USING SUPERCRITICAL CO_2 FOR CLOSED-LOOP GEOTHERMAL

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Introduction

- Geothermal provides renewable baseload power that balances intermittent wind and solar

- There are many hydrothermal installations, but the full value of geothermal is constrained by
  - Water usage
  - Seismic activity
  - Exploration risks (i.e., dry holes)
  - Thermal depletion

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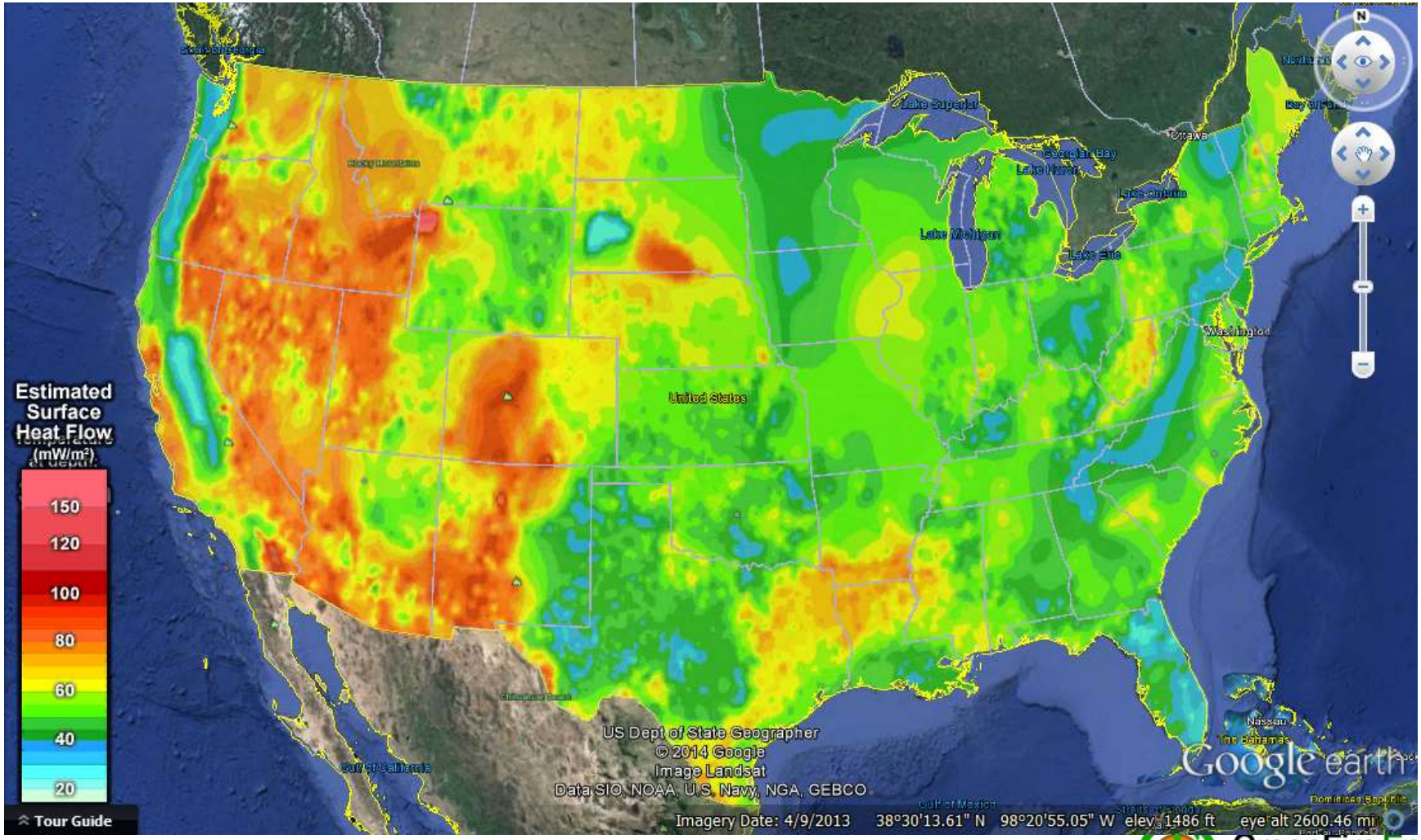
US Geothermal Resources



