SEG Evolve: Geothermal Power Production Overview

Greg Leveille

April 16, 2026

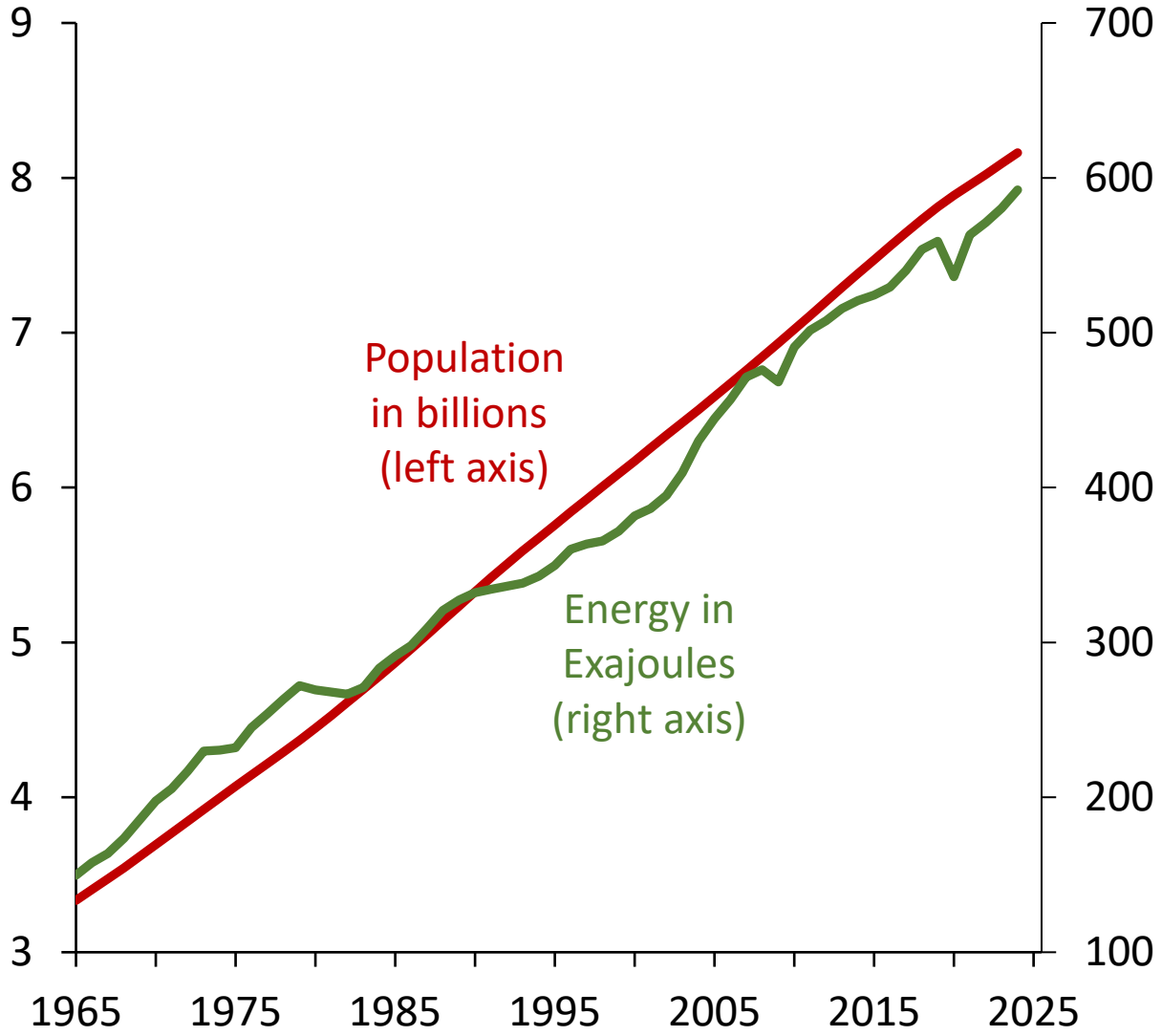
Picture from Fervo Energy's website

Presentation Outline

- Humankind’s insatiable need for energy
- The geothermal power output prize
- Techno-economic challenges
- Innovative solutions
- Achieving liftoff

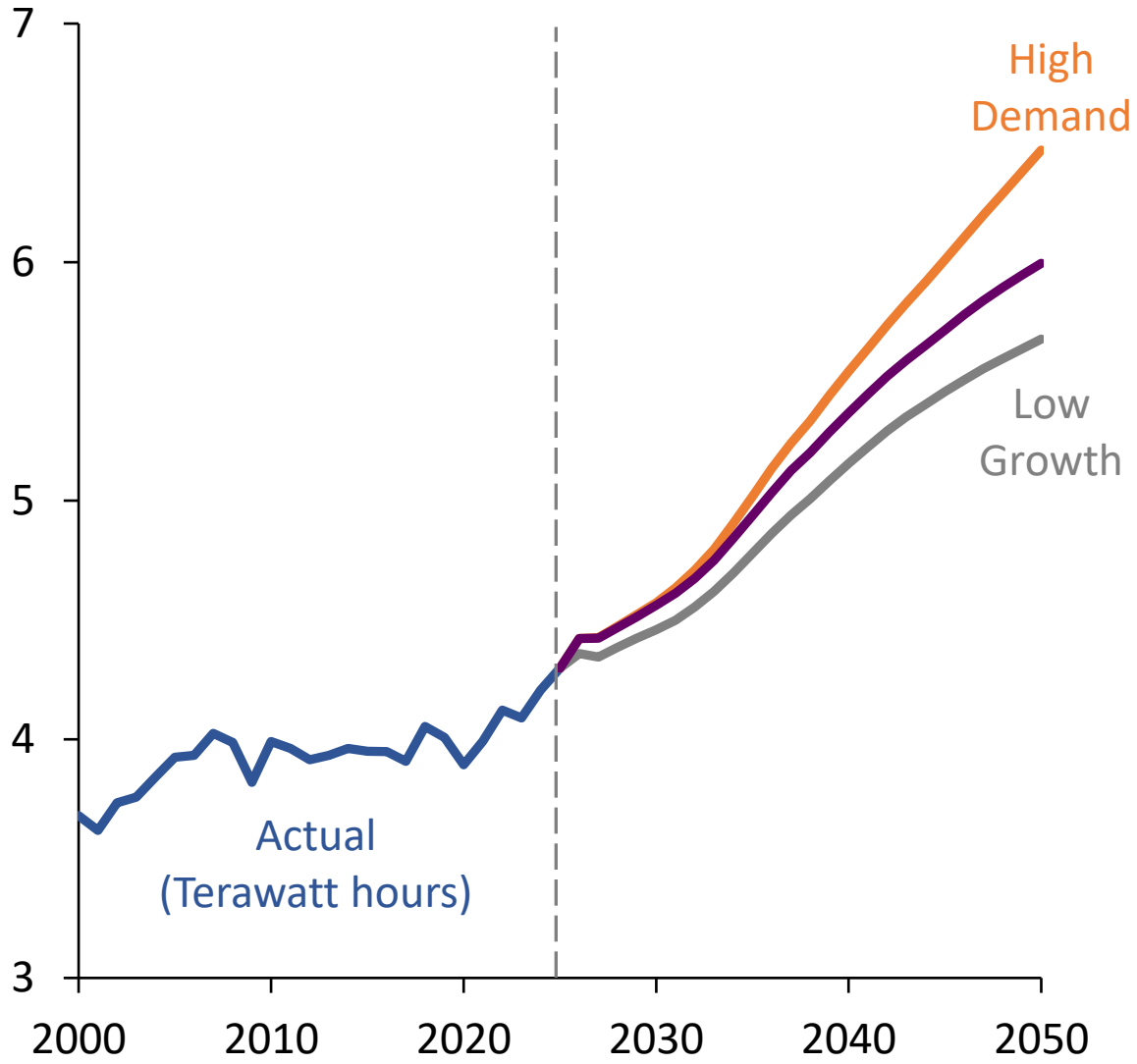
The world needs further sources of abundant, reliable, affordable, firm, dispatchable energy

