\dot{Q} = \dot{m}\, Cp\, \Delta T$$

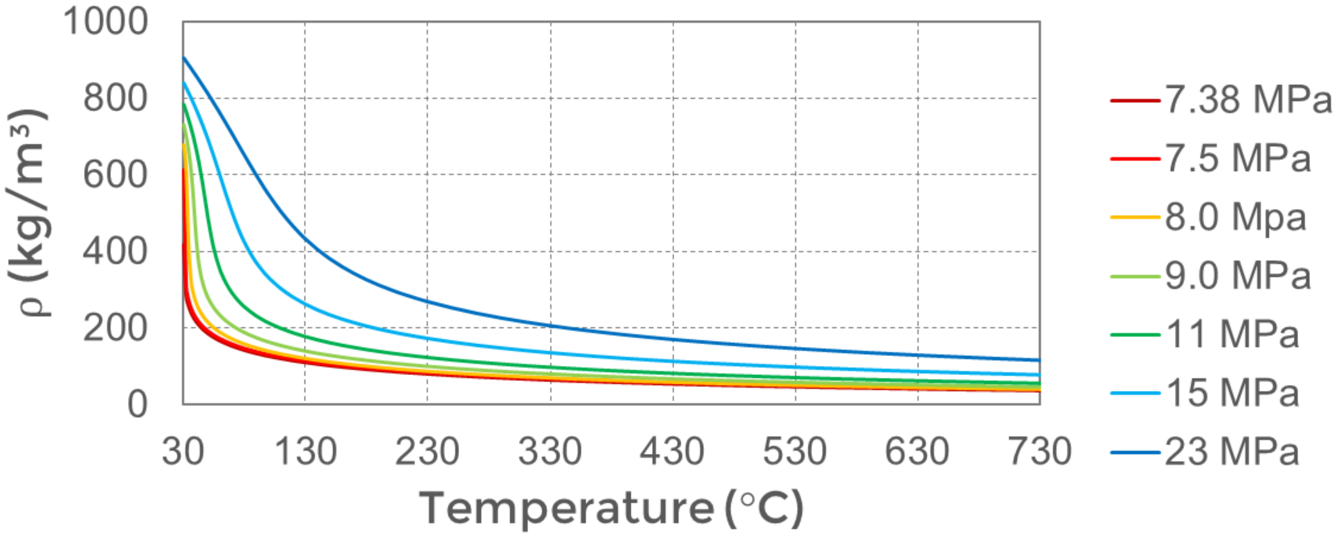
The s-CO_2 Brayton Cycle

Compression



The Properties of s-CO2

Density