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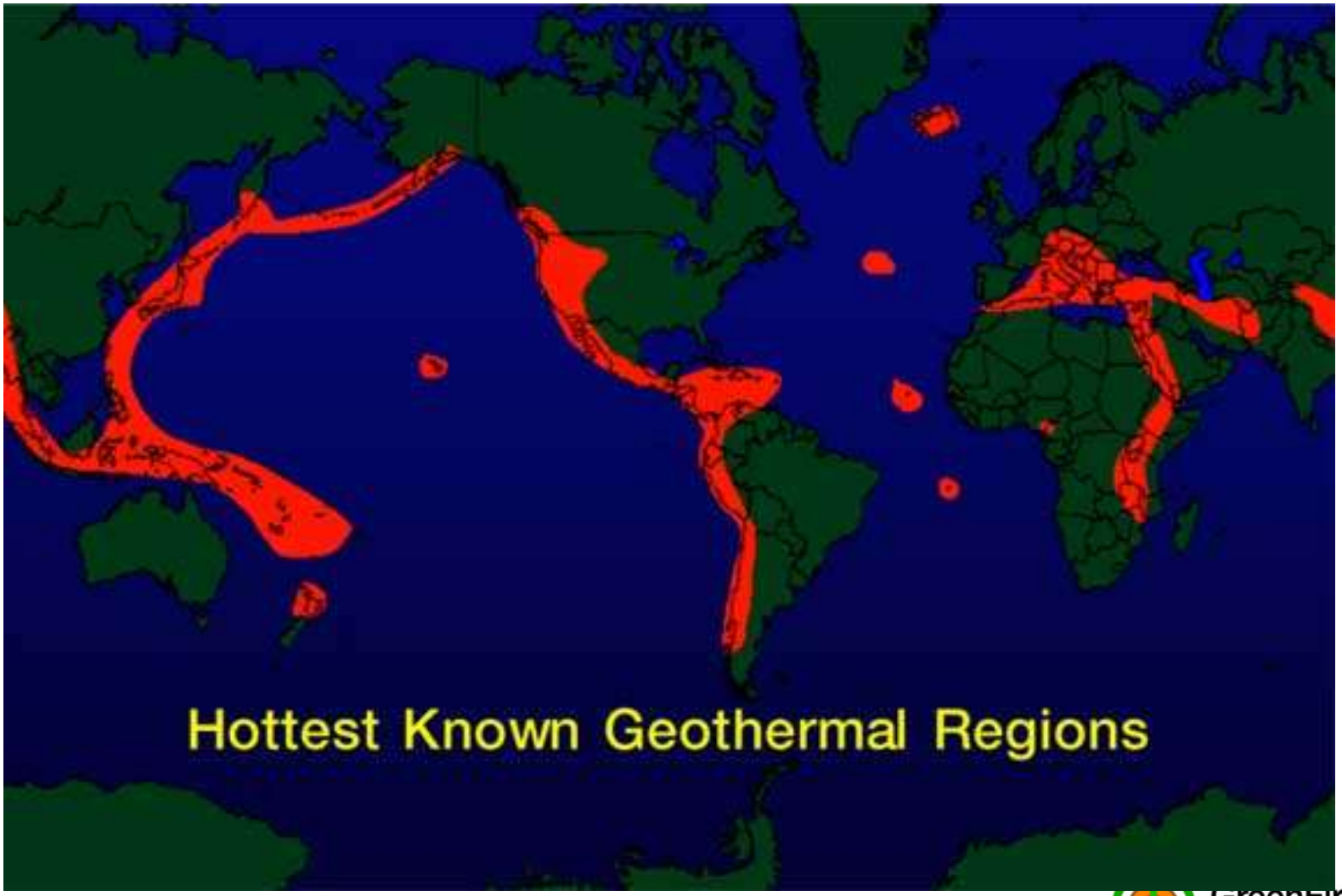
Global Geothermal Resources