Growth in global population & energy consumption



Sources: Population = World Bank; Energy consumption = Energy Institute

Projected growth in U.S. electricity consumption



Sources U.S. Energy Information Administration

Geothermal energy can provide a sixth important attribute: Low GHG emissions

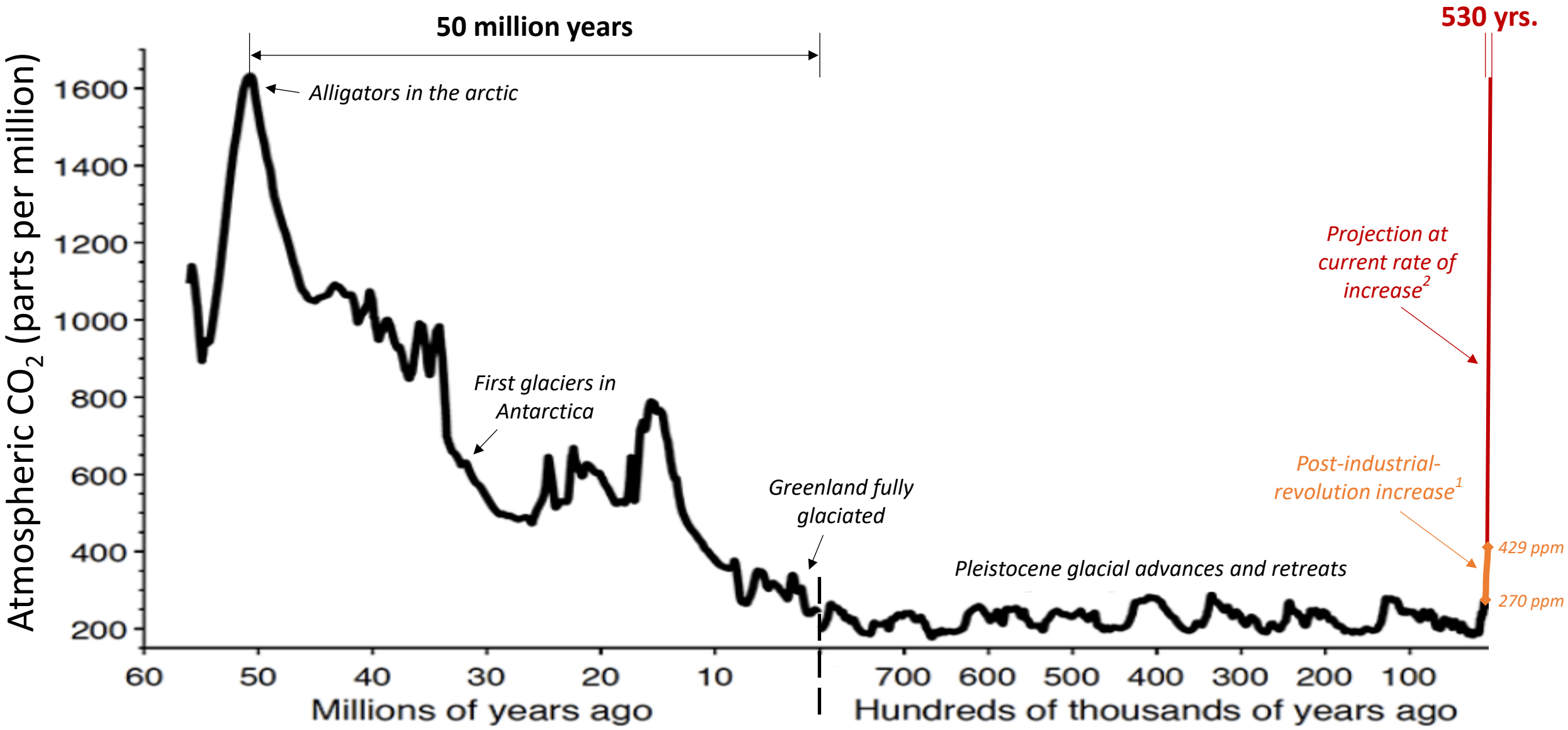
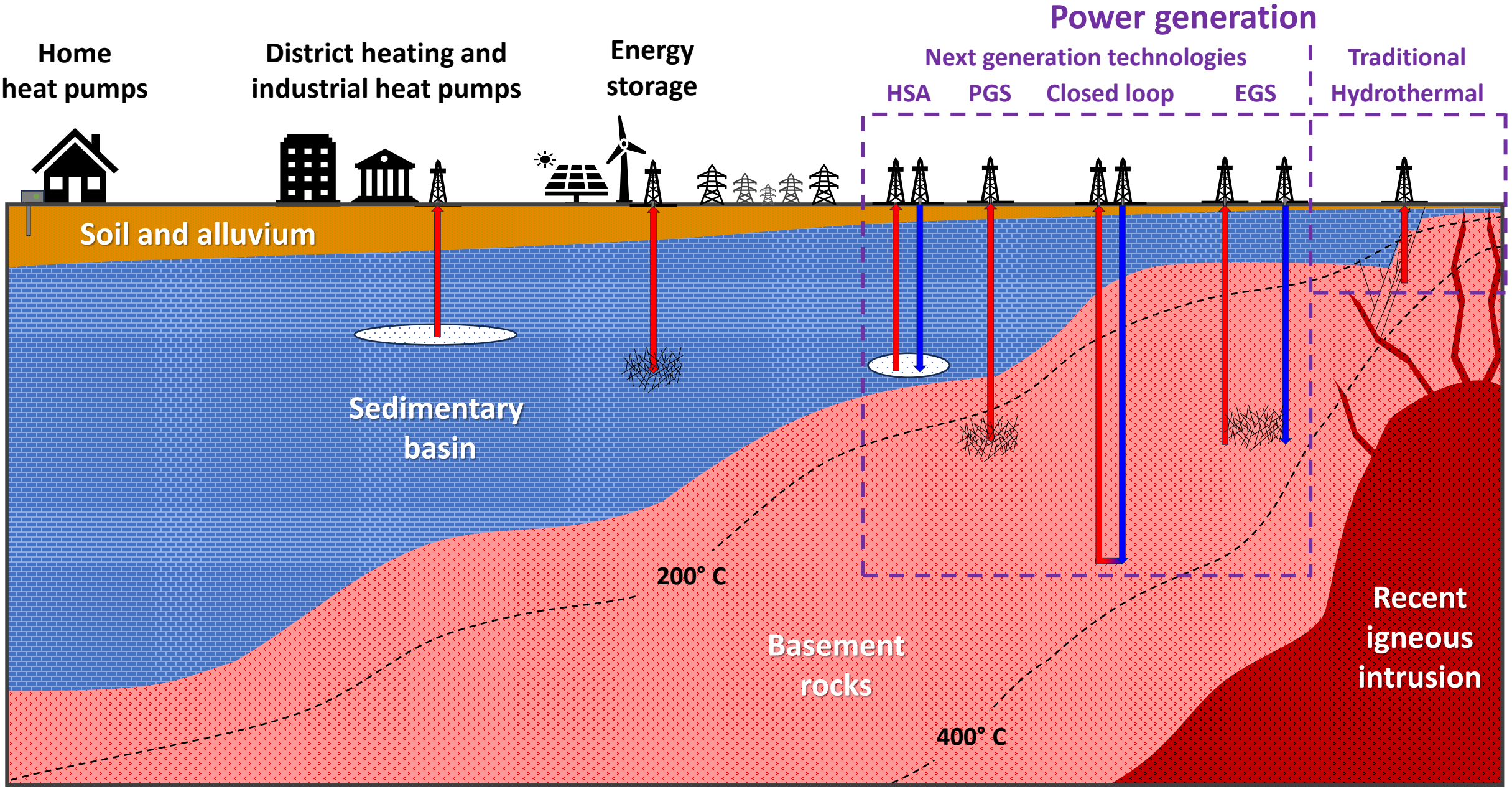


Diagram modified after Zhang, Y. and Liu, X., 2021. [1] From 270 ppm pre-industrial revolution to 427 ppm on April 17, 2025. [2] Rate of increase over the past 25 years has been 2.2 ppm per annum. PPM = Parts per million.

There are many ways to harvest energy from heat within the Earth: Power is the biggest prize



Cross section view; not to scale; depictions of geothermal systems are greatly simplified; HSA = Hot Sedimentary Aquifers; PGS = Pressure Geothermal Systems; EGS = Enhanced Geothermal Systems

Heat within the Earth is sufficient to provide an inexhaustible supply of power

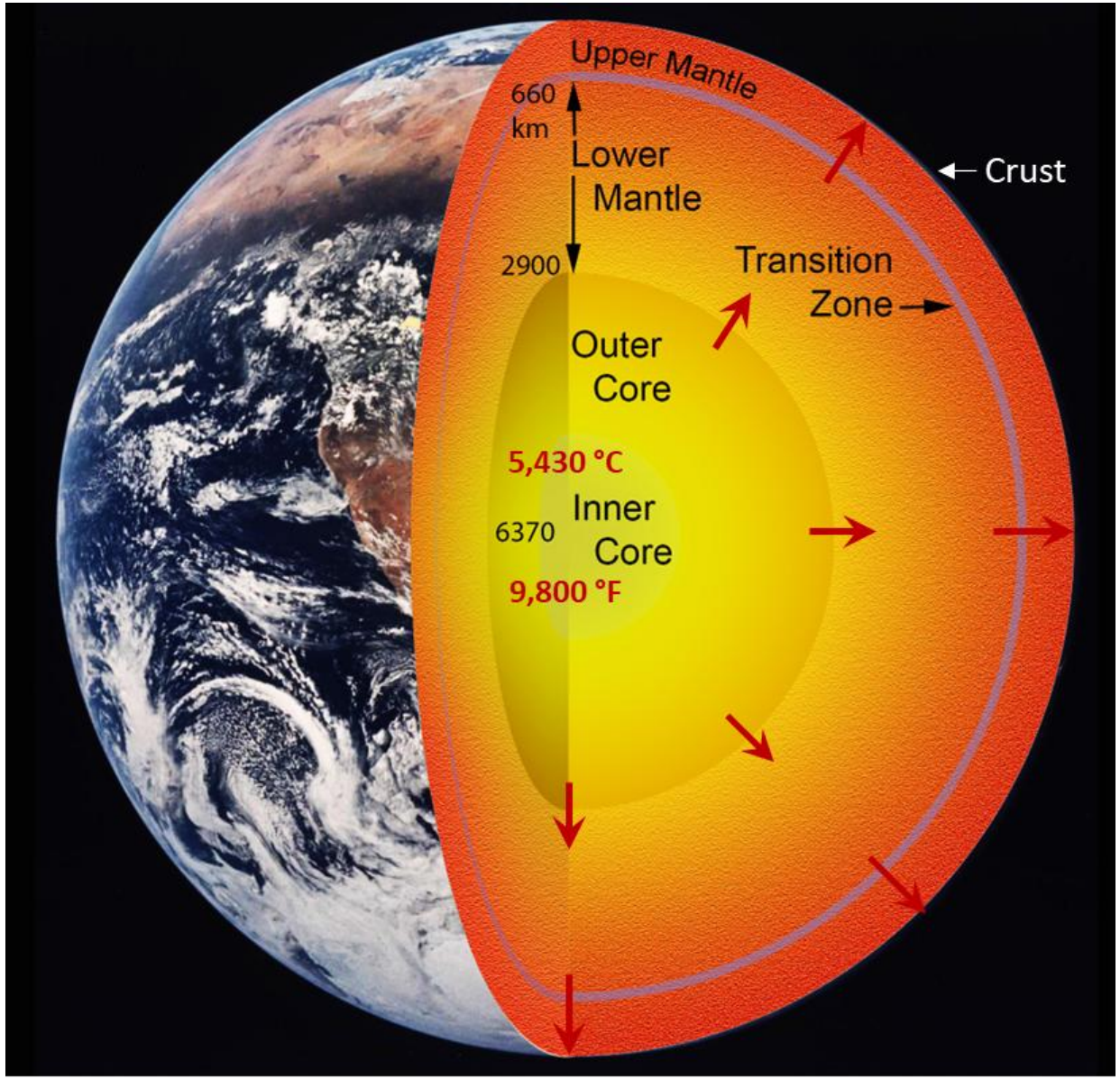
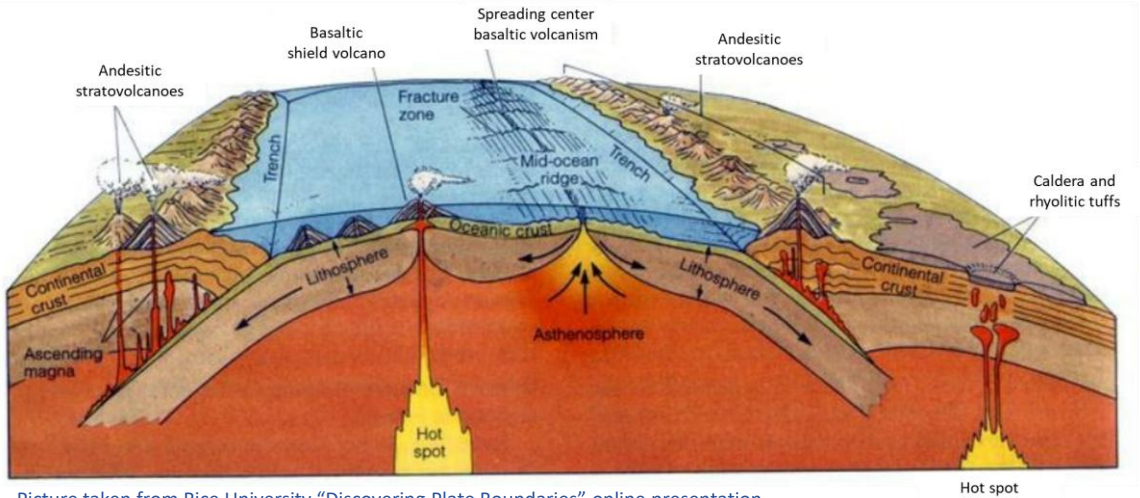
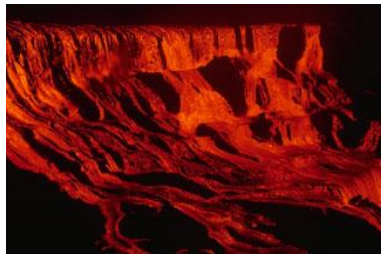


