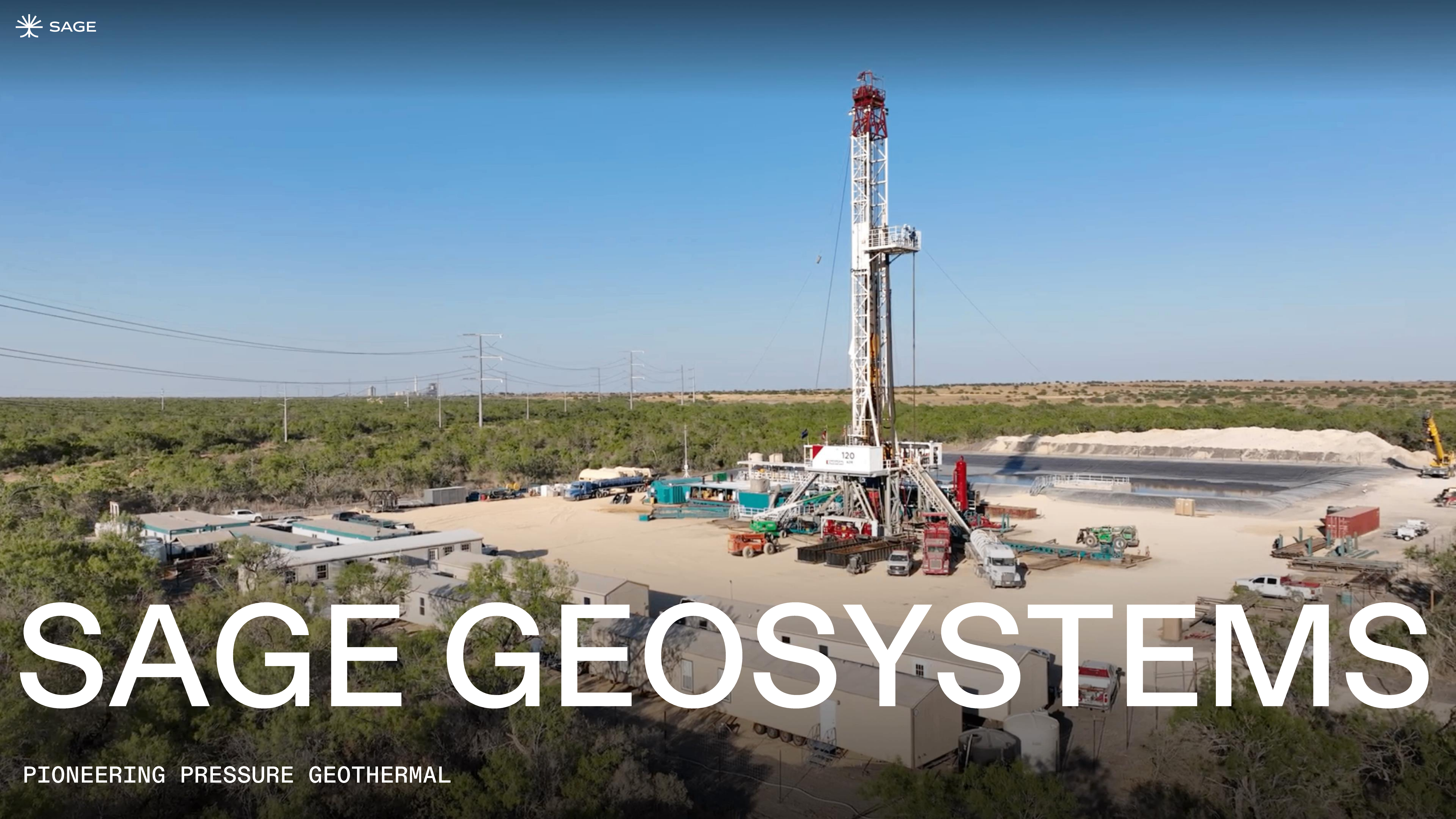

SAGE
SAGE GEOSYSTEMS
PIONEERING PRESSURE GEOTHERMAL
120

SAGE

Feasibility of Isothermal Compression for a Geothermal sCO_2 Power Plant

Lev Ring, Douglas Simpkins, Owen Pryor

11/19/25

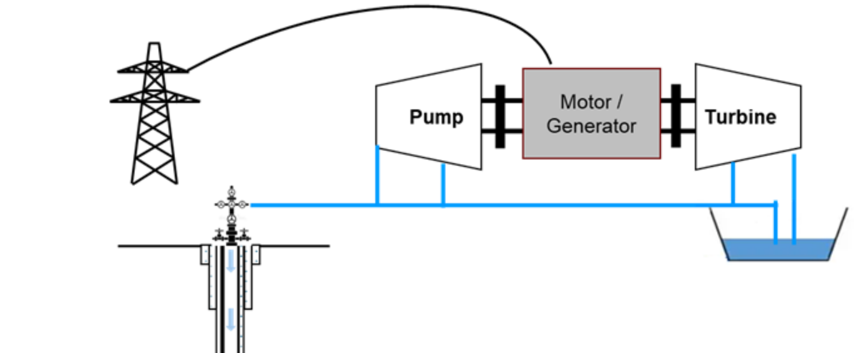
Agenda

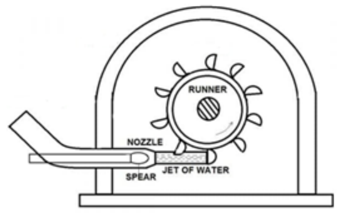
Sage Technology Staircase

2021-2025

Energy Storage

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



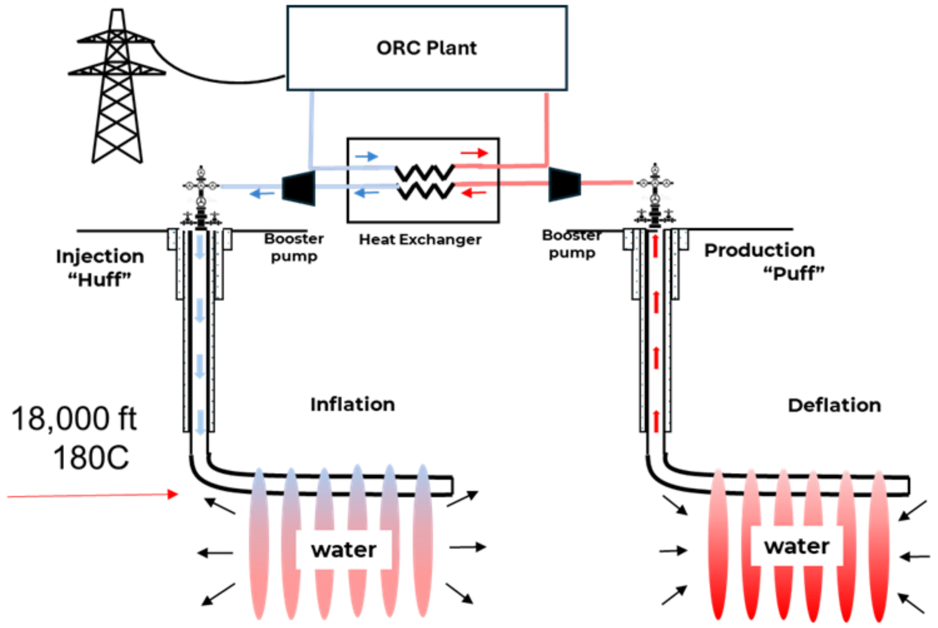


High Pressure Pelton Turbine (5,000 psi)

2022-2027

Power Generation (Pressure Geothermal)