The Properties of s-CO_2

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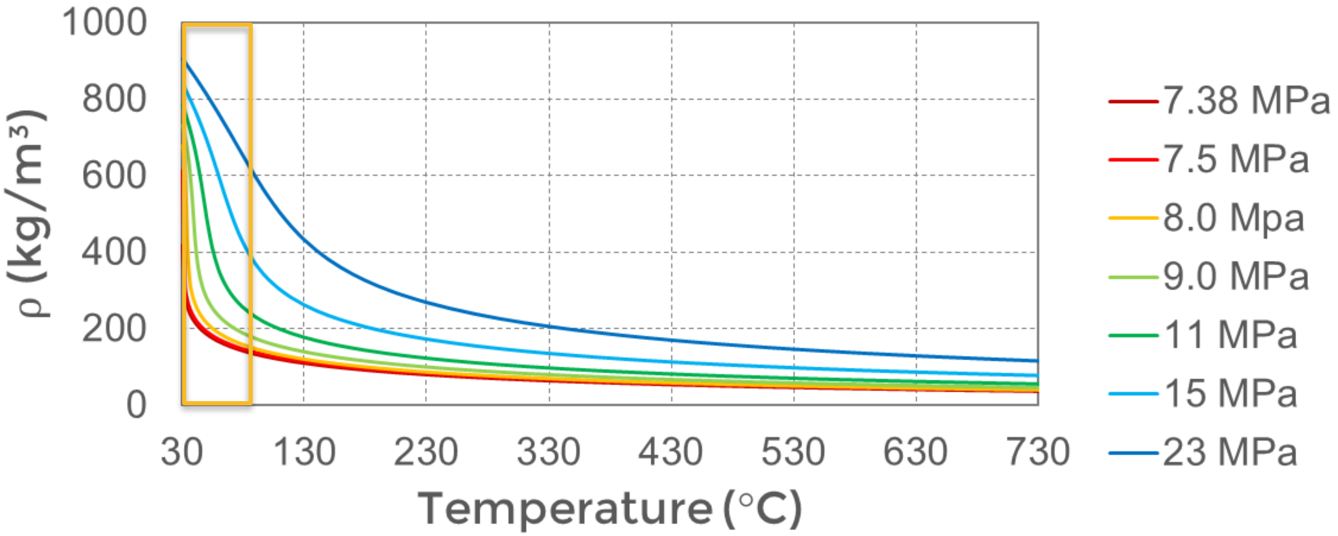
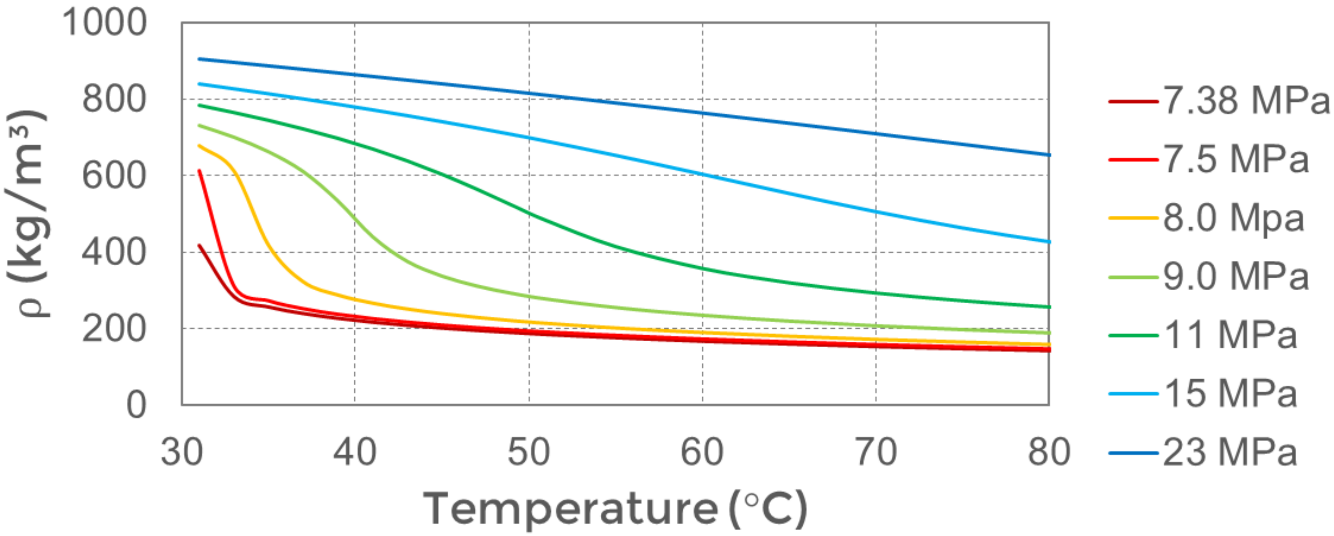


