SUPERCritical CO2 CYCLE

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Outline

- S-CO2 cycles overview
- Aspects of S-CO2 cycles
- Applications of S-CO2 cycles
- R&D needs
Supercritical Cycles - What are they?

- Thermodynamic cycles that take advantage of the changes of properties around the critical point
- 2 major types
  - Supercritical steam cycle - heating above critical pressure increases temperature of heat addition
  - Supercritical CO$_2$ cycle - compression near the critical point reduces compressor work (i.e. reduction of temperature of heat rejection)
Reduction of Compressor Work
Turbine Size

Steam turbine: 55 stages / 250 MW
Mitsubishi Heavy Industries Ltd., Japan (with casing)

Helium turbine: 17 stages / 333 MW (167 MW_e)
X.L. Yan, L.M. Lidsky (MIT) (without casing)

Supercritical CO₂ turbine: 4 stages / 450 MW (300 MW_e)
(without casing)
Comparison of S-CO2 and Helium Cycles

Supercritical CO₂ Compression Cycle

Helium Brayton Cycle

Temperature (°C)

Entropy (kJ/kg·K)
Disadvantage of Supercritical CO$_2$ cycle

- High Recuperation Heat

\[ \frac{Q_{r\text{CO}_2}}{Q_{r\text{He}}} \sim 2-3 \Rightarrow \sim 4 \text{ times bigger recuperators} \]
Pinch-point in Recuperator

![Graph showing temperature and temperature difference for low-pressure and high-pressure CO2 and temperature difference. The graph also marks the pinch-point location.](image)
Re-Compression Cycle
Liquid Metal Cooled SMRs

CEFR
China

4S
Japan

PFBR-500
India

SVBR-100
Russian Federation

PRISM
USA
Waste Heat Recovery
Geothermal

Nuclear Plant

Thermal Input to Rock

Cap Rock

Permeable Rock

Thermal Output From Rock

Fluid Return

Fluid Input

Nejavellir Geothermal power plant; Iceland; 120MW(e), Wikimedia Commons (2010)
Solar - CSP
Storage
An investigation of the supercritical CO2 cycle (Feher cycle) for shipboard application
Author: Combs, Osie V
150 kWe Military Unit
Hydrogen Production

- Nuclear Energy Options for Hydrogen Production
- B. Yildiz, M. S. Kazimi

- Materials at lower temperatures
  - Compatible to CO₂ cooled reactor and the CO₂ power cycle operating temperature
  - Lower cost
  - Eliminate very high temperature related limitations

Dostal et al., 2002
Space
Mars Surface Power System

- Sufficient power for all surface applications (i.e. ISRU, habitat etc.) Satisfy NASA DRM.
  \[ \sim 200 \ kW_e \]

- Develop long lasting Mars surface infrastructure
  - Lifetime of 25 EFPY
Economy

- Competitors
- Proven vs. new technology
- Mass production
- Uncertainty of power prices on the market
  - Opportunity or hurdle?
- Proper selection of markets and applications
Commercialization Path

- New trends in power engineering
  - Decentralization, small units
- Power electronics/power conditioning
- Small units as demos for large units
- Turbomachinery type
  - Radial vs. Axial
- Compressor development
- Devil in details
Further Considerations

- Maturity of technology
- Heat exchangers
- Compressors and turbines
- Cycle control
- Bearings
- Lubricants
- Seals
- Valves
  - freezing
Conclusion

- S-CO2 cycles are recently considered for many applications.
- Many companies are considering its application.
  - Question is in what application they can be successfully applied.
- The cycle technology and components require substantial development.
- For this development experimental loops are crucial.
- S-CO2 loop in CVR is by its design and possibilities well suited for testing components, but also for experiments in the field of thermodynamics and heat transfer.
- Projects like HeRo are very important for the cycle deployment.
The COOL Application