Geothermal Power Generation: Cycle Analysis, Surface Equipment, and System Considerations

SOUTHWEST RESEARCH INSTITUTE®

Kelsi Katcher

Nov. 29, 2023

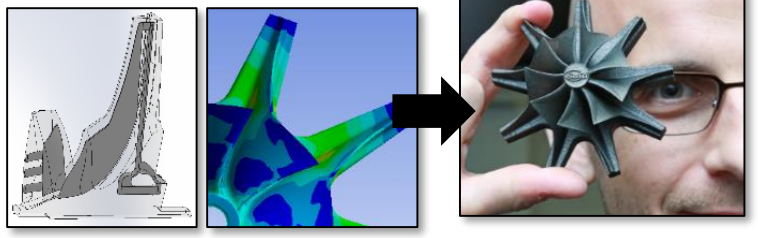
SwRI Machinery Department

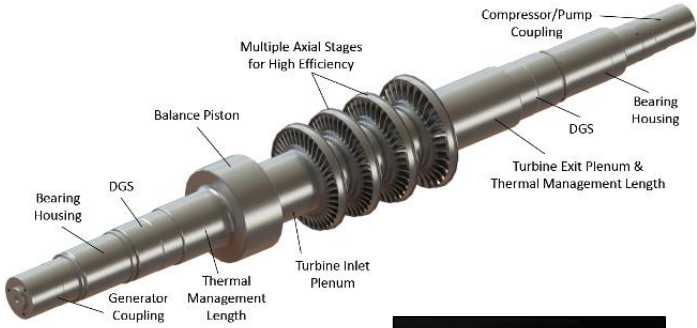
Applied Research centered around Rotating Machinery and associated systems for

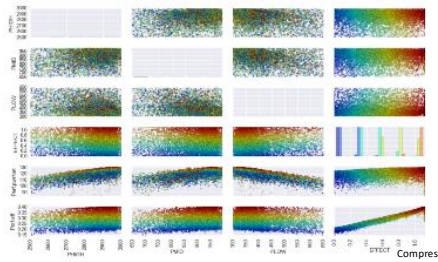
- Oil & Gas
- Aviation
- Liquid Propulsion
- Power Generation

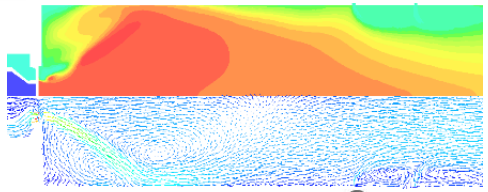
Expertise including developing technologies, prototype demonstration, and mature products and systems

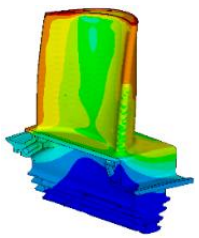
- 79 Staff
- 5 labs; open/closed-loop test facilities; powertrains up to 15 MW shaft power
- Field testing and troubleshooting
- Support OEMs in transitioning new technologies to products

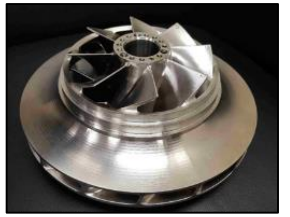


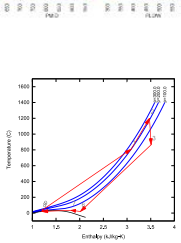


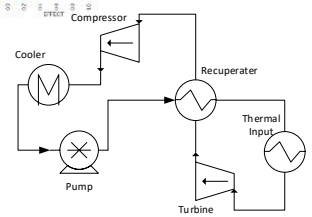


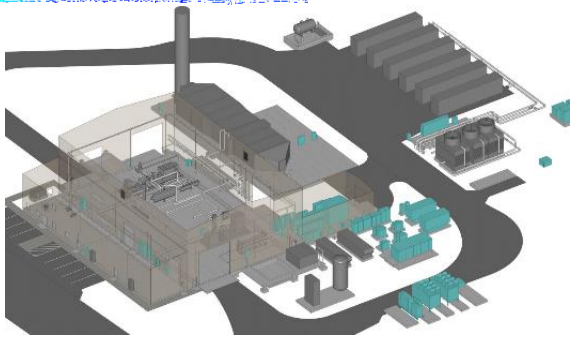


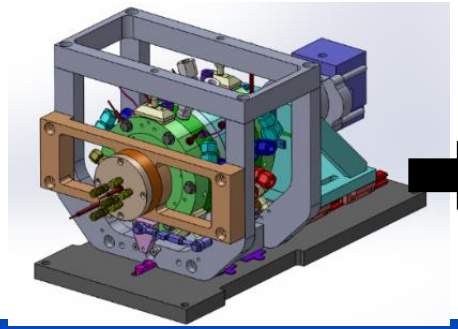


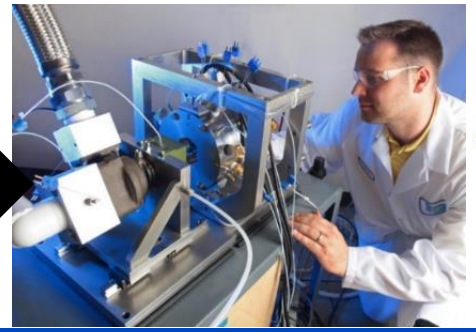


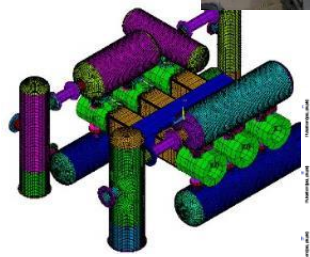


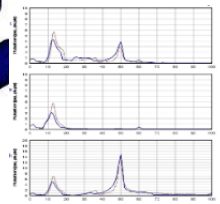










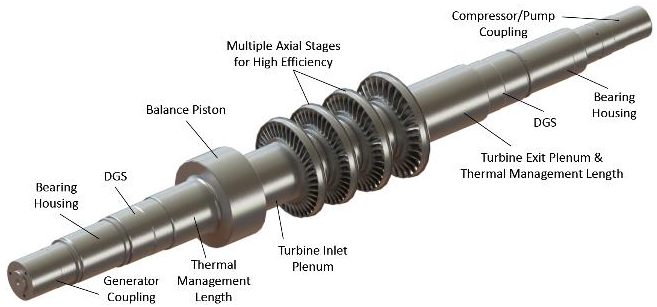


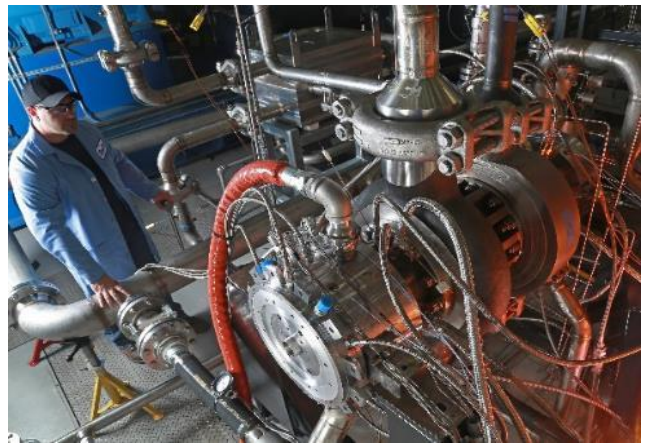
Background & Lead up to Geothermal Power Systems

