Supercritical CO_2
Power Cycles
Symposium

Techno-Economic Analysis of a Geothermal sCO2 Thermosiphon Power Plant

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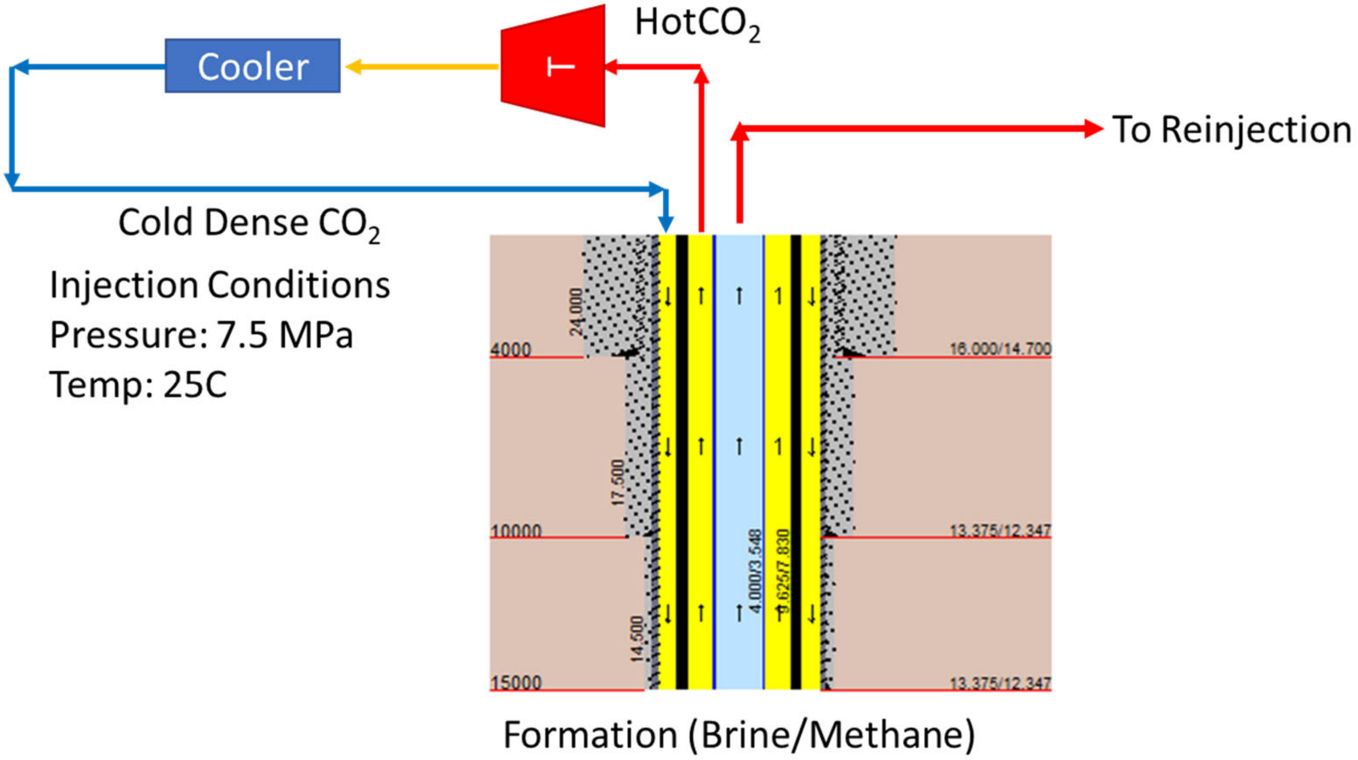
Background



Injection Conditions
Pressure: 7.5 MPa
Temp: 25C

Assumptions

- Heat Transfer occurs between each fluid barrier
- Estimate Geothermal rock temperatures at each depth
- Simulations sets a flow rate and the output is a pressure ratio for the turbine (physical reality is the opposite)
- Dry bulb temperature of 35 C and wet bulb of 21.5 C

Thermosiphon Model

- Discretized Energy Model (forward Stepping)
- Enthalpy: $\Delta H = \ g\Delta z + Q$

