The Effect of Well Density on Resource Depletion for a Vertical Closed-Loop sCO_2 Geothermal Well System

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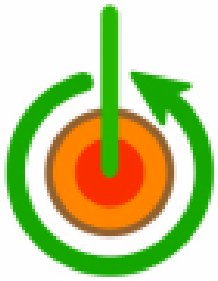
GreenFire Energy
October 25, 2016



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Introduction

- Geothermal provides renewable baseload power that compliments intermittent wind and solar, and reduces the need for battery storage

- Hydrothermal power installations can be constrained by
  - Water usage
  - Exploration risk (*i.e.*, dry holes)
  - Thermal depletion
  - Lack of permeability

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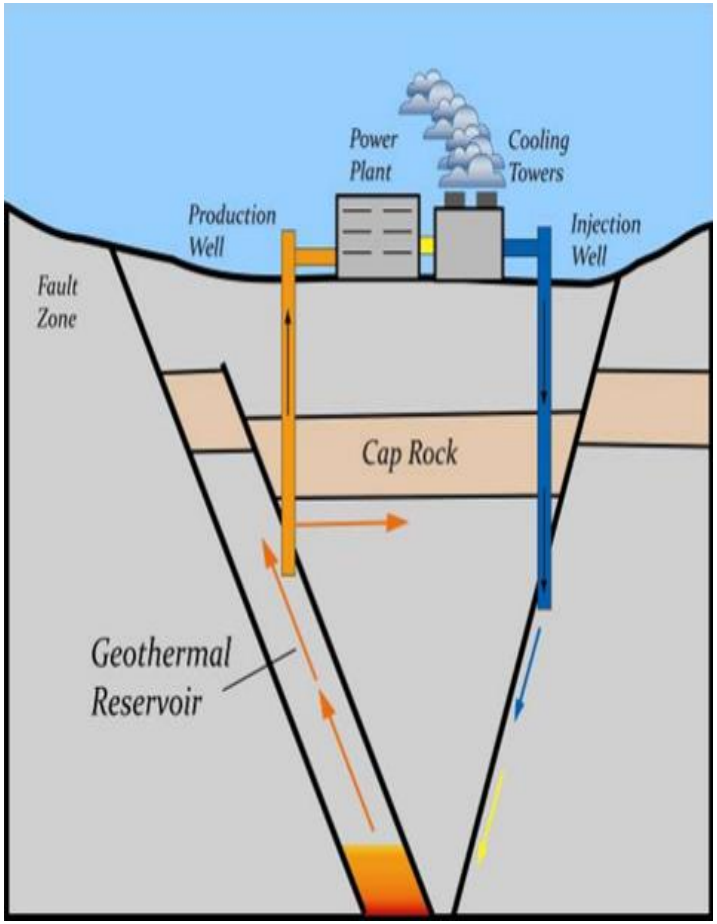
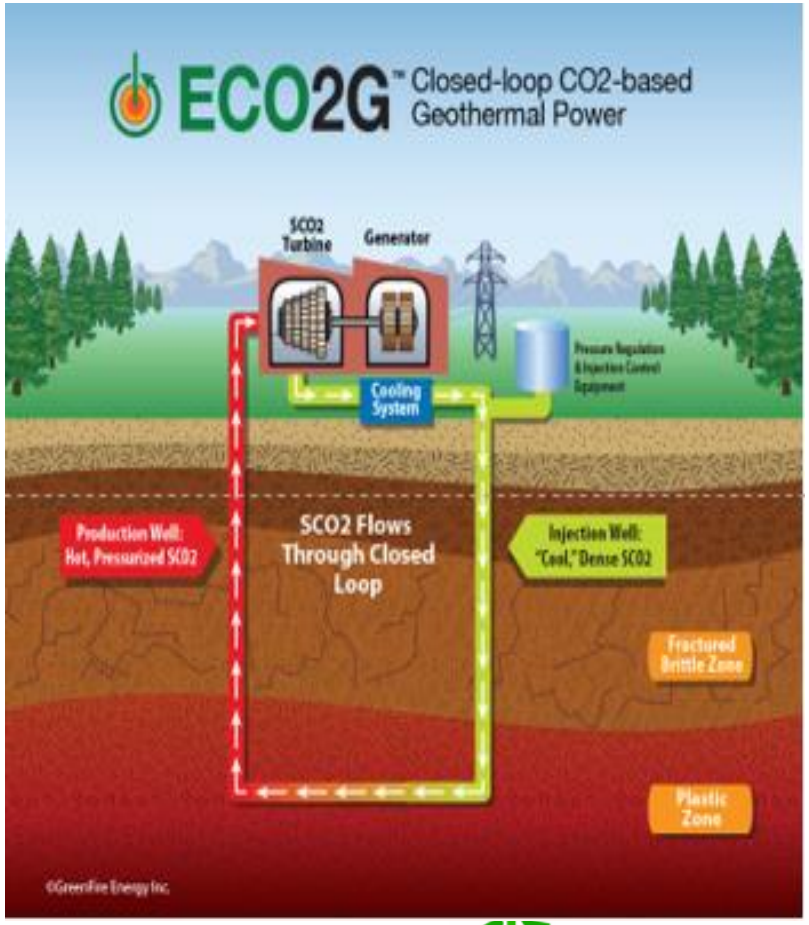
Hydrothermal

