Geopressured Geothermal Systems: From Concept to Implementation

Sage Geosystems

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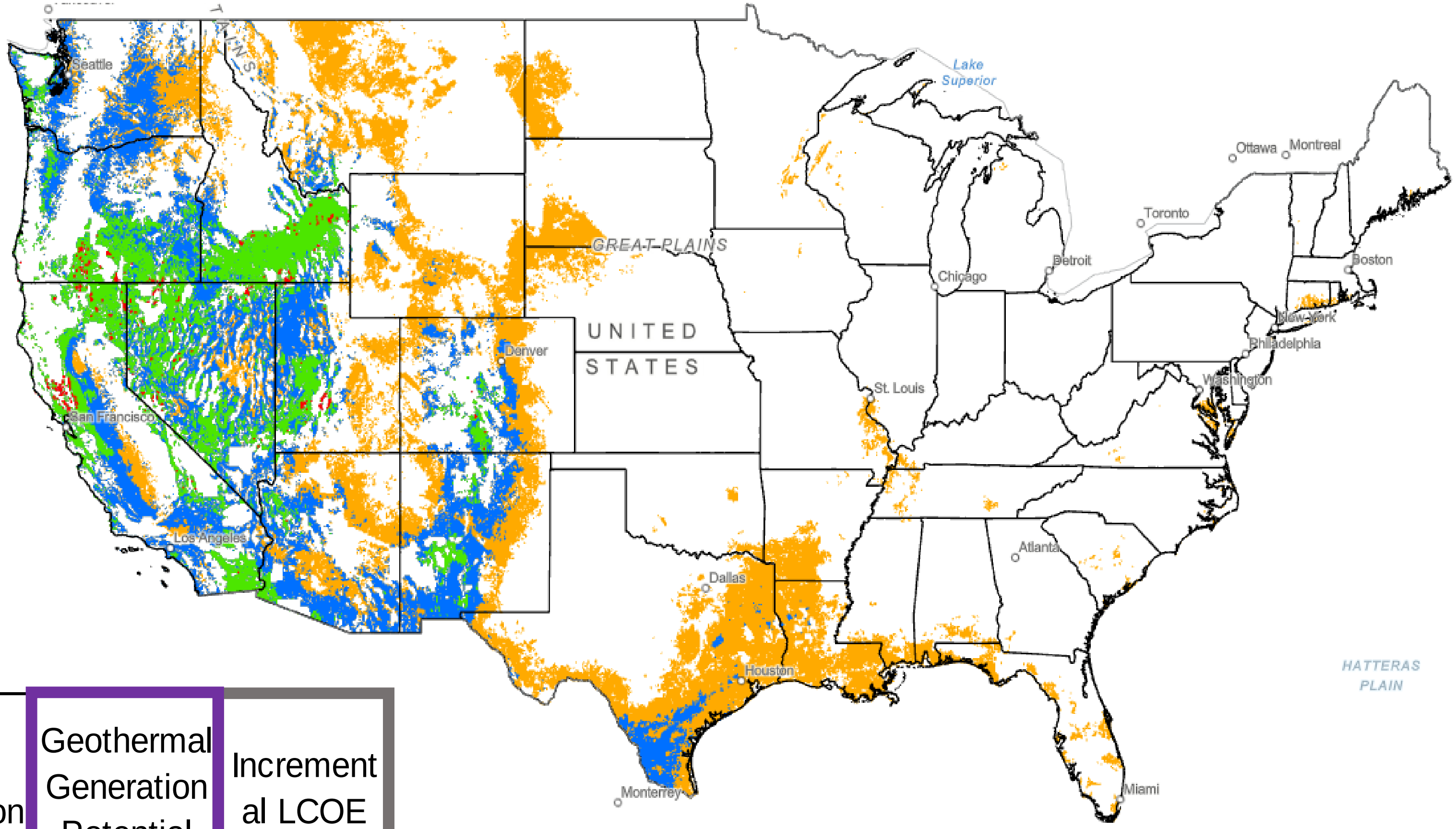
Agenda

- USA Geothermal Potential – big but deep
- Impedance as a barrier to EGS
- Geopressured Geothermal System solves impedance challenge, but can we handle pressure?
- Binary Power Plant: sCO_2 Brayton Cycle

Geothermal Generation Potential by Depth

- **Geothermal potential - ~ 4TW total, including ~ 450GW in Texas at 5-6 km depths.**
- Area utilization - We assumed only 20% market-accessible area after removing mountainous areas and national parks (conservative approach).
- Incremental LCOE above Base cost - Accounts for the additional drilling and power plant costs with depth.



Depth to 180C (km)	Depth to 180C (ft)	Surface Area (km^2)	Footprint (km^2/MW)	Area Utilization (%)	Geothermal Generation Potential (GW)	Incremental LCOE ($/MWh)
3	9,843.00	13,175	0.16	20%	**16.47**	**Base**
4	13,124.00	525,375	0.16	20%	**656.72**	**+$5**
5	16,405.00	1,029,600	0.16	20%	**1,287.00**	**+$15**
6	19,686.00	1,556,550	0.16	20%	**1,945.69**	**+$50**

* 180°C BHT to account for ~ 10°C loss from subsurface to surface and ~ 10°C "pinch" loss in heat exchanger

Depth to 180°C

Red: 2-3 km
Green: 3-4 km
Blue: 4-5 km
Orange: 5-6 km

Impedance as a Barrier to Successful EGS

What is System Impedance?

Measurement of flow resistance when circulating fluid from wellhead A to B through a subsurface system.

Why is High Impedance Bad?

Can lead to large parasitic losses that reduce system performance and impact economic viability.

