



SAGE GEOSYSTEMS

Feasibility of Interstage Cooling for a Geothermal sCO₂ Power Plant

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SAGE GEOSYSTEMS

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MECHANICAL ENGINEERING

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Outline

Background & Motivation

- Who is Sage?
- Why sCO₂ for Geothermal?
- Advantages of Interstage cooling

Cycle Modeling

- Model
- Model Assumptions

Results

Future Work and Conclusions



APPLIED

Background & Motivation



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MECHANICAL ENGINEERING

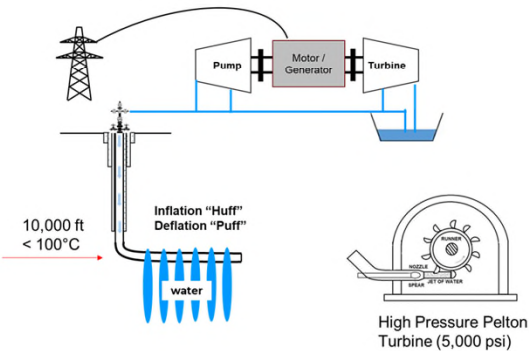
swri.org

Sage Geosystems aims to leverage geothermal to provide clean power around the world

2021-2025

Energy Storage

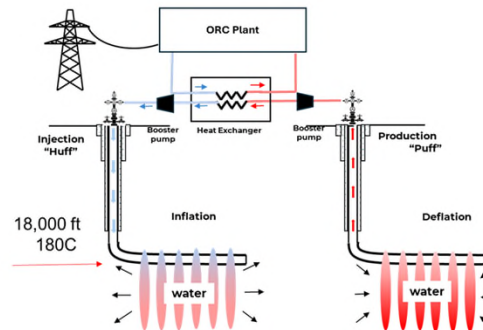
- 2MW-4MW per well
- 65-70% round-trip efficiency (RTE)
- Duration discharge of 8-24 hours



2022-2027

Power Generation (Pressure Geothermal)

- 3-5 MW net output per 2-well pair

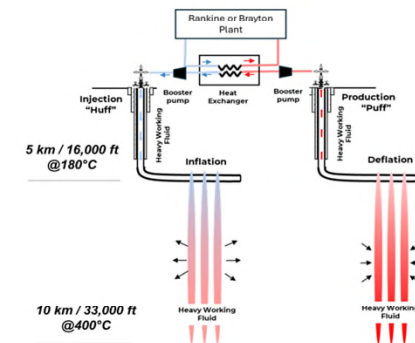


200°C LCOE: \$65-\$75/MWh

2026-2030

Drill Shallow, Frac Deep (Superhot Geothermal)

- 25-35 MW net output



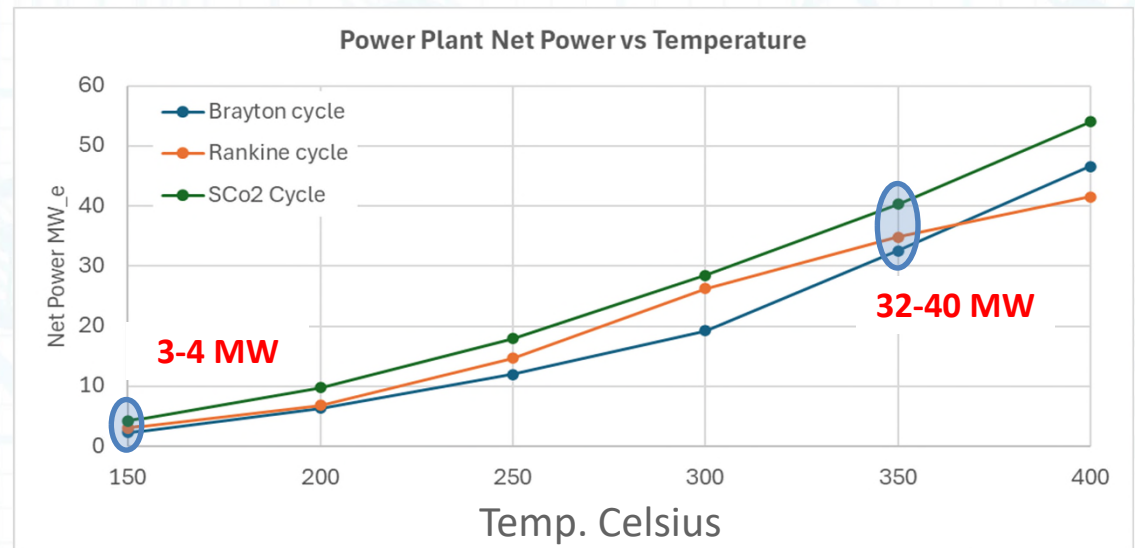
350°C LCOE: \$35-\$45/MWh

Significant advantages to sCO₂ as temperature increases

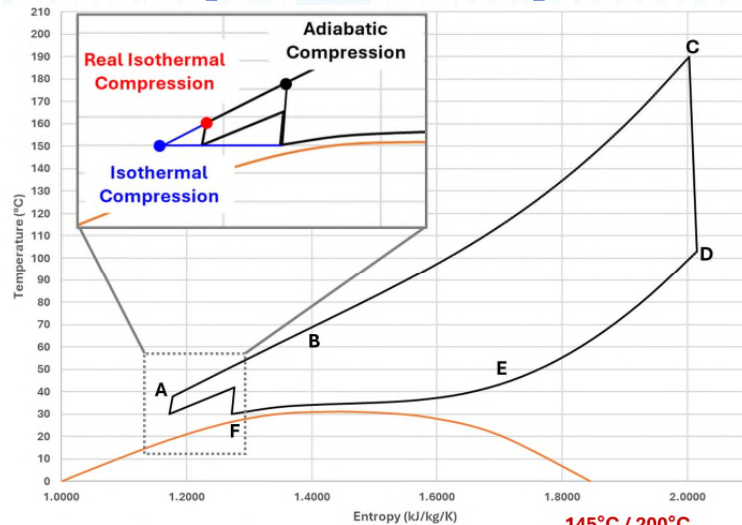
Physics tells us: 10X increase in power generation potential per well from 150°C to 350°C (at constant flow rate), assuming standard binary cycle power plants