The Properties of s-CO₂

Density



The Properties of s-CO₂

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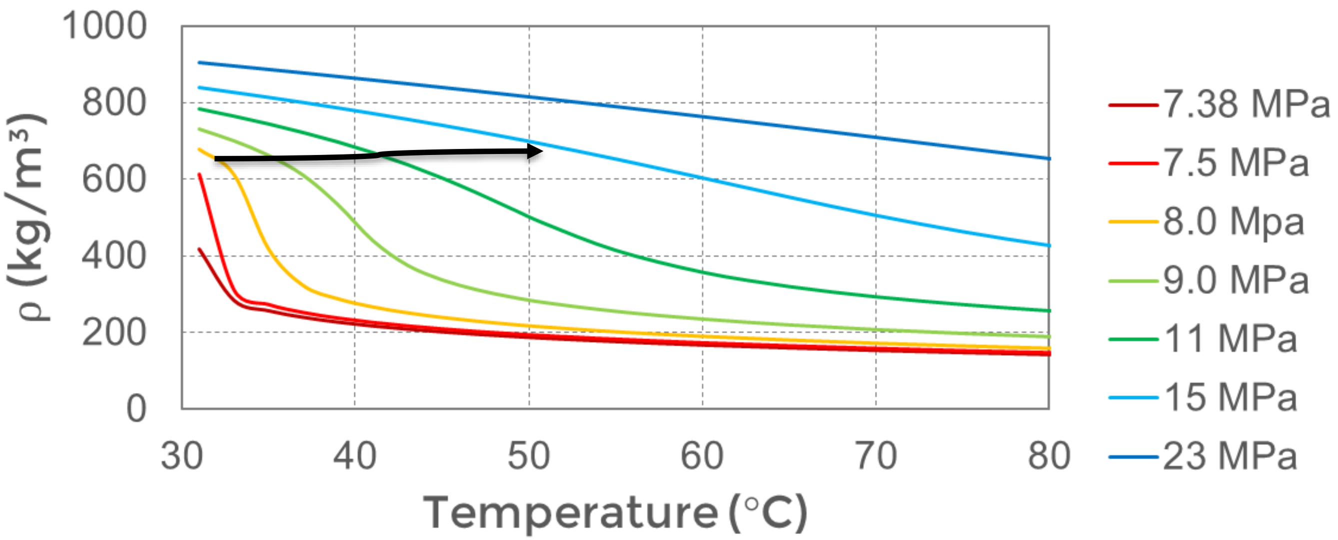
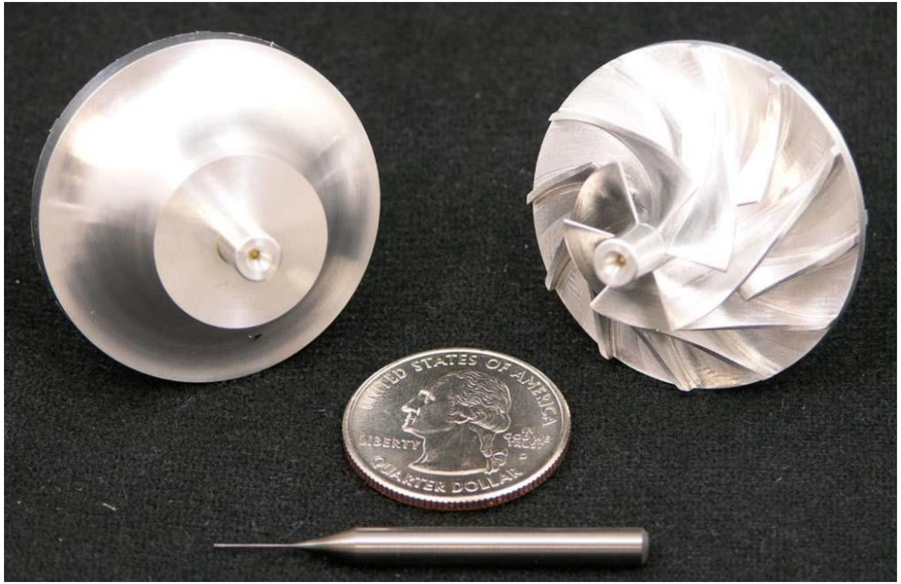