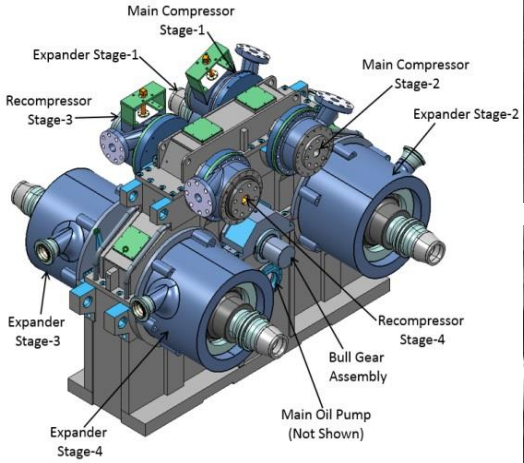
- Research in high-temperature sCO2 power cycles (up to 715°C)
- sCO2 natural convection research for cleaning processes
- Internally-funded research program: CO2 natural convection cycles for power gen

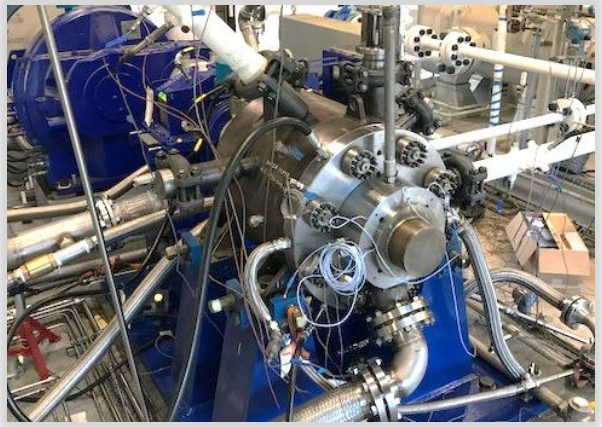
Background & Lead up to Geothermal Power Systems

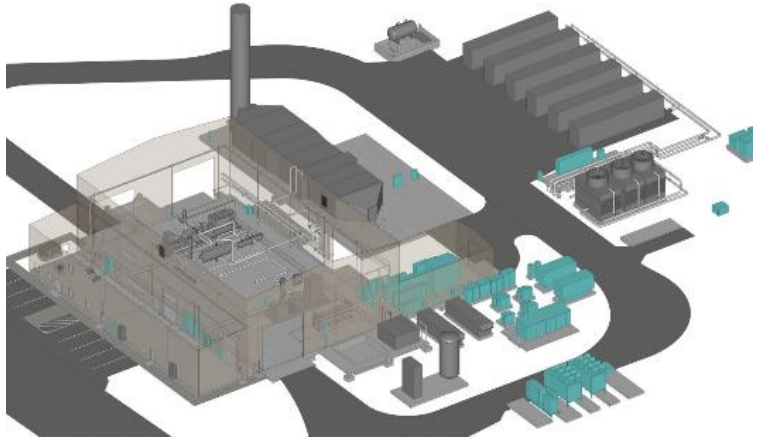
- Research in high-temperature sCO2 power cycles (up to 715°C)
  - Turbine development
  - Cycle development
  - Compressor development











STEP Pilot Plant (10 MW net)

- sCO2 natural convection research for cleaning processes
- Internally-funded research program: CO2 natural convection cycles for power gen

Background & Lead up to Geothermal Power Systems

- Research in high-temperature sCO2 power cycles (up to 715°C)
- sCO2 natural convection research for cleaning processes
  - five SwRI-owned patents issued from 1995-2004

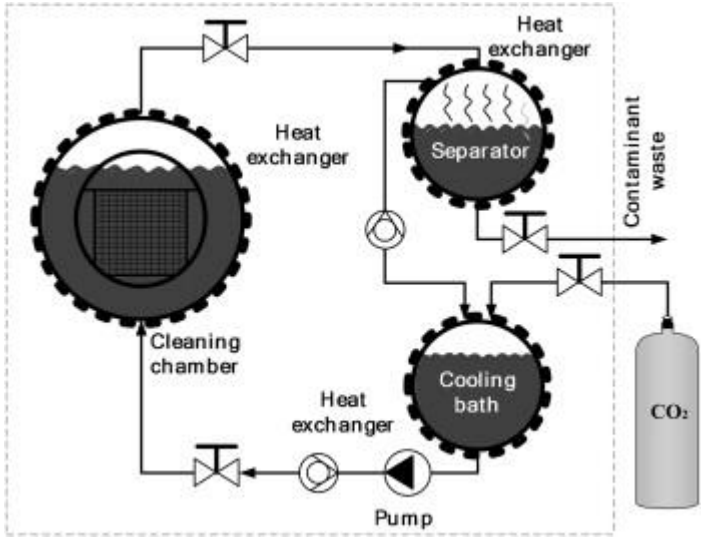


Image courtesy of Liu, W. et al.*

- Internally-funded research program: CO2 natural convection cycles for power gen

*Liu, W. et al., "Supercritical carbon dioxide cleaning of metal parts for remanufacturing industry," Journal of Cleaner Production, vol. 93, 2015, pp. 339-346, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2015.01.014.

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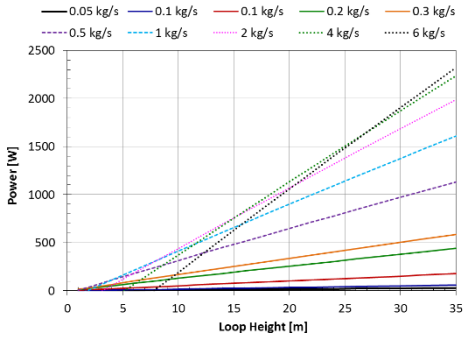