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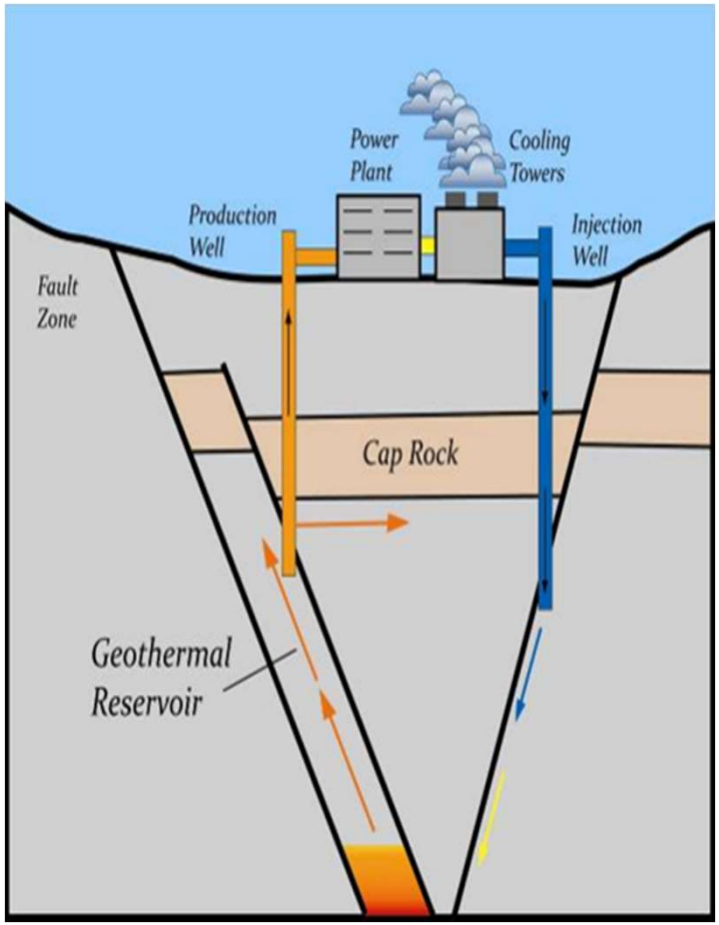
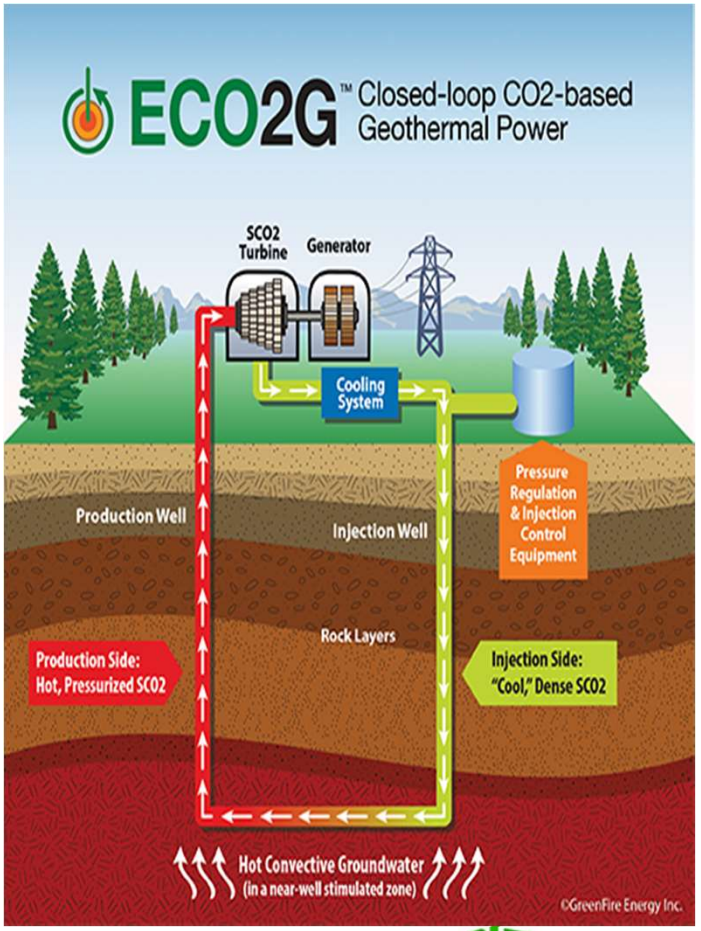
ECO2G

Conventional Hydrothermal



Closed-Loop Supercritical CO_2



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Environmentally Friendly

- No Process Water Required
  - Heat rejection can be air only or hybrid with water
- No Emissions
  - No smog, no contribution to global warming, zero liquid discharge
- No Induced Seismic Activity
  - Nor sinking (subsidence)
- Small Footprint
- Wildlife Preservation
  - Not a hazard to birds, animals, or fish

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Performance Modeling

- 1-D Process Modeling
  - Conservation of mass, momentum, and energy
- 3-D Resource Depletion Modeling
  - CFD modeling of full resource
  - Includes convection within the resource
- Surface Equipment Model
  - Isentropic turbine with specified efficiency
  - Heat rejection as a function of ambient conditions

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Governing Physics for 1-D Model

- Isentropic Compression and Expansion
  - As the gas goes down and up
- Friction
  - Darcy friction factor (Haaland Eq.)
- Heat Transfer
  - Time dependent conduction through rock (Ramey, 1962)
    - Convection through permeable rock is not considered
  - Conduction through cement and pipe walls (Fourier's law)
  - Convection into working fluid (Dittus-Boelter Eq.)
- ΔK.E. and ΔP.E.
  - Should be included, as they are not negligible

