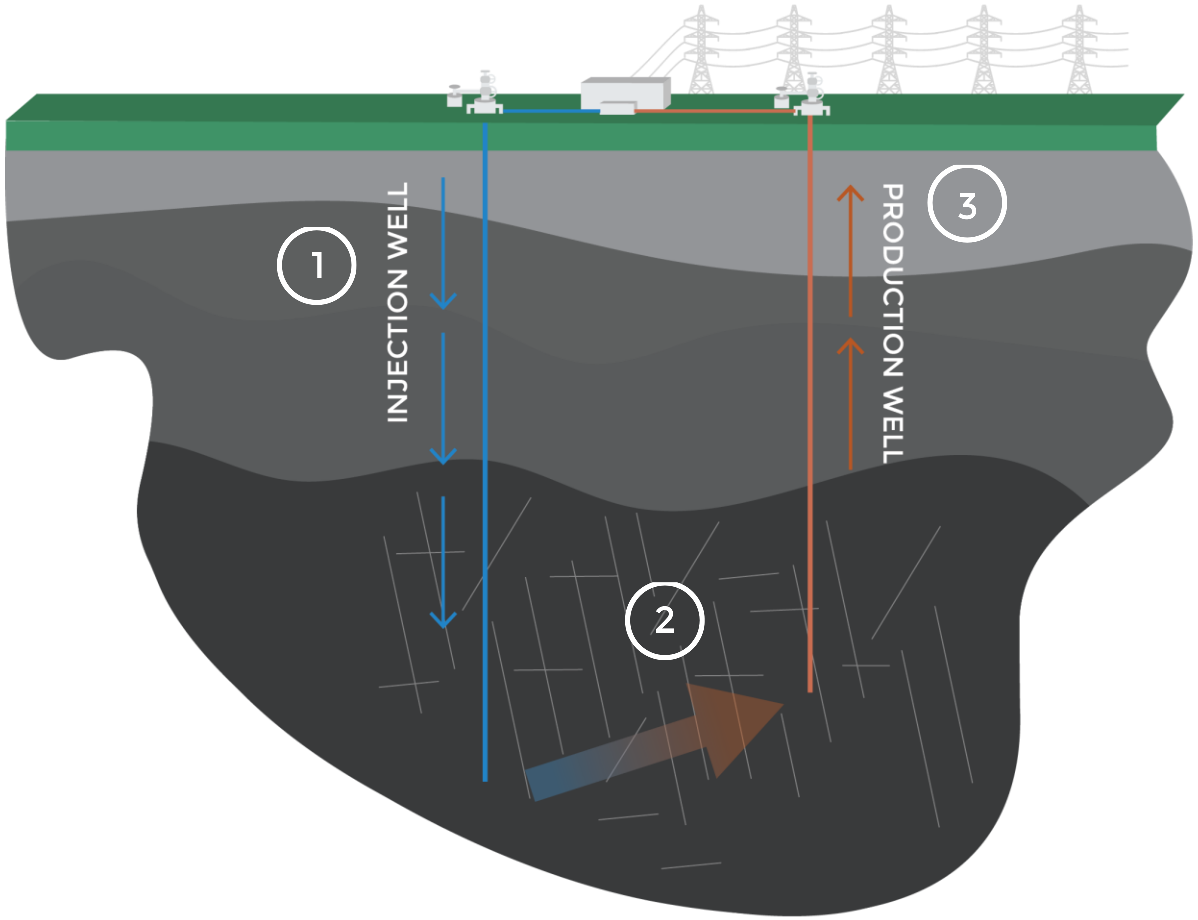
Opportunities for multifractured horizontal geothermal developments

Garrett Fowler

December 31, 2021

How geothermal works today



1. Deep wells inject cool water
2. Water heats up as it flows through the subsurface and returns through production wells
3. Steam at the surface generates electricity without emissions

1 out of every 3 geothermal wells are "dry holes" because they cannot support commercially viable flow rates

Slide credit: Tim Latimer (Fervo Energy)

We can engineer flow rate

The economically limiting factor for geothermal development is creating a dense network of flow pathways. Power production scales with reservoir contact area.

$$Q_t = \frac{NhC}{\mu D} \Delta P \rho H$$

$Q_t =$ energy production rate
N = number of fractures
h = fracture height
H = specific enthalpy of fluid (water)
C = hydraulic conductivity