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

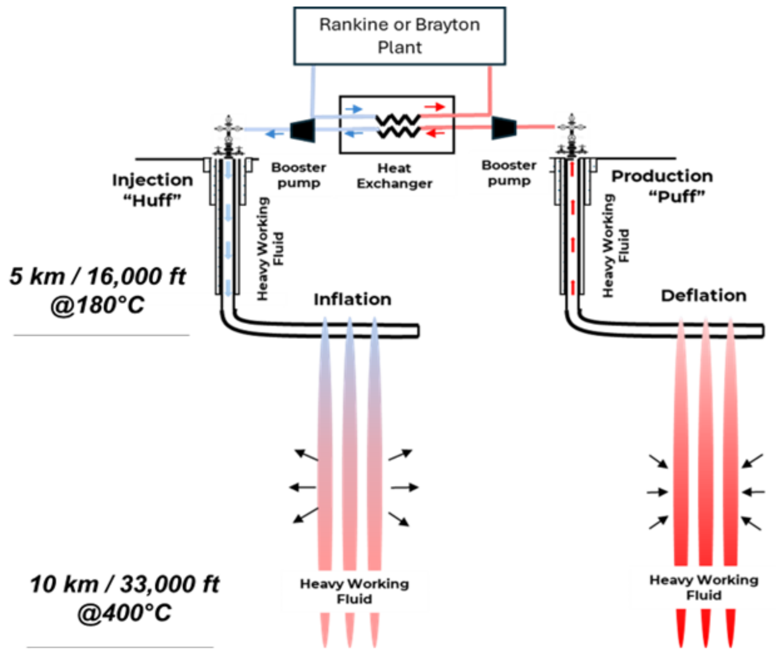


200°C LCOE: $65-$75/MWh

2026-2030

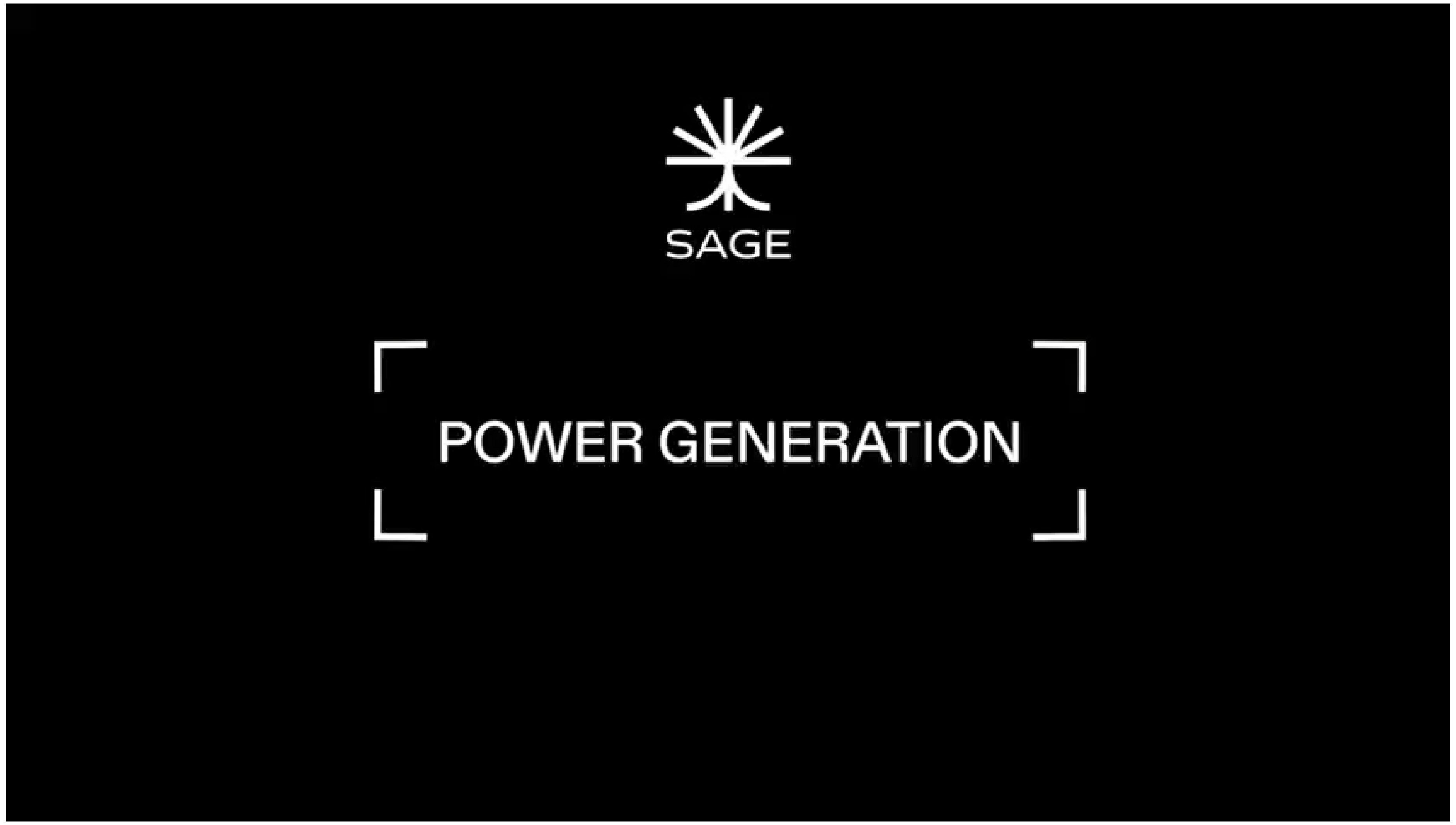
Drill Shallow, Frac Deep (Superhot Geothermal)