Relationship between temperature and net power is not linear

- 2.5X in temperature results in 10X increase in net power across multiple thermodynamic cycles
- Net output is one of the most significant factors in geothermal economics (LCOE)



Interstage Cooling allows for a significant reduction in compression power



The Challenge:

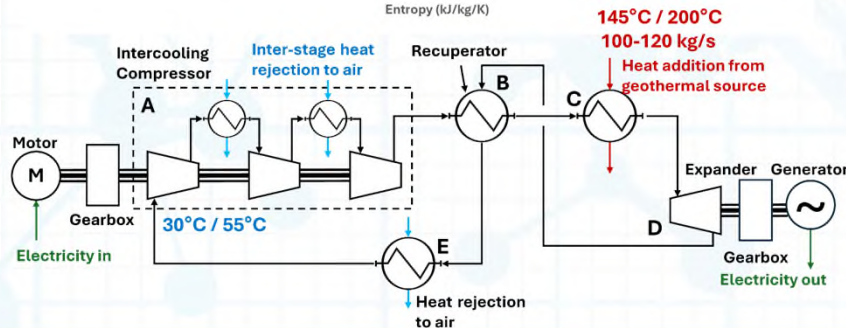
- Compressions consumes significant power in sCO₂ cycles
- CO₂ temperature rises during compression
- Increased work required as temperature increases

The Solution: Interstage Cooling:

- Maintain constant temperature during compression
- Cool CO₂ between compression stages (30-55°)

Performance Benefits:

- 1 intercooling stage: ~5% net power increase
- 2 intercooling stage: ~9% net power increase
- Minimal capital cost increase