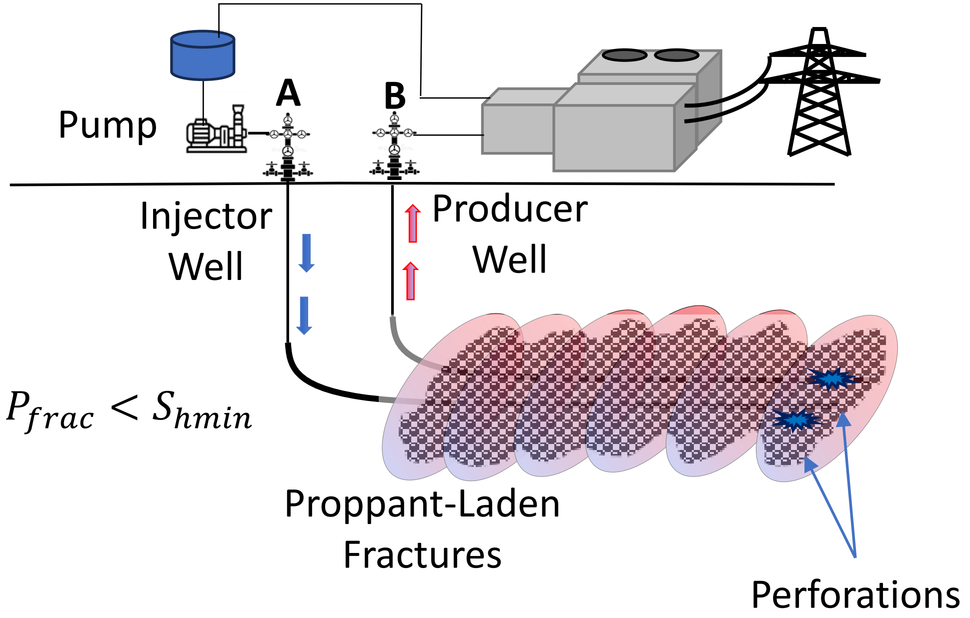
Components Contributing to Impedance:

- **Injection/Production Wellbores**
- **Perforations**
- **Fractures**

Design Challenges:

- **Minimize power lost to Injection Pump overcoming Impedance.**
- **Longer fractures are conducive for Heat Extraction, but longer lengths increase System Impedance.**

Traditional 2-Well Enhanced Geothermal System (EGS)



Parameter	
Flowrate	$50 - 100$ kg/s
Mean Wellhead Fluid Temperature	$150 - 200$ °C
Effective Heat Exchange Area	$2 \cdot 10^6$ m^2
Rock Volume	$> 2 \cdot 10^8$ m^2
Hydraulic Impedance	$< 0.1 \frac{\text{MPa s}}{\text{kg}}$
Water Loss at Surface	< 10 %

**Table according to (Garnish 2002) as cited by E. Schill, A. Genter, N. Cuenot, T. Kohl, "Hydraulic Performance History at the Soultz EGS Reservoir from Stimulation and Long-term Circulation Tests," Geothermics, Vol. 70 (2017) pages 110-124*

Observation from Fenton Hill Experiment

Hot Dry Rock Site at Fenton Hill

A. Impedance reduced when applying backpressure via choke.

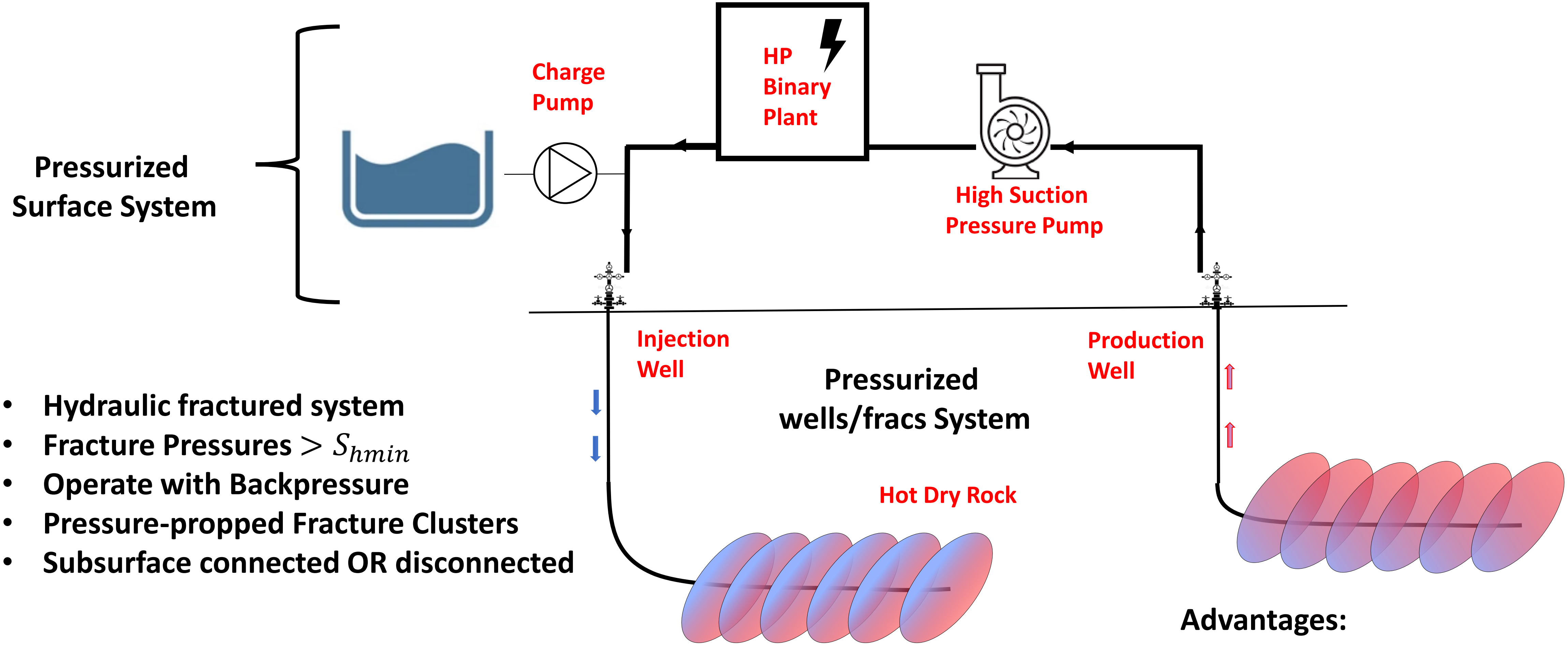
$$\text{Impedance} = \frac{P_{pump} - P_{suction}}{Q_{prod}} \left[\frac{MPa \cdot s}{l}\right]$$