- **25-35 MW net output**



350°C LCOE: $35-$45/MWh

Power Generation Technologies

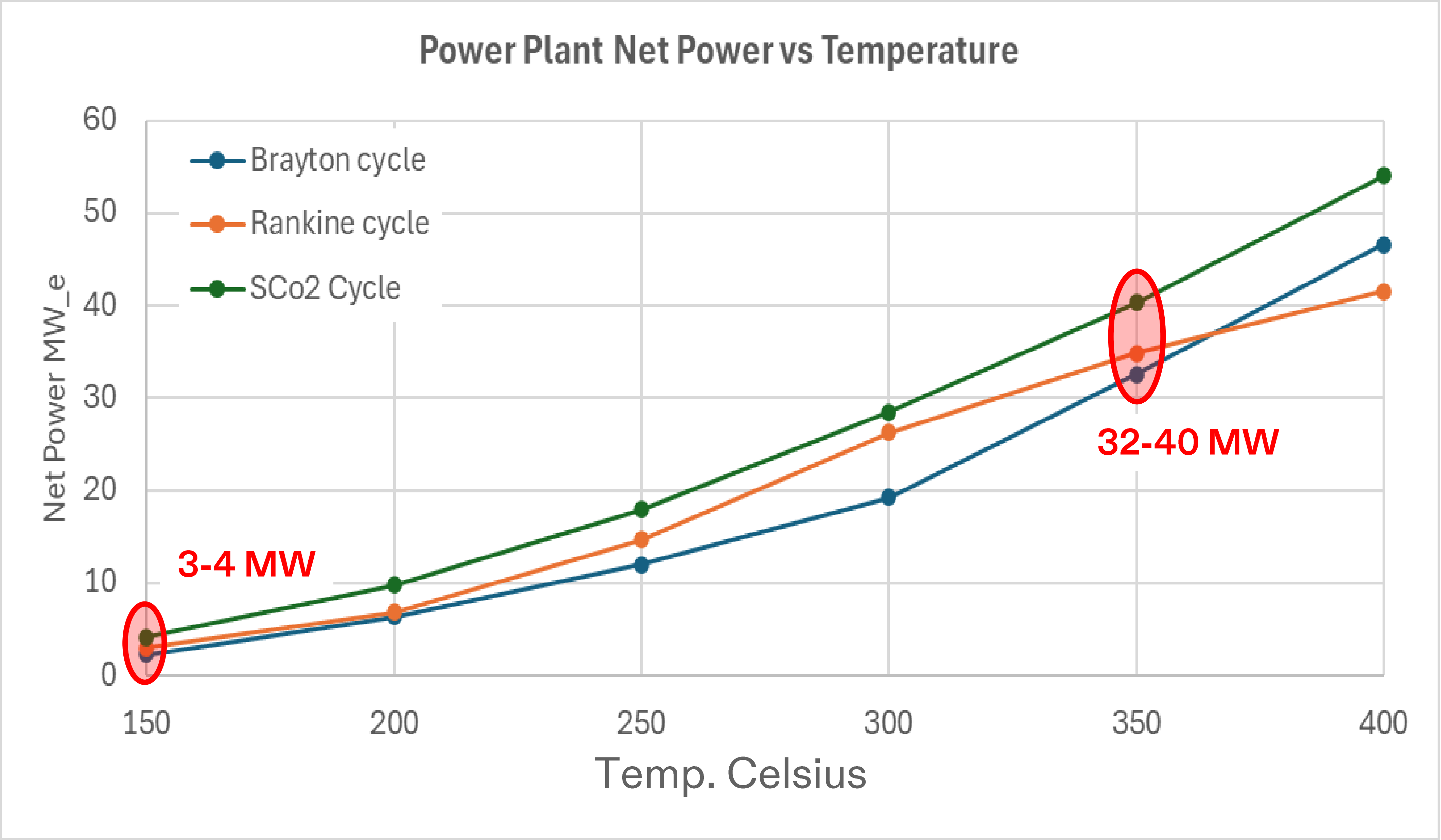


Why Super Hot and the case for sCO2 Brayton Cycle?

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)