Head

Heat Transfer

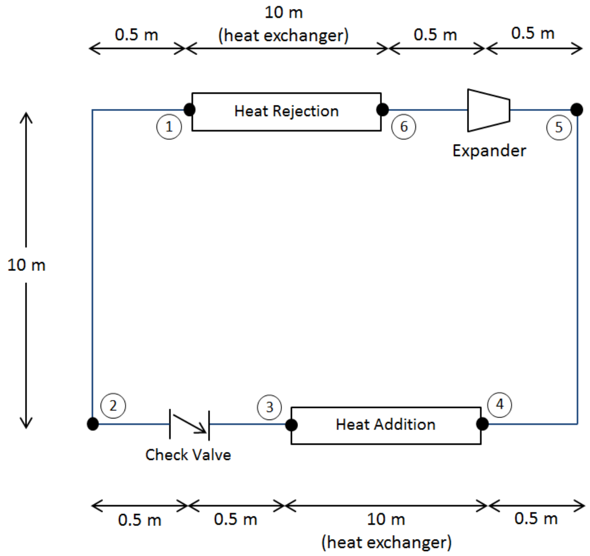
- Pressure: $\Delta P = \rho g \Delta z - \Delta P_f$

Head

Pipe Losses

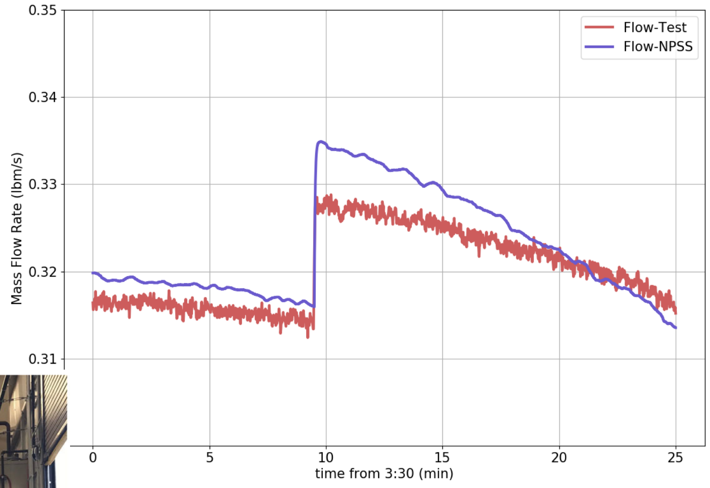
Atrens, Al.; Gurgenci, H.; Rudolph, V. CO_2 Thermosiphon for Competitive Geothermal Power Generation. *Energy Fuels* 2009, *2009*, 553–557

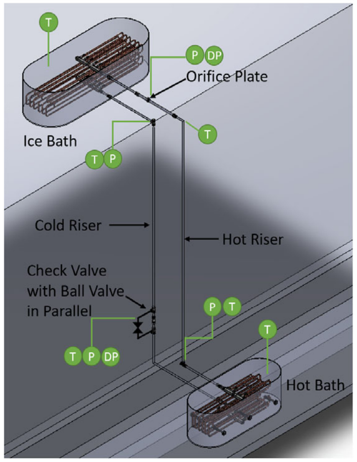
Model Validated With Flow Loop



State Point	Property	Value
1 - Cooler Outlet	Temperature	32°C
4 - Heater Outlet	Temperature	60°C
6 - Expander Outlet	Pressure	8.5 MPa

Pipe Inner Diameter = 73.66 mm (NPS3, Sch. 80)





Turbine Work and Cooler Duty

- Turbine Work:

$$\dot{W}_{Turbine} = \dot{m}\ (h_{turbine_{in}} - h_{turbine_{out}})\eta_{turb}$$

Current Study assume 85%

- Cooler Duty:

$$\dot{Q}_{Cooler} = \dot{m}(h_{turbine_{out}} - h_{injetion})$$

LCOE Calculation

Estimated from Quotes and Piping Costs

Estimated as $0.014/kWh

$$LCOE = \frac{(Capital\ Cost * CRF) + fixed\ O\&M\ cost}{8760 * Capacity\ Factor} + Variable\ O\&M\ cost$$