	LTFT	IFT	IFT2	IFT3
	7/28/92	9/29/92	12/10/92	12/27/92
Injection Pressure, MPa (psi)	27.29 (3958)	22.36 (3243)	27.32 (3963)	27.32 (3962)
Production Pressure, MPa (psi)	9.66 (1401)	9.65 (1399)	15.18 (2201)	12.40 (1798)
Production Flow Rate, l/s (gpm)	5.66 (89.7)	3.85 (61.1)	5.34 (84.6)	5.71 (90.5)
Production Temperature, °C (°F)	183 (361)	165 (329)	177 (351)	183 (361)
*Impedance, MPa/l/s (psi/gpm)	3.11 (28.5)	3.30 (30.2)	2.27 (20.8)	2.61 (23.9)

R. DuTeau and D. Brown (1993) *HDR Reservoir Flow Impedance and Potentials for Impedance Reduction*, 18th Workshop on Geothermal Reservoir Engineering, Stanford, CA

B. However, power lost to injection pump increases.

What is a Geopressured Geothermal System (GGS)?



- **Hydraulic fractured system**
- **Fracture Pressures** $> S_{hmin}$
- **Operate with Backpressure**
- **Pressure-propped Fracture Clusters**
- **Subsurface connected OR disconnected**

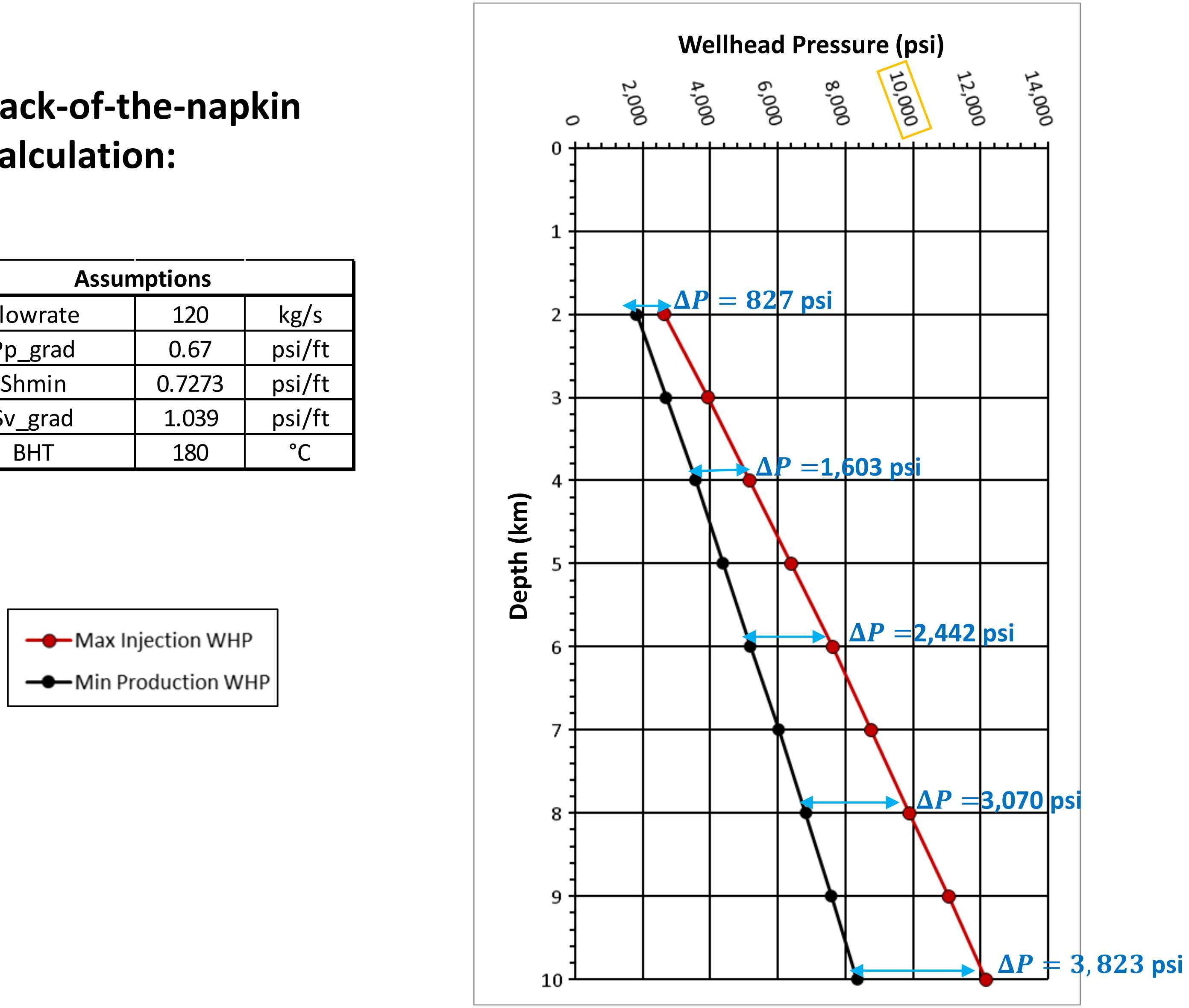
Advantages:
Magnitude reduction in
- Impedance
- Pump parasitic loss