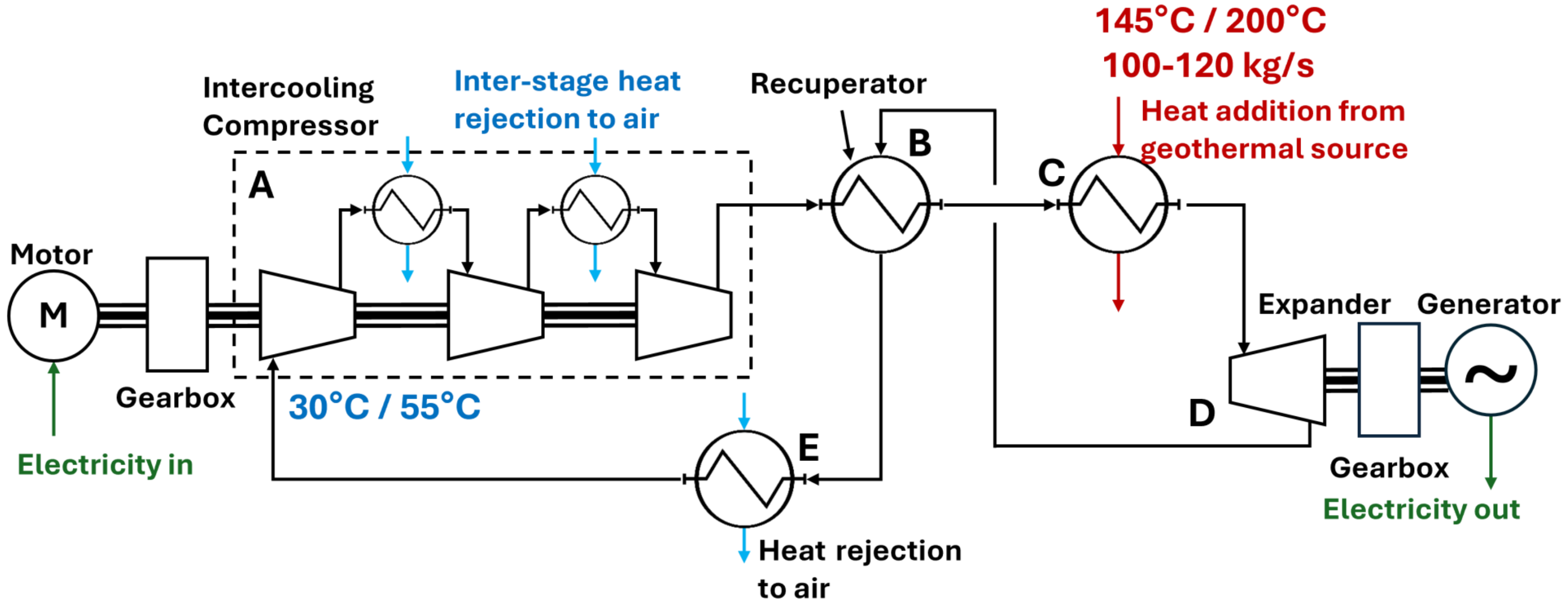


Flow Rate: *100 kg/s = 37 BPM = 1,600 GPM*

Developing 3MW sCO2 Cycle

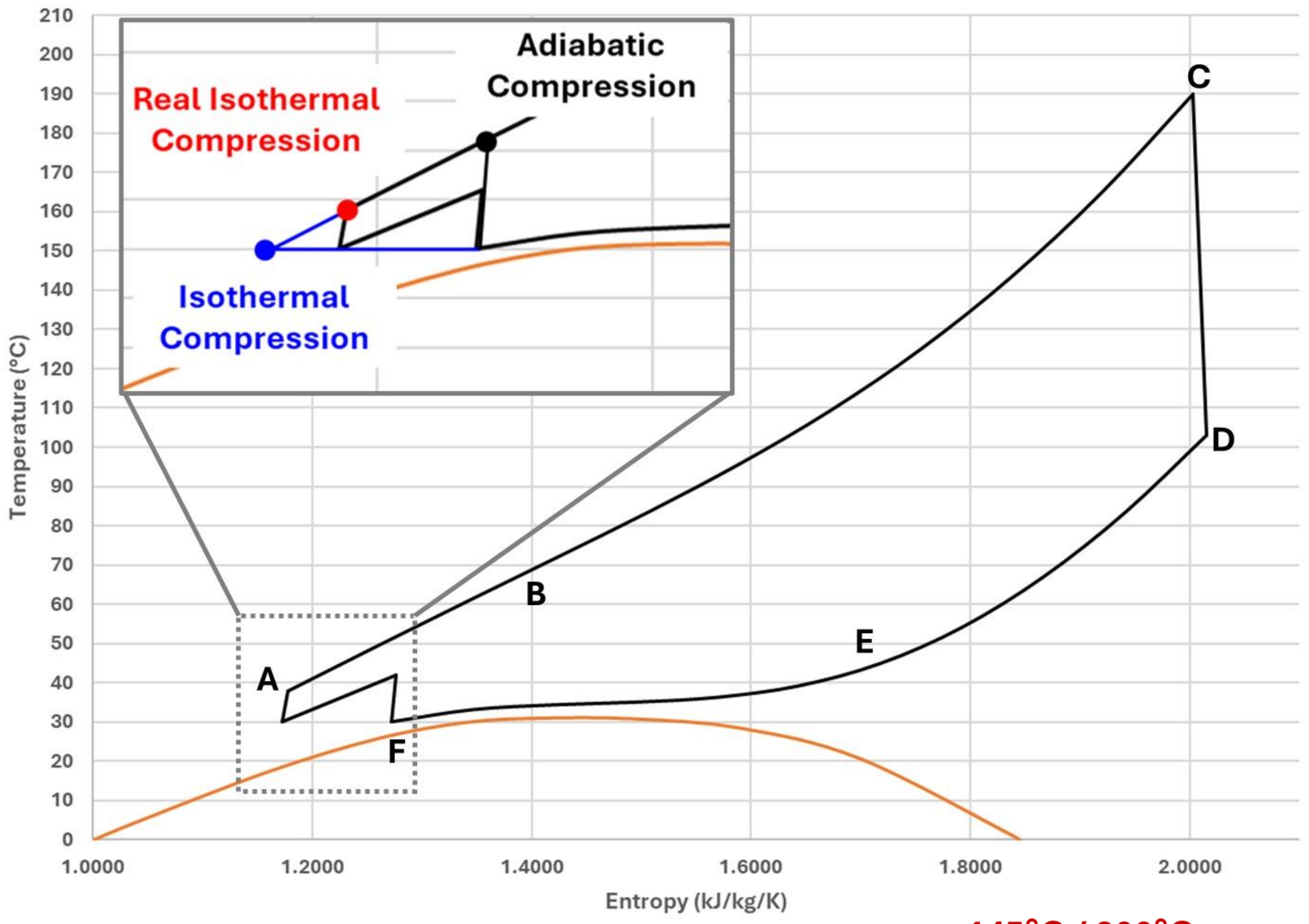
Successful load tested turbine 2024

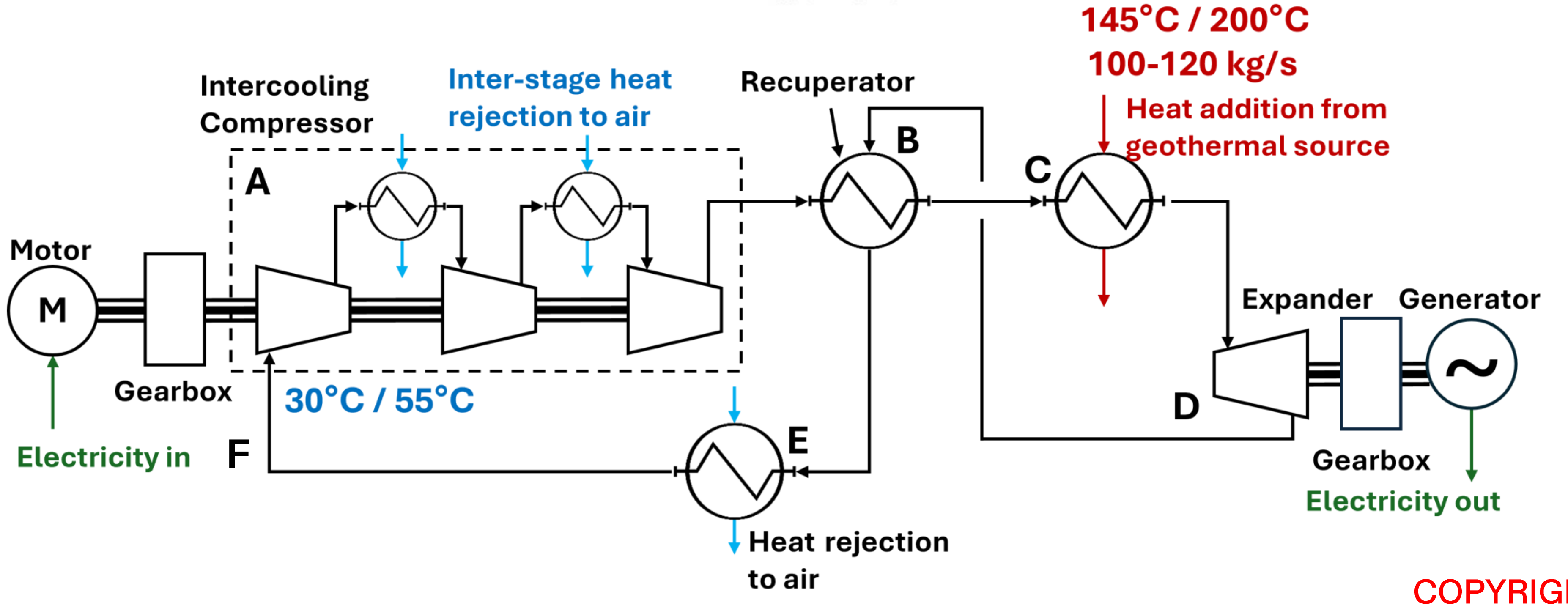
sCO2 Brayton Cycle with Isothermal Compression



- 2025 - Feasibility study with SwRI
    - **Dr. Owen Pryor** and **Reese Roddy**
- Model the Sage Geothermal system with an isothermal compressor
- Considered extreme cases
- **Target: 3-5 MW_{net}**

Why Explore Isothermal Compression?





The Challenge:

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

The Solution: Isothermal Compression

- 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

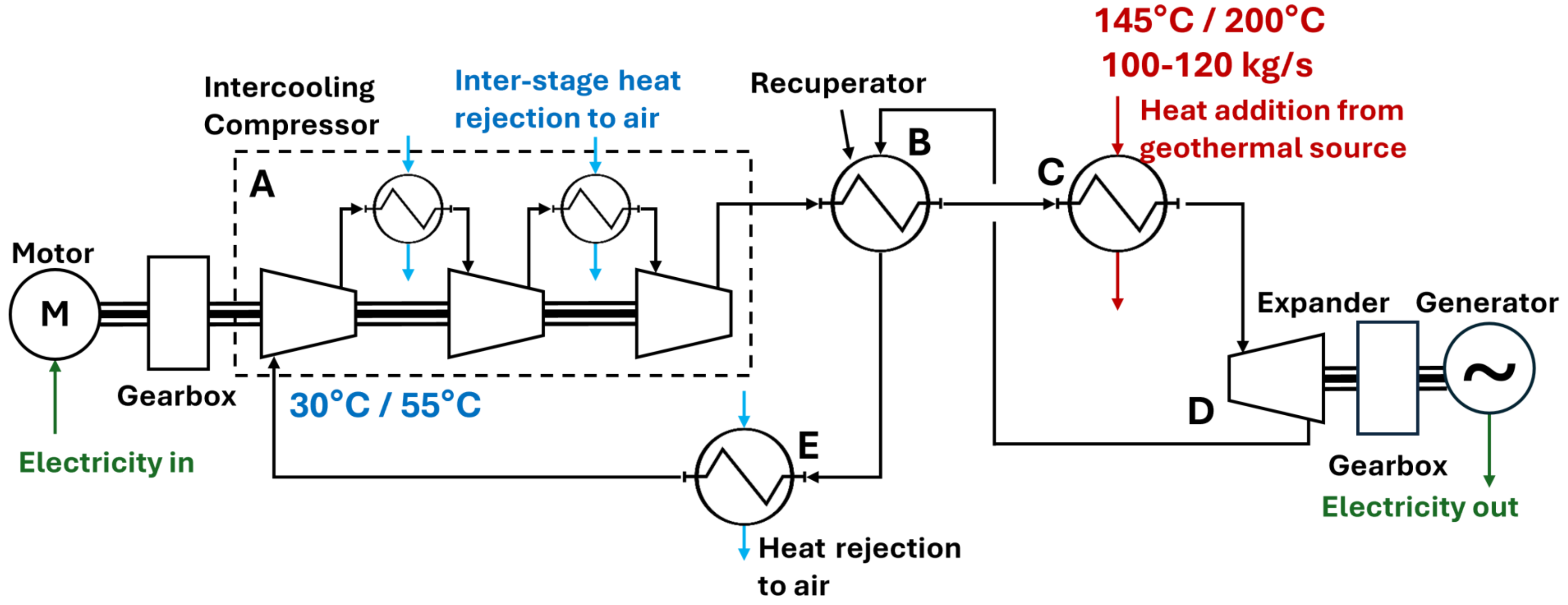
Study Modeling Assumptions

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



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

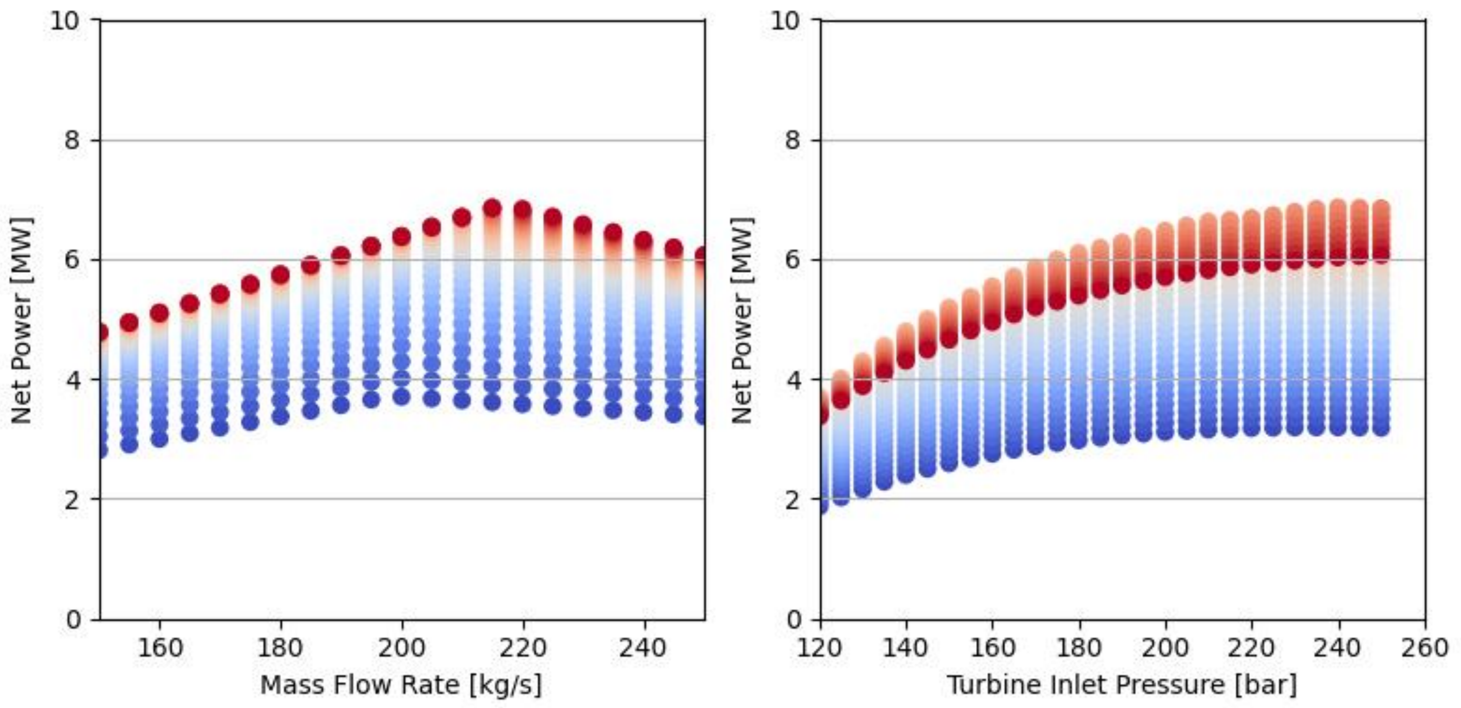
1. Weiland, N., White, C. (2019). "Peformance and Cost Assessment of a Natural Gas-Fueled Direct sCO_2 Power Plant," NETL-PUB-22274, National Energy Technology Laboratory, U.S. Dept. of Energy, March 15, 2019.

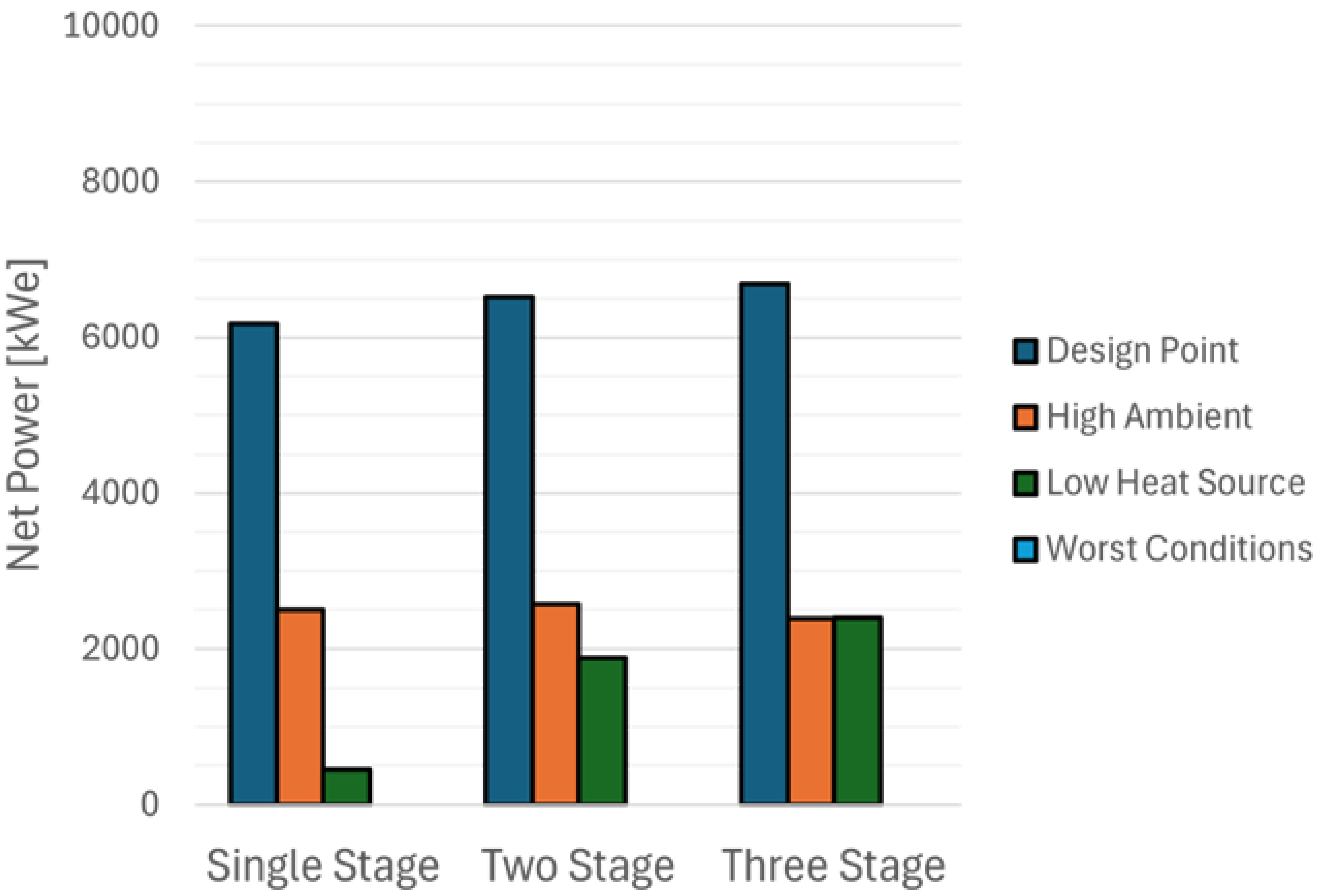
Summarized Results – Gross and Net-Power