μ = viscosity
D = distance between wells
ΔP = pressure drop between wells
ρ = fluid density

ResFrac

We can engineer flow rate

The economically limiting factor for geothermal development is creating a dense network of flow pathways. Power production scales with reservoir contact area.

$$Q_t = \frac{NhC}{\mu D} \Delta P \rho H$$

Q_t = energy production rate
N = number of fractures
h = fracture height
H = specific enthalpy of fluid (water)
C = hydraulic conductivity

μ = viscosity
D = distance between wells
ΔP = pressure drop between wells
ρ = fluid density

ResFrac

Modern shale designs create massive contact area with reservoir

$$P_{pf} = \Delta P_p = \frac{0.2369 \times Q^2 \times \rho}{N_p^2 \times D_p^2 \times C_d^2}$$

ΔP_p = Pressure drop across a perforation(s) (psi)

Q = Total flow rate (bbl/min)

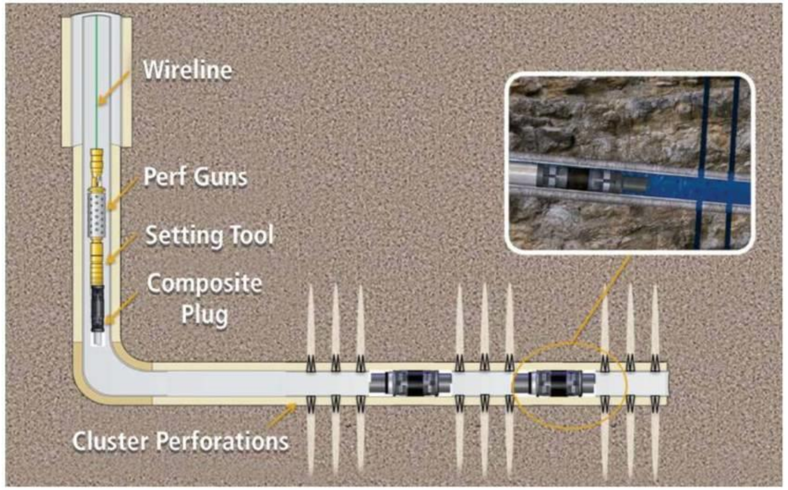
ρ = Density of fluid (lb/gal)

N_p = Number of open perforations

D_p = Diameter of perforations (in)

C_d = Coefficient of discharge

Lorwongngam et al. (2020)



Bagci et al. (2019)

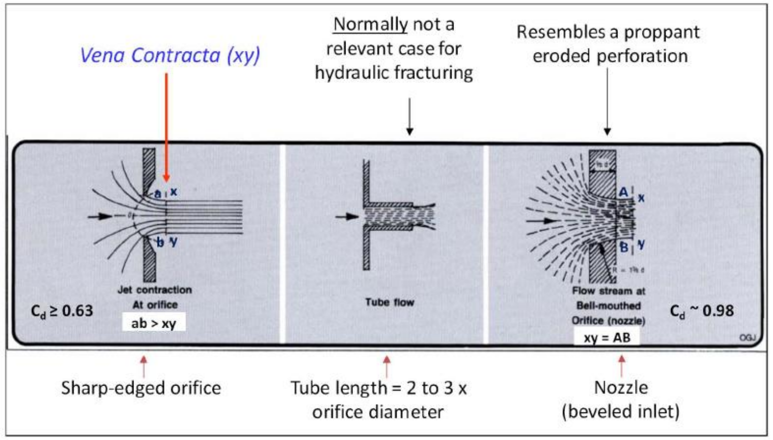
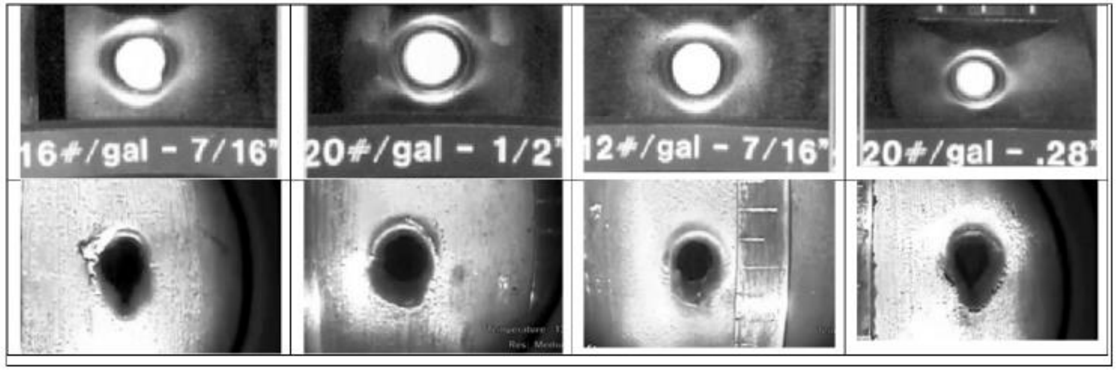