Diagram modified after Steve Jacobsen, Department of Earth, Environmental, and Planetary Sciences, Northwestern University



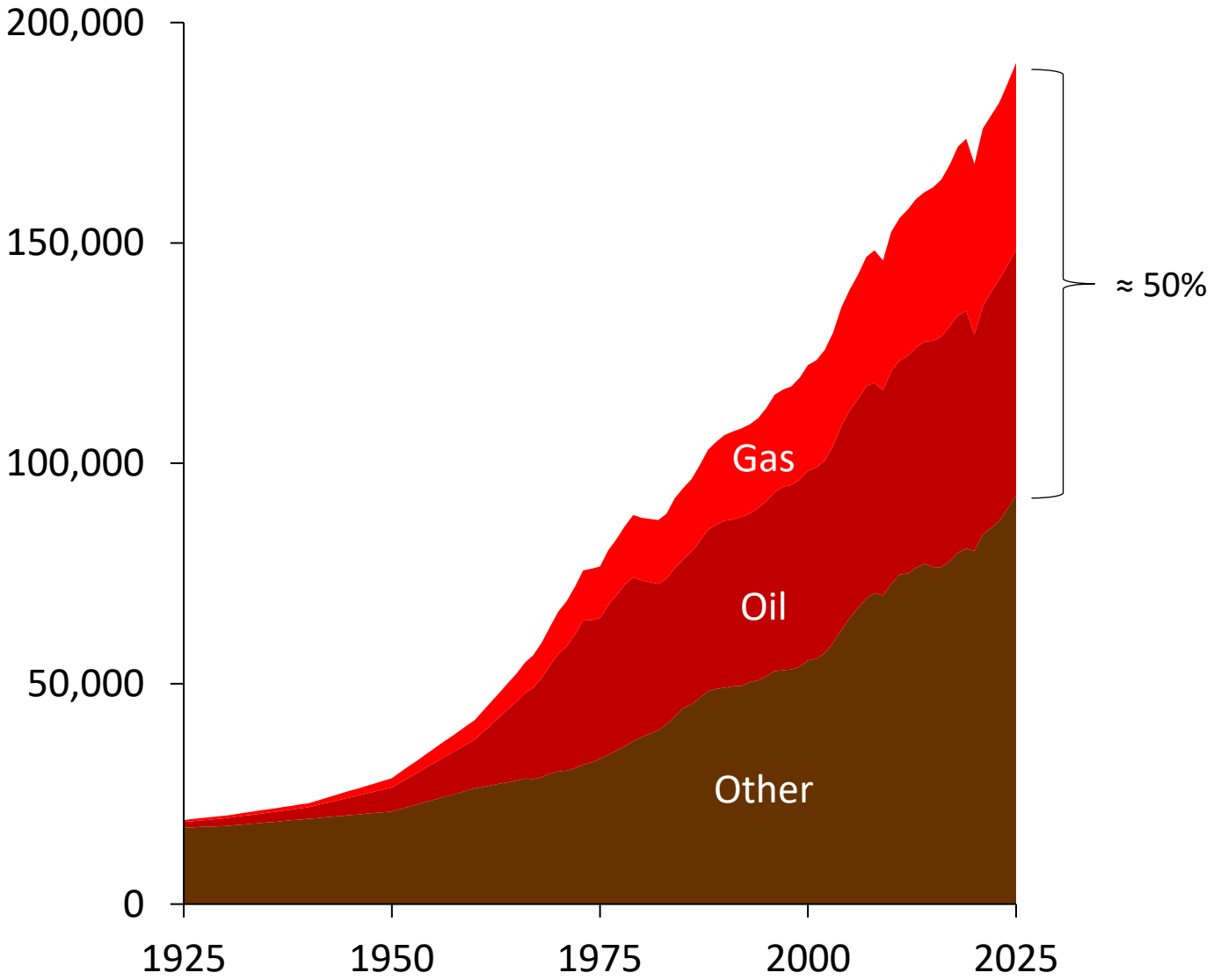
Picture taken from Rice University "Discovering Plate Boundaries" online presentation



Pictures taken from Smithsonian Institute Global Volcanism program website

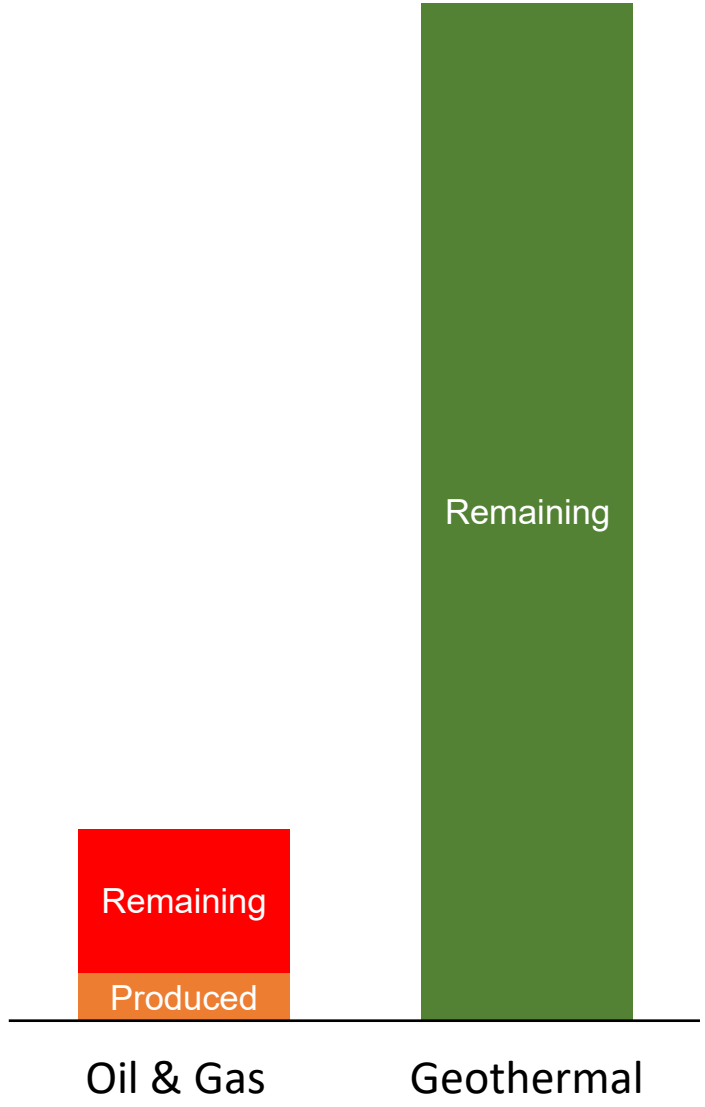
The amount of energy in geothermal resources is many times greater than oil and gas

Global primary energy consumption
(terawatt hours)