Open Loop



ECO2G

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 waste streams
  - No contribution to global warming
  - No contact with subsurface water
  - Zero liquid discharge
- No Subsidence
- Small Footprint

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Supercritical CO_2

- Highly Compressible
  - Produces a strong thermosiphon
- Inexpensive
- Relatively Inert
- High-Efficiency, Small Turbines (Expanders)
- Outperforms Hydrothermal
  - Steam (flash tank) and binary (ORC) cycles

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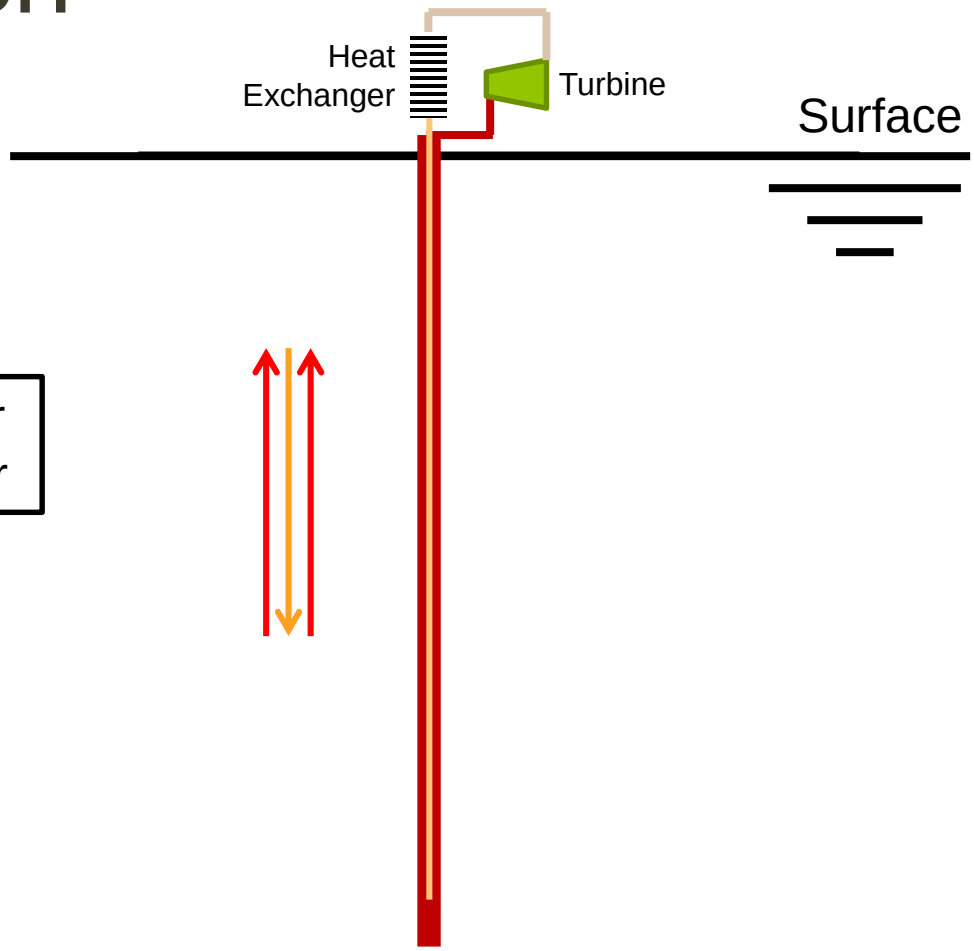
Pipe-in-Pipe Configuration