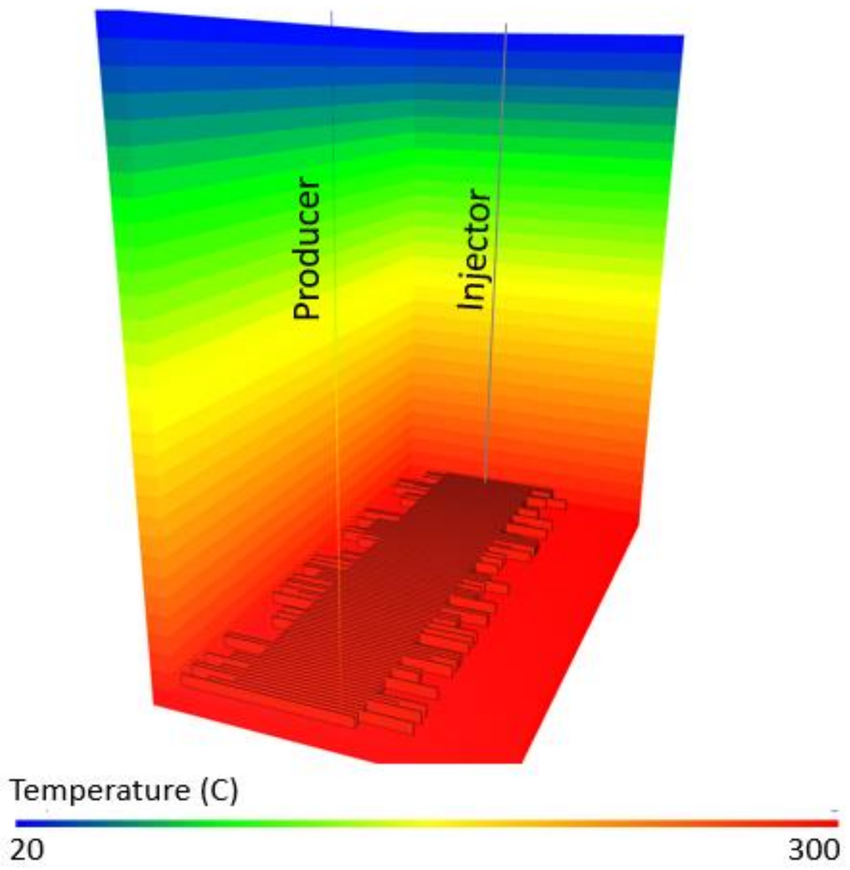
Figure 2—Flow through an orifice (Gross, 1985).



Cramer et al. (2019)