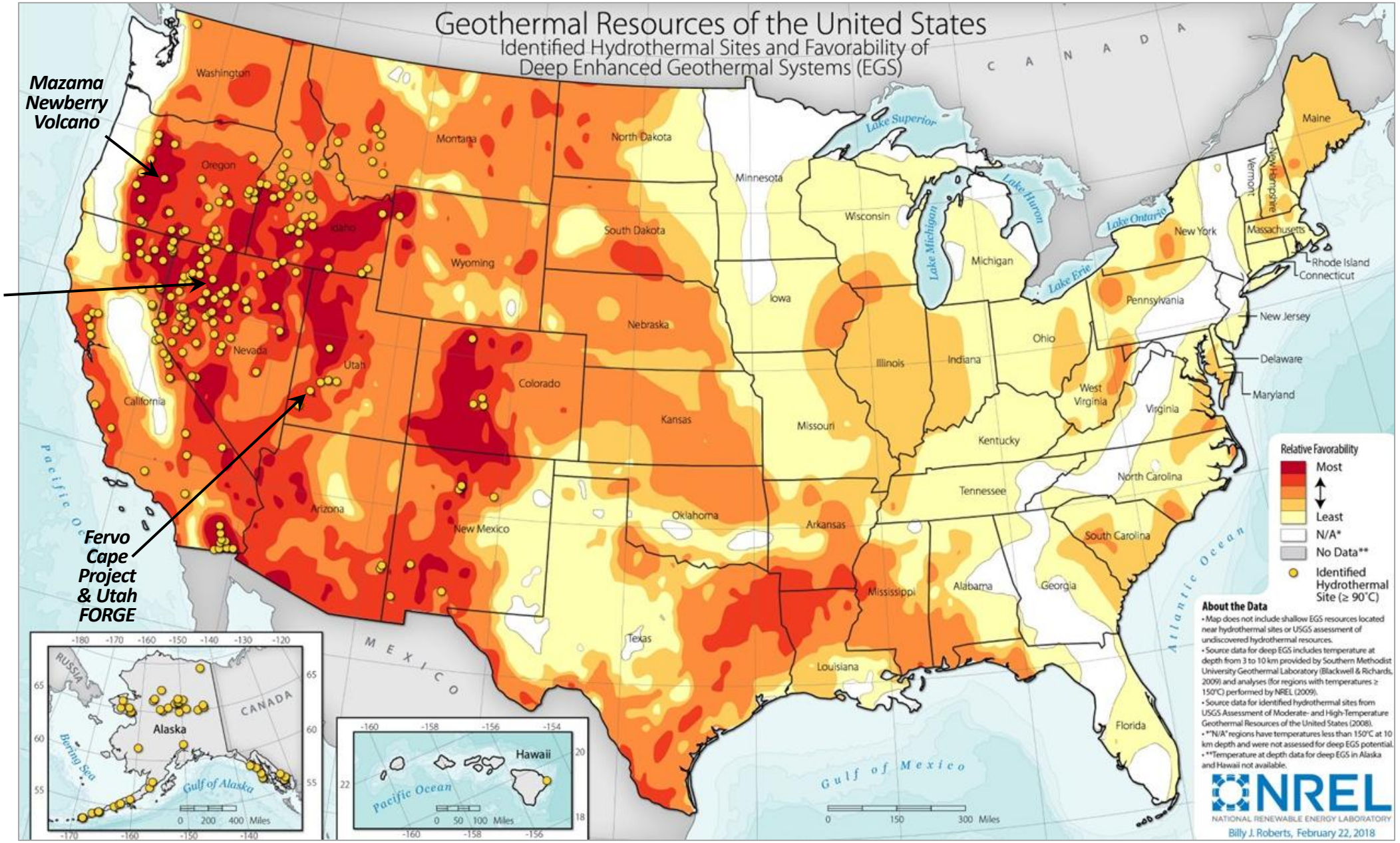
Sources: 1925 to 1964 = Vaclav Smil 2017; 1965 onwards = Energy Institute

Global energy resources
(estimated recoverable volumes)



Sources: Oil & Gas from Energy institute, EIA and other sources; geothermal based on Tester et al. 2006

America possesses abundant geothermal resources that could be converted to power

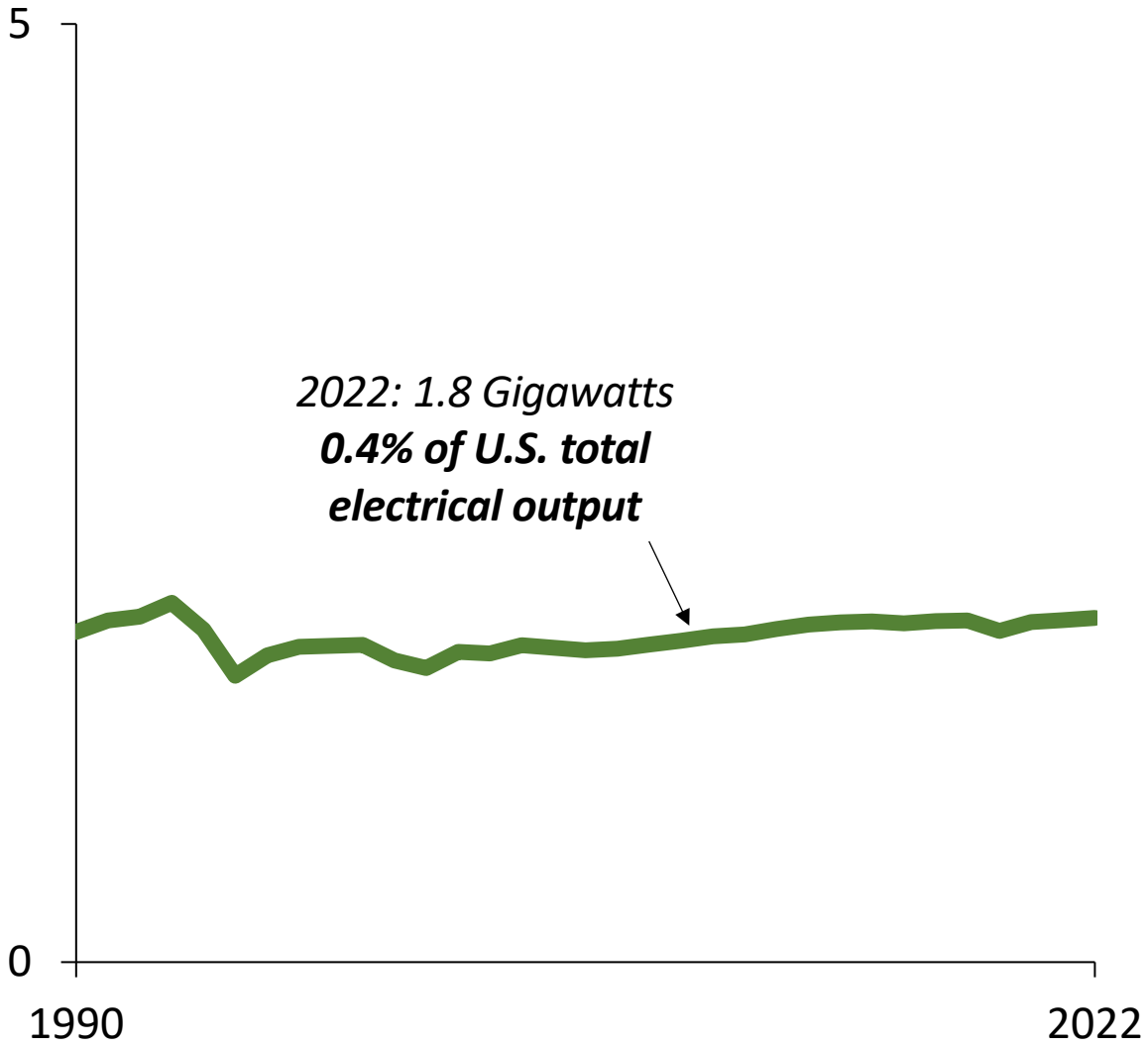


Map taken from U.S. National Laboratory of the Rockies website

But U.S. geothermal power output is trivial

U.S. average instantaneous power generation

(Gigawatts of geothermal power)



Source: U.S. EIA; curve shown is the average instantaneous output from geothermal power plants on an annual basis

Geothermal power economic scorecard

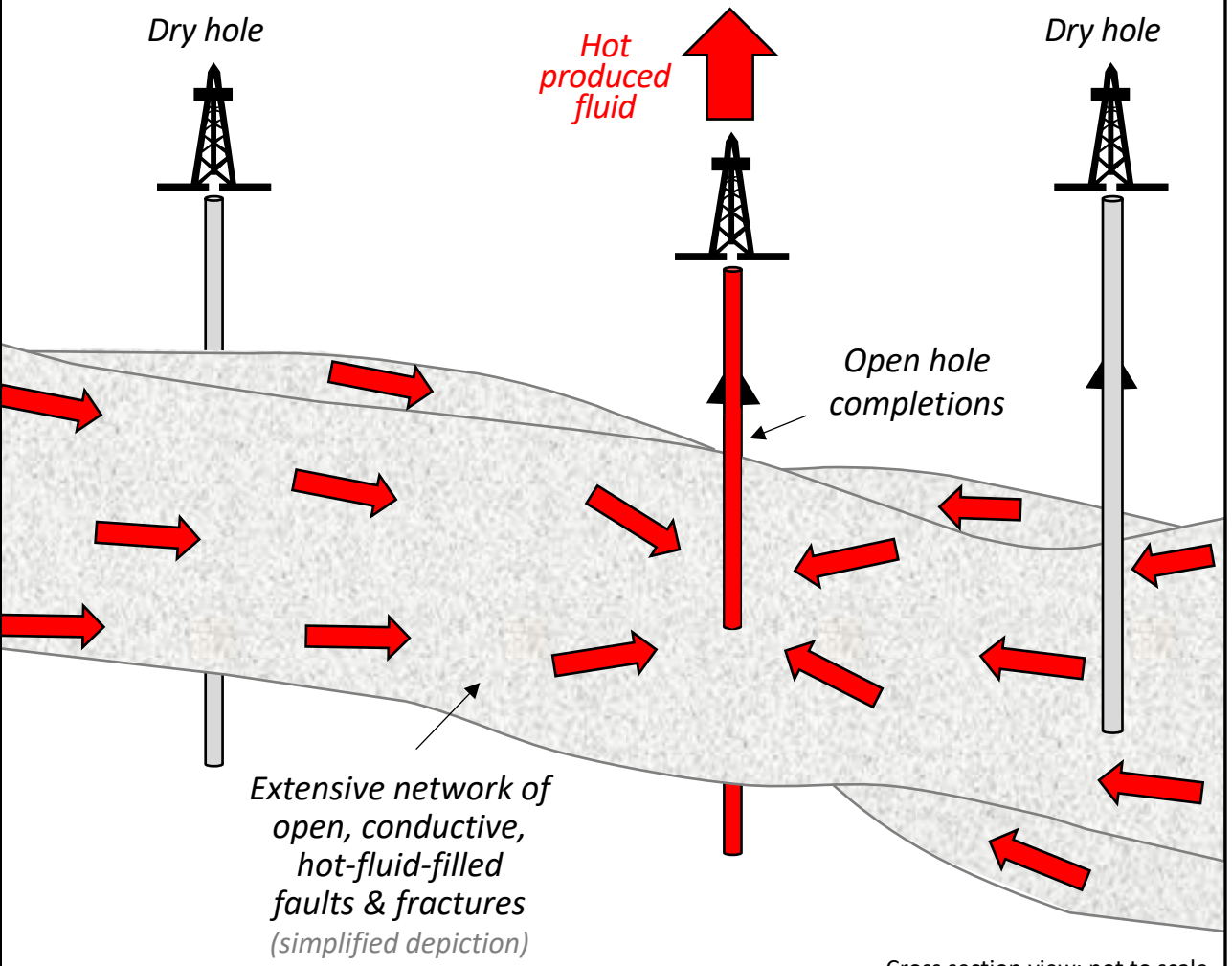
(Historical record; pre-2024)