No Compressor
No Recuperator

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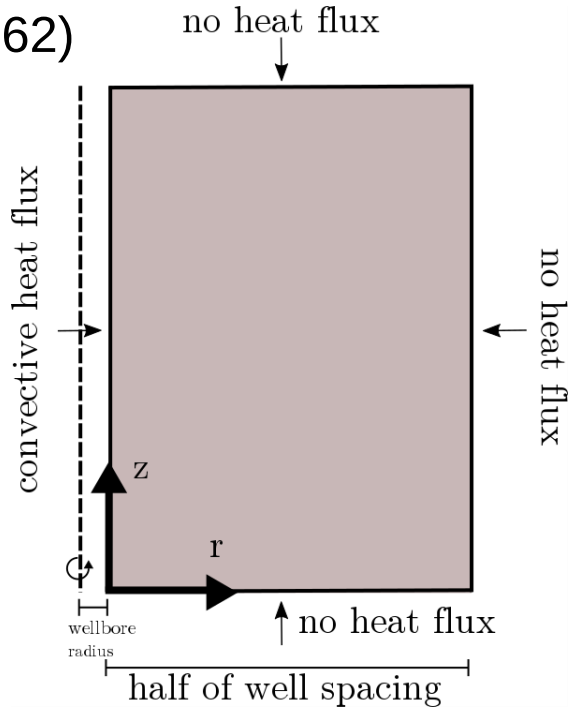
Performance Modeling

- 1-D Process Modeling
  - Conservation of mass, momentum, and energy
  - Heat transfer and friction correlations
  - Conduction through resource by Ramey Eq. (1962)
- 3-D Resource Depletion Modeling
  - Finite Element Method
  - Cylindrical symmetry
  - Solution to the Transient Conduction Eq.:

$$\frac{\partial T}{\partial t} - \alpha_r \nabla^2 T = 0.$$

- Surface Equipment Model
  - Isentropic turbine with specified efficiency
  - Heat rejection as a function of ambient conditions



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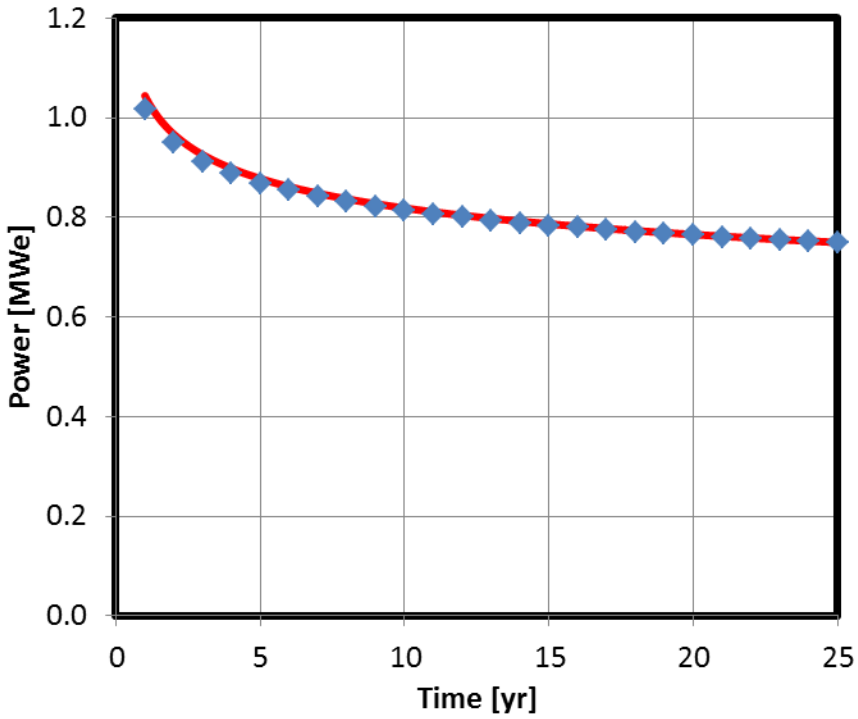
1-D Model *versus* 3-D Model Results single well (infinite boundary)



