ELECTRIC POWER RESEARCH INSTITUTE

Supercritical CO_2 Brayton Power Cycles

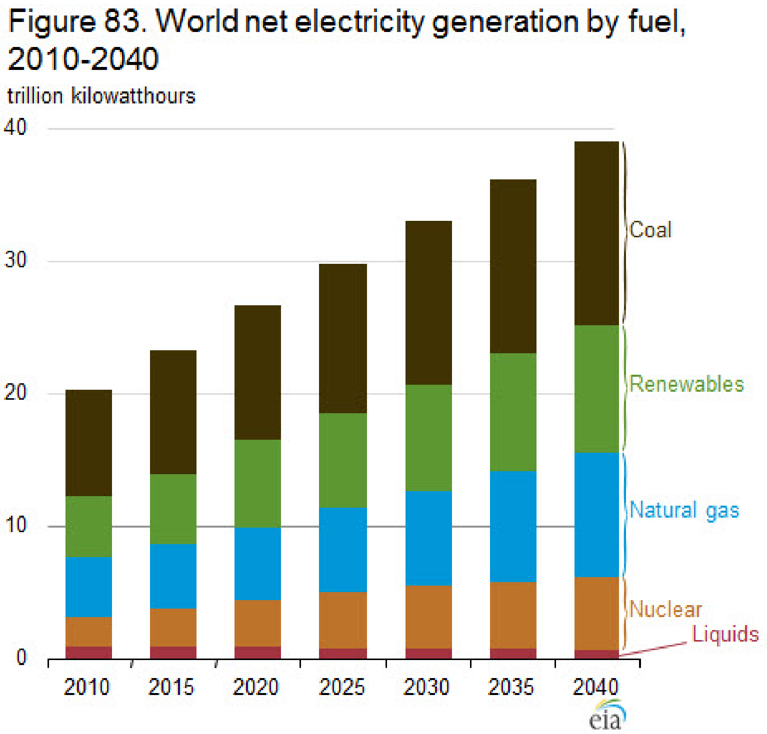
Potential & Challenges

Dr. Jeffrey N. Phillips
Senior Program Manager

5th International Supercritical CO_2 Power Cycles Symposium
March 30, 2016

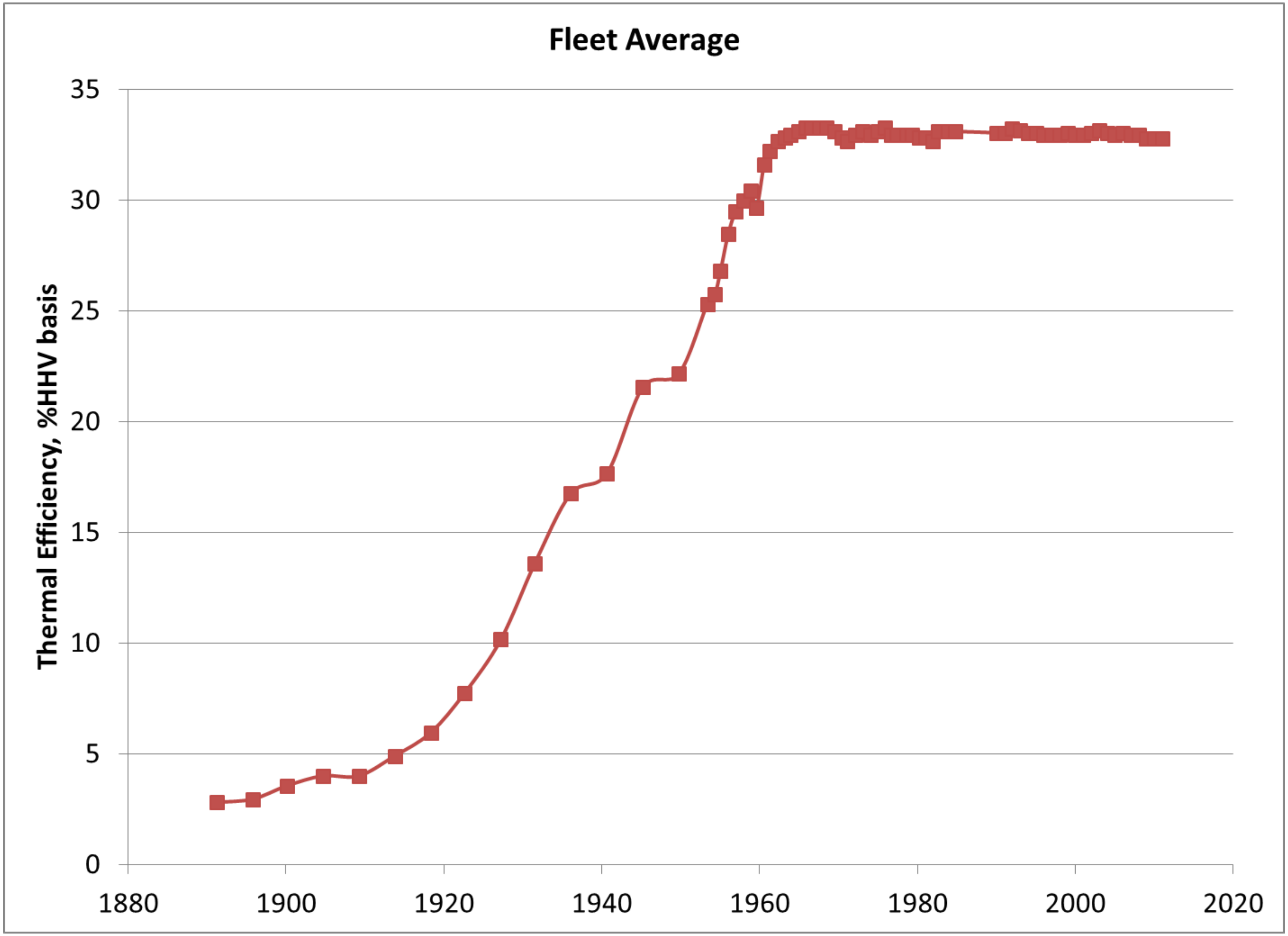
Foundational Assumptions

- The CO_2/climate change issue is not going away
- Fossil fuels are not going away
- More power from renewable energy is coming



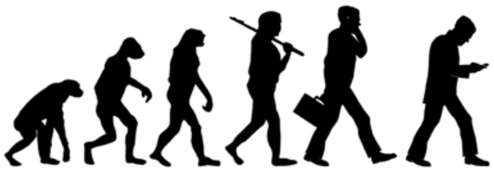
- Lower CO_2 emissions from fossil fuel-based power => higher efficiency fossil fuel power plants
- Lower cost power from renewable energy sources
- Lower cost power from nuclear energy
- Increased operating flexibility from all power plants

U.S. Coal Power Plant Thermal Efficiency Over Time



ELECTRIC POWER RESEARCH INSTITUTE

Evolutionary versus Revolutionary Improvements



Evolutionary Path

- Make the technologies we already know better
- Incremental improvements
- Faster to market
- Lower risk of failure

Revolutionary Path

- Fundamentally change the way we make power
- Bigger potential for improvement
- Takes longer to bring to commercial reality
- Bigger risk of failure

Fossil Power: Two Approaches to Lower CO_2 Emissions

Evolutionary

- Steam-Rankine cycles
  - Higher efficiencies via hotter steam temperatures (advanced ultra-supercritical steam conditions)
  - Improved post-combustion CO_2 capture processes
- Air-Brayton cycles
  - Higher efficiencies via hotter gas turbine inlet temperatures
  - Improved pre- or post-combustion CO_2 capture

Revolutionary

- Closed Brayton cycles using supercritical CO_2 (sCO_2) as the working fluid
- Oxy-combustion with steam-Rankine or open sCO_2 Brayton power cycles
  - Includes chemical looping
- Fuel cells
  - Using natural gas or coal-derived syngas
- Other novel cycles
- Bulk energy storage
  - Allows best fossil plants to operate at optimum efficiency while others are retired

sCO_2 Brayton Power Cycles Appear to Offer Efficiency Advantages

But….