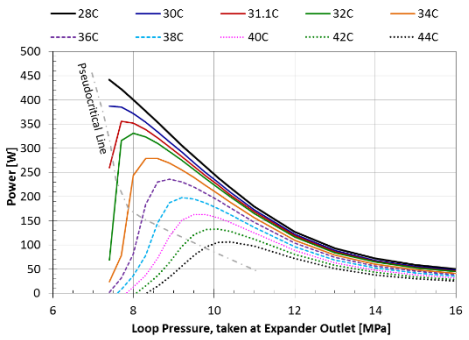

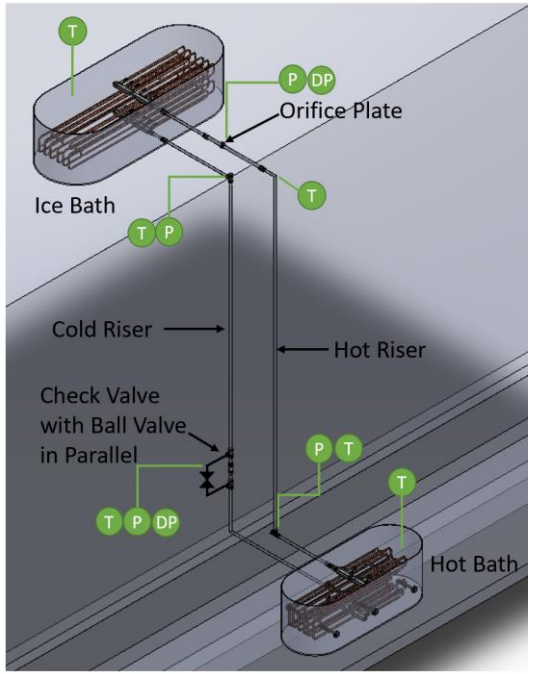

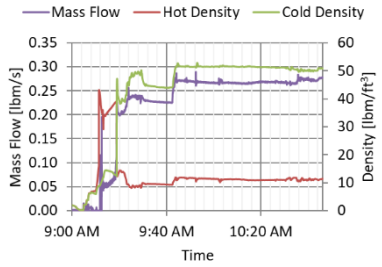

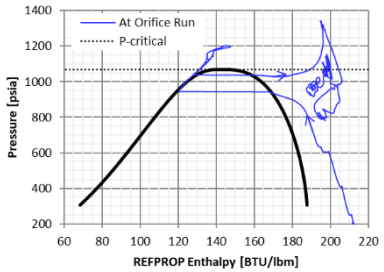

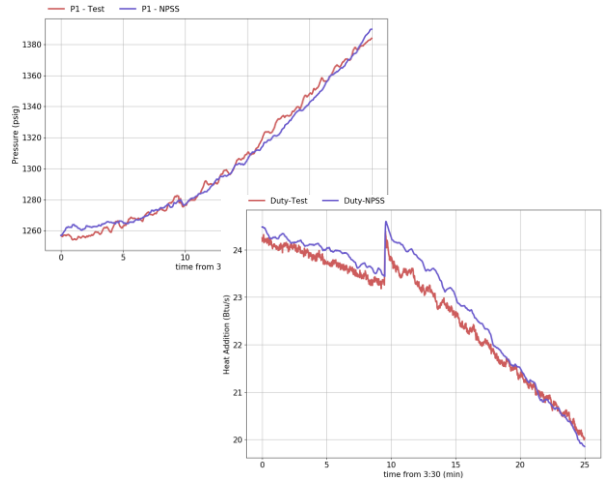

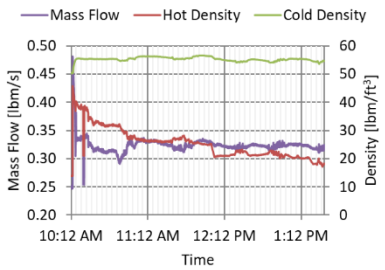

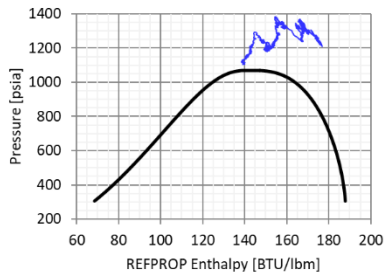

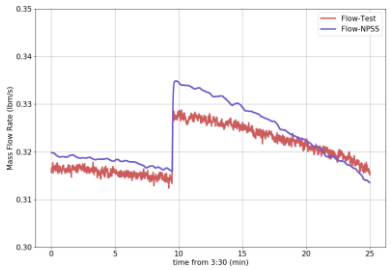

Measurable mass flow with ΔT of 1°F

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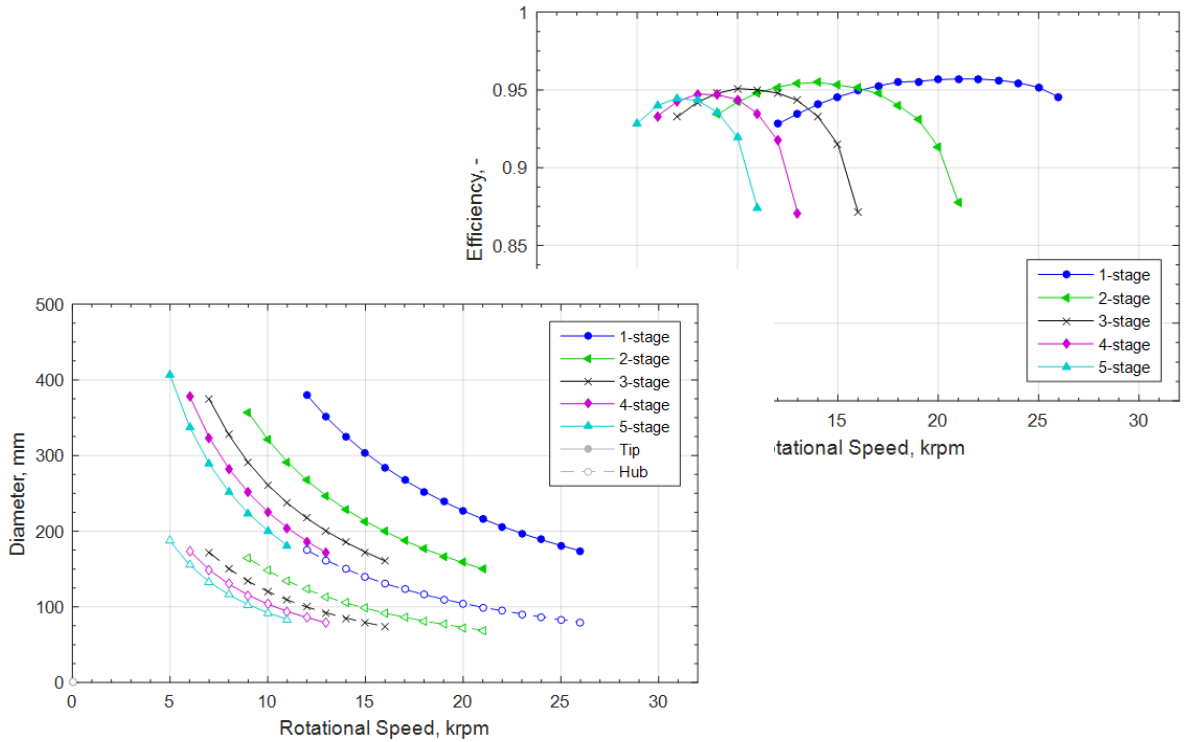
		80 MWth Geothermal	4 MWth Data Center	45 MWth Data Center
Mass Flow	*kg/s*	230	18	205
Inlet				
Temperature	*°C*	210	76.25	76.24
Pressure	*MPa*	20	8.55	8.55
Enthalpy	*kJ/kg*	611.51	480.14	480.12
Entropy	*kJ/kg-K*	2.08	1.89	1.89
Exit				
Temperature	*°C*	133.73	75.80	75.79
Pressure	*MPa*	8.5	8.5	8.5
Enthalpy	*kJ/kg*	559.71	479.93	479.92
Entropy	*kJ/kg-K*	2.08	1.89	1.89
Assumed Efficiency	-	0.85	0.75	0.75
Power	***kW***	**11915.3**	**3.7**	**42.5**