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Question:

- In the 1-D model, the resource is infinite
- In the 3-D model, we can set boundary conditions
- <u>How does well spacing affect power production over time?</u>
- To answer the above question, we place a zero thermal gradient ($^{\partial T}/_{\partial r} = 0$) at the midpoint between wells

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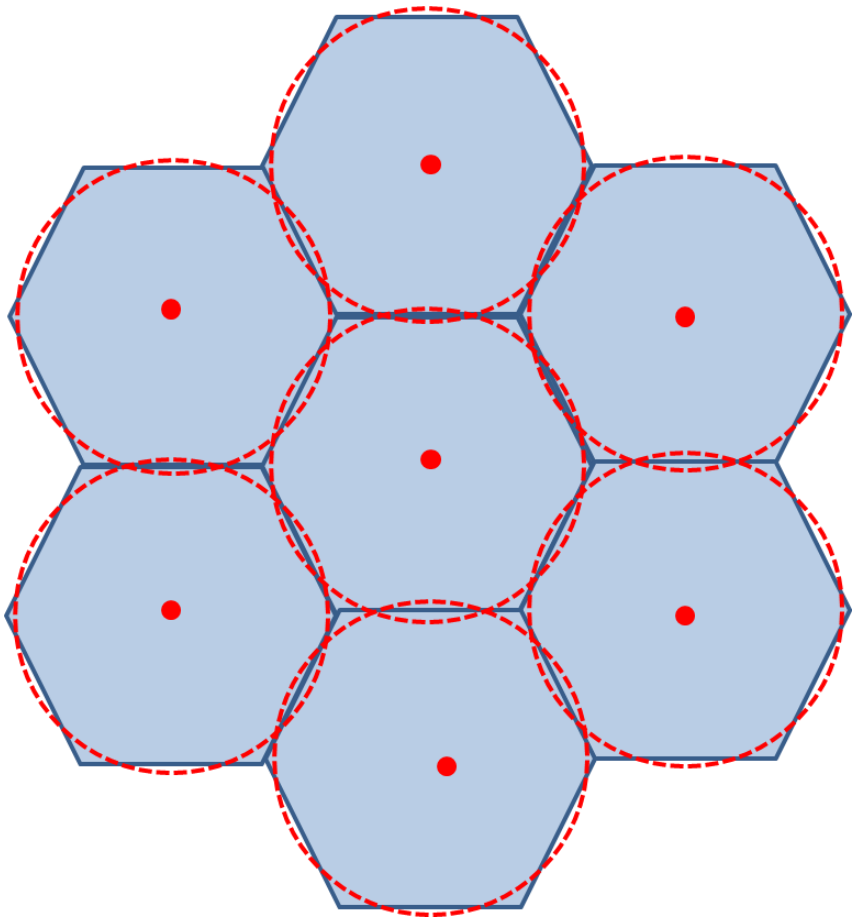
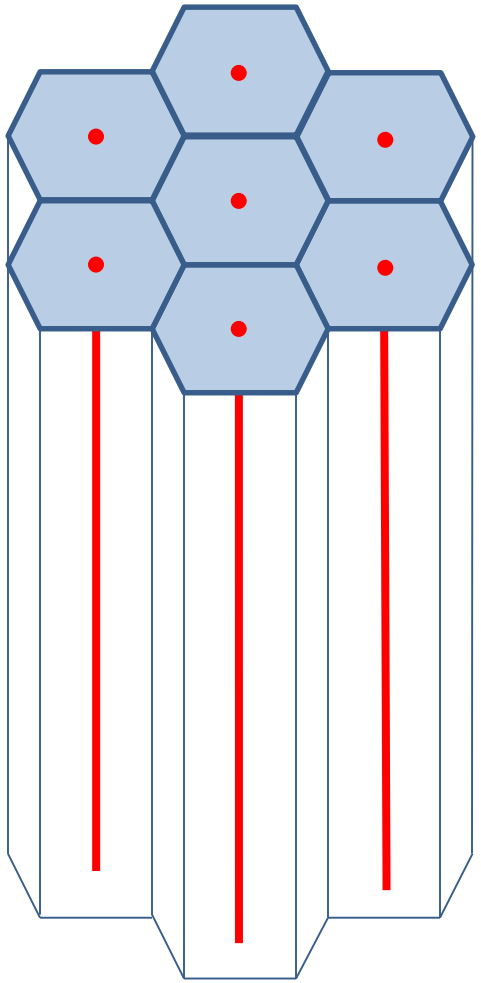
Hexagonal Well Placement has *Nearly* Cylindrical Symmetry