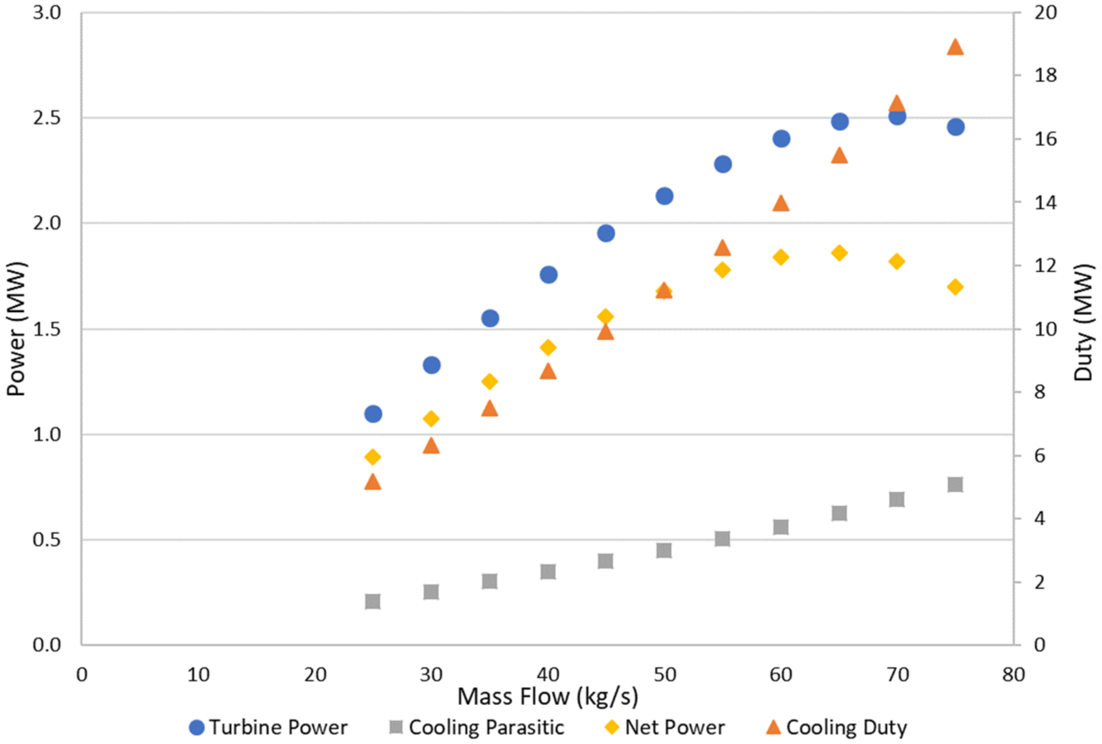
Estimated as 90%

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

i assumed as 8%
n assumed as 30 years

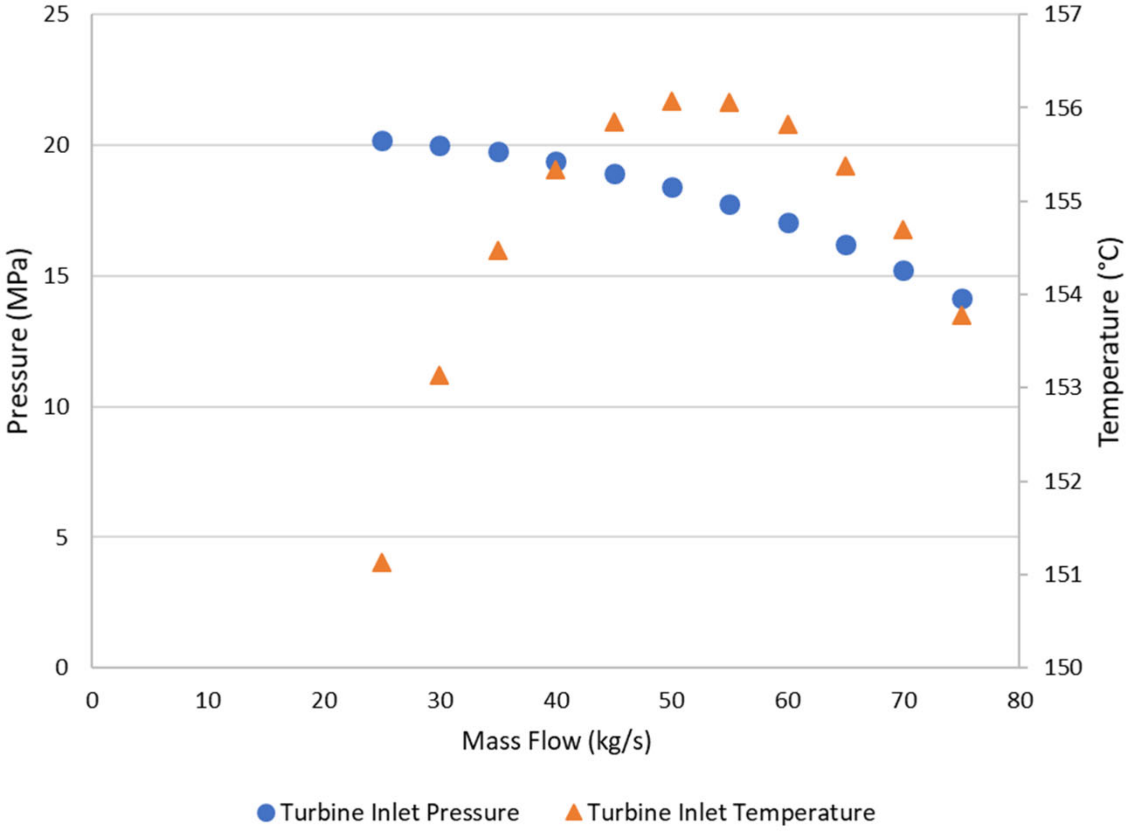
Results

- Power has a parabolic curve that increases with flow rate until pipe losses become significant