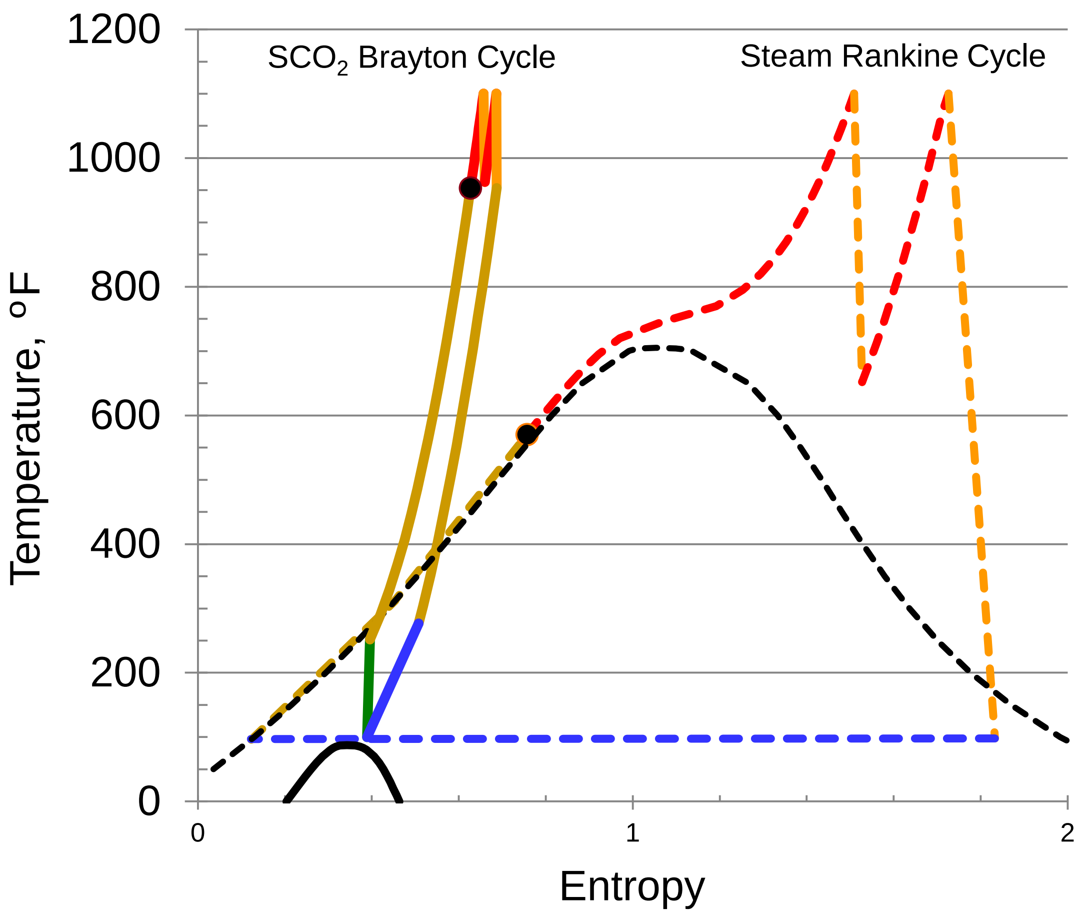
Power Cycle Comparison (Typical)

	Steam-Rankine	Open Air Brayton	Closed sCO_2 Brayton
Working Fluid	Steam/water	Air	CO_2
Compressor/Pump Inlet Pressure	0.01 MPa (1 psia)	0.1 MPa (14.5 psia)	7.5 MPa (1087 psia)
Turbine Inlet Pressure	30 MPa (4350 psia)	2 MPa (290 psia)	32 MPa (4640 psia)
Turbine Pressure Ratio	3000	35	4.3
Turbine Inlet Temperature	600°C (1112°F)	1350°C (2462°F)	600°C (1112°F)
Turbine Outlet Temperature	38°C (100°F)	530°C (986°F)	500°C (932°F)

sCO_2 Brayton-Rankine Cycle Comparison

sCO_2 Brayton Power Cycle Features:

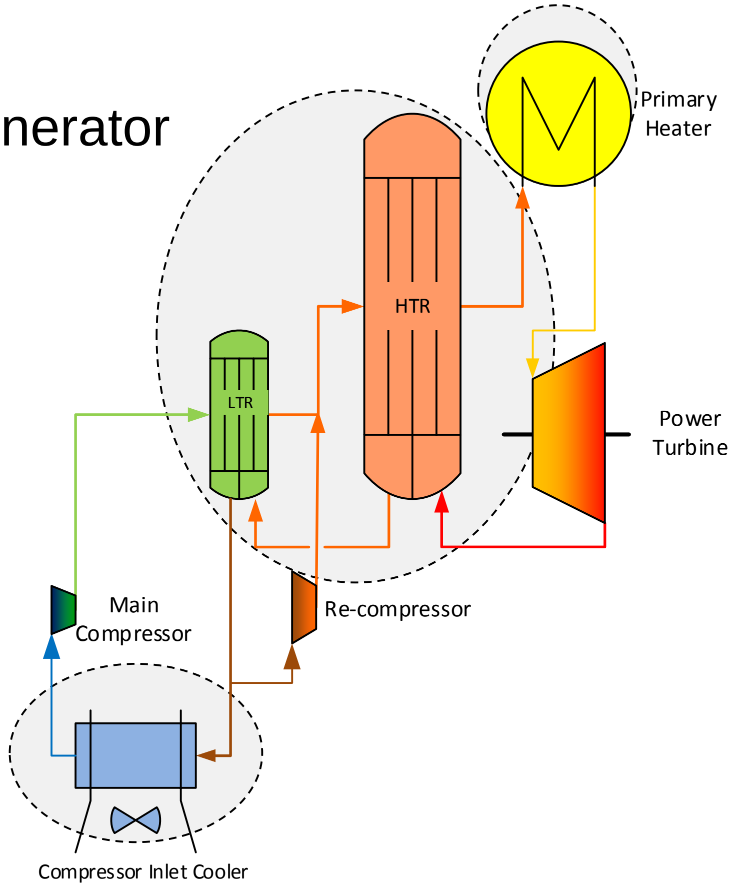
- Primary heaters add heat at higher average temperature
  - Good for efficiency, challenging for heater design
- Power per unit mass flow is low
  - CO_2 mass flow is ~5x steam mass flow
- Heat rejection at comparatively high temperatures
  - Would facilitate use of air-cooled condensers



ELECTRIC POWER RESEARCH INSTITUTE

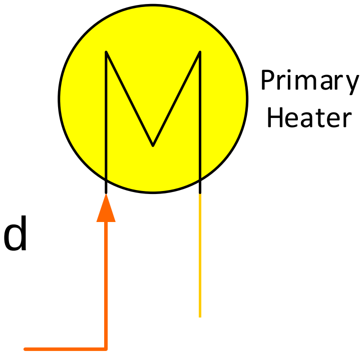
sCO_2 Brayton Cycle Heat Exchanger Classes

- Primary Heater
  - Analogous to Rankine cycle steam generator
- Low-Temperature and High-Temperature Recuperators
  - Analogous to Rankine cycle feedwater heaters
- Compressor Inlet Cooler
  - Analogous to Rankine cycle condenser