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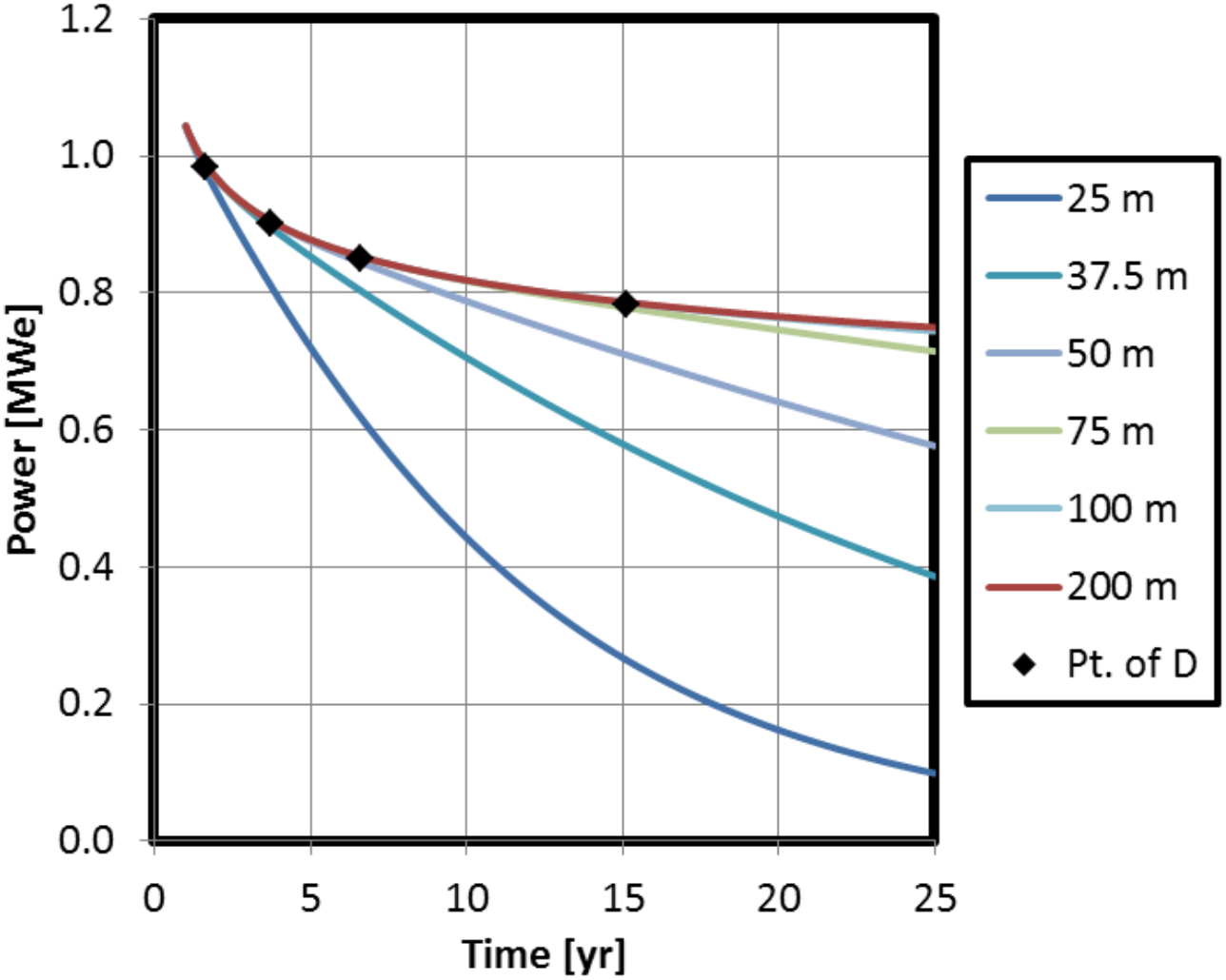
Power *versus* Time for varying separation distance