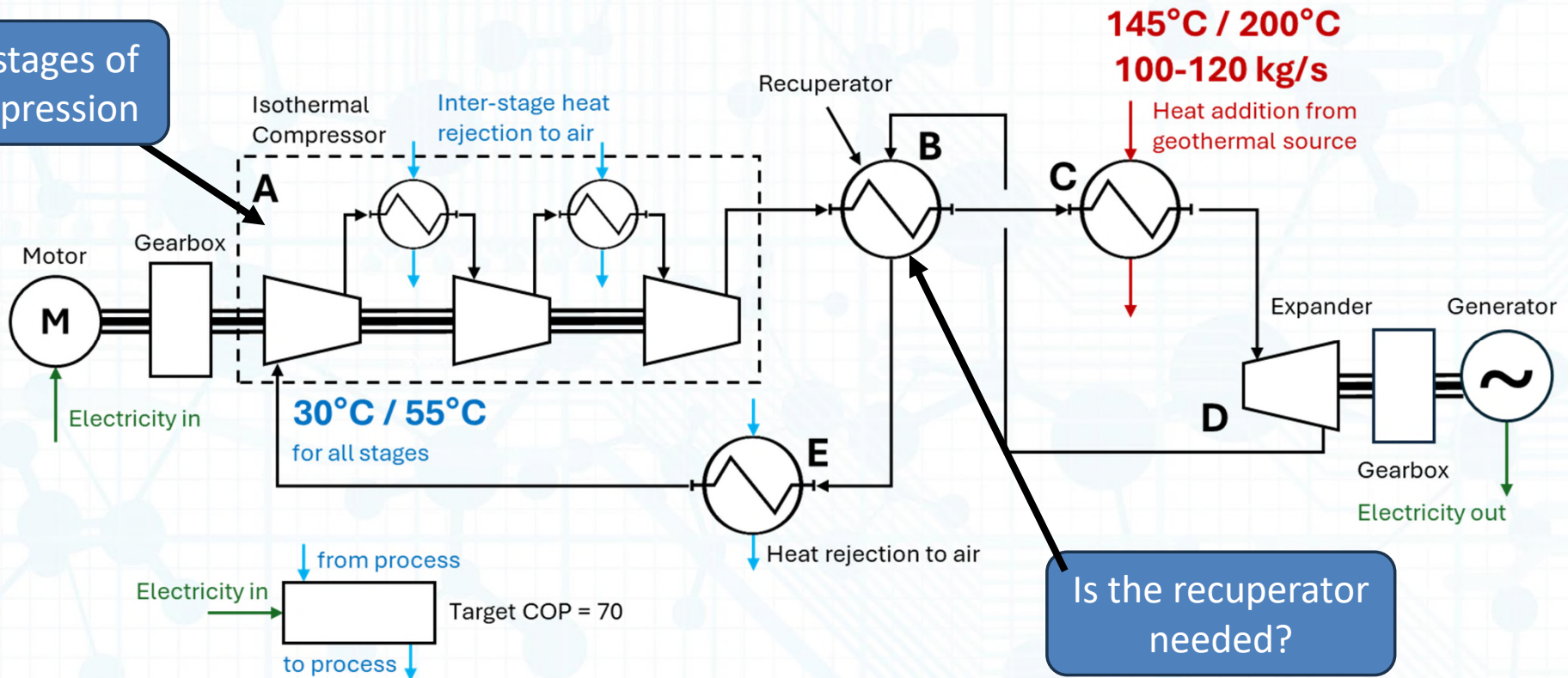


Cycle Model



SwRI and Sage built a cycle model to answer several questions

1-3 stages of compression

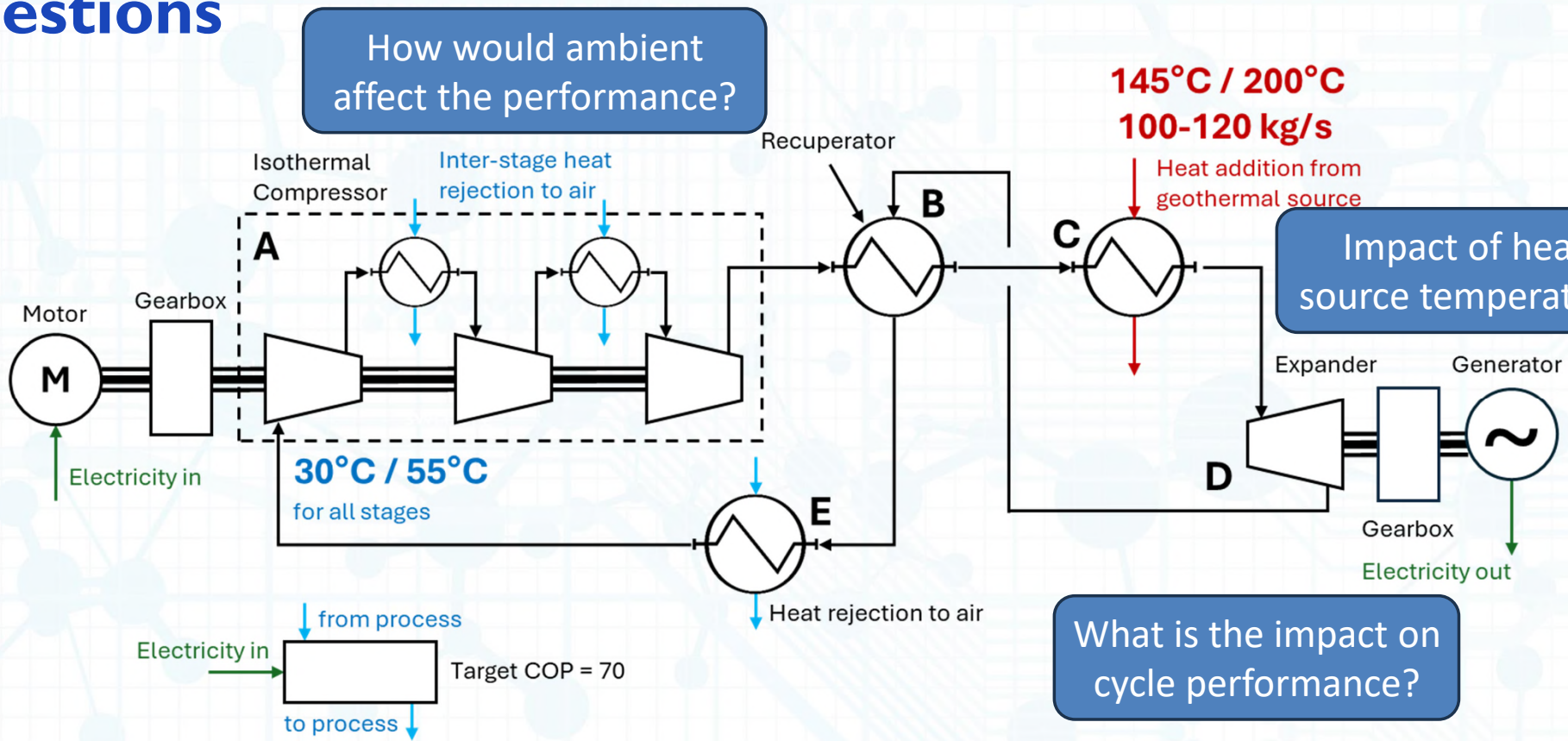


SwRI and Sage built a cycle model to answer several questions

How would ambient affect the performance?

Impact of heat source temperature

What is the impact on cycle performance?



Key Model Assumptions

Key Assumptions

- Motor efficiency – 95%
- Generator efficiency – 95%
- Gearbox efficiency – 98%
- Turbine (isentropic) efficiency – 92%
- Compressor (isentropic) efficiency per stage – 84%
- Primary heat exchanger pinch point – 10°C
- Recuperator pinch point – 5°C
- Process cooling heat exchanger pinch point – 5°C

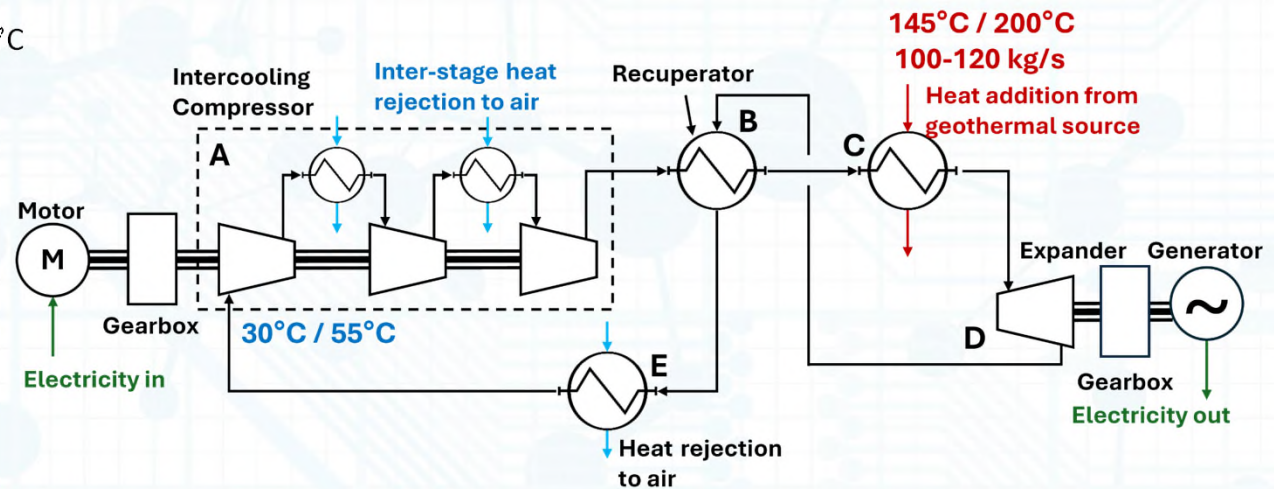
Loop Set Points

- Brine Inlet Temperature: 200 °C
- Brine Flow Rate: 100 kg/sec
- Compressor Inlet Pressure: 80 bar
- Compressor Inlet Temperature: 30 °C