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Supercritical CO_2

- Highly Compressible
  - Produces a strong thermosiphon
- Inexpensive
- Relatively Inert
- High-Efficiency, Small Turbines
- No Process Water
- Outperforms Hydrothermal
  - Steam (flash tank) and binary (ORC) cycles

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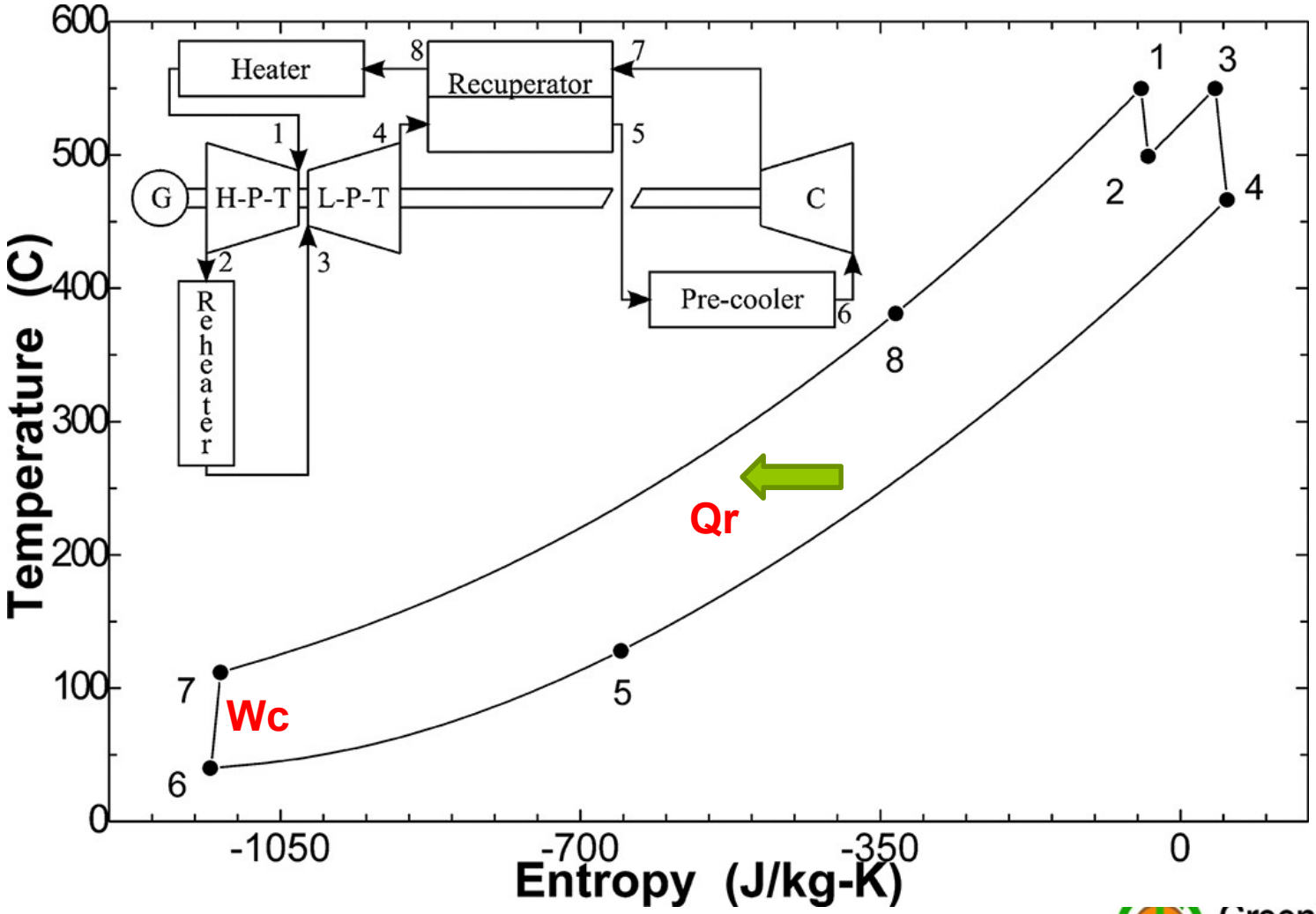
Normal Brayton Cycle
(with compression and recuperation)