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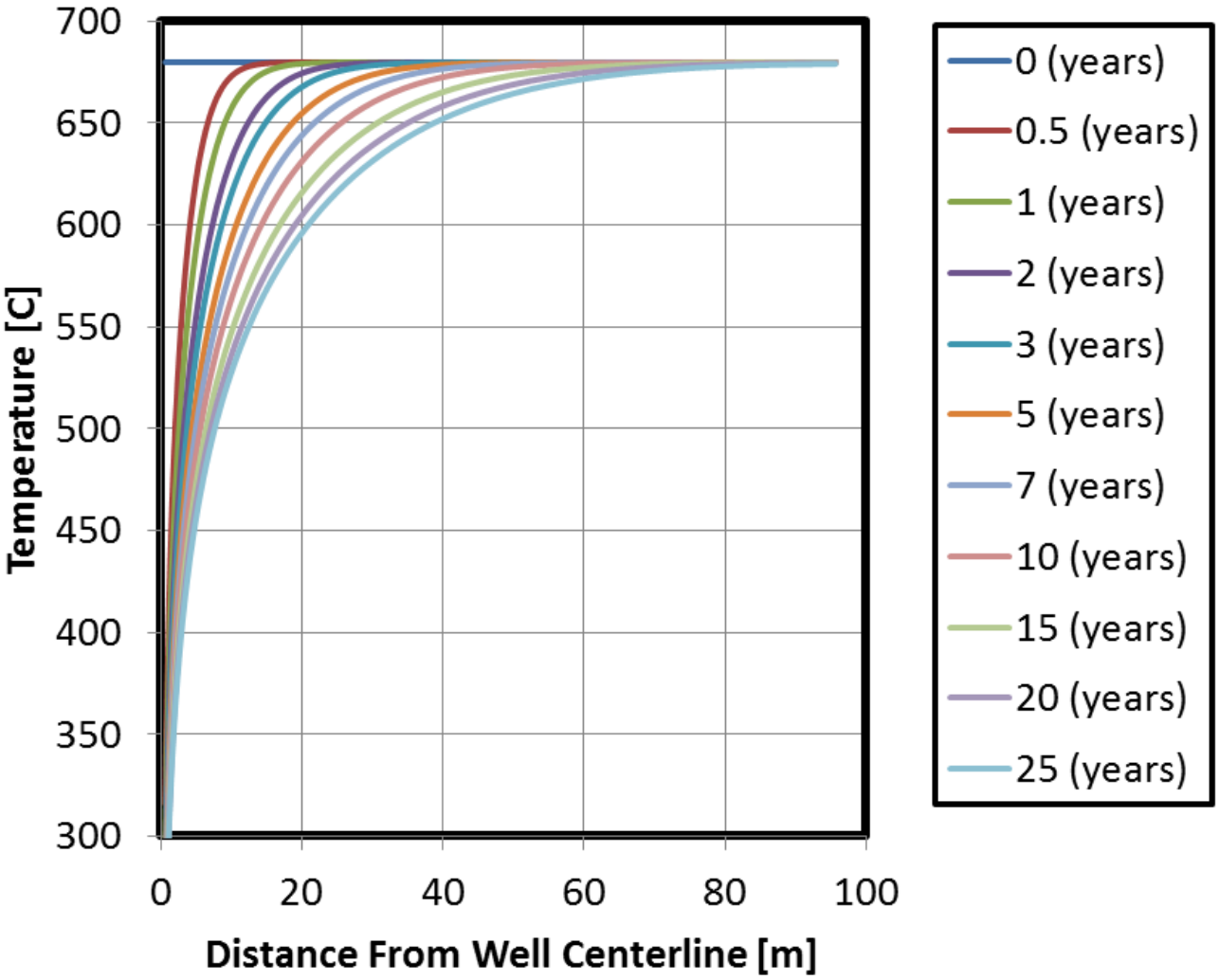