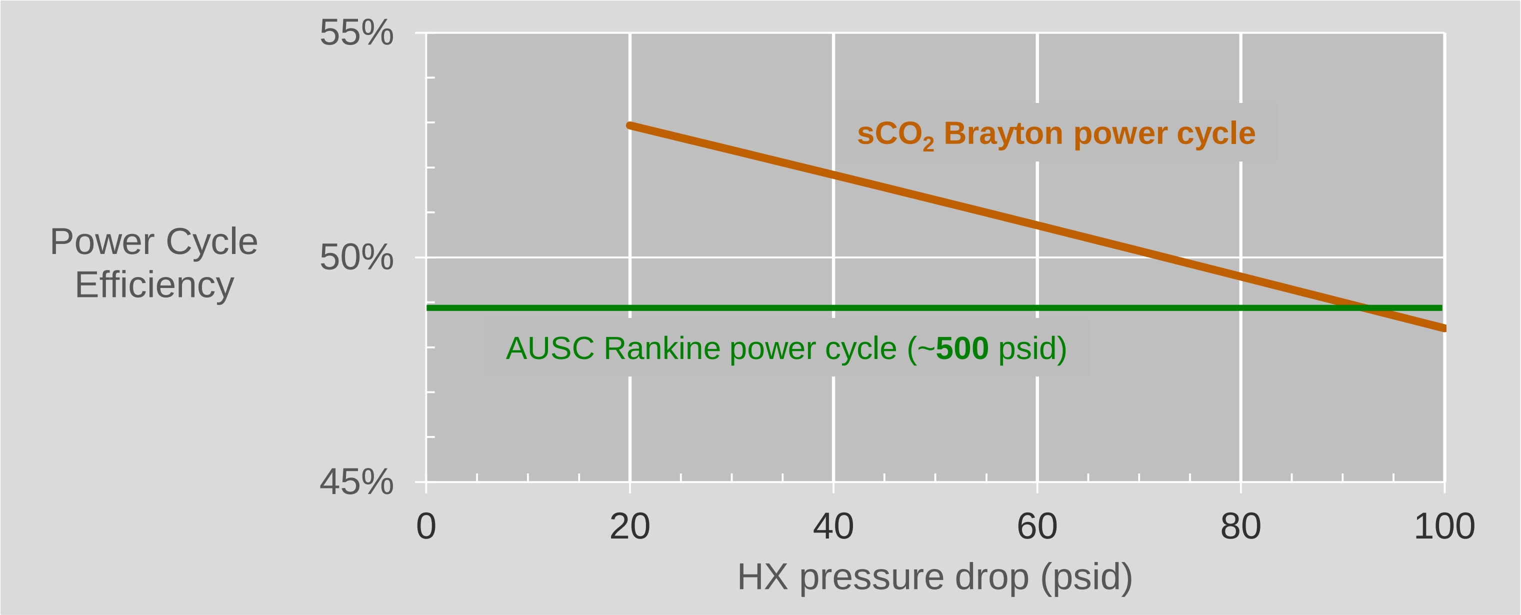


Similar components for cascading and direct-fired Brayton power cycle configurations

Primary Heat Exchangers



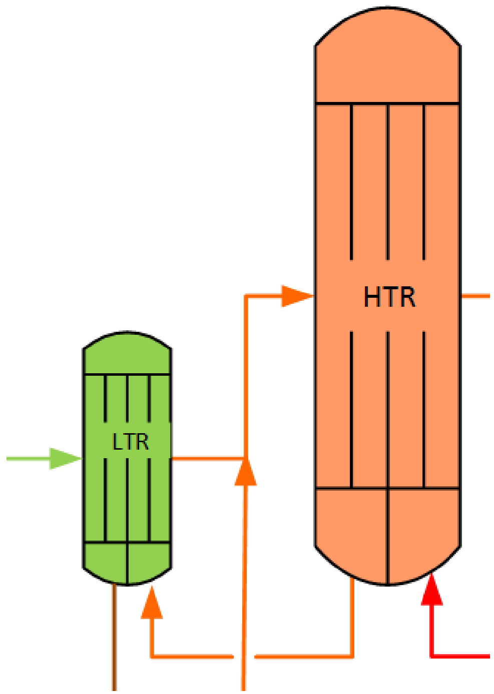
- Due to higher mass flow and greater power consumption for fluid pressurization, sCO_2 Brayton power cycles must minimize pressure drop within the heat exchangers