Cycle Performance Sweep

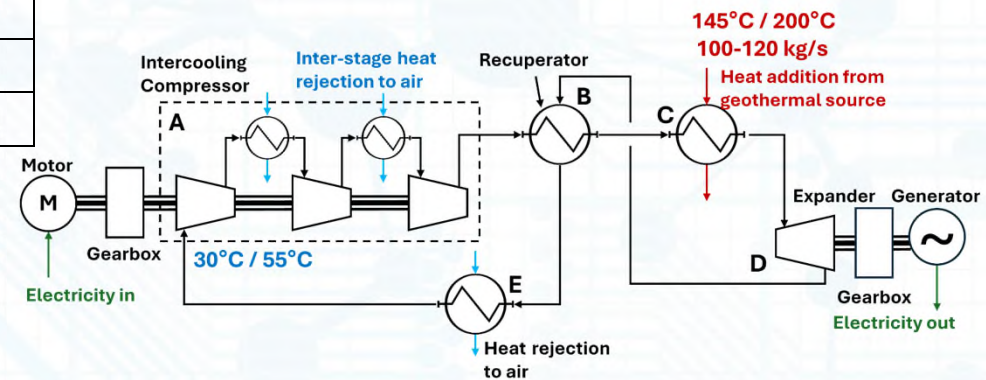
- CO2 Flow Rate: 100 – 250 kg/sec
- Turbine Inlet Pressure: 150 – 280 bar

Vary number of stages: 1, 2, 3



Key Cost Assumptions

Component	Unit	Equation	Weiland Component
Compressor	MWsh	$C = 1,230,000 \cdot p^{0.3992}$	Radial IG Compressor
Turbine	MWsh	$C = 406,200 \cdot p^{0.8}$	Radial Turbine
Primary Heater	MWth	$C = 632,900 \cdot Q^{0.60}$	Recuperator
Recuperator	W/K	$C = 49.45 \cdot UA^{0.7544}$	Recuperator
Process Cooler	W/K	$C = 32.88 \cdot UA^{0.75}$	Direct Air Cooler
Intercooler	W/K	$C = 32.88 \cdot UA^{0.75}$	Direct Air Cooler
Generator	MWe	$C = 108,900 \cdot p^{0.5463}$	Generator
Motor	MWe	$C = 399,400 \cdot p^{0.6062}$	Motor
Gearbox	MWsh	$C = 177,200 \cdot p^{0.2434}$	Gearbox

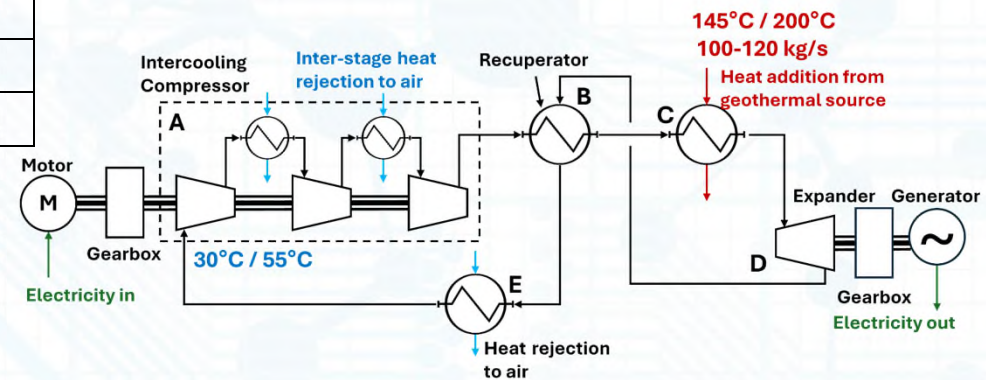


Results & Discussion



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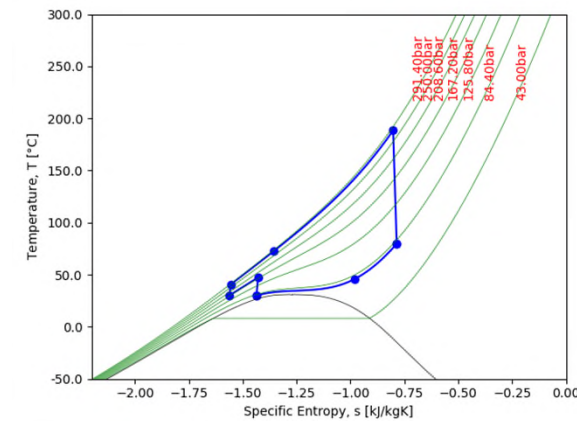
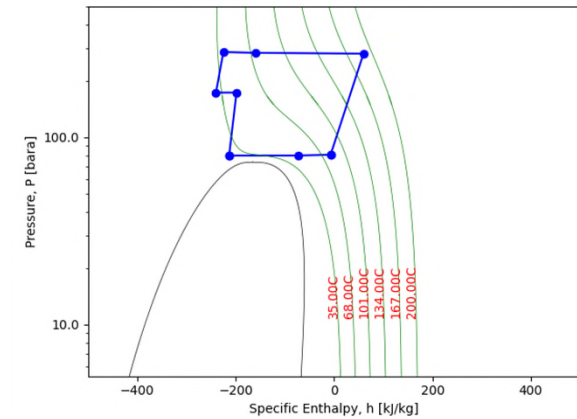