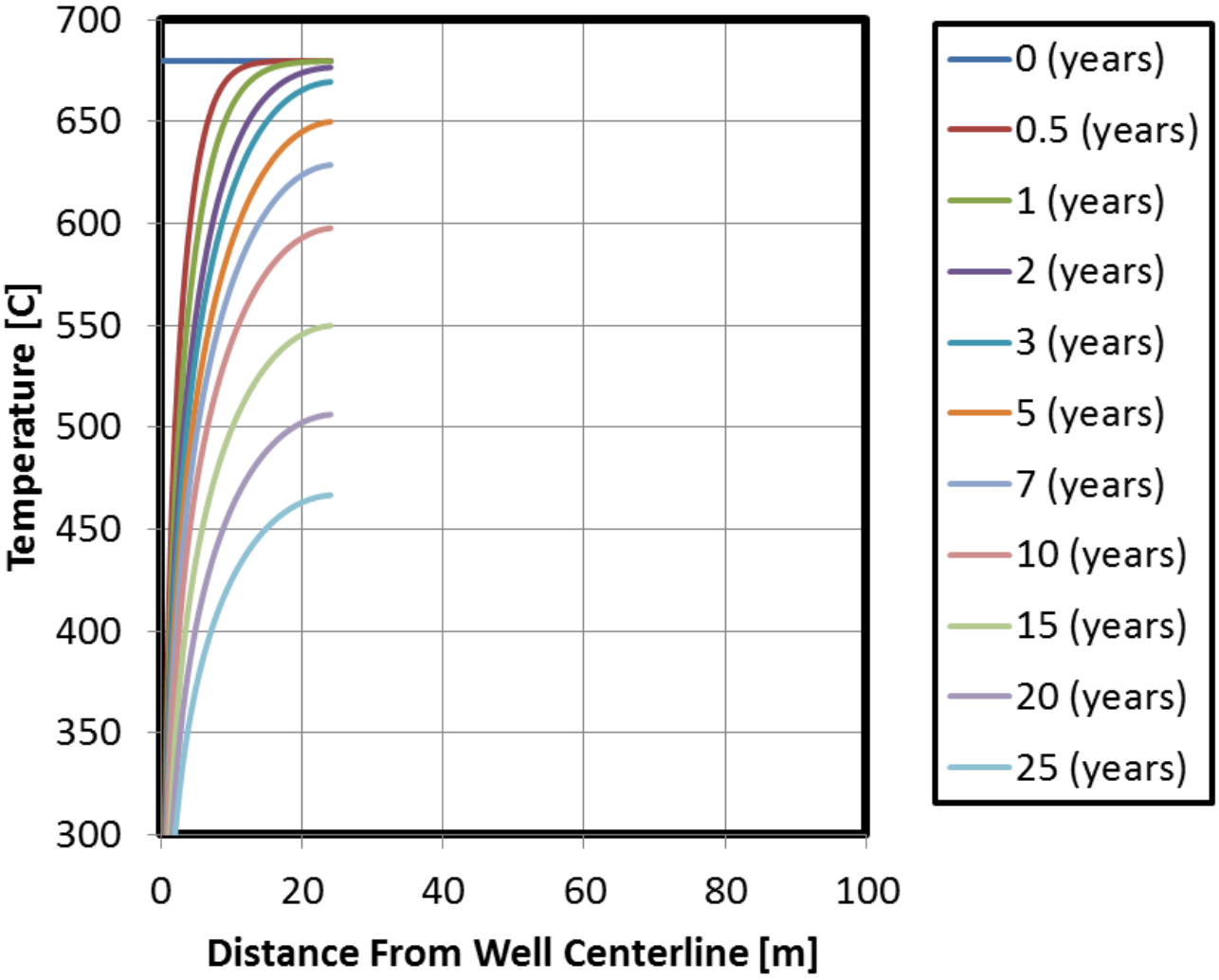
Temperature *versus* Time & Distance (200 m separation)