- Max turbine power and net power occur at different flow rates
- Cooling power and parasitic are non-linear but increase with flow rate



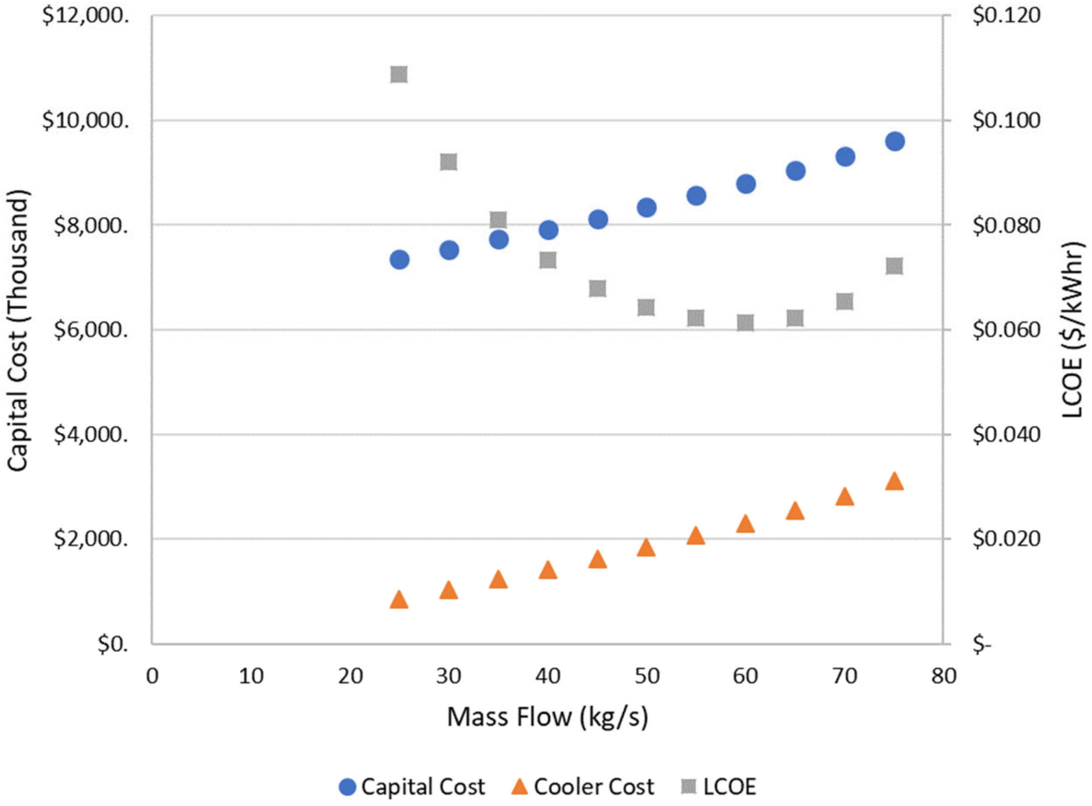
Results

- Temperature is parabolic, but the problem is not significantly heat transfer limited
- Turbine inlet pressure decreases with increased mass flow rate due to pipe losses