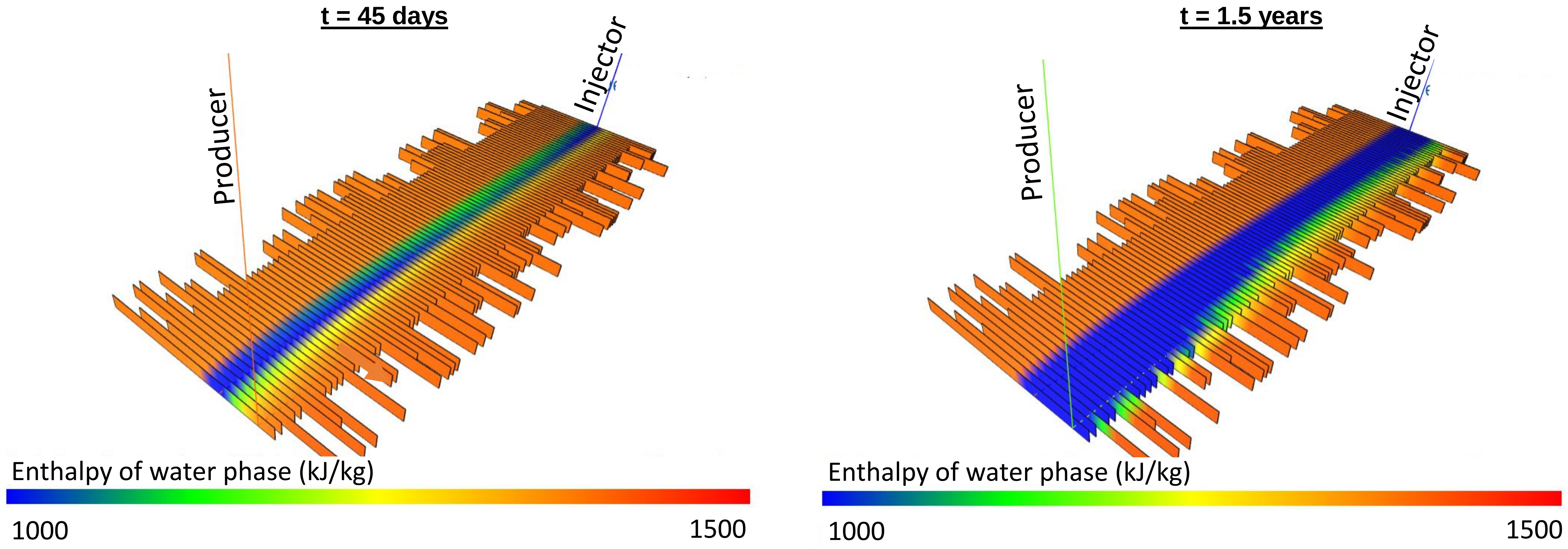
ResFrac

Well doublet: conceptional example



- Modeled in "**A Feasibility Study on Three Geothermal Designs: Deep Closed-Loop (with and without Conductive Fractures) and Open-Loop Circulation Between Multifractured Laterals**", Fowler and McClure, 2021
- Two 3km laterals, spaced 200 m apart
- Injector cased and perforated every 30 m
- Producer open hole
- Generic granite-like rock properties
- Use conceptual model to demonstrate sensitivity to injection rate, reservoir temperature, well spacing, etc.