Temperature *versus* Time & Distance (50 m separation)



Power Production

- Well spacing affects total power produced

- At 100 m spacing, there are 115 wells per sq. km
  - ~ 120 MWe (year 1)
  - ~ 88 MWe (year 25)

- At 50 m spacing, there are 462 wells per sq. km
  - ~ 480 MWe (year 1)
  - ~ 270 MWe (year 25)

- Well spacing produces a trade off between
  - Power Density and Resource Depletion

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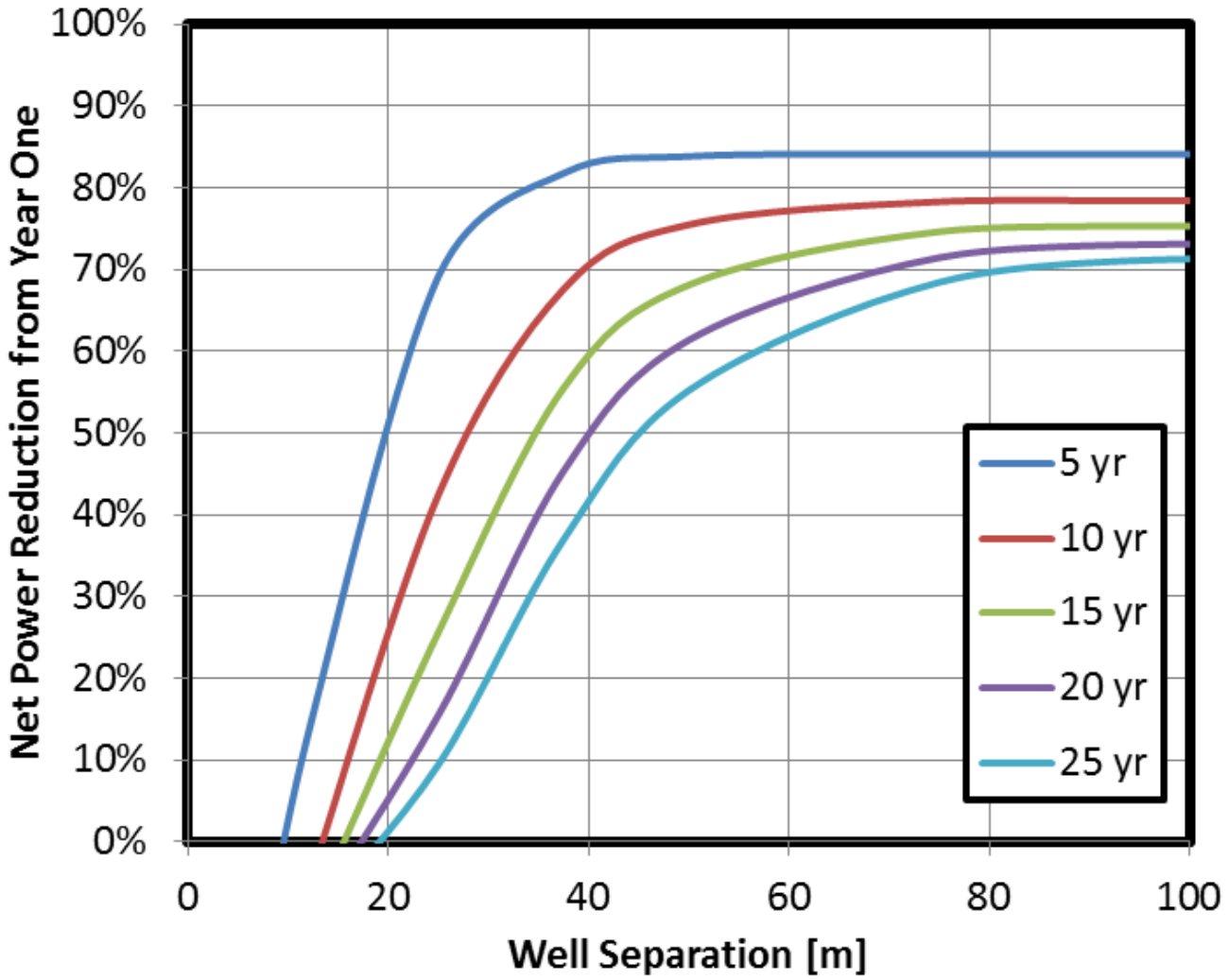
Power Production *versus* Separation



Conclusions

- A Pipe-in-Pipe Configuration was modeled
  - Analytical methods, 1D, and 3D modeling all agree
  - Although 3D modeling gives more information
- Resource depletion is due to conduction only
  - “Heat Farming”
- In 25 years, only rock within 50 m of the well is affected by the heat extraction
- A square km can contain 115 wells without resource depletion
  - Hexagonal layout
- 8 km^2 (~2000 acres) is about 1 GWe

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Next Steps

- Proof of Concept
  - Finished Modeling
- Fundraising
  - Ongoing
  - Series A – Winter 2017
- 12 Month Goal
  - Demonstration well
- 18-36 Month Goal
  - Commercial Scale Installation

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THANK YOU!

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