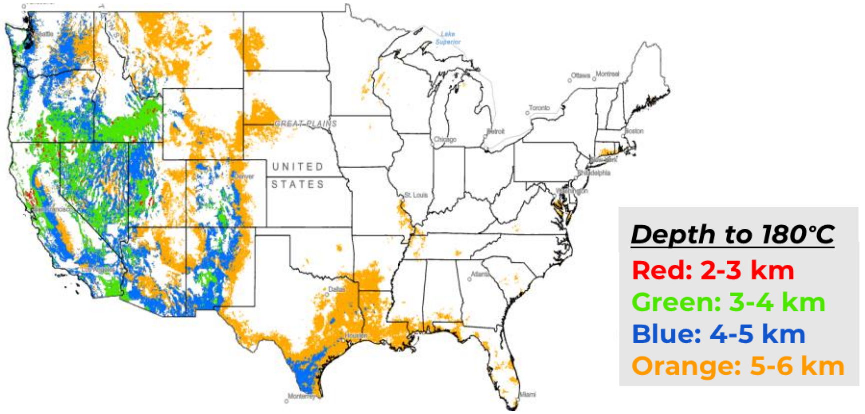
M.A. Rivas, V. McGuire, D. Simpkins, L. Ring, "Geopressured Geothermal Systems: An Efficient and Sustainable Heat Extraction Method," GRC (2024)

Surface Pressure Management Challenge

Back-of-the-napkin Calculation:

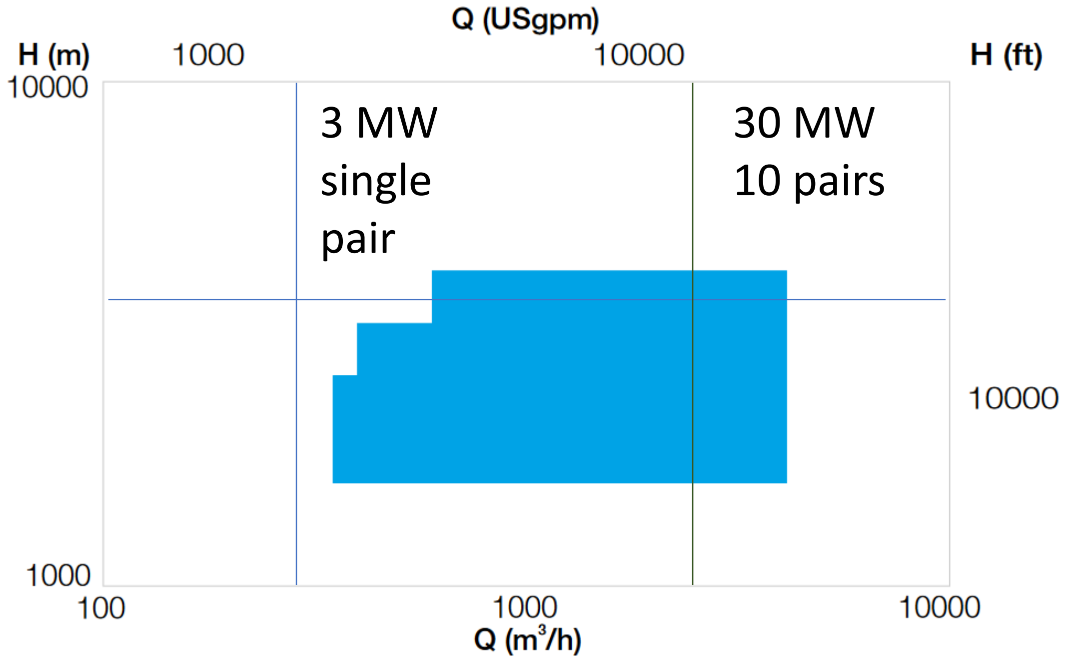
Assumptions		
Flowrate	120	kg/s
Pp_grad	0.67	psi/ft
Shmin	0.7273	psi/ft
Sv_grad	1.039	psi/ft
BHT	180	°C