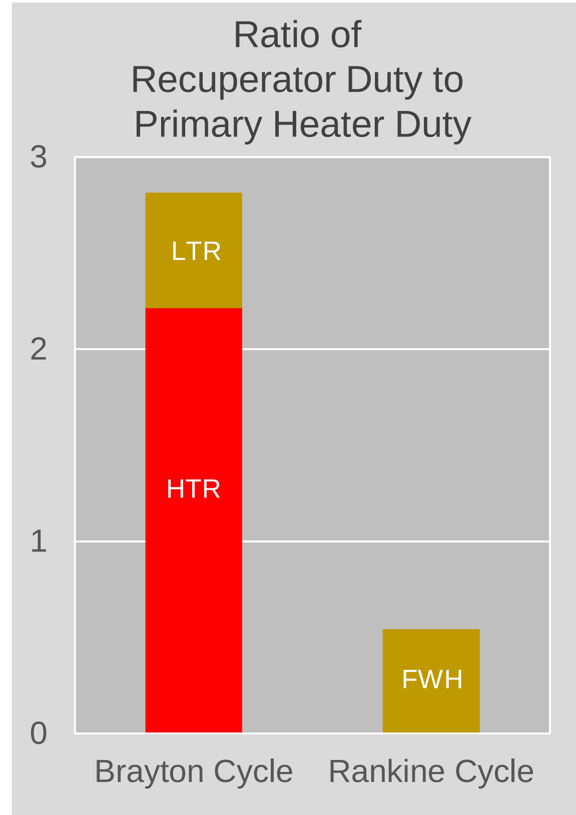


Challenge is to achieve uniform flow/heat absorption for much higher flows and lower allowed pressure drops than steam generators