Circulation between wells “mines” heat from the rock



Source: Fowler and McClure, 2021

ResFrac

Sensitivity to major design parameters

Higher reservoir temperatures = greater energy transfer to working fluid

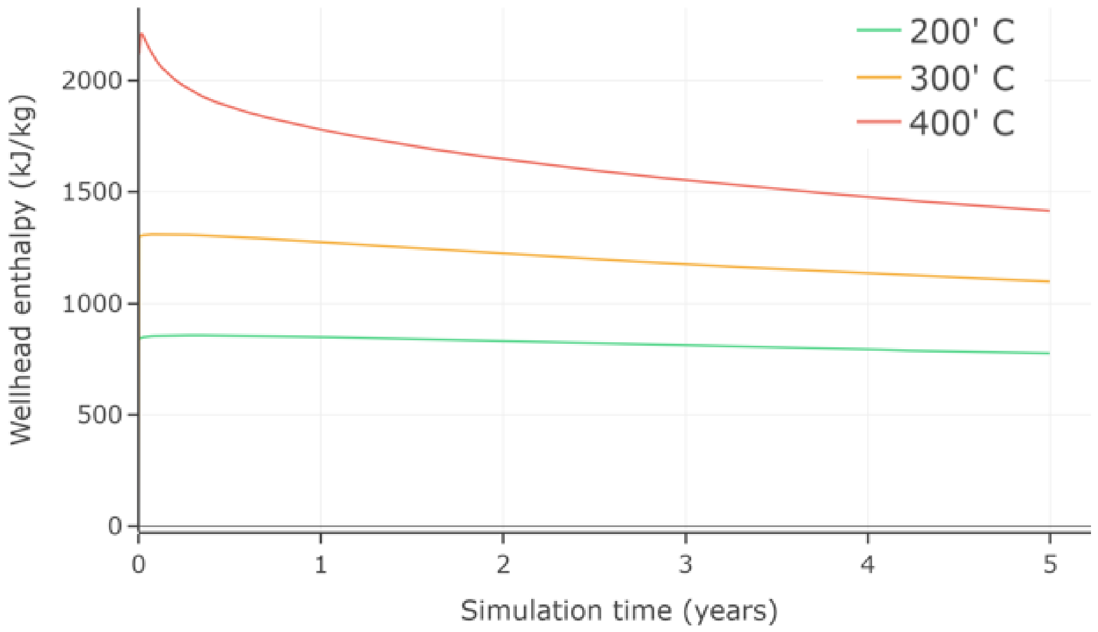
But…

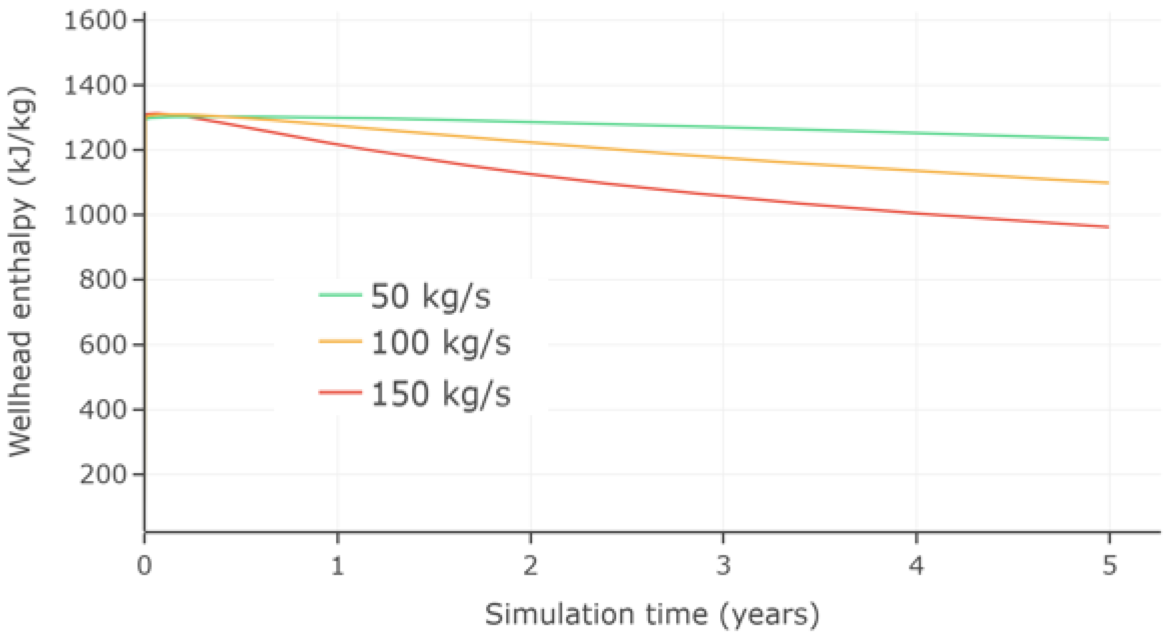
Higher temperatures necessitate more expensive / rare tooling