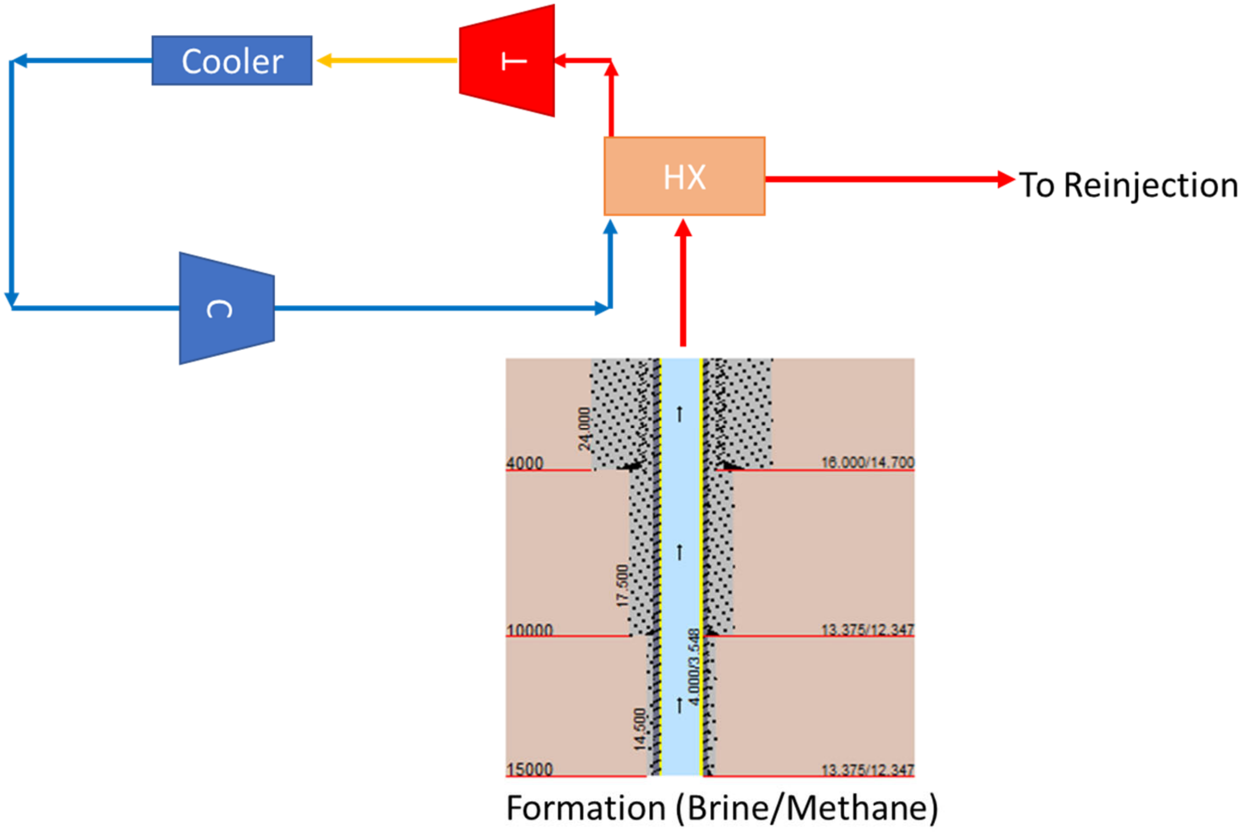


Results

- Capital cost of the surface equipment is linear and is driven by the cost of cooling equipment
- LCOE is parabolic and has a minimum different than both turbine power and net power