ELECTRIC POWER RESEARCH INSTITUTE

Recuperators



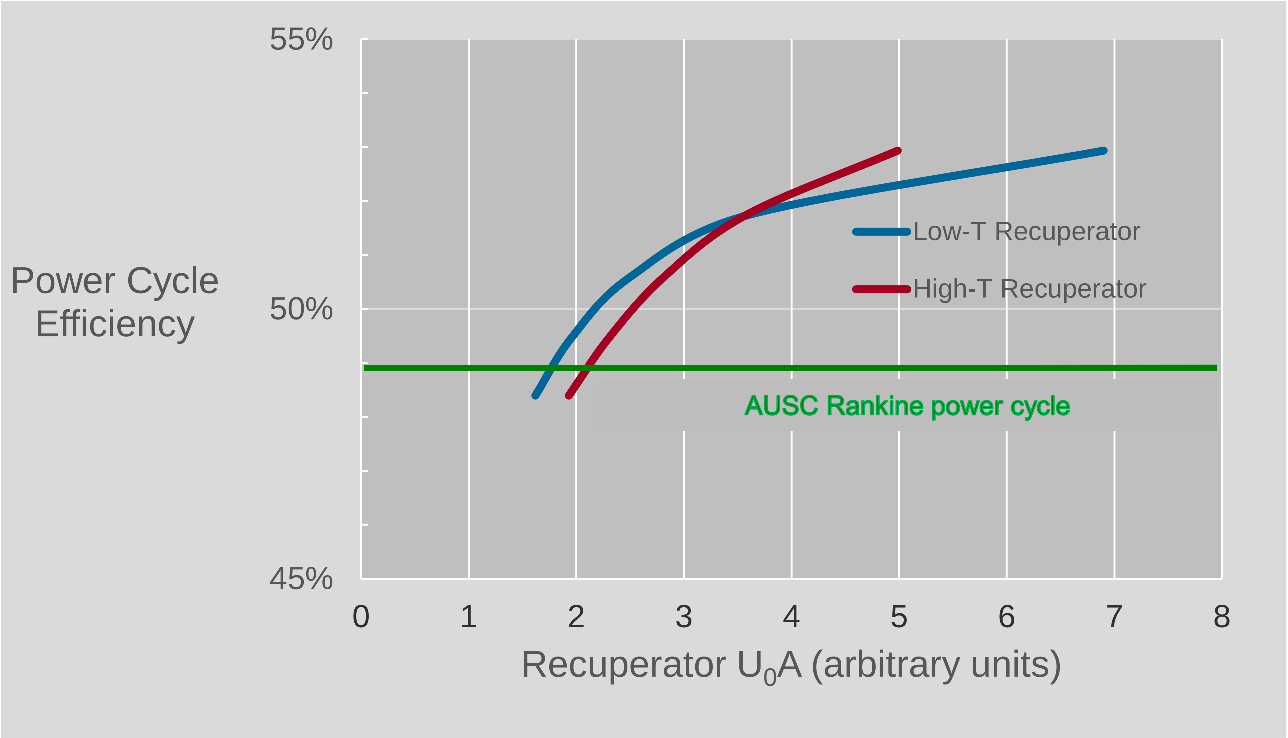


High heat duty makes for large area heat exchangers

Area = $, £, ¥, €

High temperature requires more exotic materials = $, £, ¥, €

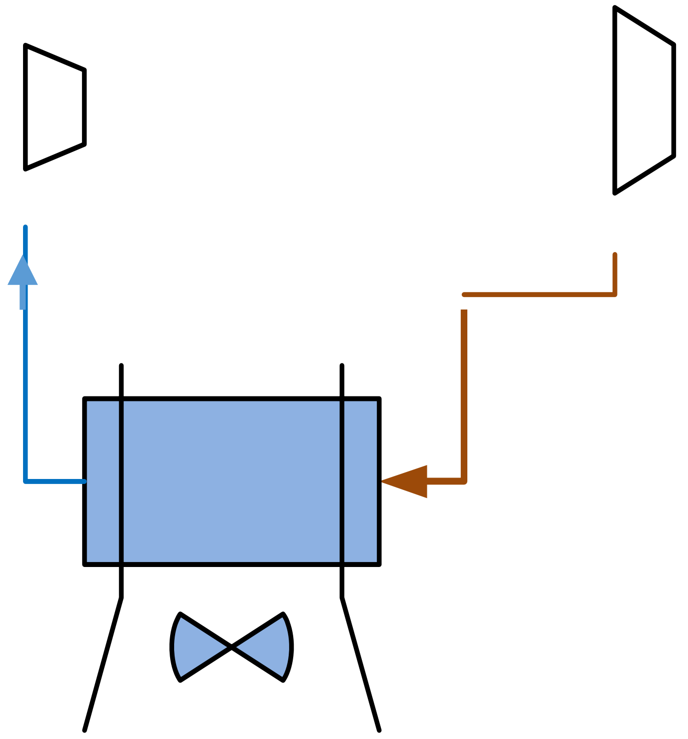
Recuperators (cont.)



- High cycle efficiency requires high U_0A
  - Some (limited) opportunities to increase heat transfer coefficient (U_0)
  - Compact heat exchangers reduce weight/U_0A (reducing materials cost) but are generally associated with higher manufacturing costs

Compressor Inlet Cooler

- Similar in design to compressor inter-coolers
  - Coolant is outside of the tubes compared with coolant flowing within the tubes in Rankine cycle condensers
- Direct-fired cycles include condensation/water removal
  - Materials challenge due to potential for acidic condensate due to H_2CO_3, etc.



Compressor Inlet Cooler

Flexible Operations

- Will sCO_2 Brayton power cycles be able to operate in tomorrow's power market?
  - Respond quickly to changes in demand?
  - Wide turndown capability?
  - Good heat rate at lower loads?
- It is probably too early to answer these questions definitively
- Important that upcoming sCO_2 Brayton power pilot plants help answer these questions

In Conclusion

- Power industry is seeking higher efficiency power cycles: sCO_2 Brayton power cycles show promise to deliver on this goal
- Recuperators will be the primary cost adder compared to steam-Rankine power plants
  - Also the key to delivering higher efficiency
  - Least-cost approach to recuperation is yet to be demonstrated
- Primary heater designs confront hydraulic/heat transfer challenges not present in steam generators
- Need to also gain insight into flexible operating capabilities of sCO_2 Brayton power cycles
- Many opportunities for clever engineers and scientists!

Together…Shaping the Future of Electricity