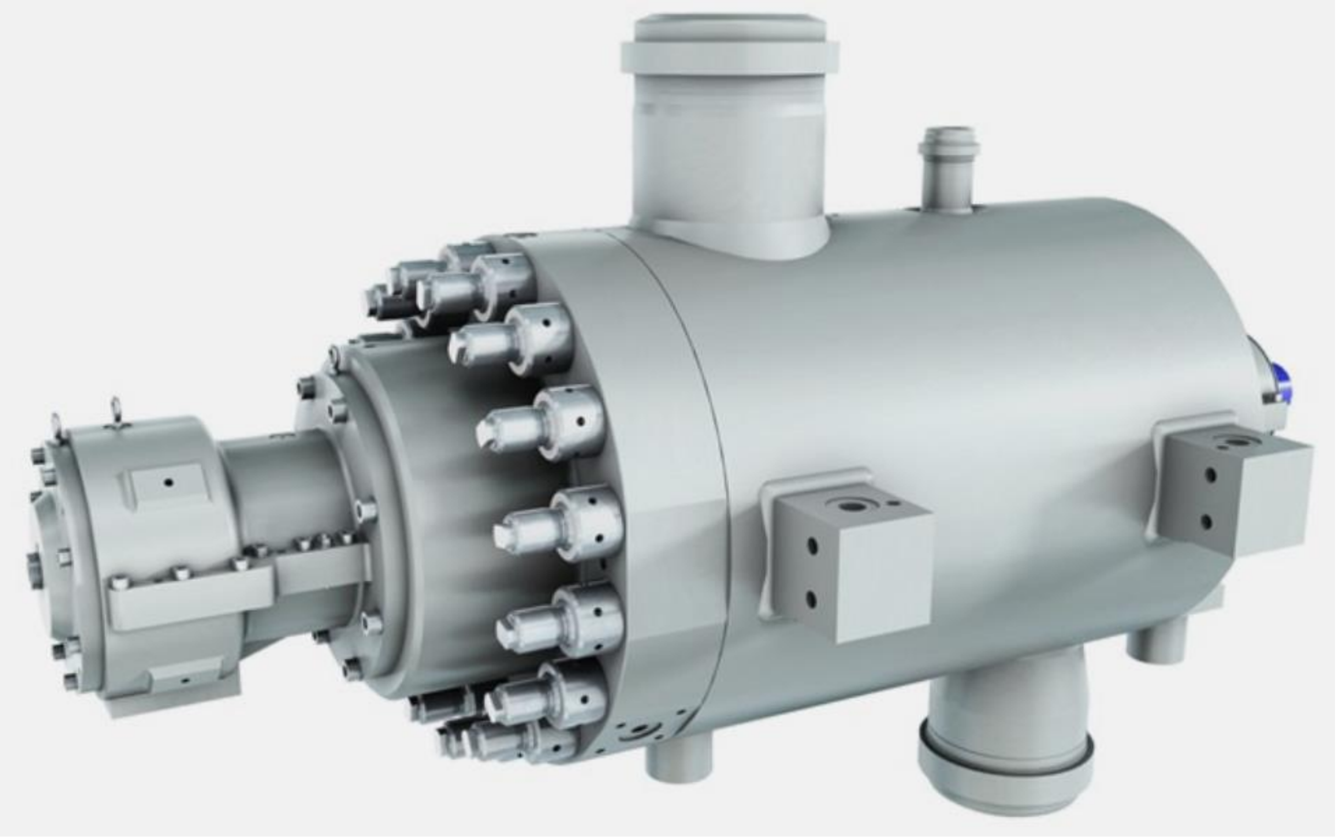


Surface equipment will have to manage 10,000 psi – 15,000 psi pressure

HPT high pressure barrel casing pump



Performance Range

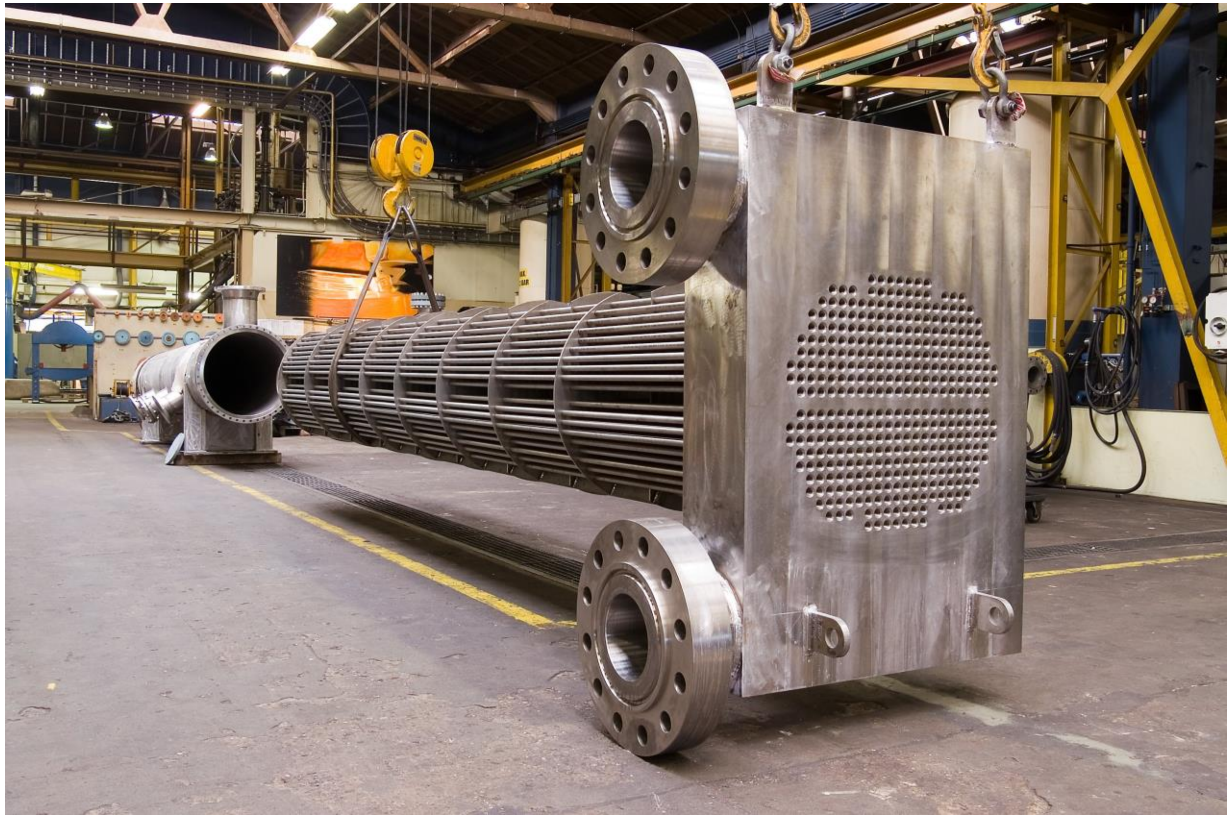


Maximum rated

- *Head* : 4,200 m (13,800 ft)
- *Capacity* : 4,000 m3/h (17,600 US gpm)
- *Pressure* : 54.5 MPa (7,905 psi)
- *Temperature* : 220 °C (430 °F)