Abundant:	☑
Reliable:	☑
Firm:	☑
Dispatchable:	☑
Low GHGs:	☑
Affordable:	X

Reliable refers to plant uptime after first several months of production; firm = 24/7/365 output

Past approaches to extracting heat from the Earth's crust have met with limited success

Hydrothermal (naturally occurring) systems

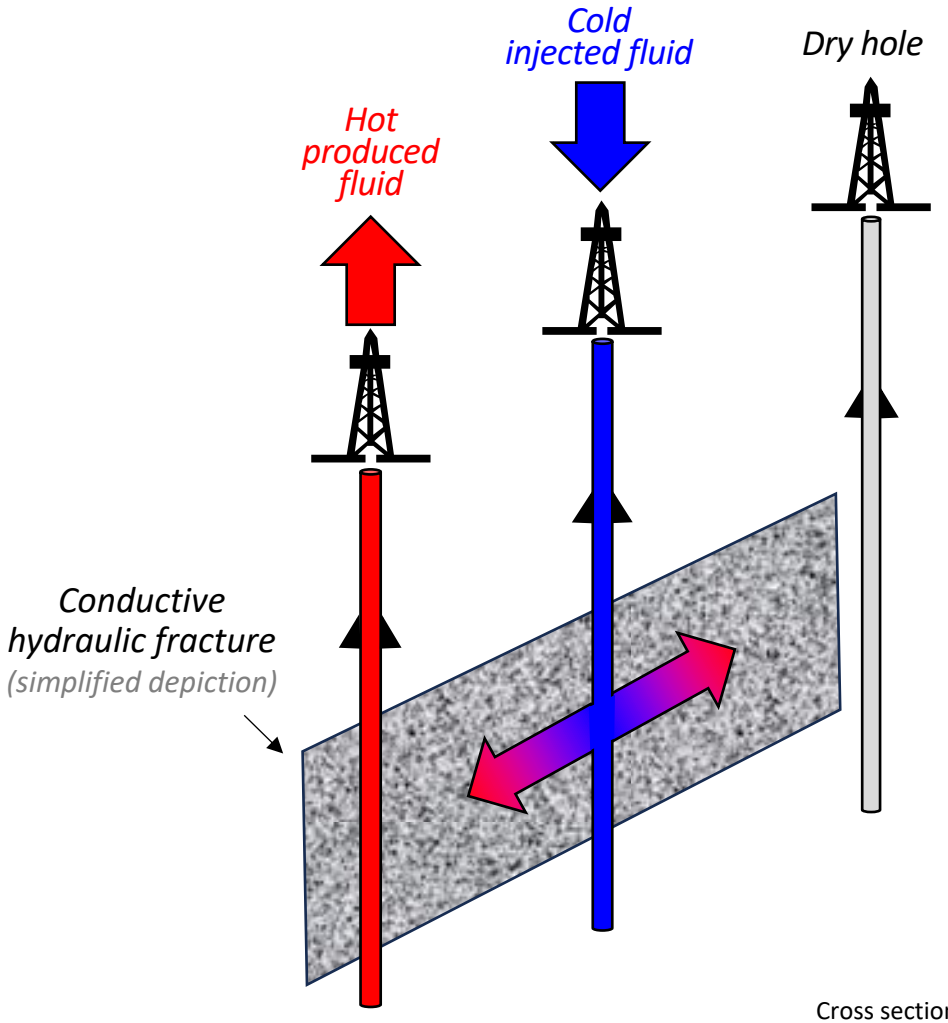


Cross section view; not to scale

HARD TO FIND; PERCEIVED TO BE RARE

Examples: The Geysers, California; McGinnis Hills, Nevada

Enhanced geothermal systems with vertical wells



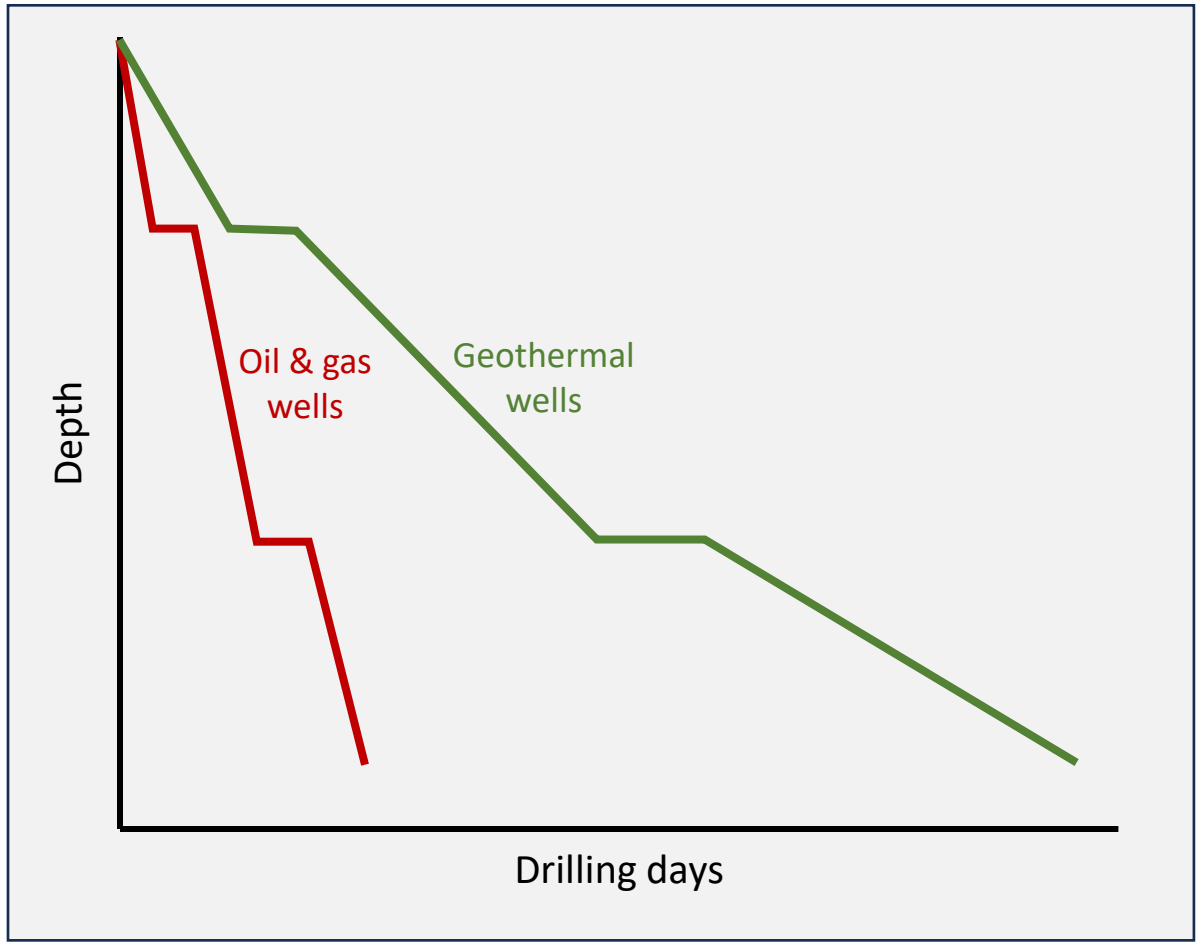
Cross section view; not to scale

EXCEEDINGLY DISAPPOINTING

Examples: Most EGS projects between 1970-2023

Historical performance was also hampered by high well costs and low energy density