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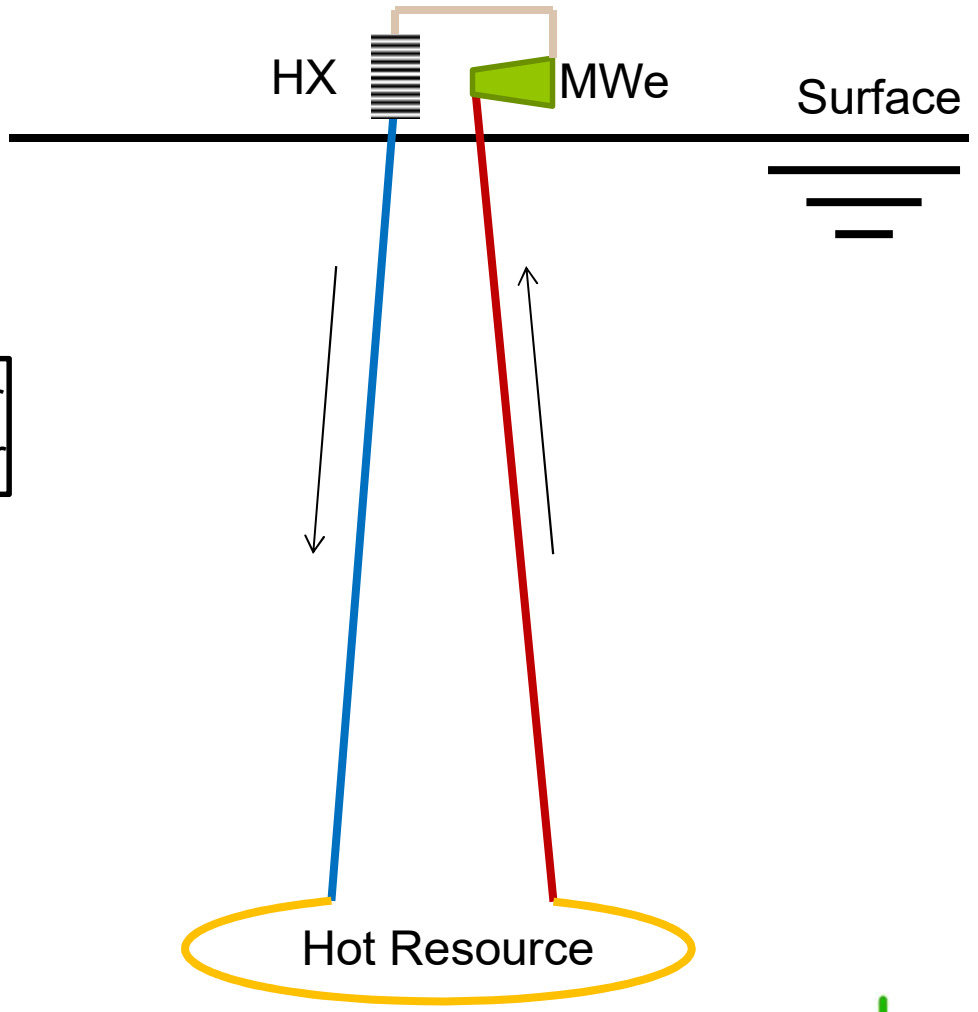
U-Loop Well