[HPT high pressure barrel casing pump | Sulzer]

Bronswerk Heat Exchanger

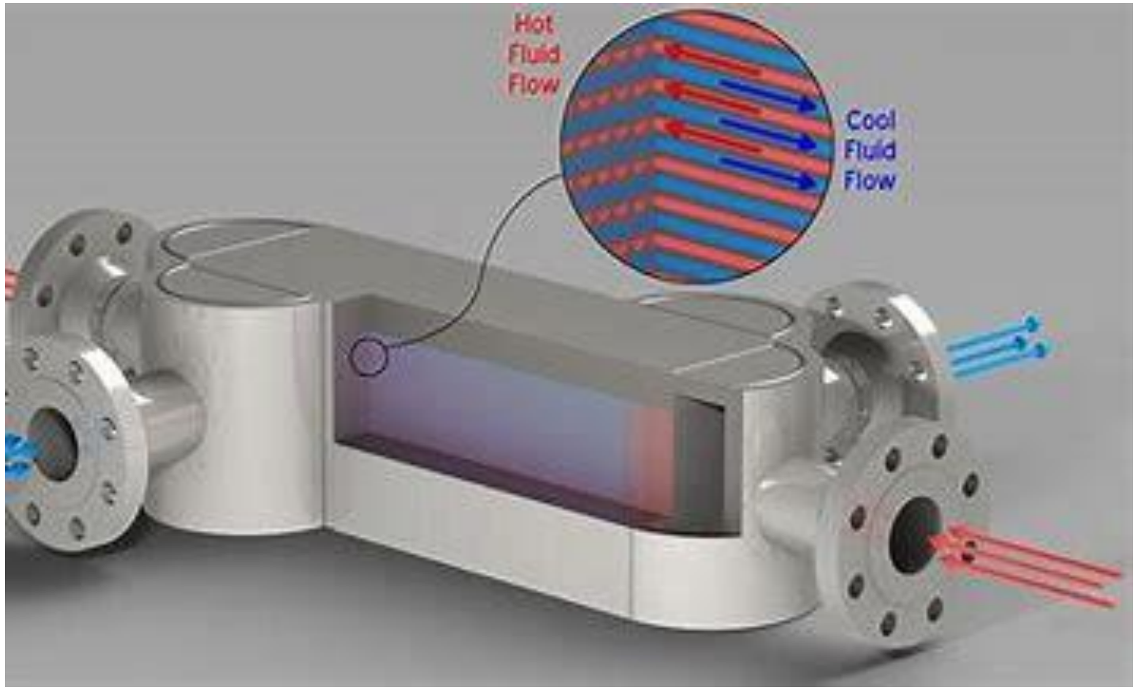


Up to 14,000 psi

- O&G processes have HPHX but are inefficient
- Example of magnitudes to work with: →
- There's opportunity to improve efficiency

		m	P		T
		kg/s	MPa	psi	°C
Working Fluid	In	120	2.07	300	70
	Out	120	1.38	200	178
Well Fluid	In	120	103.42	15,000	188
	Out	120	102.73	14,900	75

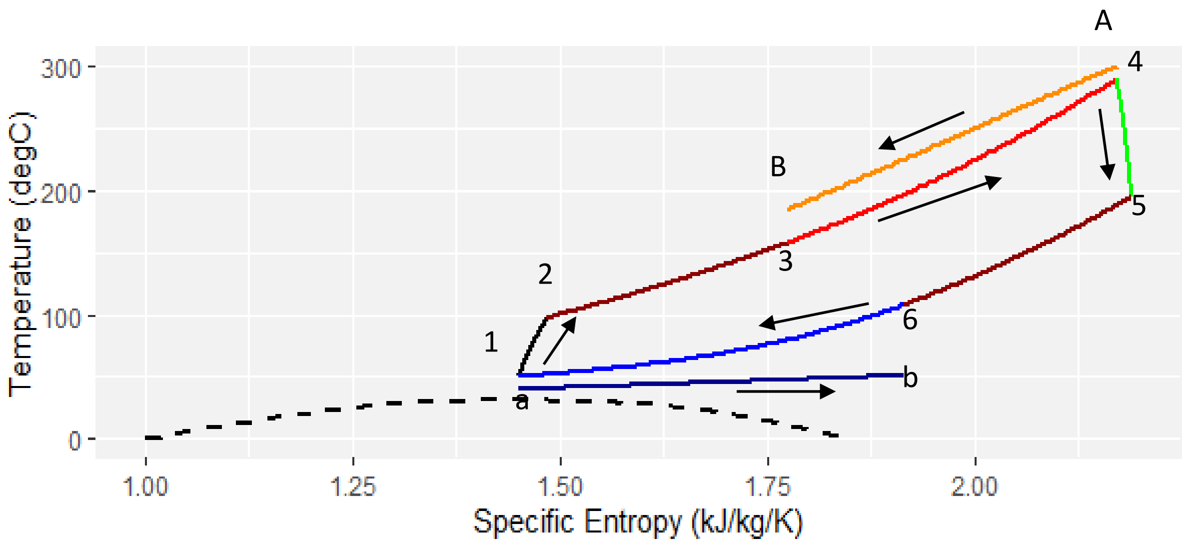
Need for Innovative Heat Exchanger Technologies