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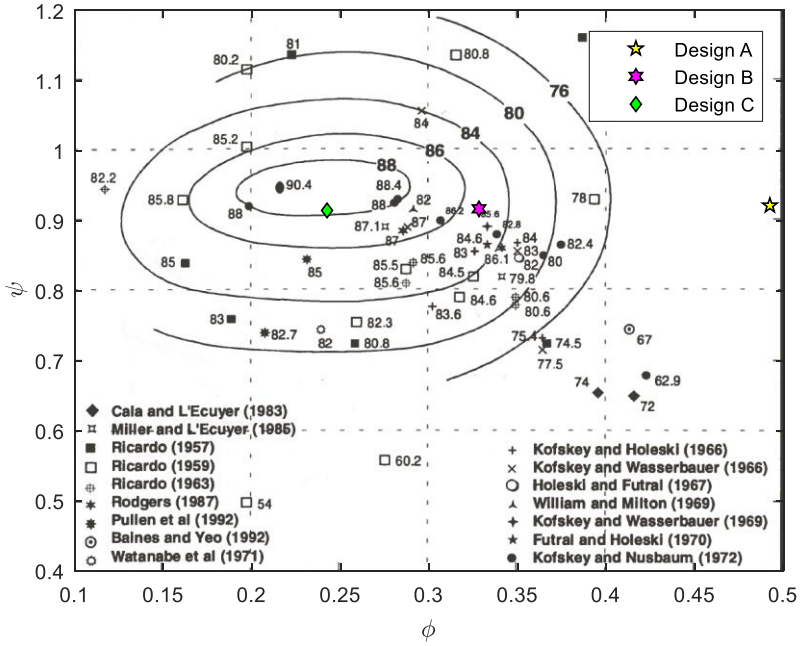
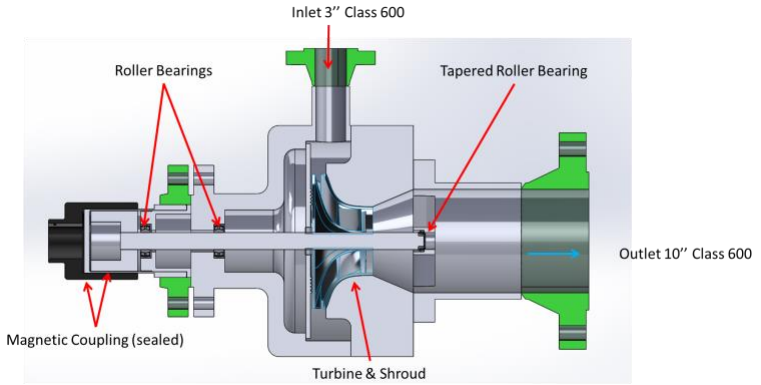
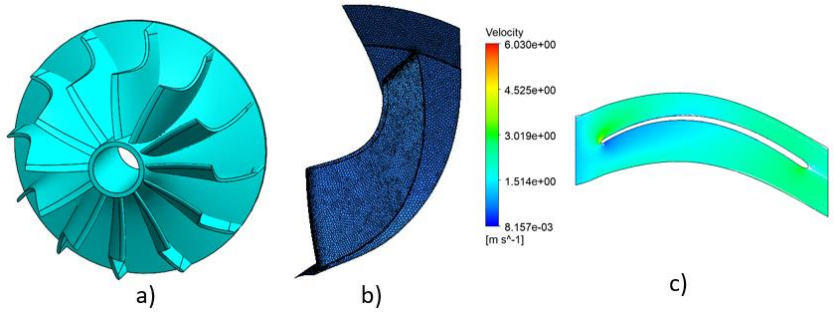
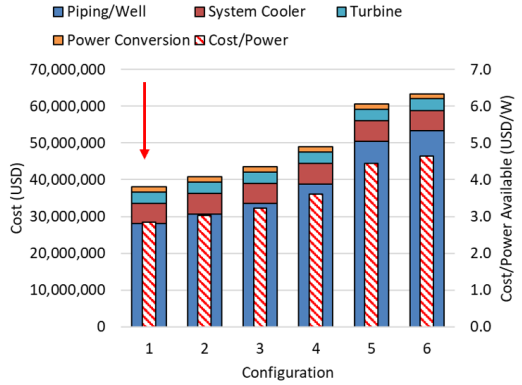
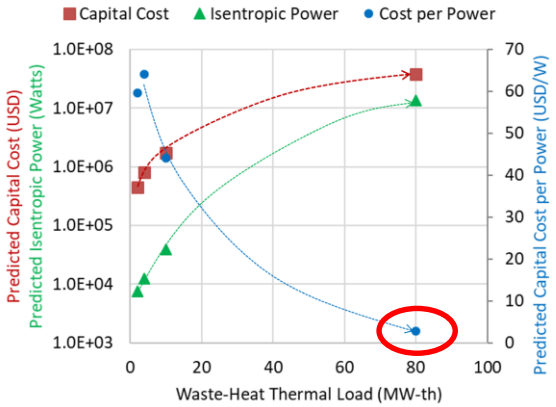