4 Different Cases were studied for different configurations

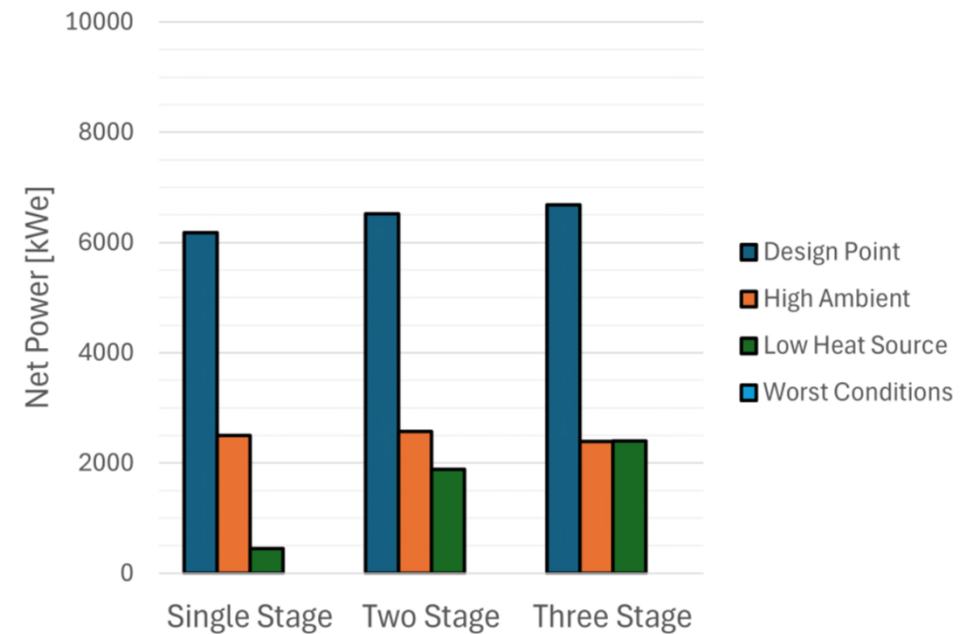
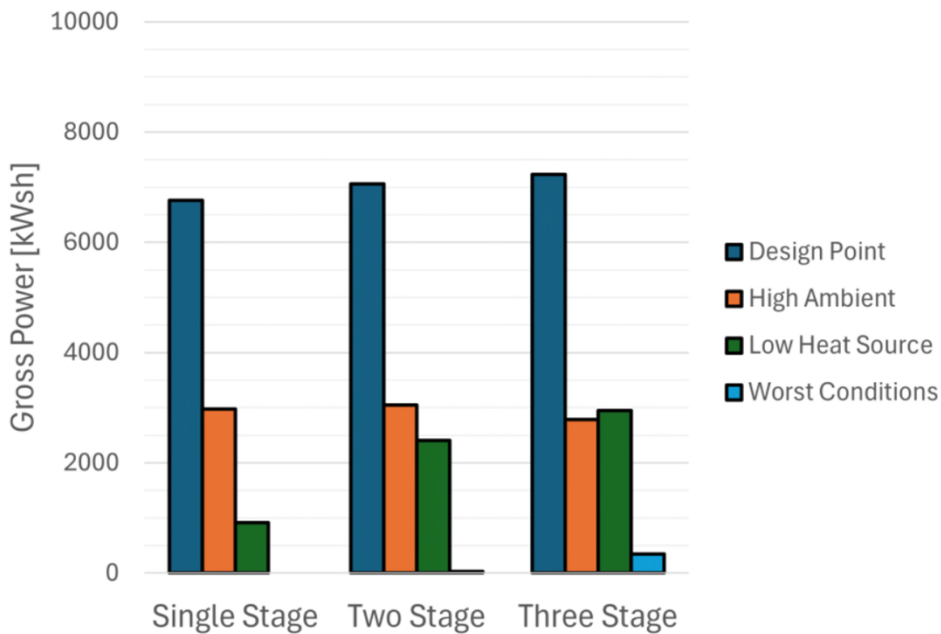
Wellhead/Ambient Conditions

Case Number	Case	Ambient Temperature	Source Temperature
1	Design Point	25°C	200°C
2	High Ambient Temperatures	50°C	200°C
3	Low Heat Source Temperature	25°C	145°C
4	Worst Conditions	50°C	145°C

- With and without a recuperator
- Heat rejection performance
- Maximizing power vs minimizing costs