The Properties of s-CO_2

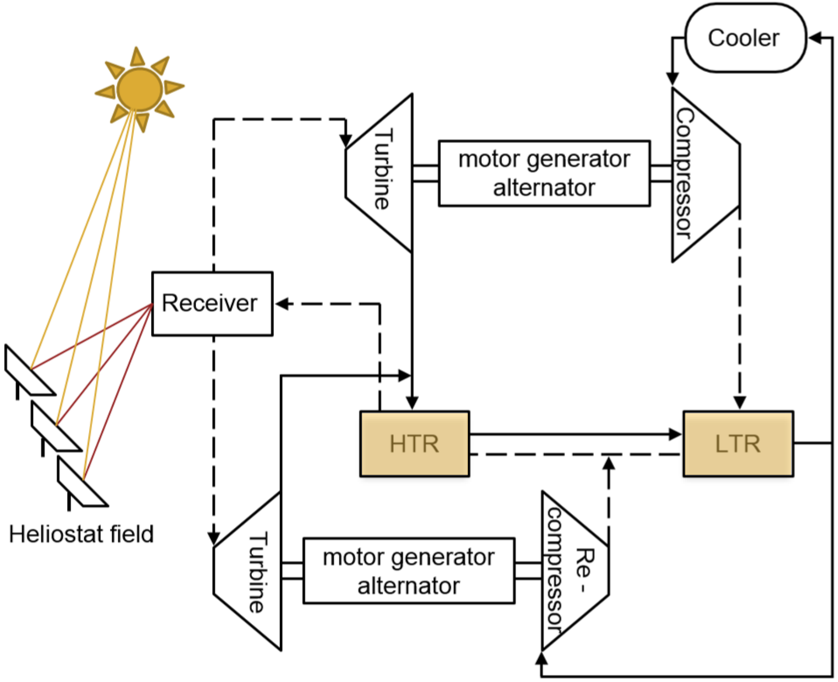
Compact turbomachinery



Wright, 2010, Operation and Analysis of a Supercritical CO2 Brayton Cycle

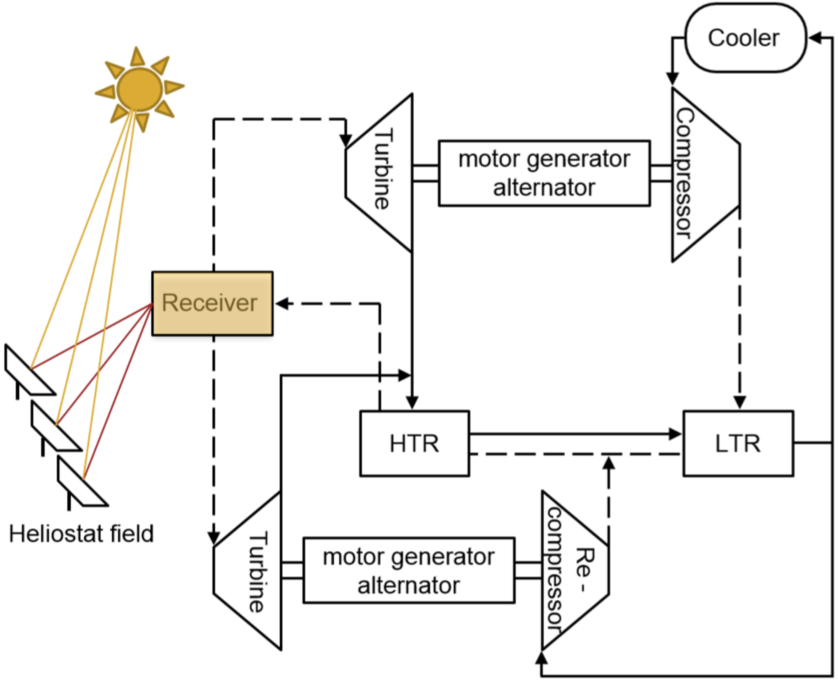
The s-CO$_2$ Brayton Cycle

Recuperation



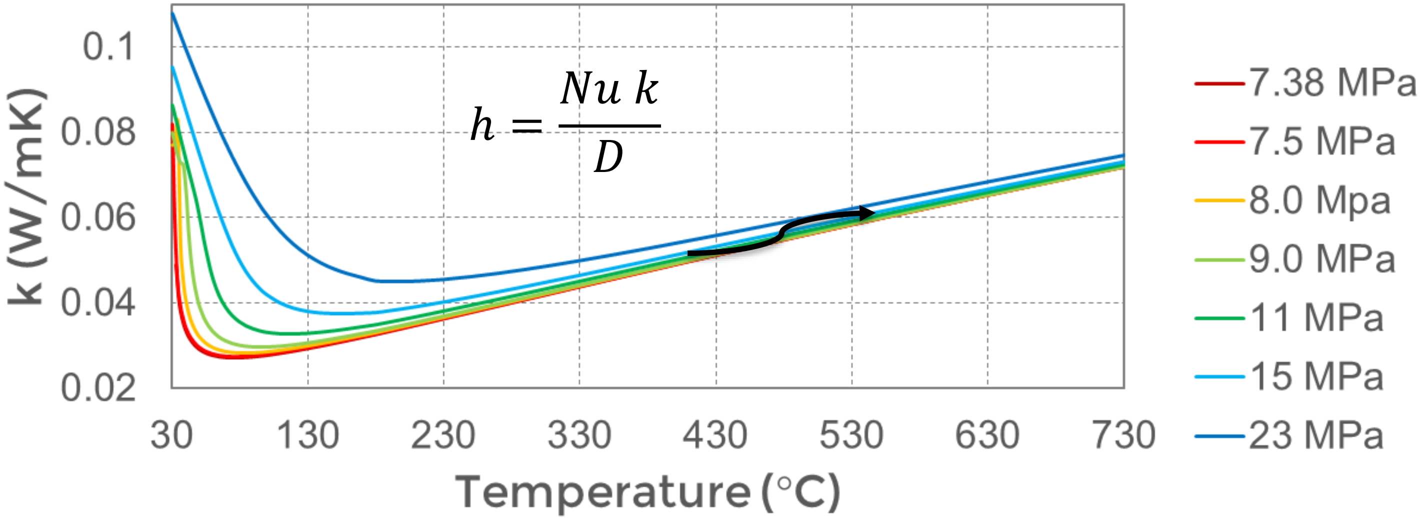
The s-CO_2 Brayton Cycle

Heating



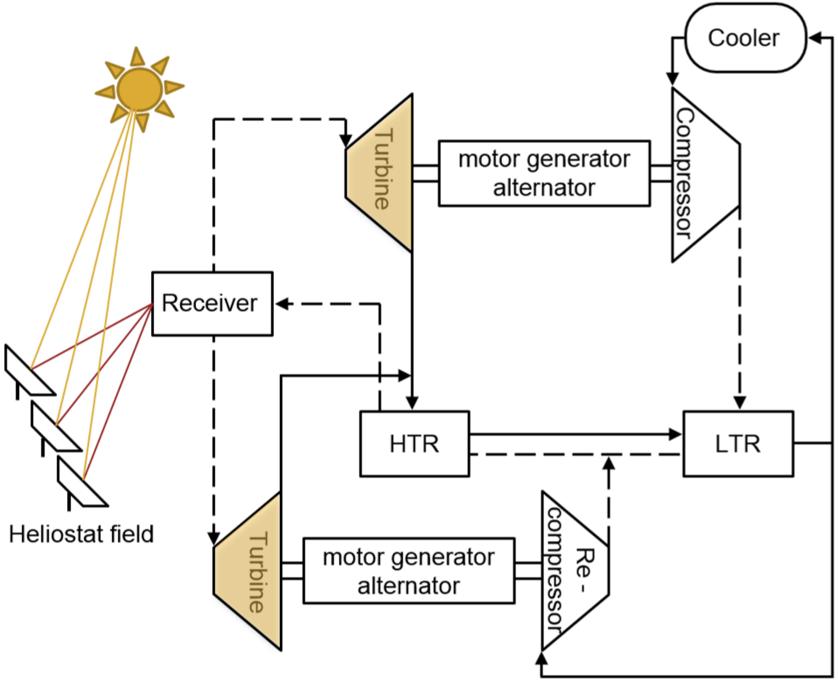
The Properties of s-CO_2

Thermal Conductivity



The s-CO$_2$ Brayton Cycle

Expansion



CSP Plant Requirements

Temperature range

- Parabolic trough systems have concentration ratios of 80 and can reach temperatures of up to 400 °C.
- Central receiver power plants have ratios of up to 600 and can reach temperatures up to 1000 °C (Elsaket, 2007)
- Central receiver plants preferred

s-CO2 BC applicability to CSP

Temperature range

- Non-combustible
- No upper temperature limit
- Non-explosive
- Chemically stable
- Inexpensive
- Abundant

s-CO2 BC applicability to CSP

Pressure range

- Moderate pressure
- With pressures from the critical point of 7.38 MPa to around 20 MPa
- These pressures require sturdier components
- Seals and bearings

Central Receiver Plant Requirements

Dry Cooling

- Dry-cooling reduces water consumption compared to wet cooling
- This is important as recent water shortages have demonstrated the scarcity of this resource in South Africa

s-CO2 BC applicability to CSP

Dry cooling

- Critical point ,31.1 °C, close to ambient temperature
- Must keep the inlet conditions pseudo-critical
- Control system is important
- Dramatic changes in fluid properties near the critical point

s-CO2 BC applicability to CSP

Thermal Energy Storage

- Improved storage capacity
- Lower levelized cost of energy
- Controlled input
- Lower temperatures
- Higher efficiencies than steam