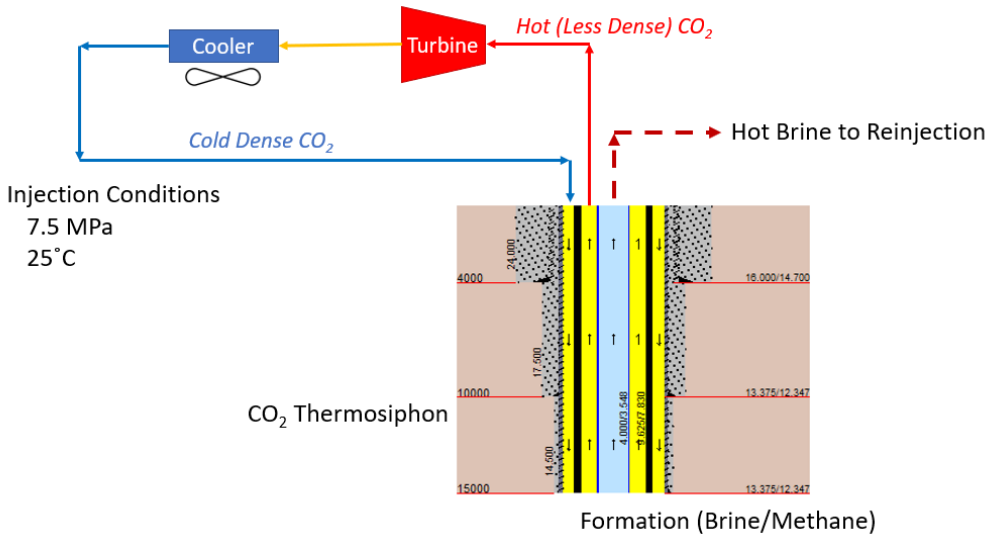


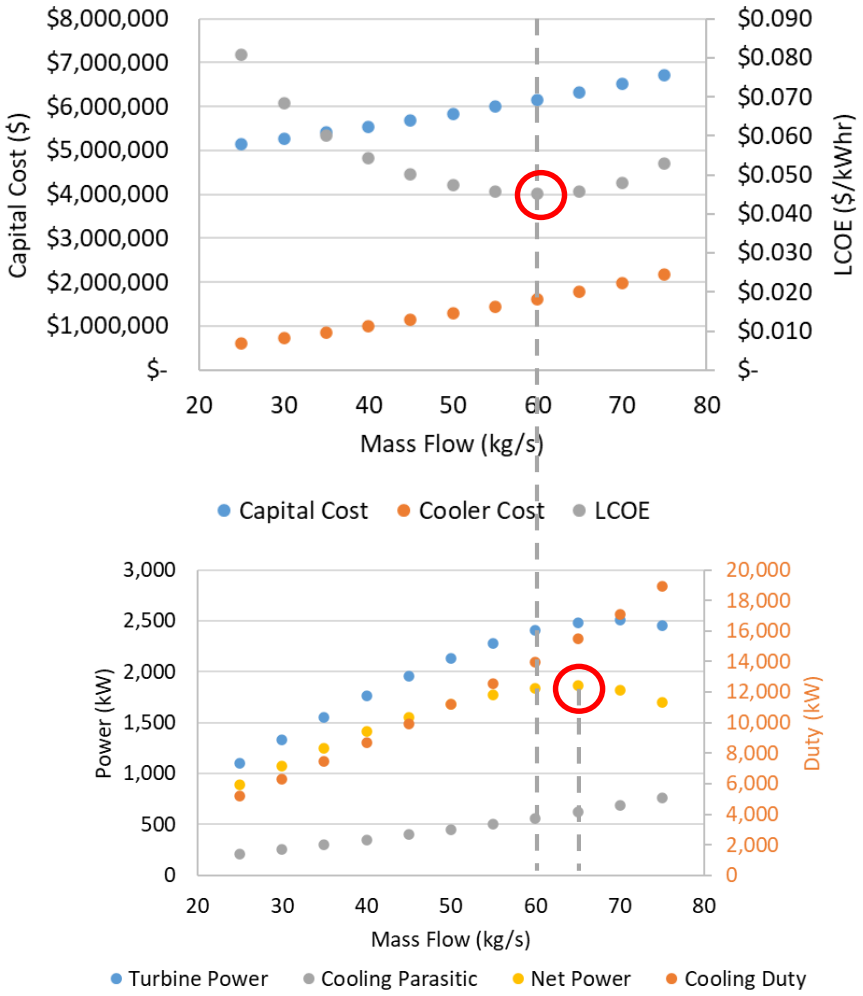




Commercial Geothermal Power Cycle Development

- Power cycle studies, cooler design studies, turbine design, plant control, off-design performance, impact of seasonal changes, impact of circulating fluid selection, impact of downhole temperature change

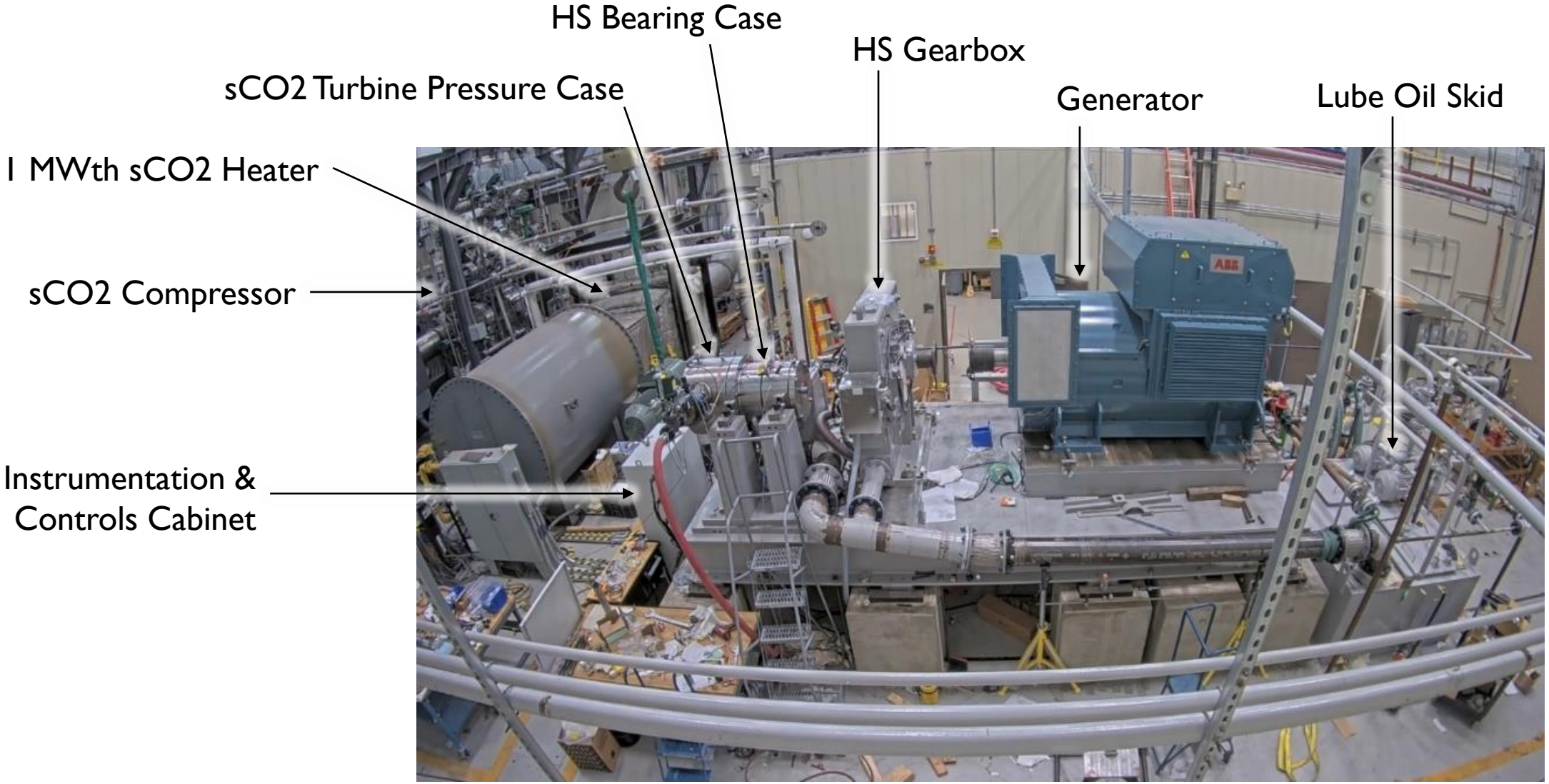




Images courtesy of Sage Geosystems.