No Compressor
No Recuperator

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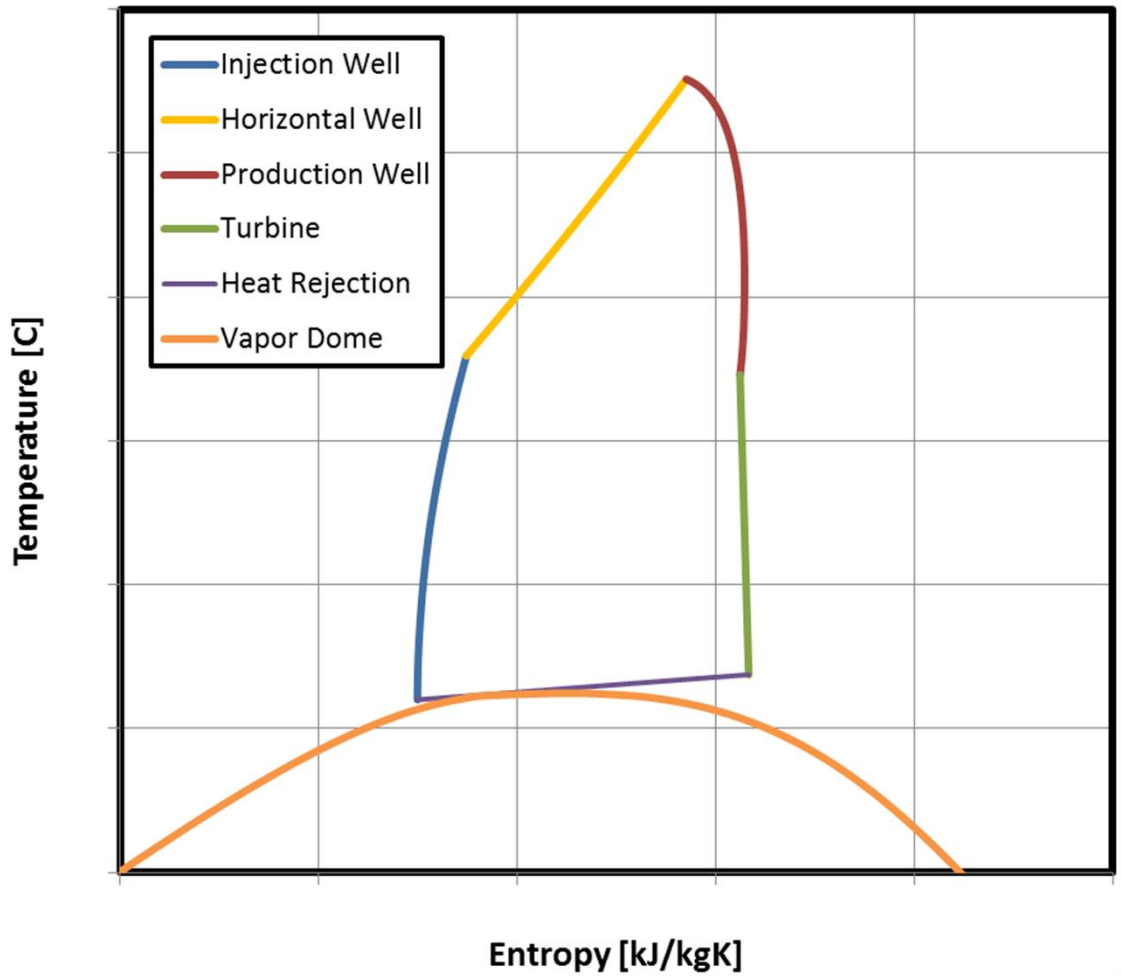
T-s Diagram



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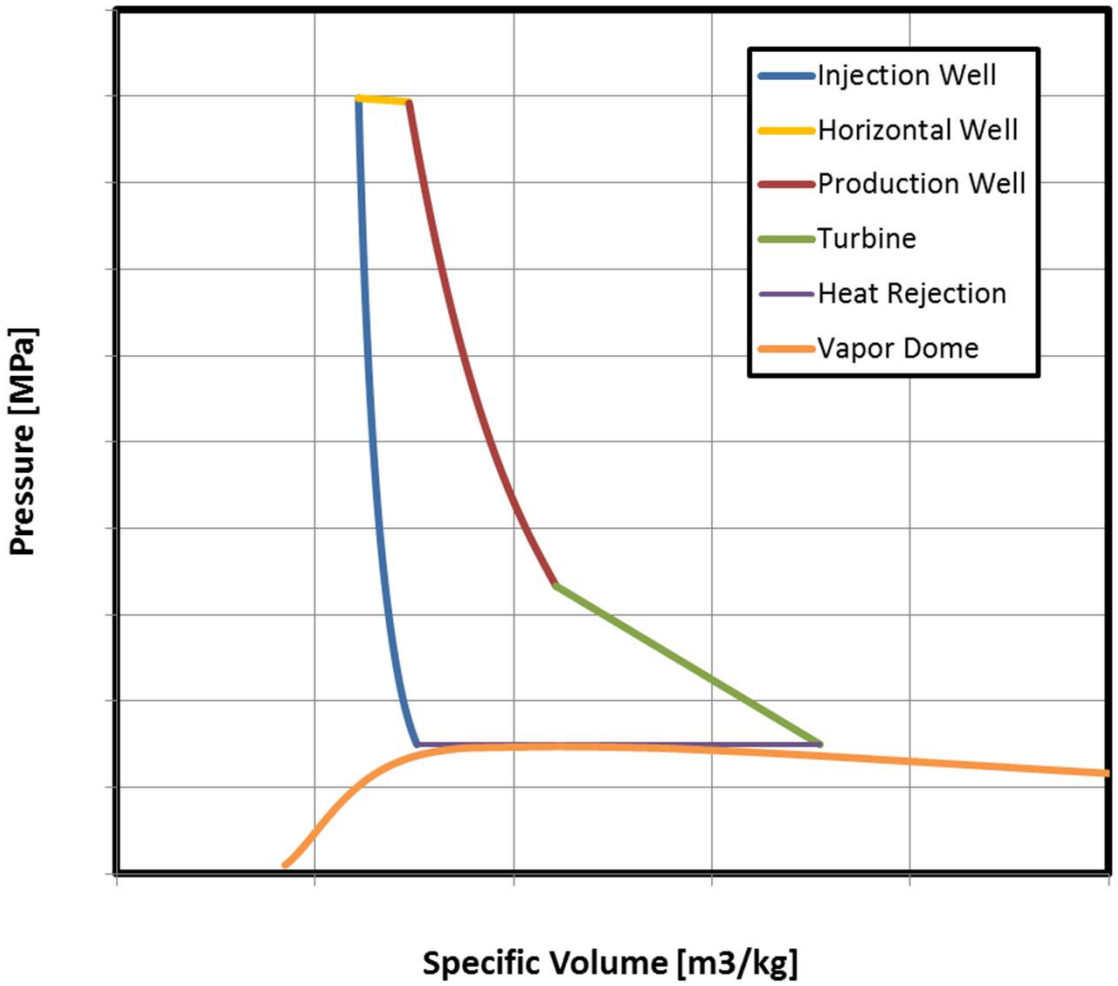
P-v Diagram