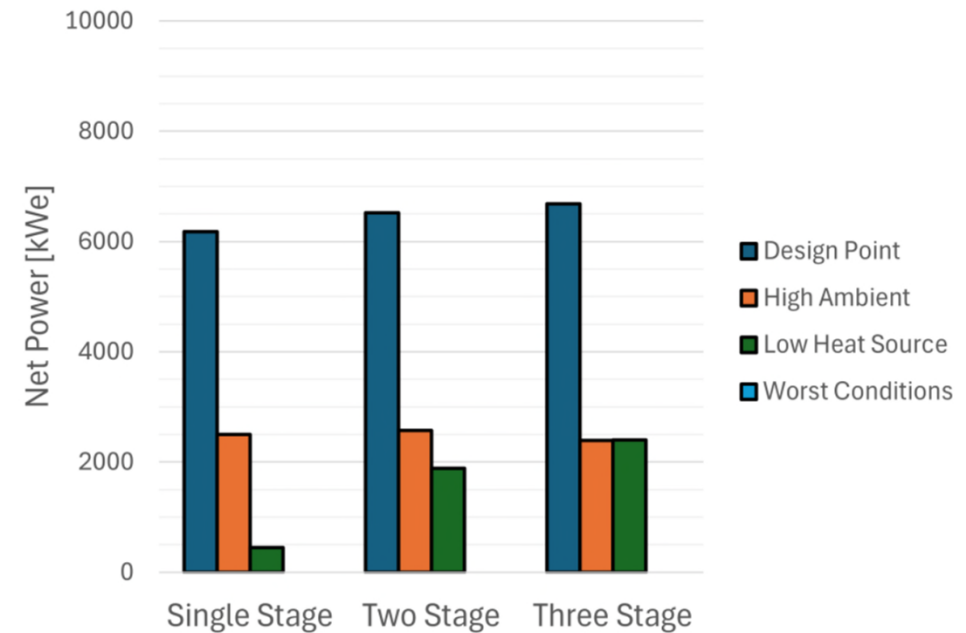
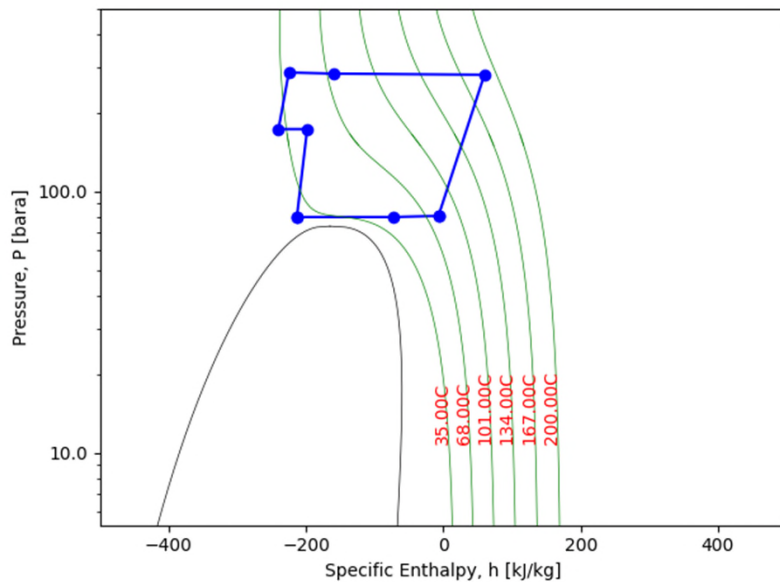


sCO₂ produces significant power at the design but struggles otherwise

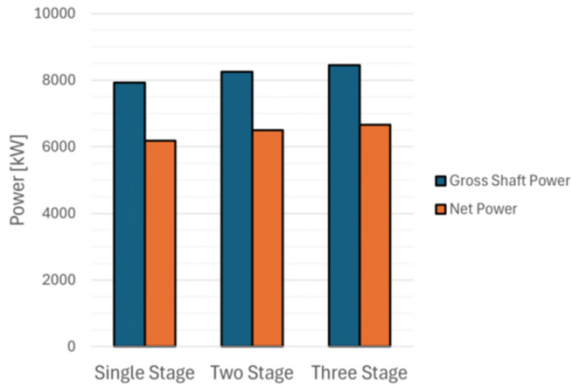


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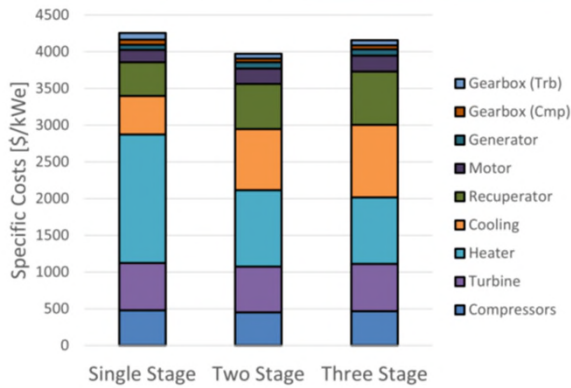
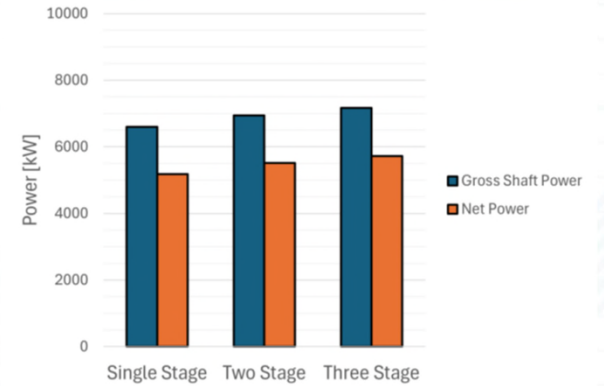
Around 10% power increase with at least 1 intercooler



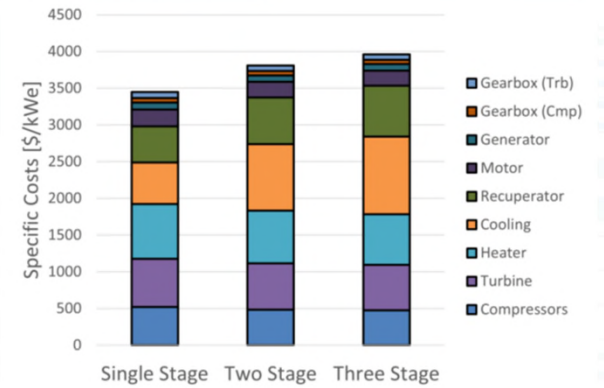
Optimizing for cost vs performance produced different cycles