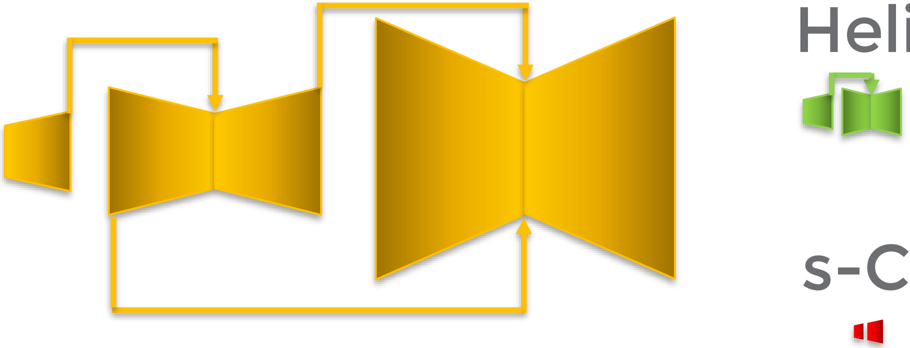
s-CO2 BC applicability to CSP

Direct heated closed loop cycle

- No use of fluids that are toxic, flammable, or have a high global warming potential
- Flexibility due to temperature range
- Stability in operation due to single phase
- Can place entire power cycle in the receiver

The Properties of s-CO_2

Overall size of power conversion system



Helium turbine

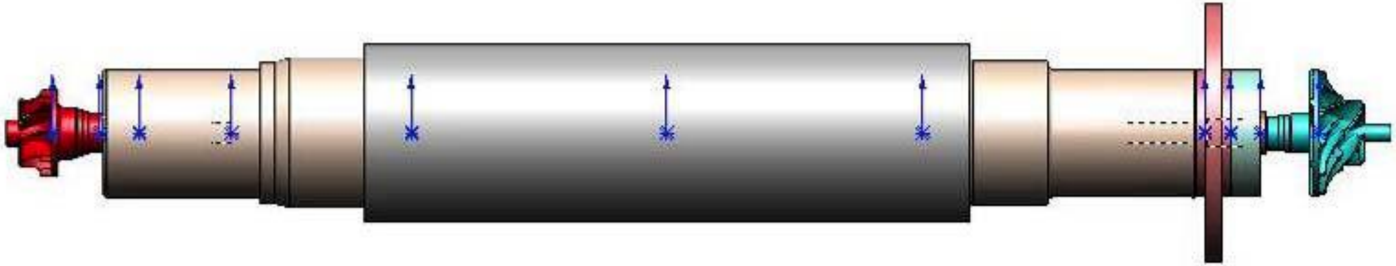
s-CO2 turbine

Steam turbine

Source: Rochau, 2014, Commercializing the sCO2 Recompression Closed Brayton Cycle

Challenges for s-CO2 Brayton cycles

- Large shafts to transmit torque



Wright, 2010, Operation and Analysis of a Supercritical CO2 Brayton Cycle

Challenges for s-CO2 Brayton cycles

- Large shafts to transmit torque
- Large or expensive heat exchangers
- Specialised components such as bearings and seals
- Thermal stresses and fatigue failure
- Non-linearity of properties

Challenges for s-CO2 Brayton cycles

- Large shaft ue
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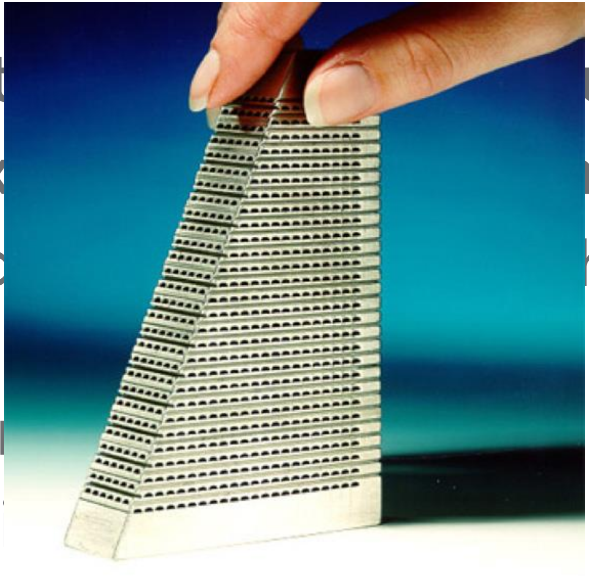
- Thermal st failure
- Non-linear



Flamant, 2013, Design of Compact Heat Exchangers for Transfer Intensification

Challenges for s-CO2 Brayton cycles

- Large shafts to transmit torque
- Large or expensive heat exchangers
- Specialised components such as bearings and seals
- Thermal stresses and fatigue failure
- Non-linearity of properties

Conclusion

- Increased electricity production
- Reduced investment costs
- Off design operation possible
- Better understanding of operation
- Quantifying the improvements
- There is still work to be done

ACKNOWLEDGEMENTS:

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