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

Example of Gross Shaft Power Parameterized Sweeps

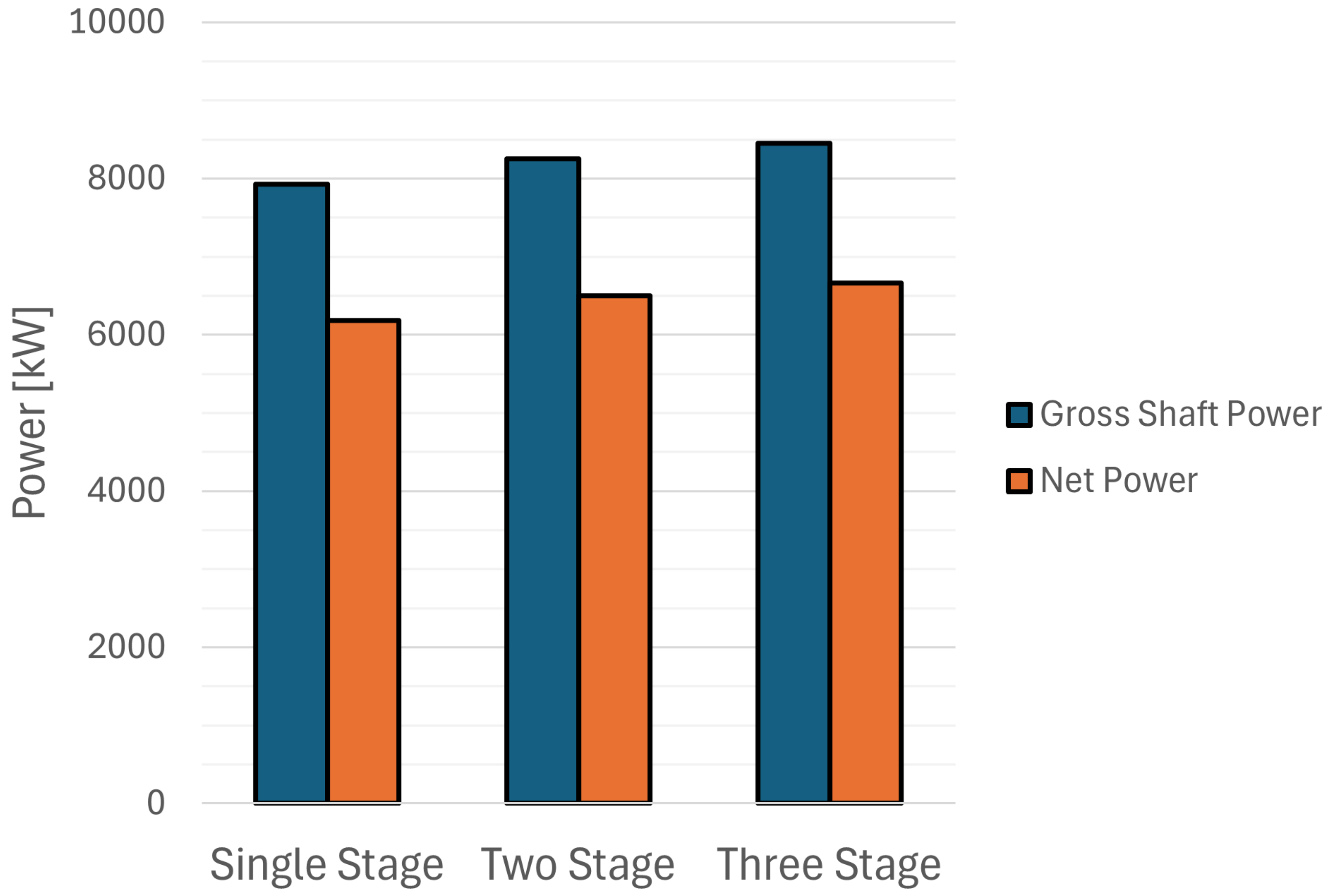




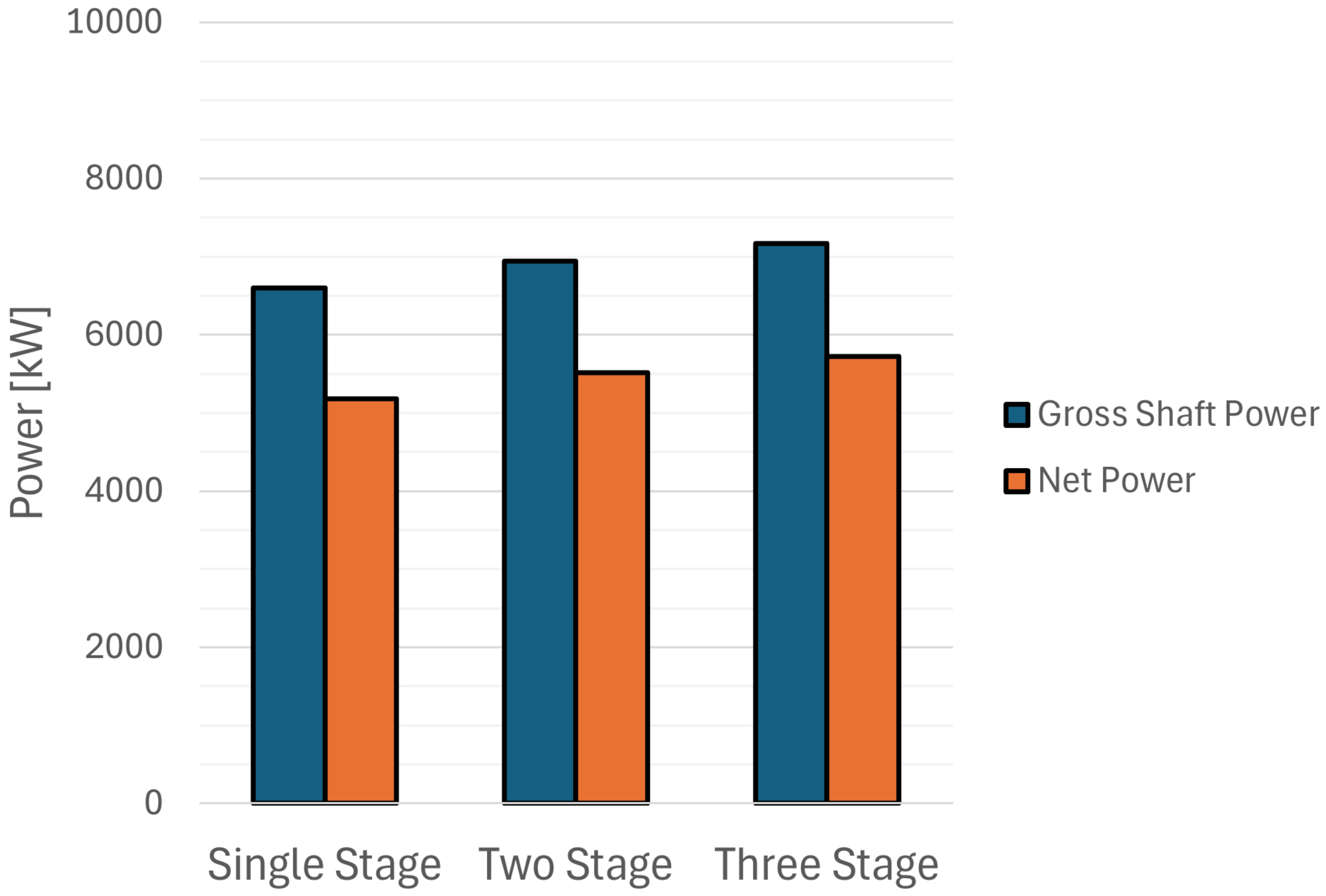
- > 6MWe Net at design point
- 2.5 – 6 MWe Net across large ambient
- Two-Stage helps stabilize ambient increase
- sCO2 is not feasible for WHT - 145C at high ambient