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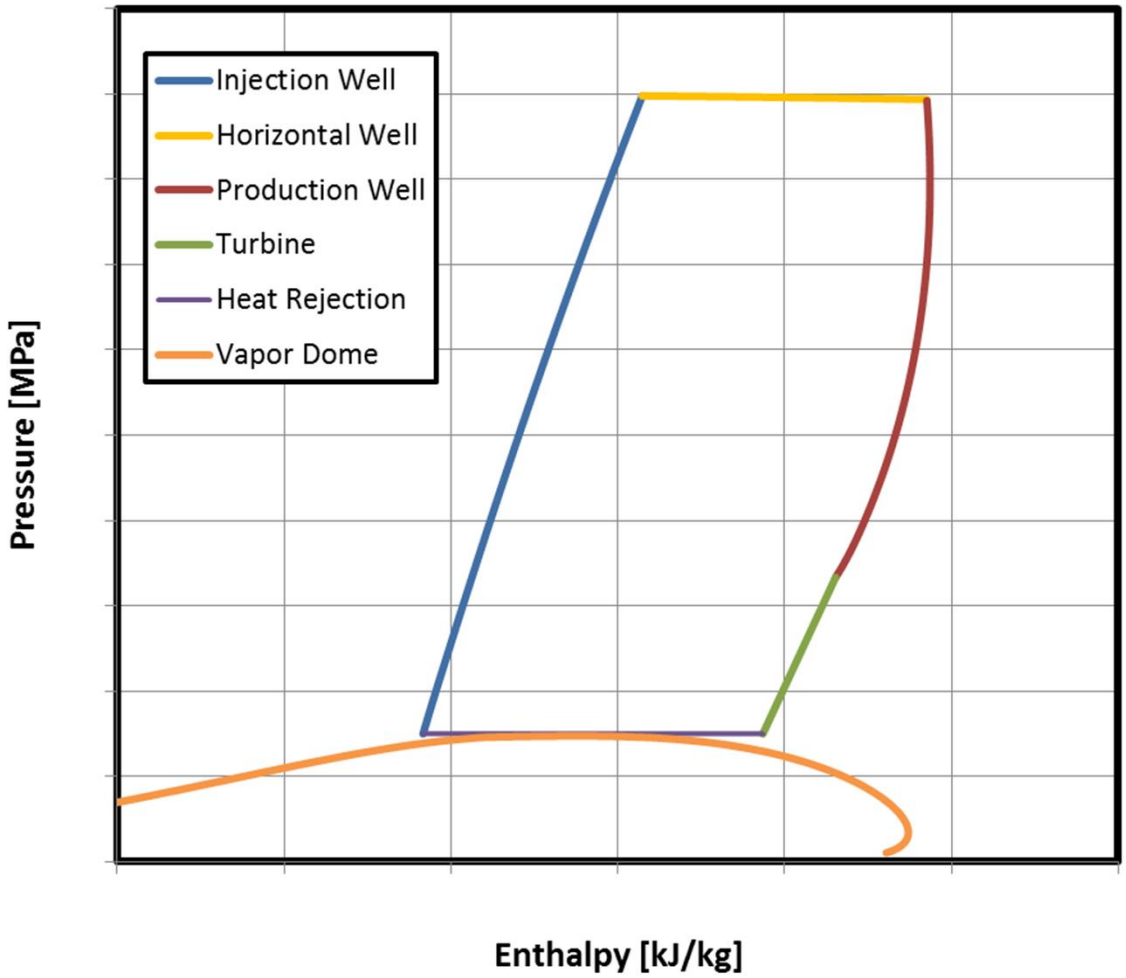
P-h Diagram