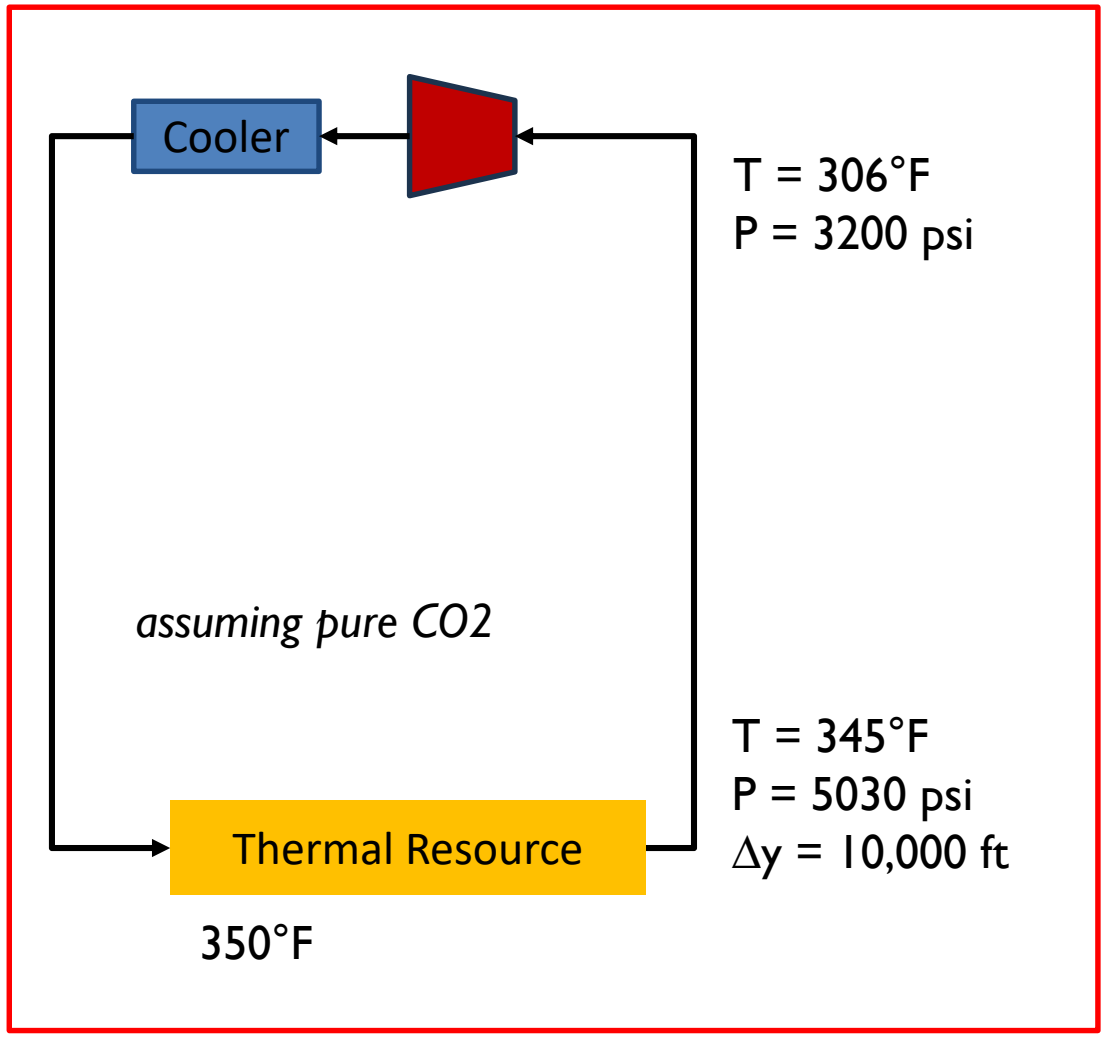
Nielson, J.T., Simpkins, D., and Katcher, K. "Techno-Economic Analysis of a Geothermal sCO2 Thermosiphon Power Plant," in Proceedings of The 7th International Supercritical CO2 Power Cycles Symposium, February 21-24, 2022, San Antonio, Texas. Paper No. 189.

3MW Power Turbine



The Boring (but Important) Things

- Power cycle dependent on fluid temperature at surface, not formation temperature



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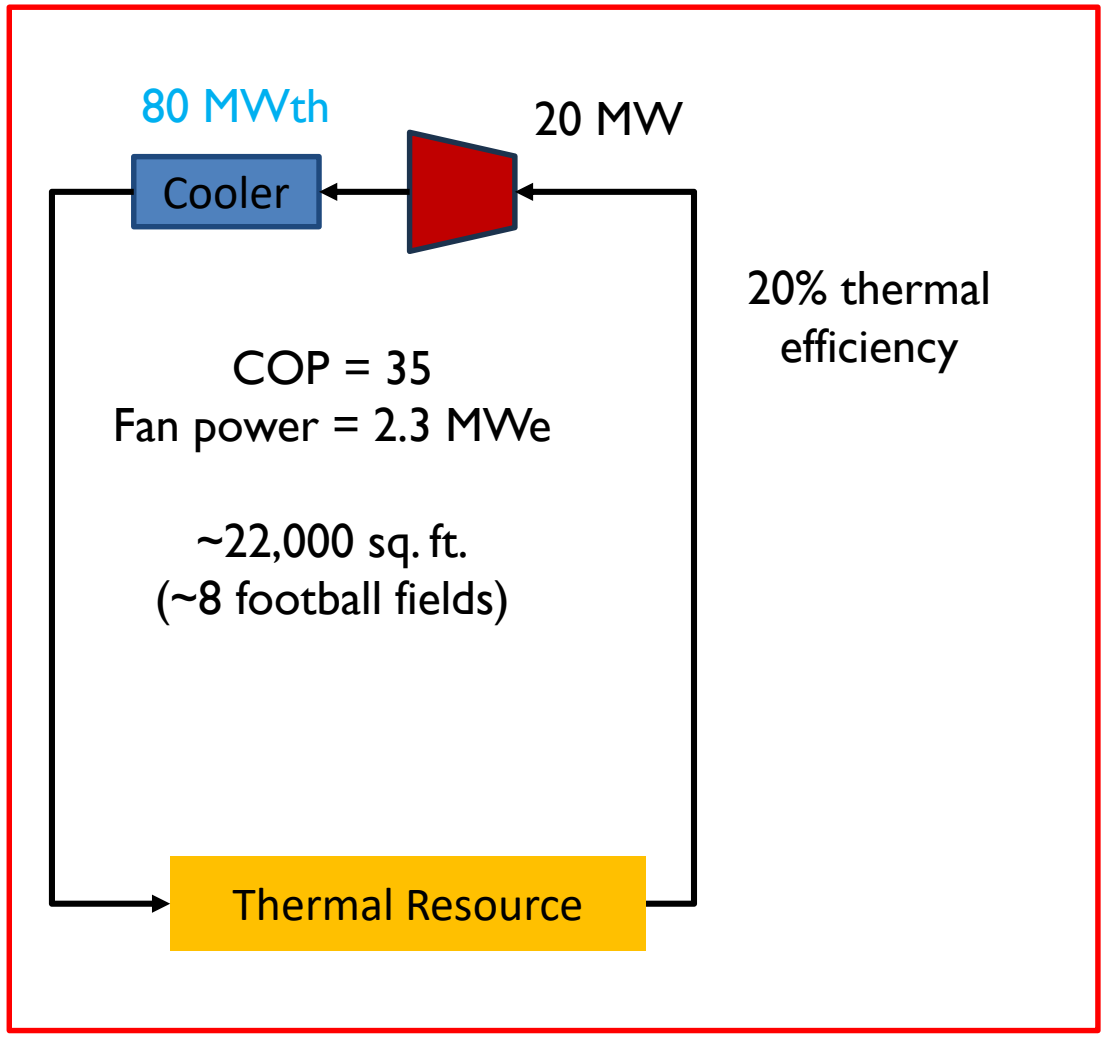
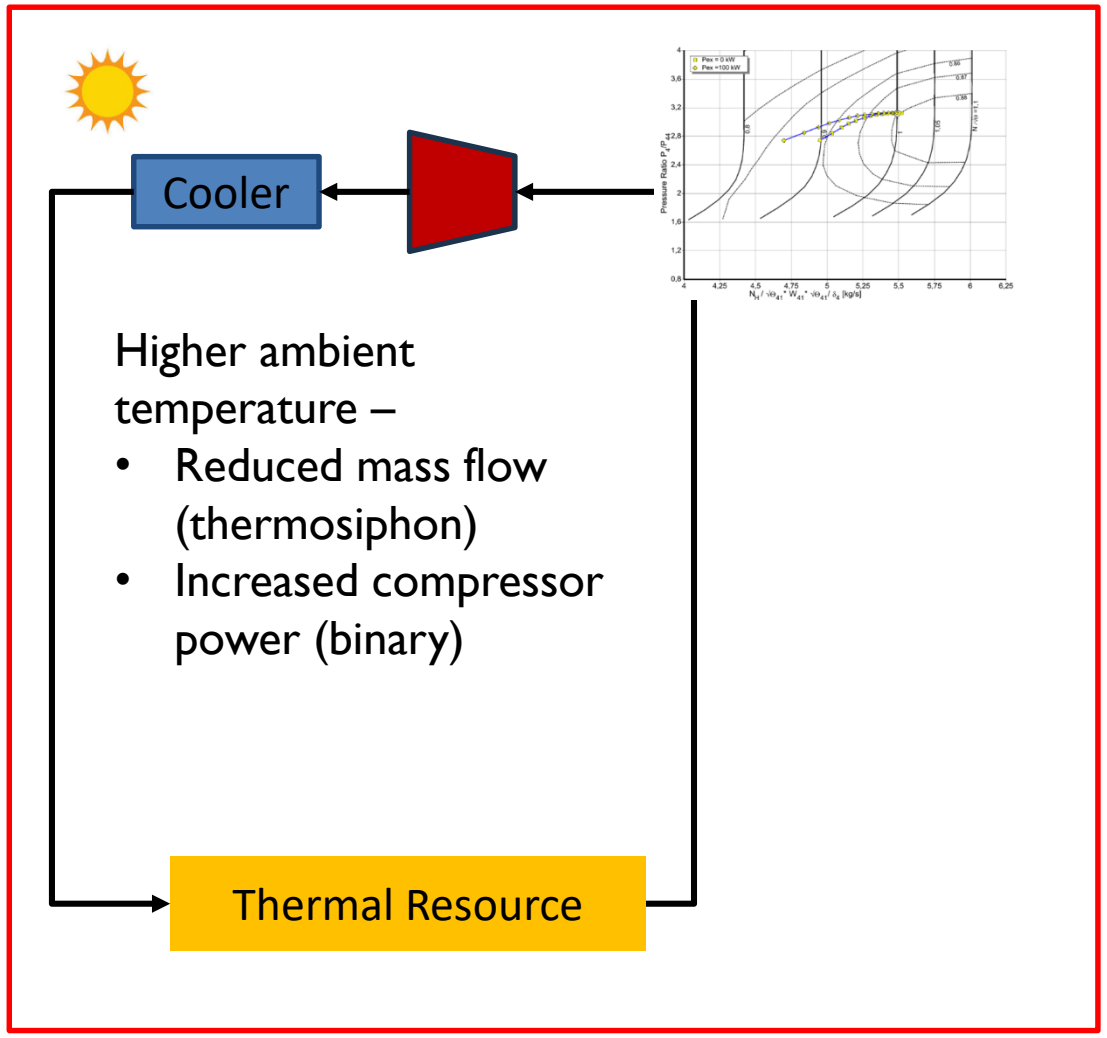