Geothermal wells historically took far longer to drill



Drilling time comparisons are schematic representation of performance

Great Basin geothermal wells: Temperature & flow rate

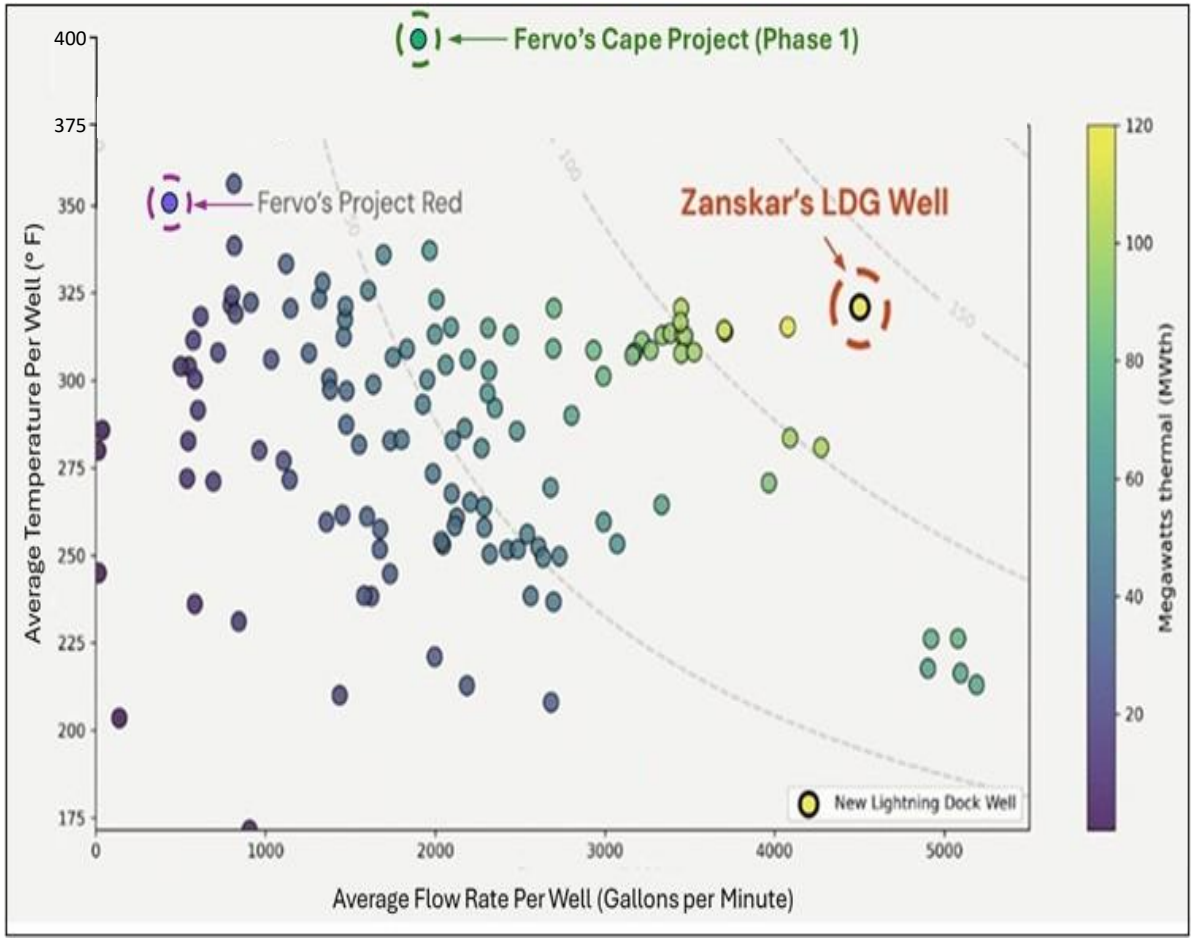
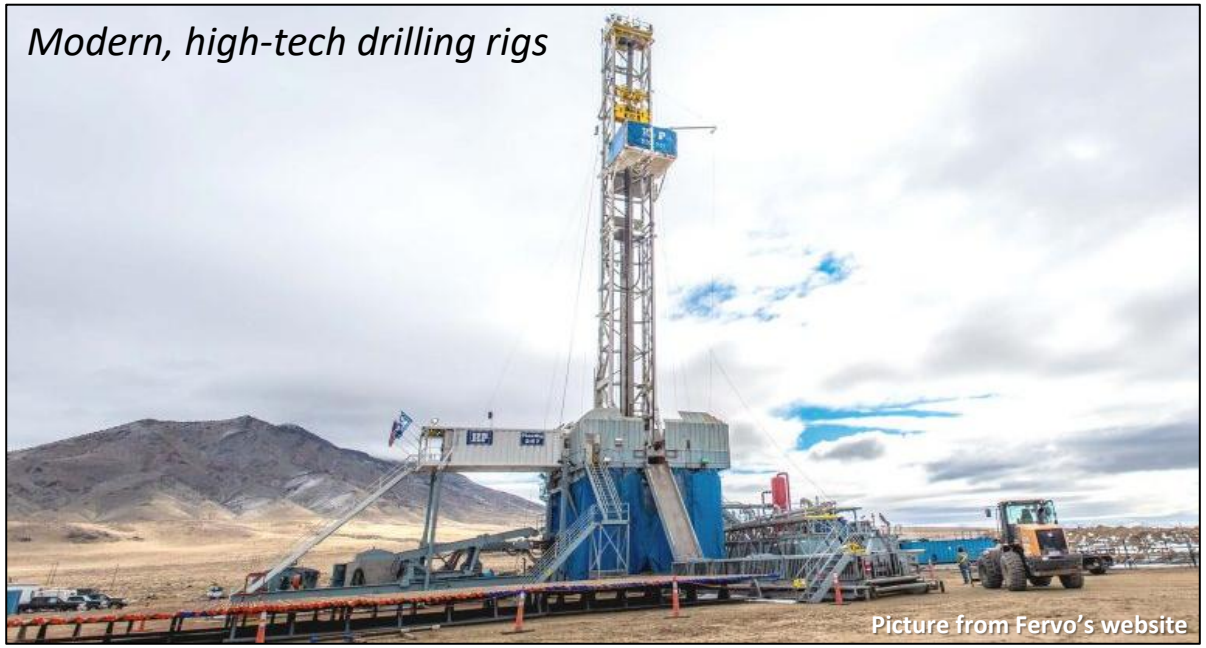


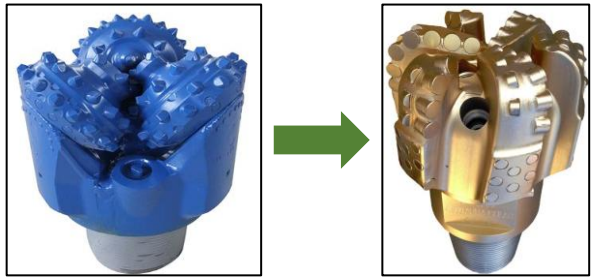
Figure modified after diagram in Zanskar February 3, 2025, Substack post (LINK)