Higher flow rates = higher rates of energy depletion

But…

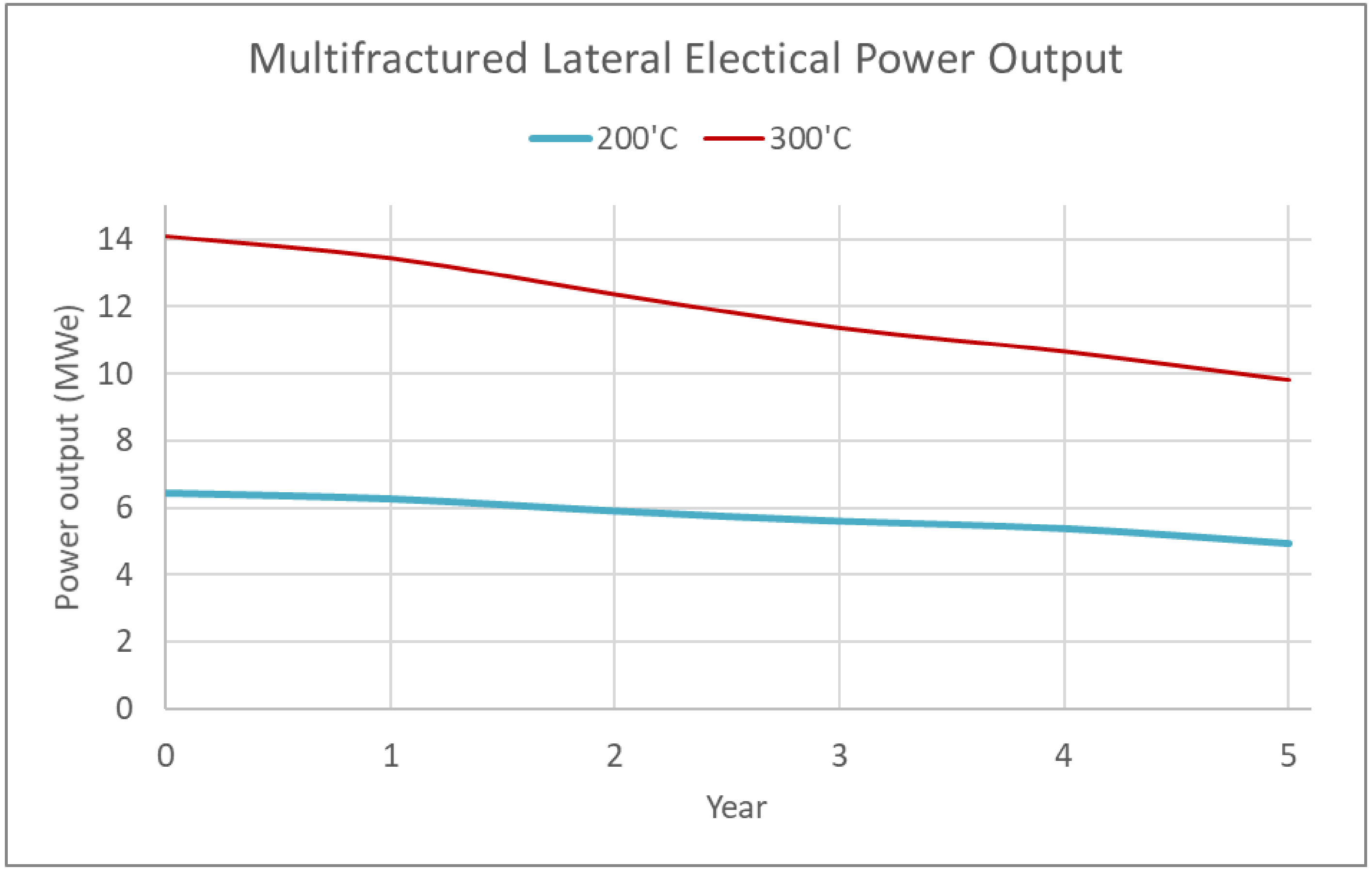
Power = flow rate x energy content so there is an optimization





Source: Fowler and McClure, 2021

Multifractured laterals produce commercial levels of electricity



300’ Celsius Economics

Well cost	$20M	$20M
Electricity price ($/kWh)	$0.10	$0.05
Discount rate	10%	10%
Break-even year	**3**	**7**

ResFrac

Source: Fowler and McClure, 2021

Additional reading

https://www.resfrac.com/blog/why-multistage-stimulation-most-exciting-idea-geothermal

PROCEEDINGS, Thirty-Ninth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 24-26, 2014
SGP-TR-202

EGS Designs with Horizontal Wells, Multiple Stages, and Proppant

Sogo Shiozawa and Mark McClure
The University of Texas at Austin
200 E. Dean Keeton, Austin, TX 78712
sogo@utexas.edu; mcclure@austin.utexas.edu

GRC Transactions, Vol. 45, 2021

A Feasibility Study on Three Geothermal Designs: Deep Closed-Loop (with and without Conductive Fractures) and Open-Loop Circulation Between Multifractured Laterals

Garrett Fowler, Mark McClure
ResFrac Corporation

GEOTHERMAL

Why Multistage Stimulation Could Transform the Geothermal Industry

Flow rate is a major challenge for geothermal. However, the techniques used in shale to prevent flow localization can be applied directly to geothermal. If we can create hundreds or thousands of flowing fracture pathways around a horizontal or deviated geothermal well, then we will have truly "changed the game."

October 1, 2021 By Mark McClure
Journal of Petroleum Technology

The DEEP project in Saskatchewan, Canada, recent executed a multistage stimulation for geothermal production in a sedimentary formation. *Source: DEEP*

Thank you!

Garrett Fowler, COO

garrett@resfrac.com