Summarized Results – Minimal Specific Costs

System that maximizes power at the design point



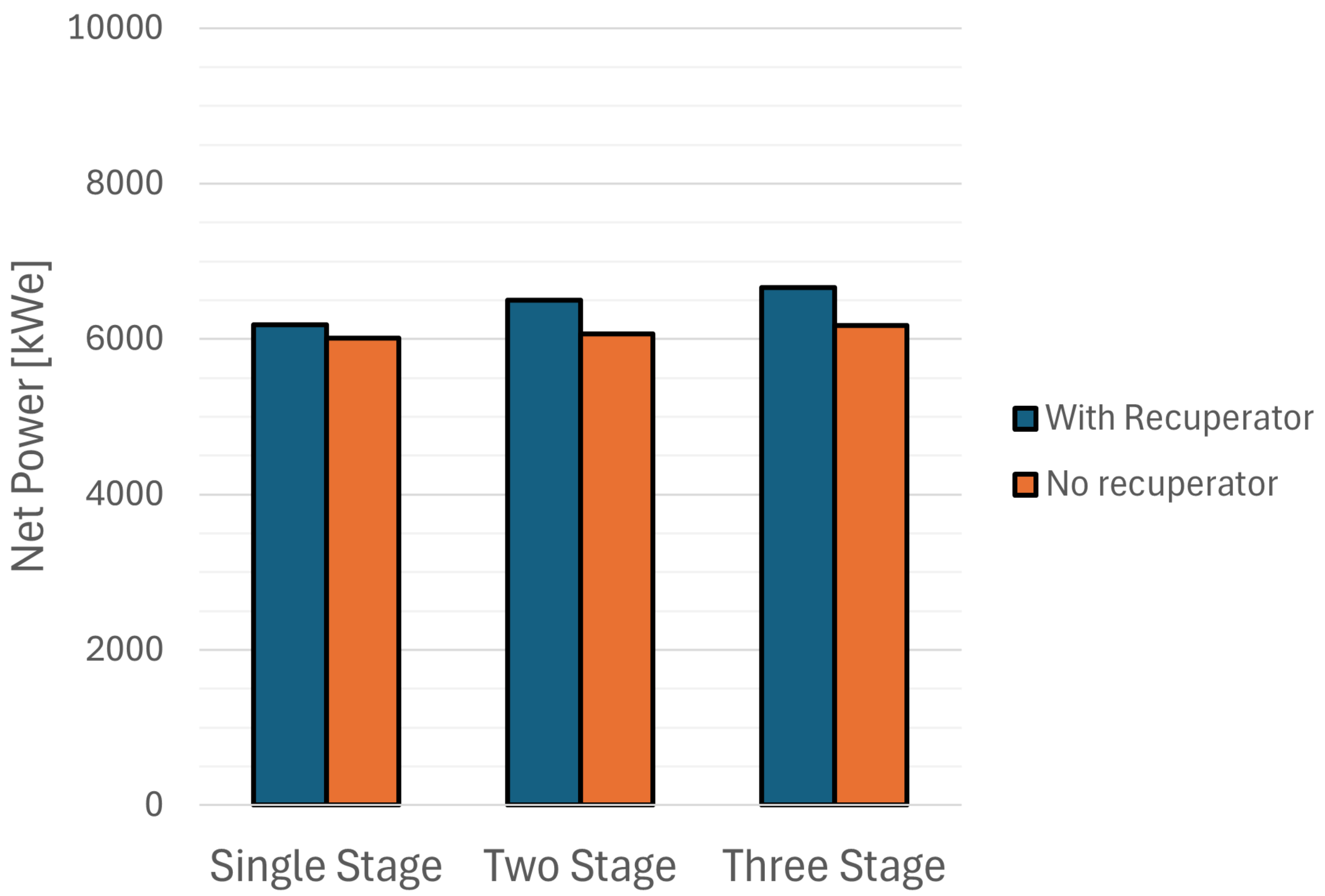
System that maximizes power at the design point at minimal specific costs