Technology transfer from the O&G industry has transformed geothermal economics

Latest oil and gas drilling technologies



Drill bit design



Roller Cone → PDC

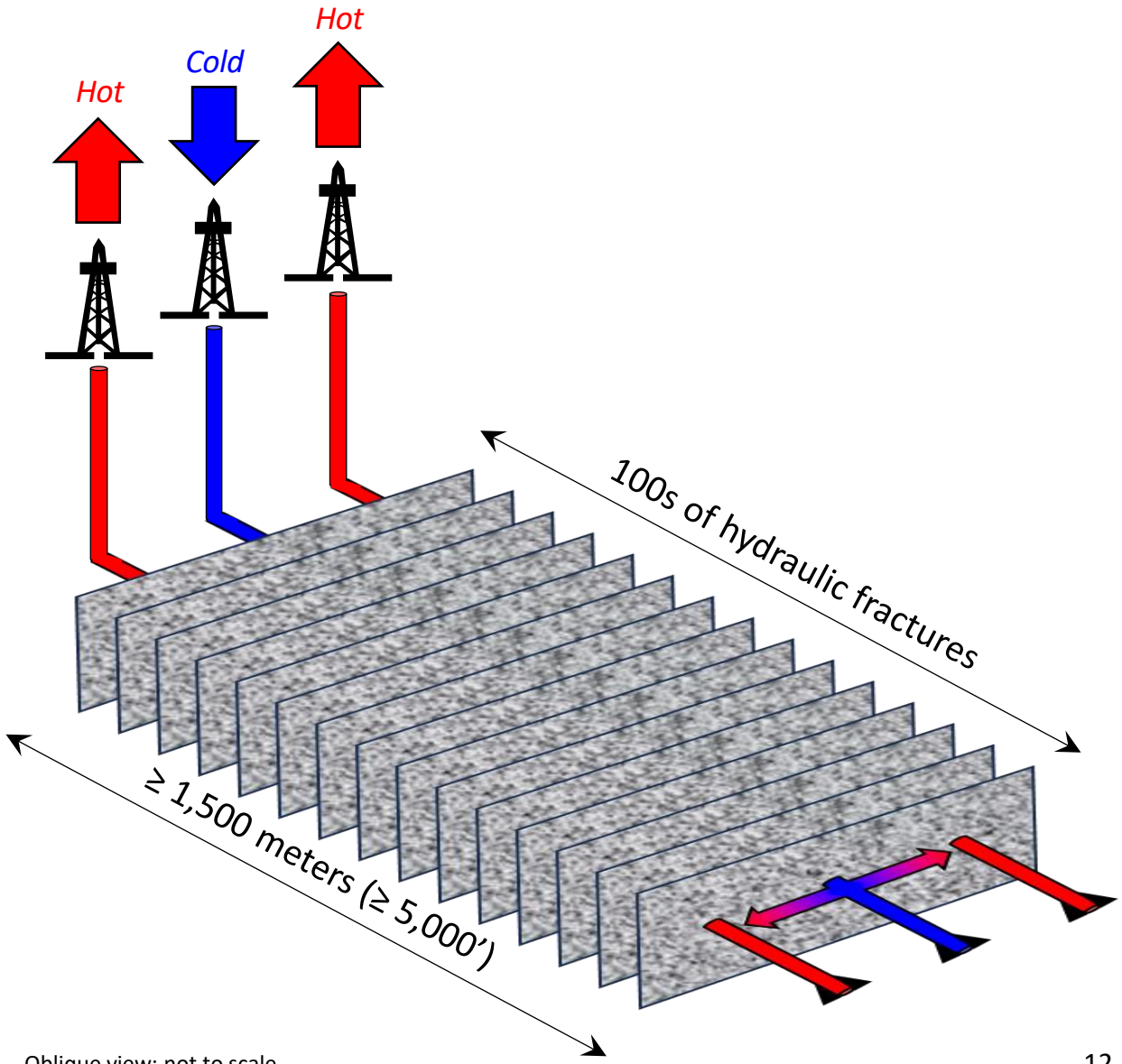
Physics-based drilling

Fred Dupriest
& Sam Noynaert

Texas A&M University

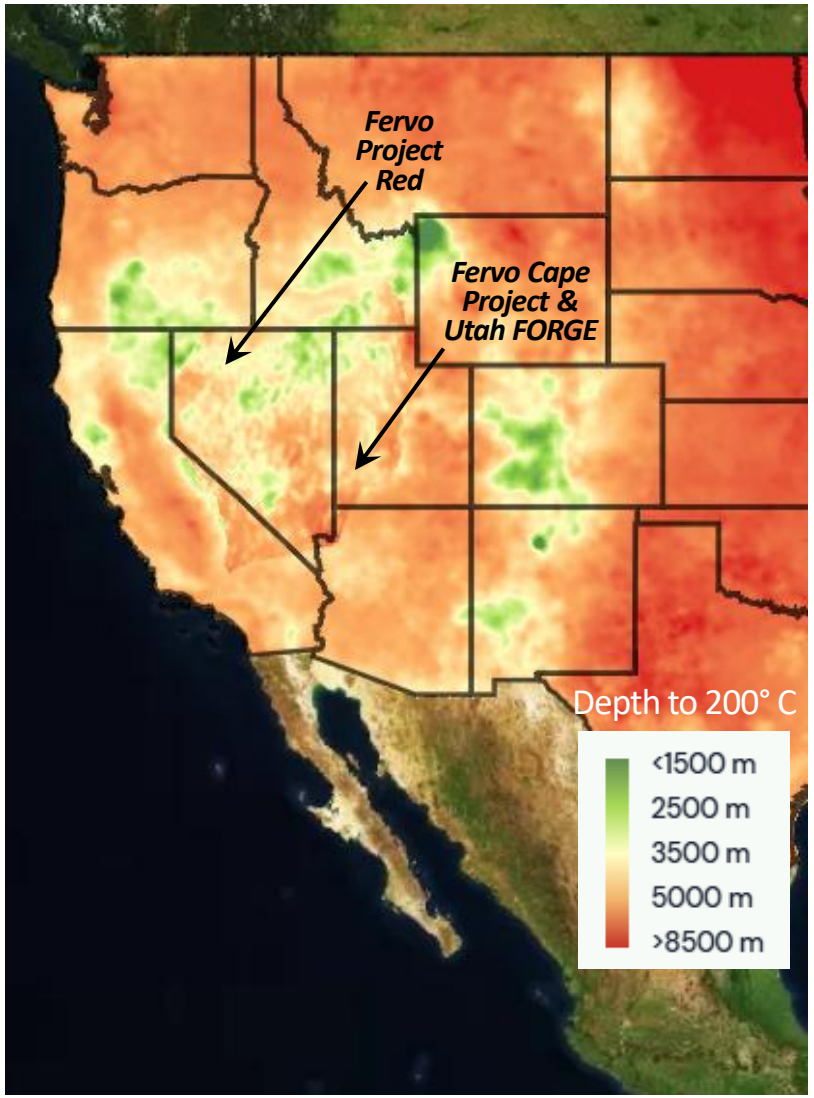
EGS = Enhanced geothermal systems; PDC = Polycrystalline diamond compact (bits)

Hydraulically fractured horizontal wells

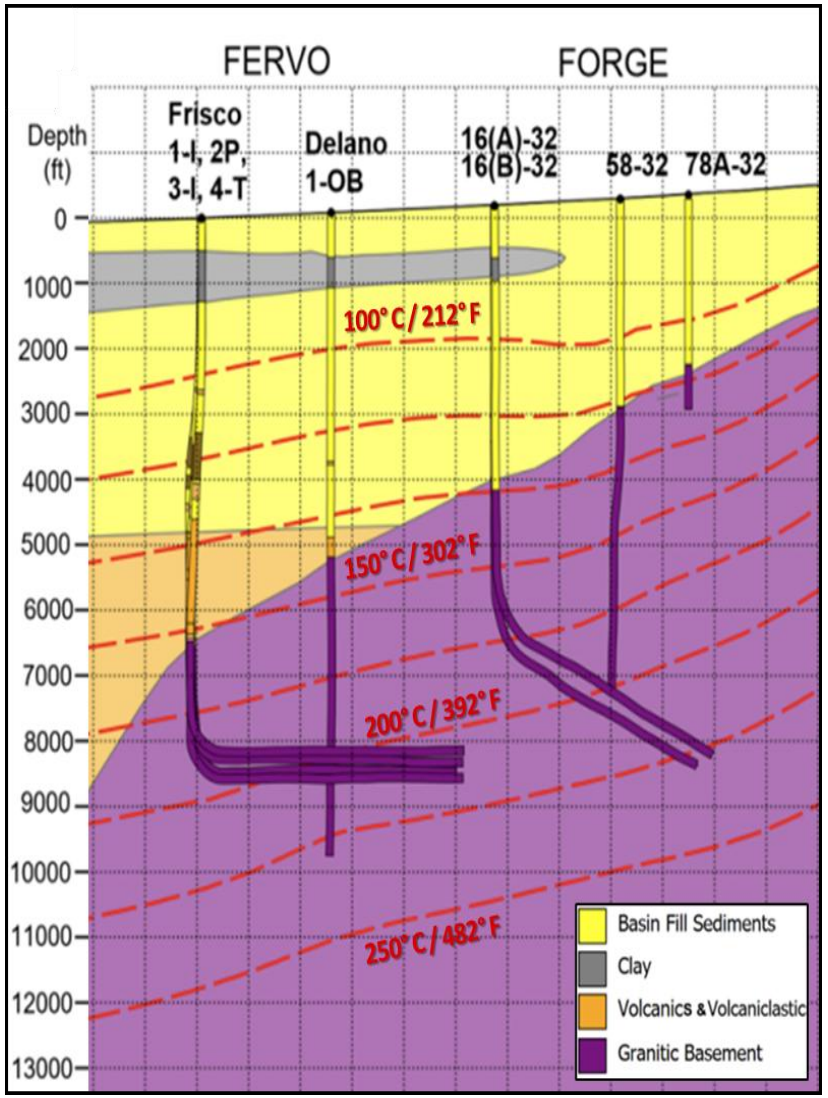


Oblique view; not to scale

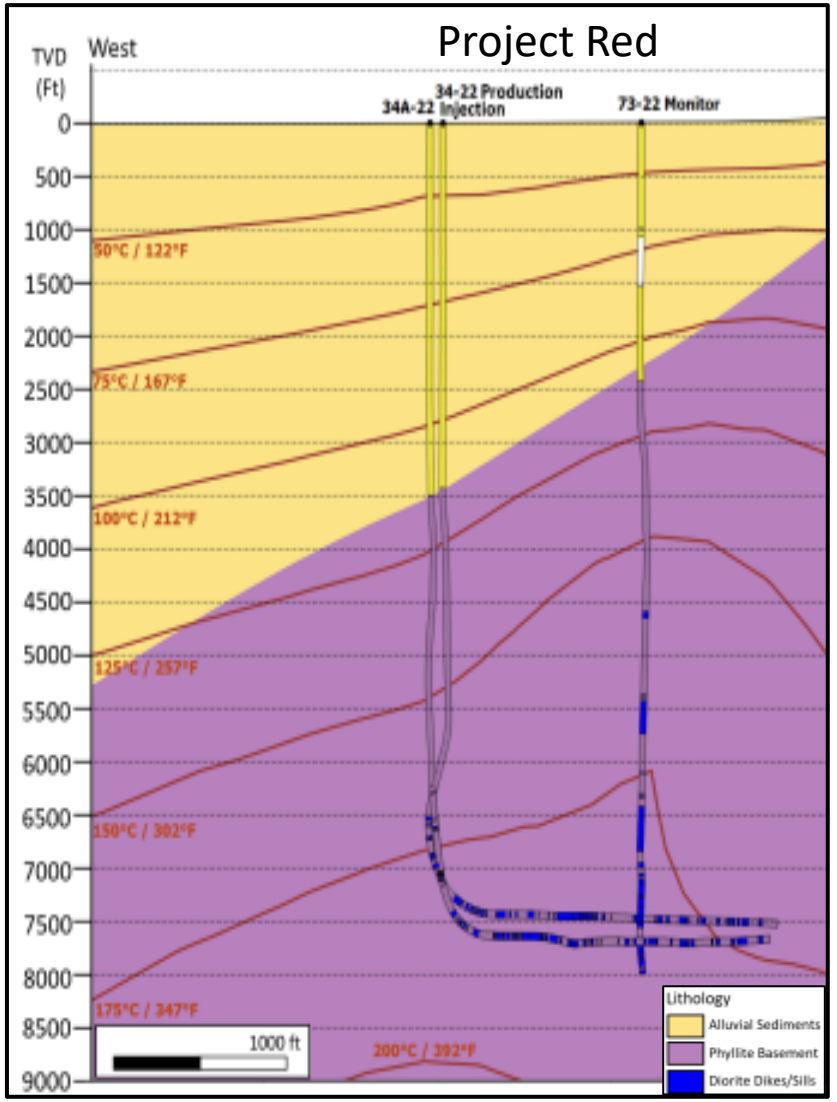
Cutting edge oil and gas industry technologies were first deployed at the U.S. DOE funded Utah FORGE project and Fervo Energy's Red and Cape projects



Map copied from Project Innerspace's website, February 2025



Cross section view parallel to horizontal lateral direction taken from 2024 paper presented at the 49th Stanford Geothermal Workshop by Fercho et al.

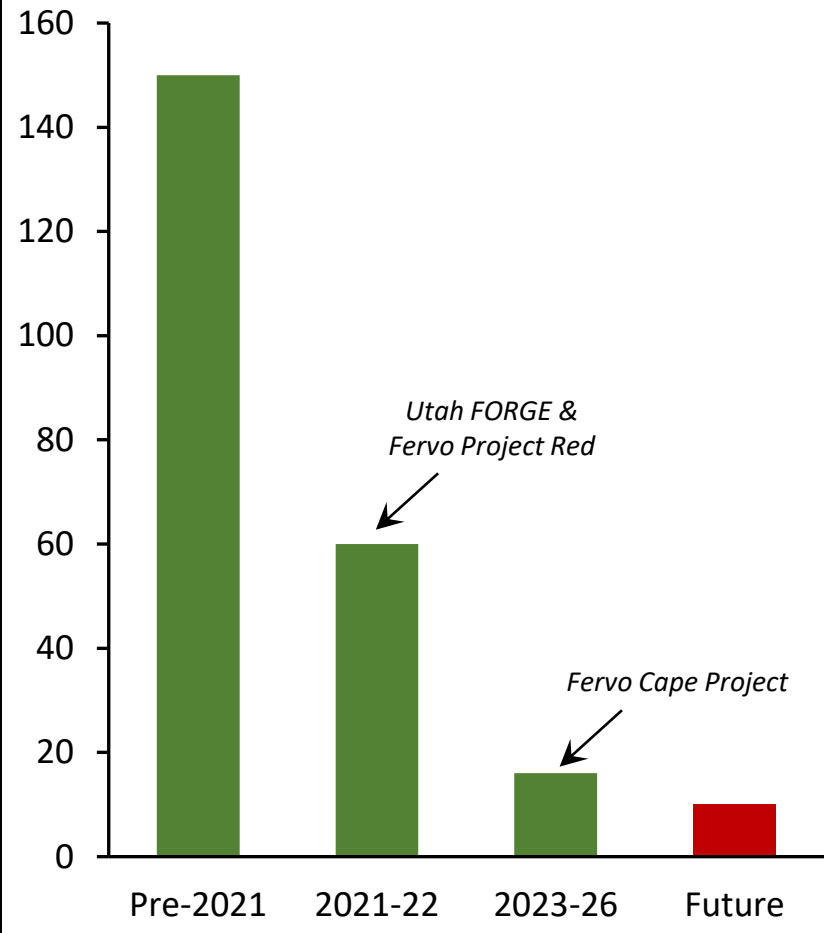


Cross section view parallel to horizontal lateral direction taken from 2023 by Jack Norbeck and Tim Latimer