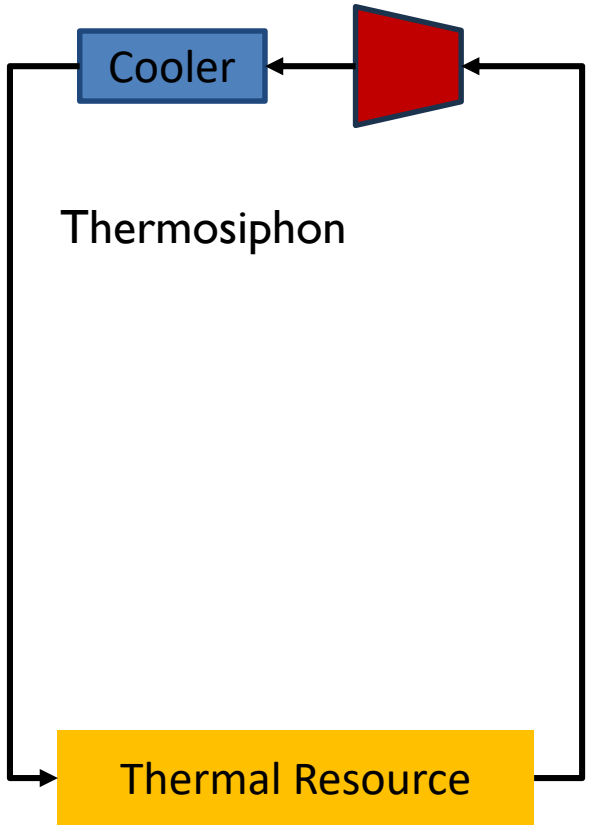
The Boring (but Important) Things

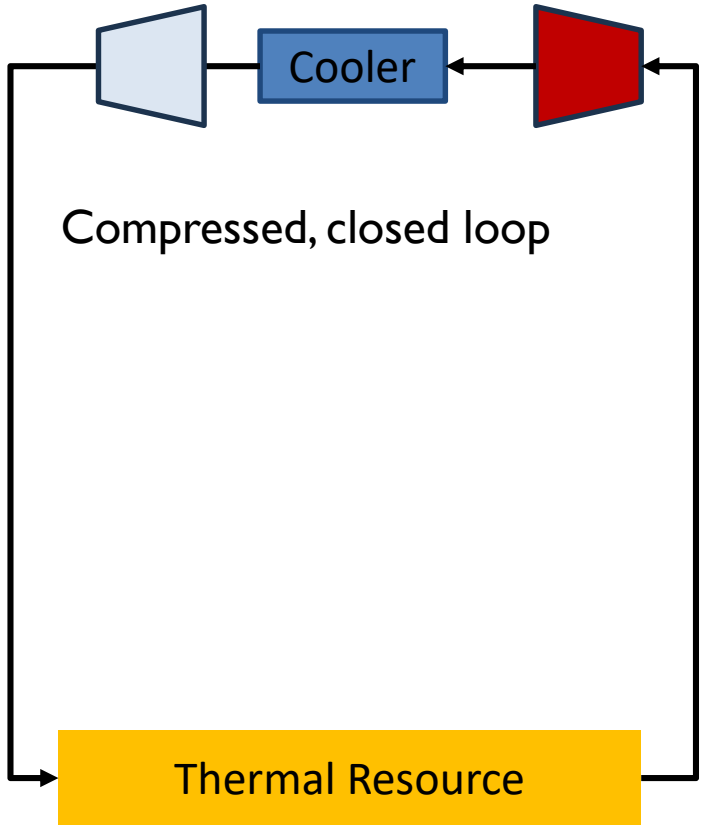
- Power cycle dependent on fluid temperature at surface, not formation temperature
- Cooling parasitic & footprint
- Plant considerations:
  - Off-design plant control / inventory management
  - Transients / part load / maintenance
  - Plant adjustment as the well temperature depletes
- Well control: similar risks to sequestration, leak detection