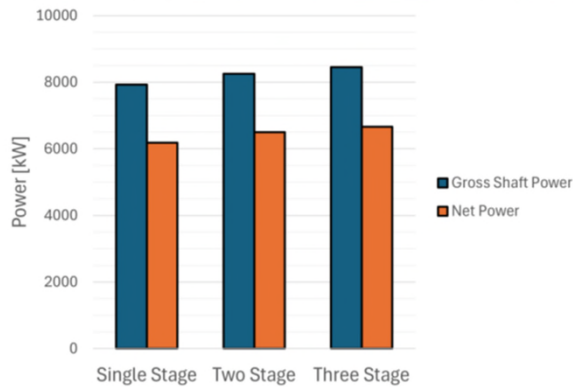
Maximizing net power output



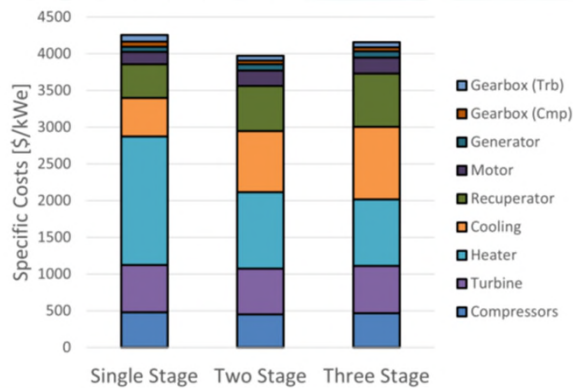
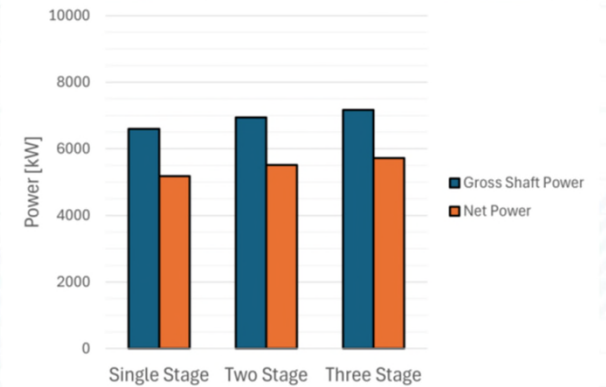
Minimizing specific cost of system output



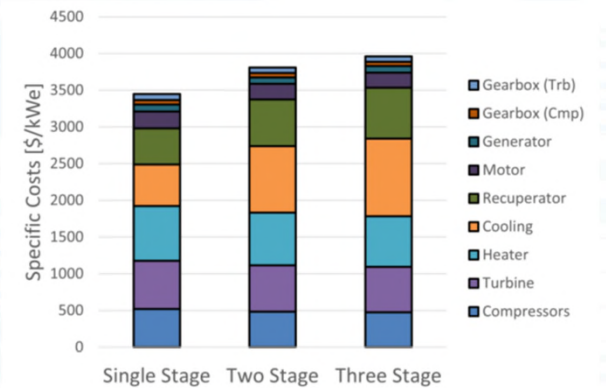
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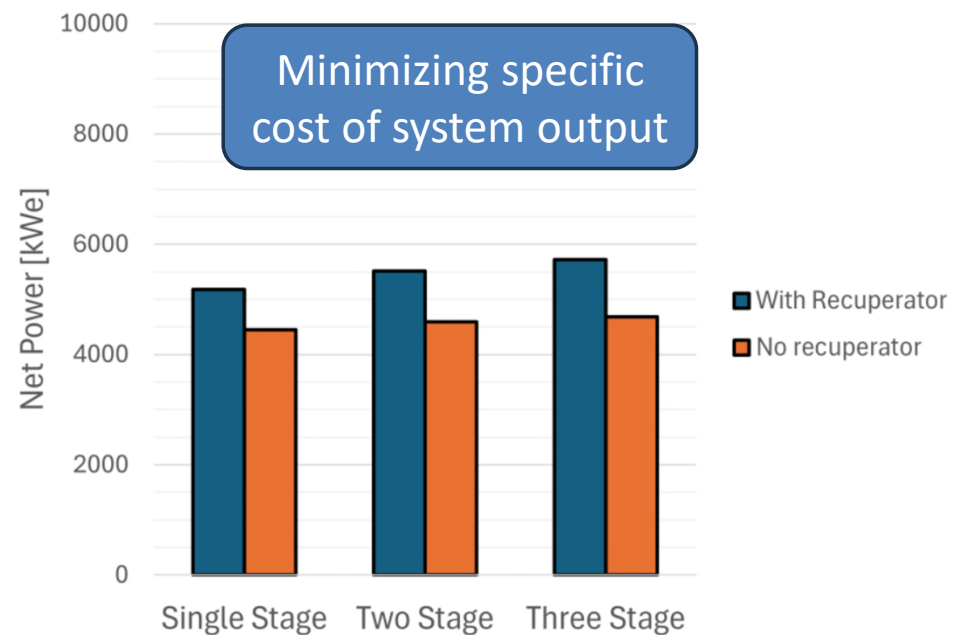
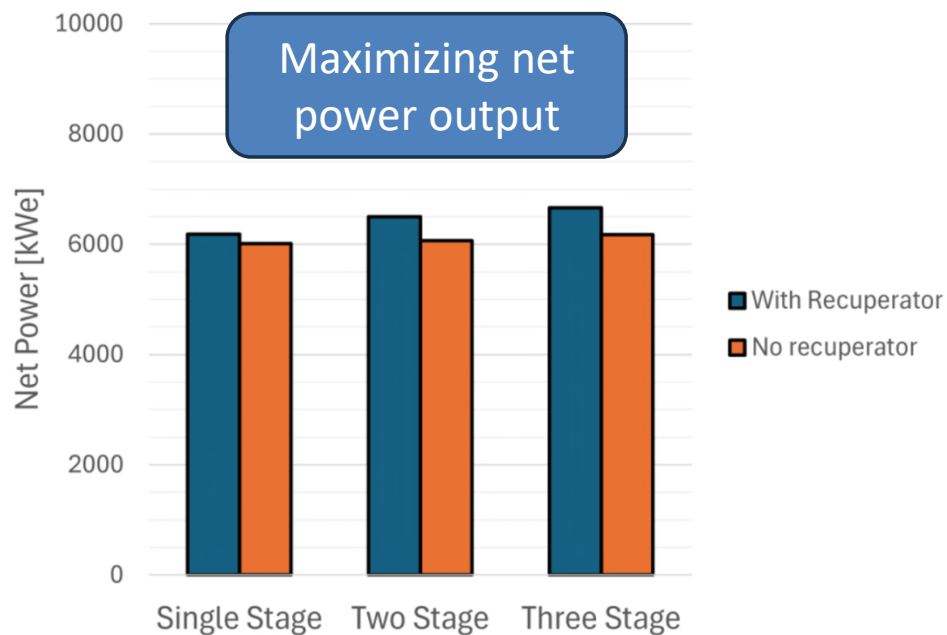
Maximizing net power output