Binary Plant Comparison



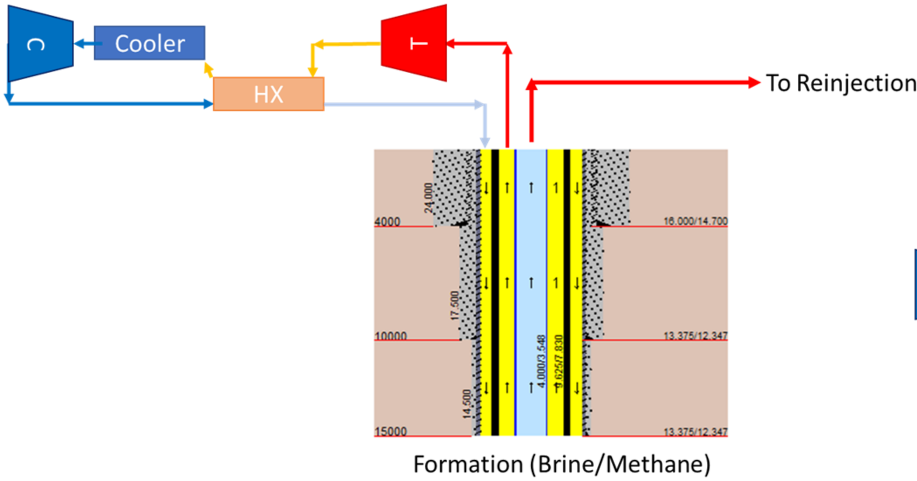
Differences

- Smaller well drilling costs
- Less downhole pipe costs
- Surface equipment utilizes a compressor/pump and a heat exchanger
- Added parasitic cost for compressing the CO_2 at the surface

Thermosiphon vs. Binary Plant

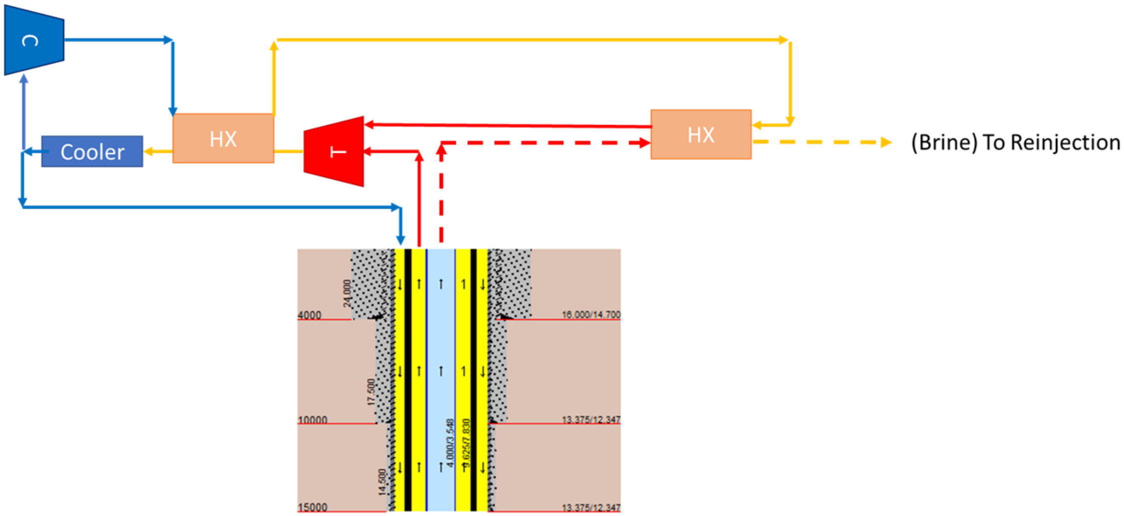
	Binary Pump	Binary Compressor	Thermosiphon
Turbine Power (kW)	5133	4199	2404
Pump Power (kW)	2503	2678	0
Cooling Duty (kW)	19857	15353	13978
Cooling Parasitic (kW)	839	649	591
Net Power (kW)	1791	872	1813
Compressor/Pump	$2,000,000	$650,000	$ -
Heat Exchanger	$ 930,008	$ 678,734	$ -
Turbine	$ 1,300,000	$ 1,300,000	$ 1,000,000
Cooler	$ 3,266,519	$ 2,525,601	$ 2,299,411
Well	$ 3,500,000	$ 3,500,000	$ 5,500,000
Total	$ 10,996,527	$ 8,654,335	$ 8,799,411
LCOE $/kW-hr	$ 0.077	$ 0.128	$ 0.062