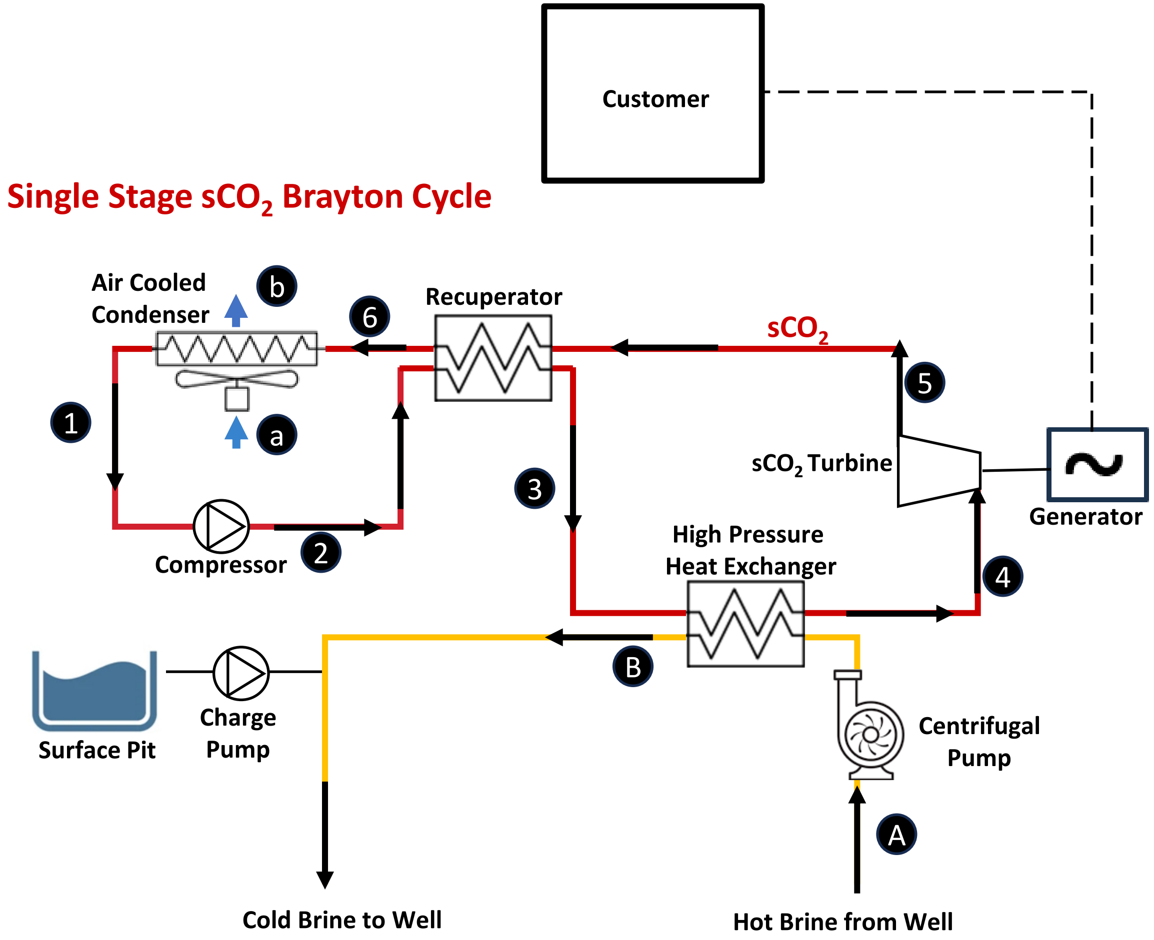


Specialized heat exchanger for:
- High Pressure
- Low temperature

Goals:
- 50X smaller
- 5X cheaper
- 30% higher efficiency

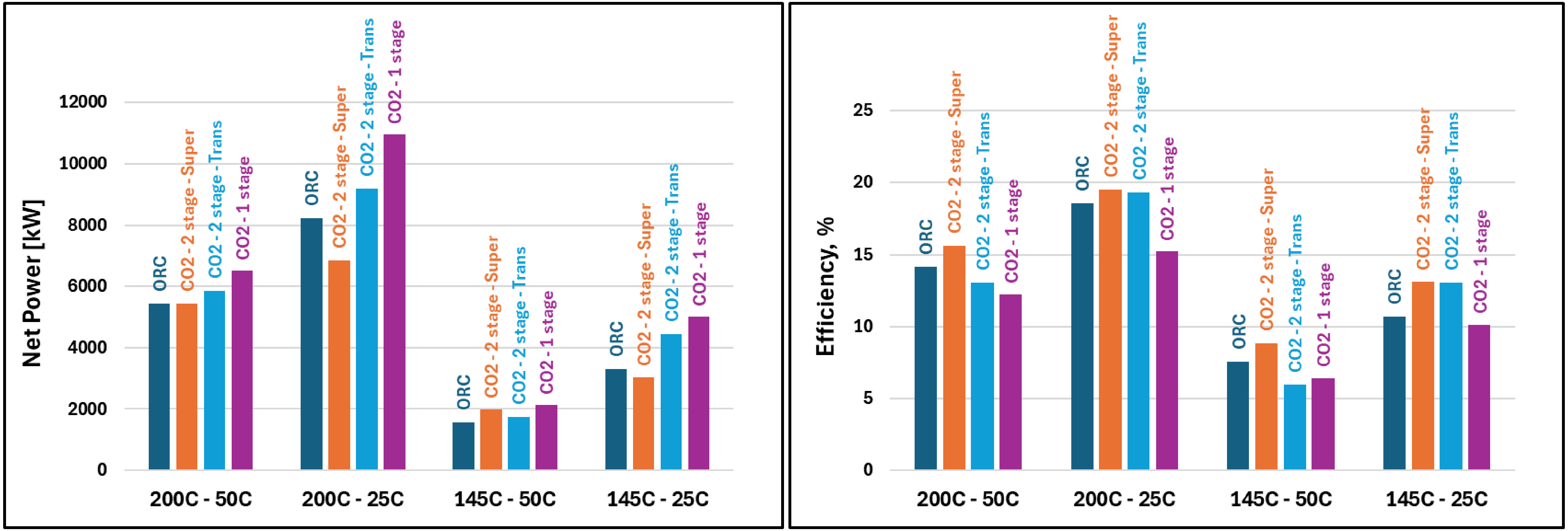
Binary Power Plant: sCO2 Brayton Cycle





- More thermally efficient than ORC
- Stable and environmentally friendly
- Low maintenance
- Zero emissions
- Smaller size components

sCO2 Delivers more Net Electricity!



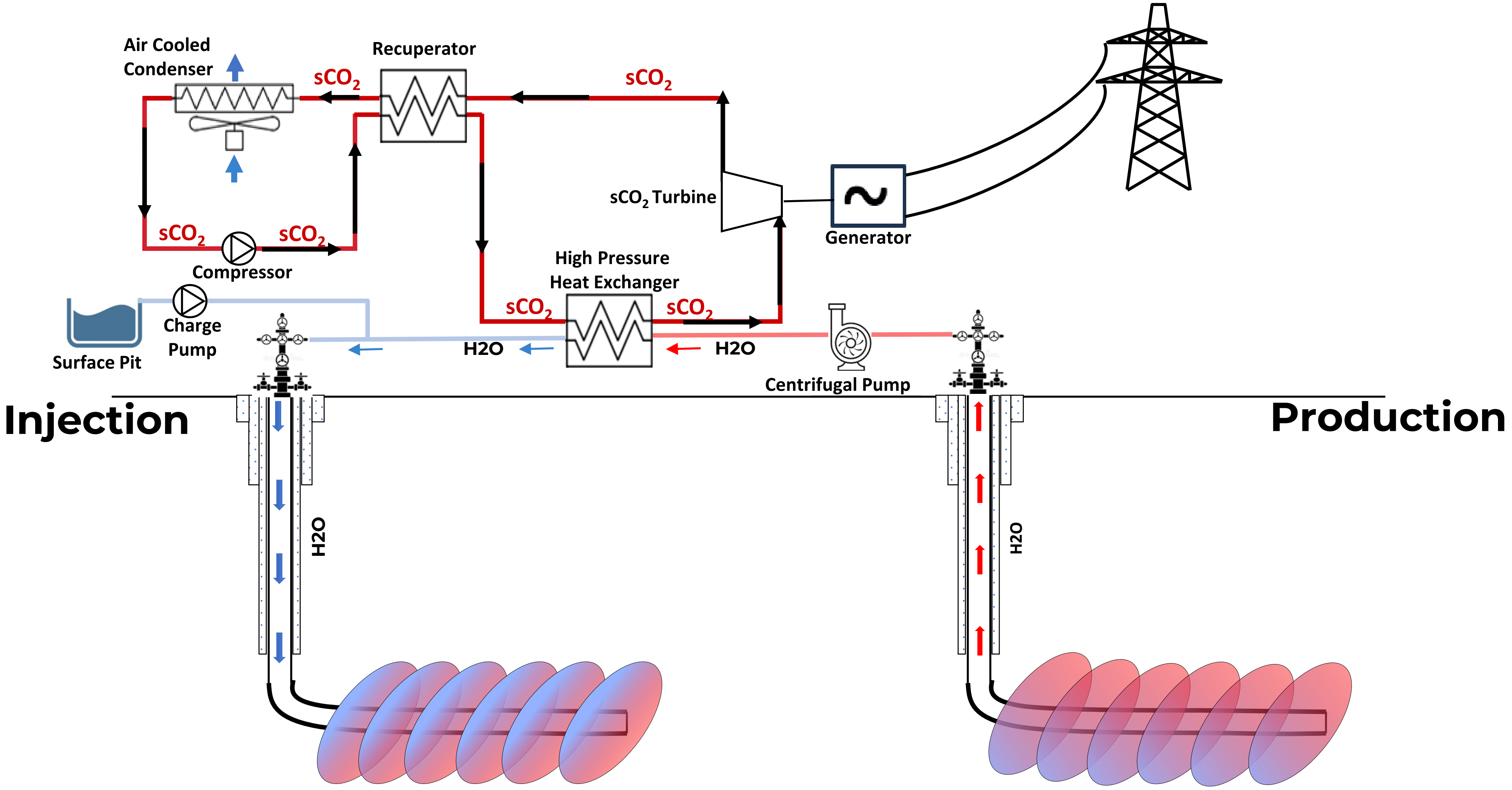
sCO2 Brayton cycle provides maximum net power output for the entire geothermal temperature application range

Supercritical CO_2 Turbine

Cheaper to build and delivers more electricity

- Full-size 3MW prototype sCO_2 turbine
- Compared to Organic Rankine Cycle (ORC) turbines used today:
  - **Less cost due to small size**
  - **Delivers more electricity**
- Sage owns IP on sCO_2 turbine
- Successful load test in Sep'24

GGS with sCO2 Binary Plant



Conclusion

When subsurface/surface systems are both pressurized

- Need for HPHX
- Need for HSP pump
- Trading efficiency for reducing impedance.
- Eliminates wasteful venting of pressure at production side.

- Full-size 3MW prototype sCO_2 turbine (SwRI/Sage)
- It is feasible to build this surface kit.