- Minimizing cost reduces net-power by 1 MWe

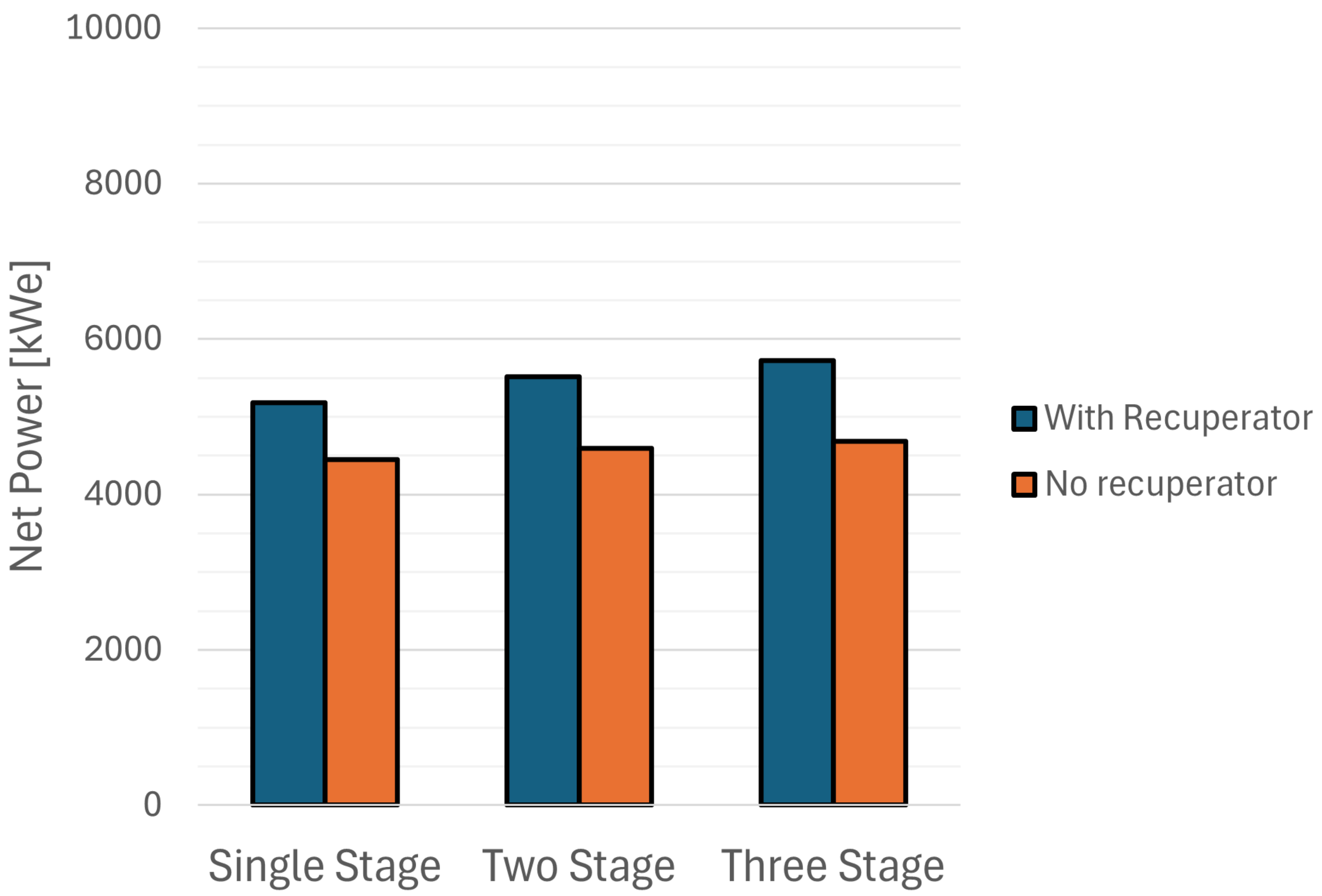
Summarized Results – Recuperator

System that maximizes power at the design point



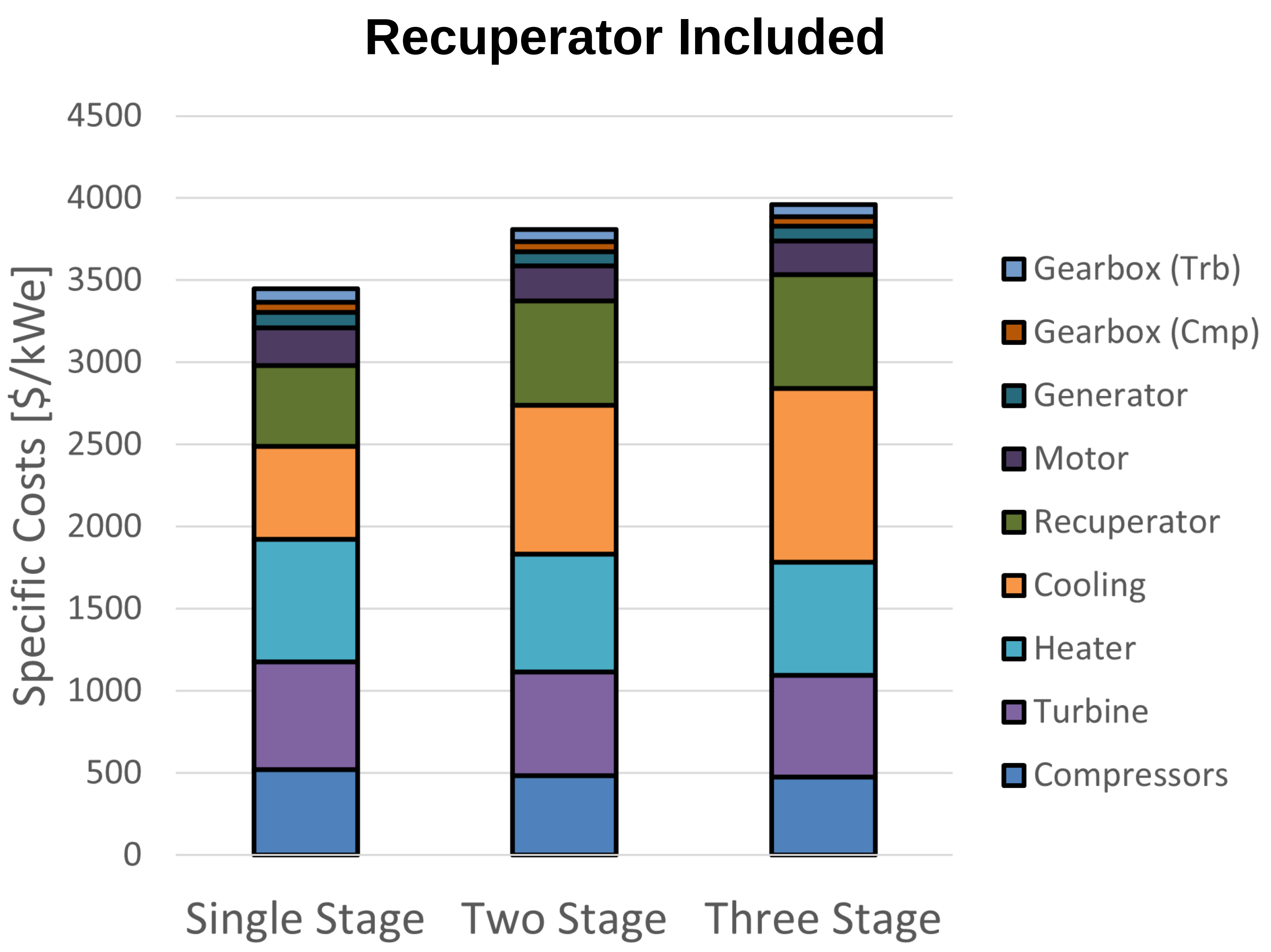
Marginal Benefit

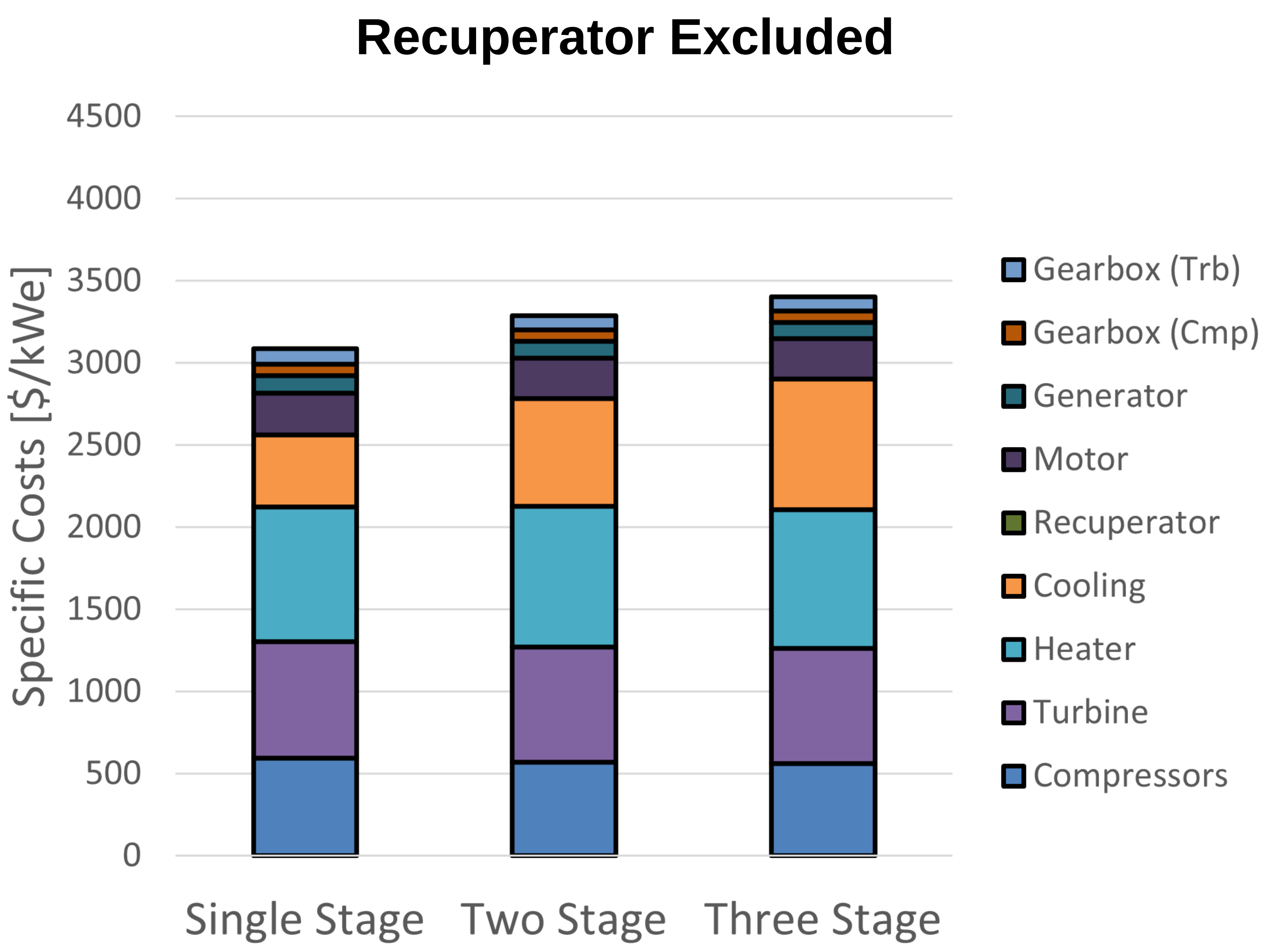
System that maximizes power at the design point at minimal specific costs



~700 kW net-power improvement

Summarized Results – Distribution of Costs





- Approach a $3/ MWe target

Conclusions

- sCO2 cycle single stage with ambient ≤ 25 °C and WHT > 180°C is perfomant
- 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