Alternate Cooling Strategies

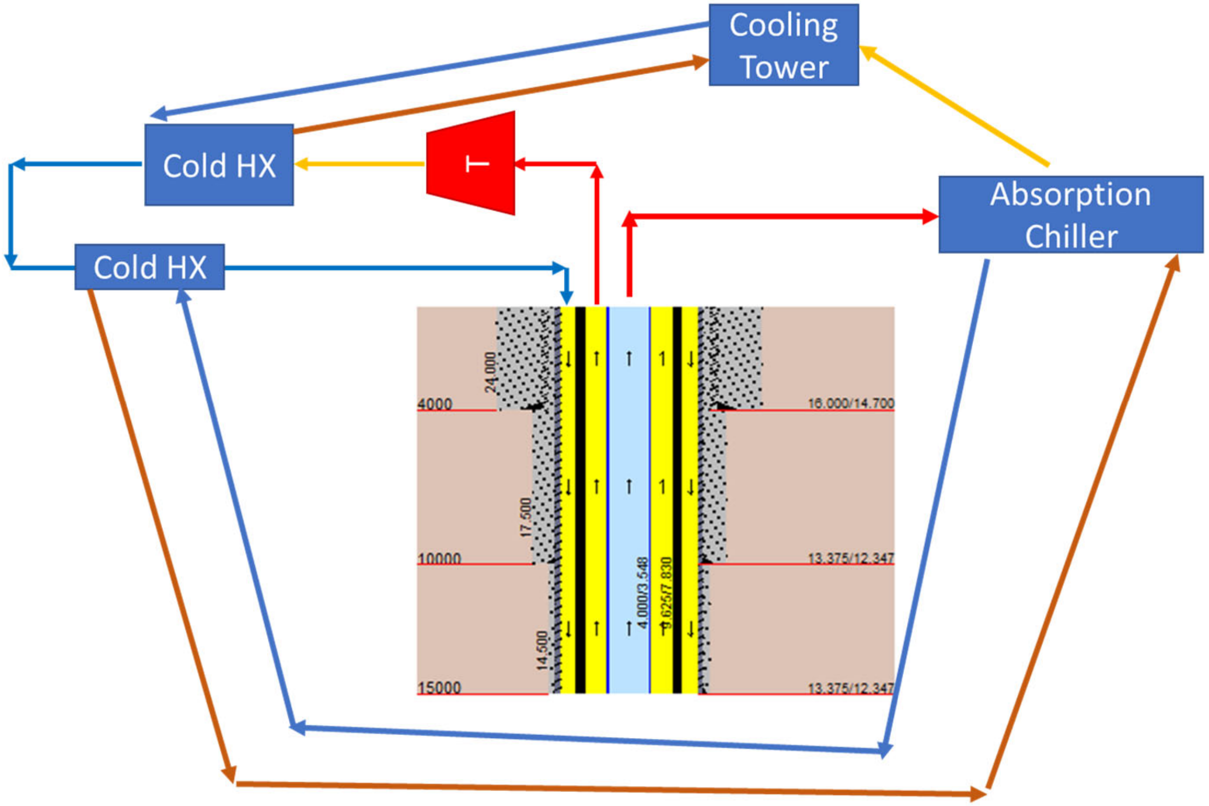


Recuperation

Bottoming Cycle



Absorption Chiller

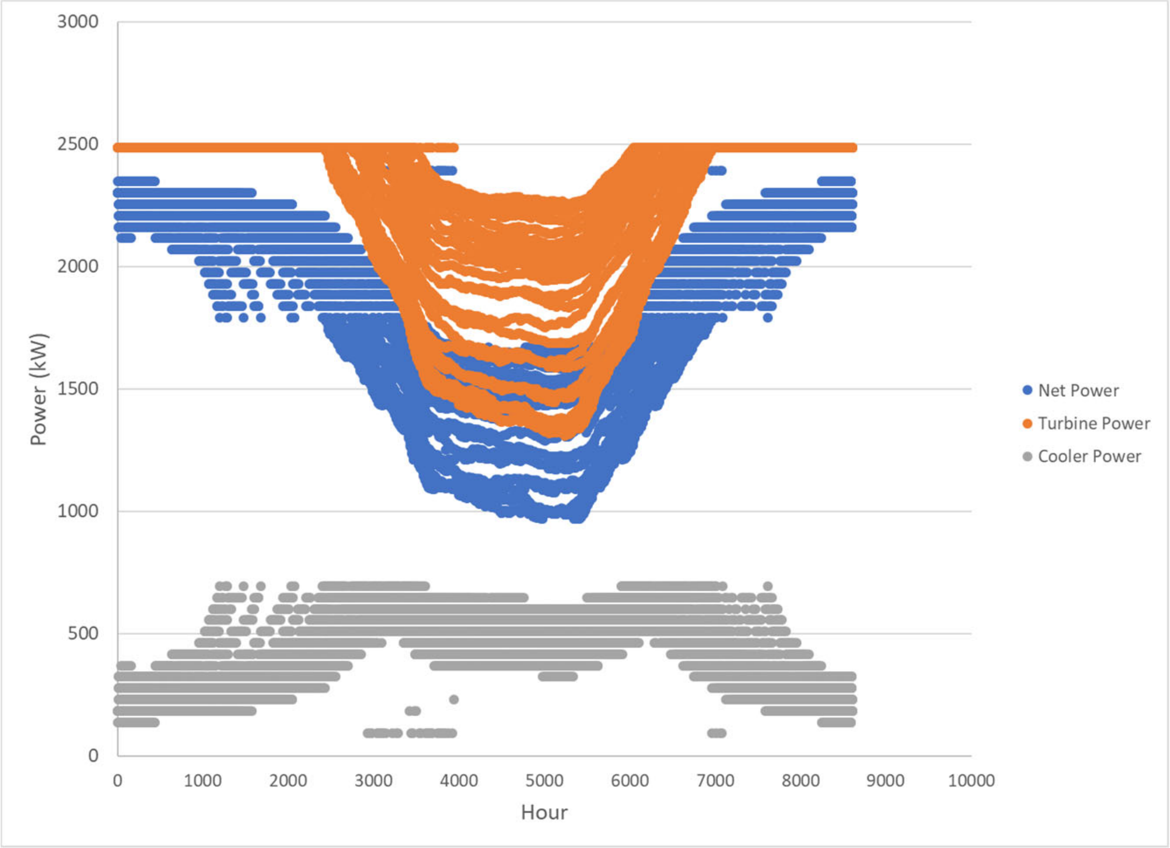


Alternate Cooling Strategies

	Capital Cost Turbine	Capital Cost Cooling	Capital Cost Well	Total Cost	Net Power (kW)	LCOE/kW-hr
Baseline Thermosiphon	$ 1,000,000	$ 2,299,411	$ 5,500,000	$ 8,799,411	1,813	$ 0.062
Absorption Chiller	$ 1,000,000	$ 1,500,508	$ 5,500,000	$ 8,000,508	1,753	$ 0.059
Recuperator	$1,000,000	$ 2,716,525	$ 5,500,000	$ 9,216,525	1,300	$ 0.091
Absorption/Recuperator	$ 1,000,000	$ 1,200,327	$ 5,500,000	$ 7,700,327	960	$ 0.105
Bottoming Cycle	$ 1,600,000	$ 4,008,620	$ 5,500,000	$11,108,620	1,758	$ 0.079
Refrigeration Cycle	$ 1,000,000	$ 2,098,981	$ 5,500,000	$ 8,598,981	1,580	$ 0.070

Current Work

- Developed reduced order models to simulate a year long operation with varying ambient conditions
- Identify how the power output changes over the year
- Get a better LCOE estimate and better comparison of different cooling strategies
- Currently working on a turbine design



Conclusions

- Initial estimates for the geothermal sCO_2 thermosiphon show competitive LCOEs for both renewables and fossil fuels
- Cooling strategies will be (both size and cost) will have a large impact on LCOE
- Binary plants show higher LCOEs but move engineering challenges to the surface compared to downhole.
- Peak turbine power (70 kg/s), peak net power (65 kg/s) and minimum LCOE (60 kg/s) all occur at different flow rates.

Thank you!