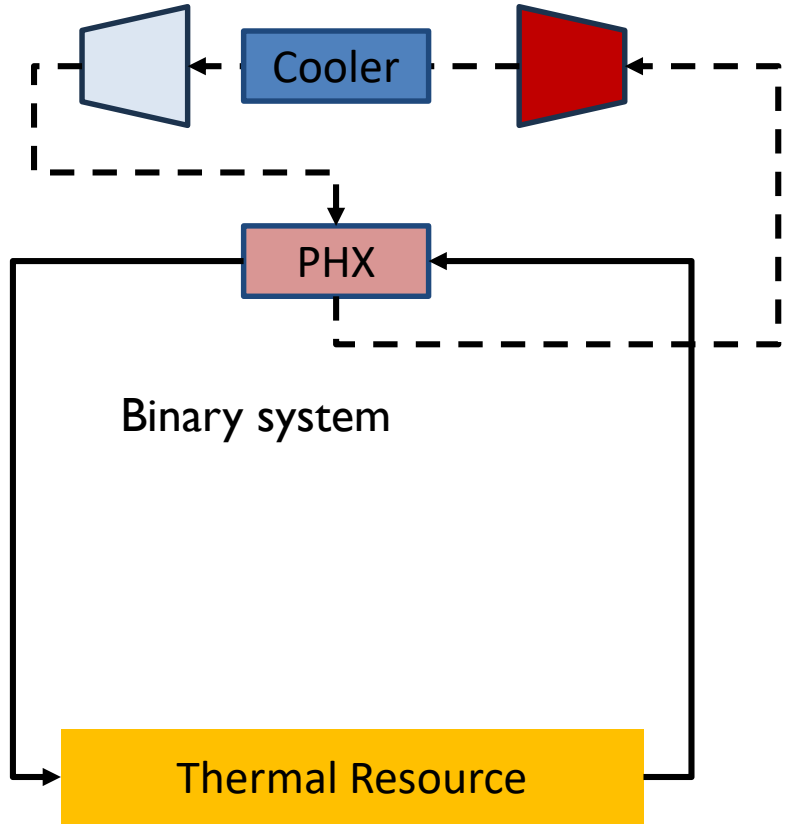


Application Space

- Hot dry rock, closed loop cycle, semi-closed loop cycle, binary cycles, pumped hydro

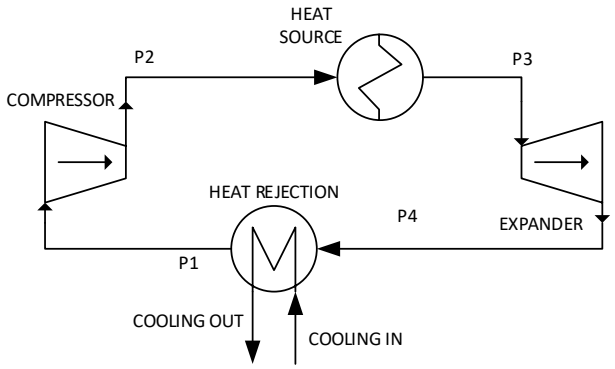


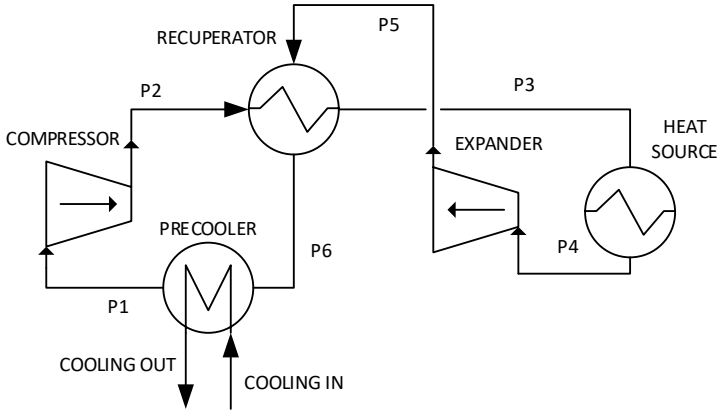


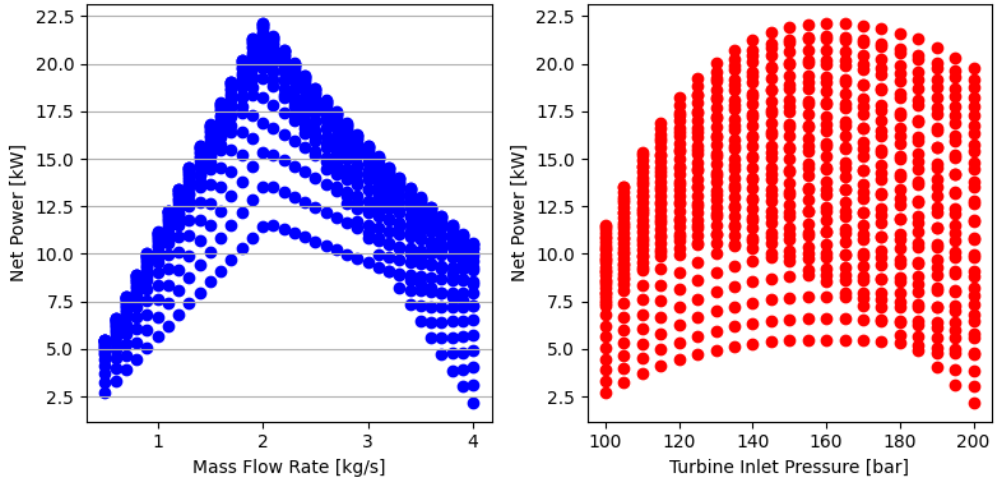


Current Geothermal Efforts at SwRI

- Internally funded project – **Geothermal Power in Texas** (w/ UT Austin)
  - Wilcox / Eagle Ford / Austin Chalk Play
  - Considering different cycle architectures & working fluids for geothermal power based on the subsurface conditions
  - Downselect >> machinery sizing & conceptual design
  - Technoeconomic analysis







Thank you.

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- Nielson, J.T., Smith, N.R., Katcher, K.M., Allison, T.A., and Marshall, M. "Novel Power Con-version to Utilize sCO2 Natural Convection for Low-Grade Waste Heat Recovery," in Proceedings of ASME Turbo Expo 2020, June 22-26, 2020, London, England. Paper No. GT2020-15416.
- Katcher, K.M., Marshall, M., Smith, N.R., and Replogle, C. "Estimated Cost and Performance of a Novel sCO2 Natural Convection Cycle for Low-Grade Waste Heat Recovery," in Proceedings of The 4th European sCO2 Conference for Energy Systems, March 22-26, 2021, Prague, Czech Republic. Paper No. 2021-sCO2.eu-156.
- Katcher, K.M., Allison, T., Marshall, M., and Smith, N. "Low-Cost, Low-Grade Waste Heat Recovery Using sCO2 Natural Convection," in Proceedings of The 7th International Super-critical CO2 Power Cycles Symposium, February 21-24, 2022, San Antonio, Texas. Paper No. 88.

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