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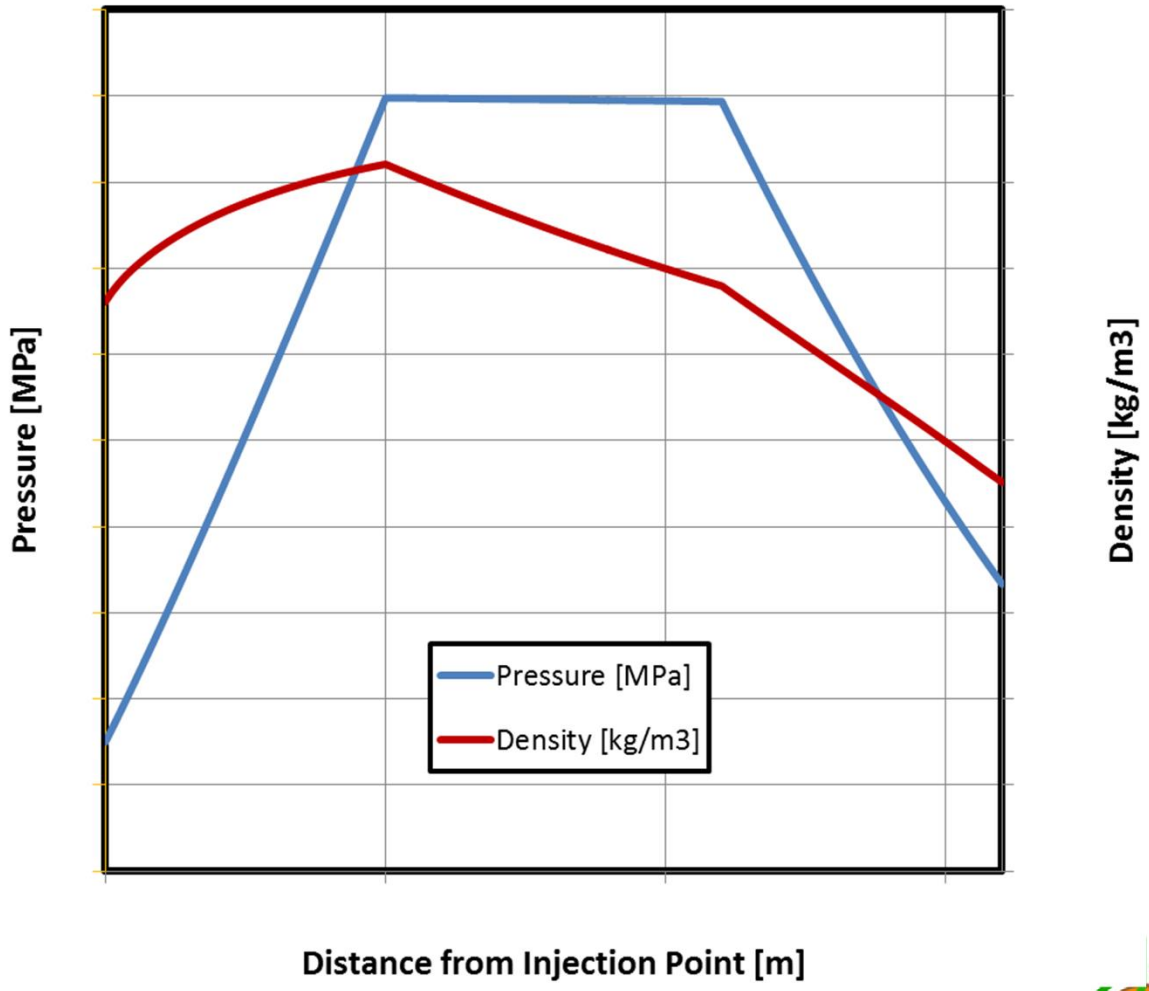
Thermosiphon
P & ρ *versus* Distance



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Conclusions

- Components
  - Process design analysis (model optimization)
  - Drilling plan
  - Surface equipment design
  - Financial model
    - LCOE
- Encouraging Results
- Power Production
  - Electrical power is typically 1 to 2 MWe per well
  - Electrical power can exceed 5 MWe for some cases
- Financial Projections
  - 25 Year LCOE ranges from $0.05 - $0.10/kWh

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Challenges

- Drilling
  - Directional drilling (“meeting in the middle”)
  - Completion (“connecting the two wells”)
  - High costs of drilling are all upfront
- sCO_2 Turbines (Expanders)
  - Commercial availability
  - Design schedule and costs

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Next Steps

- Proof of Concept
  - Finished
- Fundraising
  - Series A – Spring 2016
- 12-18 Month Goal
  - Demonstration well
- 18-36 Month Goal
  - First commercial Installation

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THANK YOU!

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