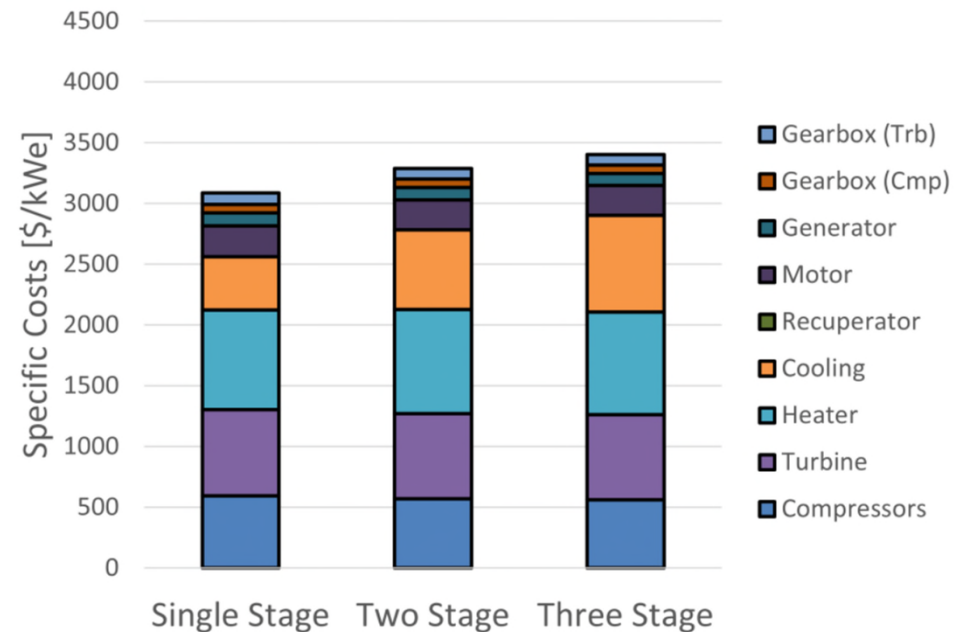
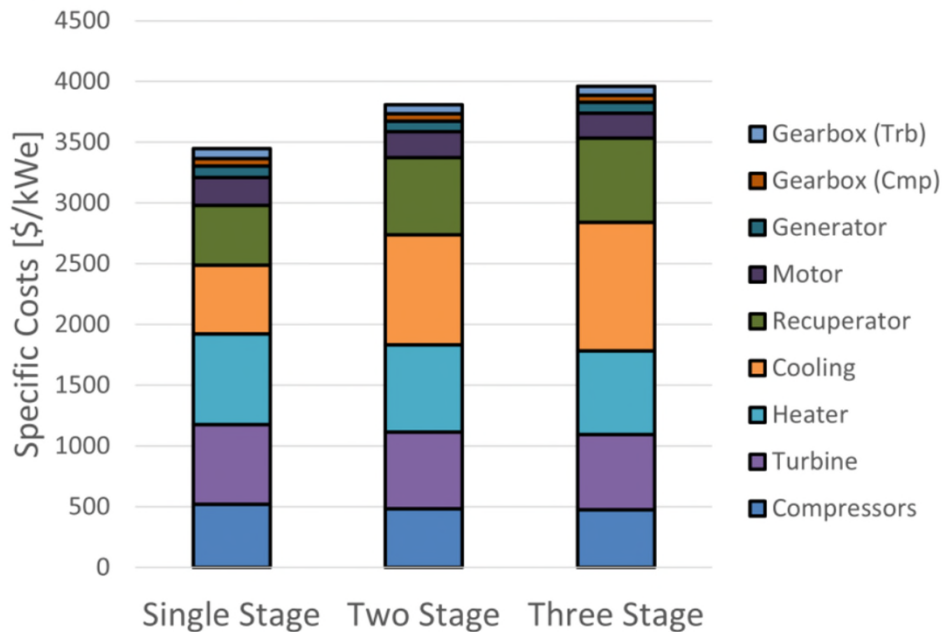
Minimizing specific cost of system output



Removal of the recuperator reduced net power by 10-15%



But significantly reduced the cost of the system



Conclusions

- sCO₂ cycle single stage with ambient ≤ 25 °C and WHT > 180 °C is performant
- sCO₂ cycle at WHT ≤ 145 °C does not produce power
- Two-stage intercooled compression helps stabilize performance when ambient conditions and WHT's swing
- Three-stage compression adds marginal benefit
- For WHT ≤ 200 °C, a recuperator can sometimes improve performance but additional costs may not make sense

Questions

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