O&G technologies have allowed Utah FORGE and Fervo Energy to shatter long-held geothermal industry paradigms much like Mitchell Energy did in the Barnett Shale

Spectacular drilling performance improvements

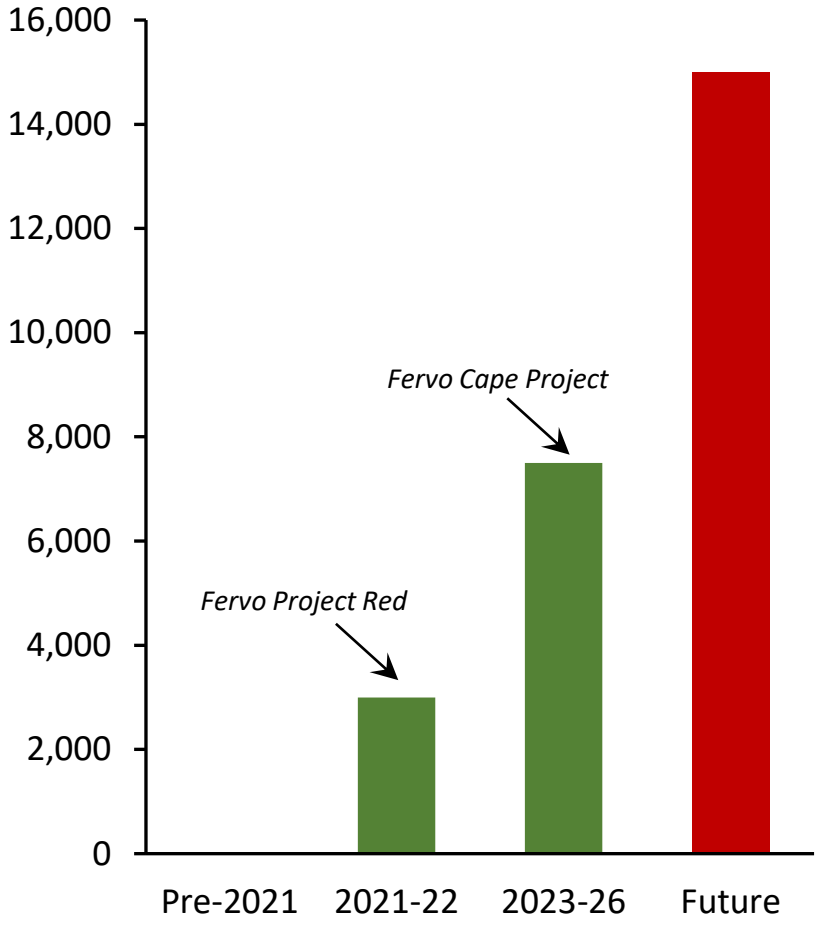
Drilling days to 12,000' MD (≈ 3,600 m)



Sources: El-Sadi et al, 2024, Review Of Drilling Performance In A Horizontal EGS Development; Winkler & Swearingen, 2021, Summary of Drilling Activities, Utah FORGE; MD = Measured depth

Ability to D&C horizontal EGS wells in basement rocks

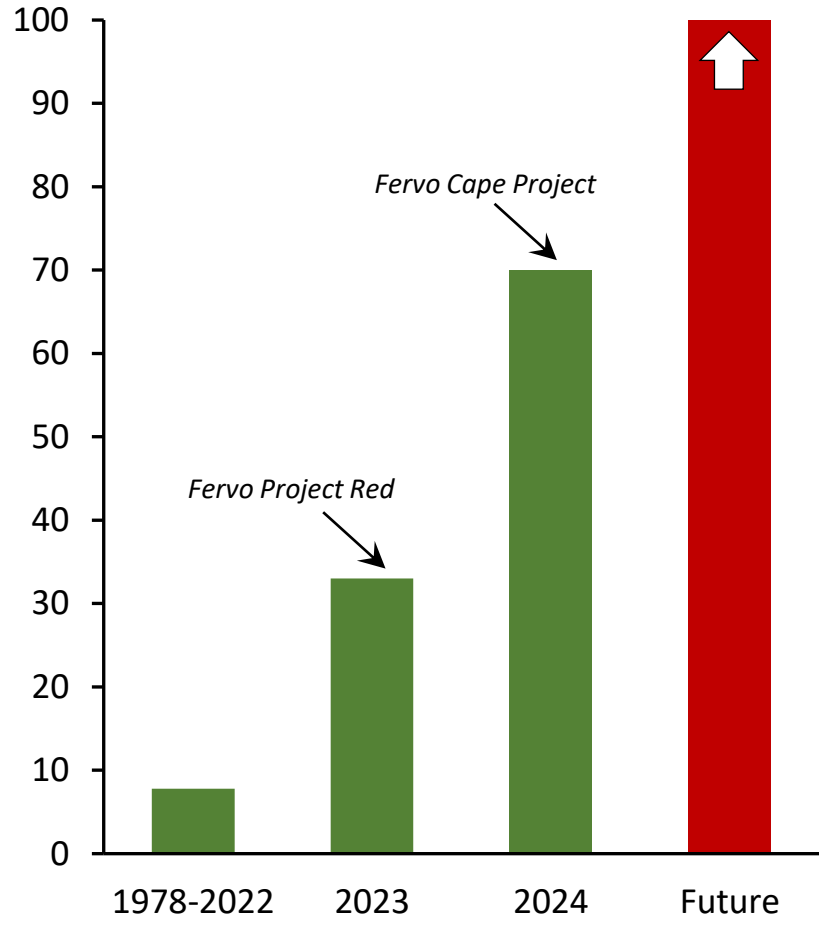
Lateral length (feet)



Note: The first fully horizontal EGS wells drilled were those drilled by Fervo at their Blue Mountain project in 2022. D&C = drill and complete

Near order-of-magnitude increase in per well production

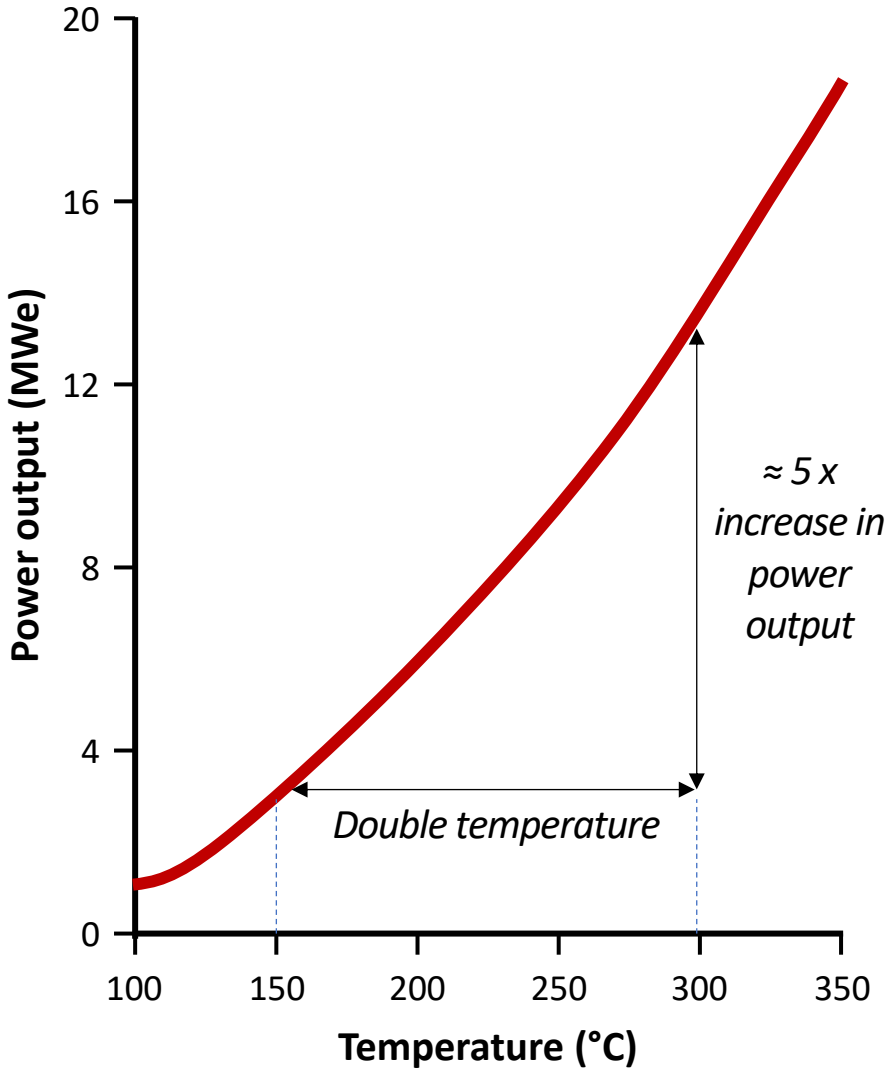
Peak EGS production flow rate (MBFPD)



Note: 1978 – 2020 data from 11 projects; average peak flow rate shown (7,800 bfpd); range was from 2,700 to 16,300; MBFPD = thousands of barrels of fluid per day

Super hot temperatures – greater energy density, much higher power output

Power generation vs. temperature[1]

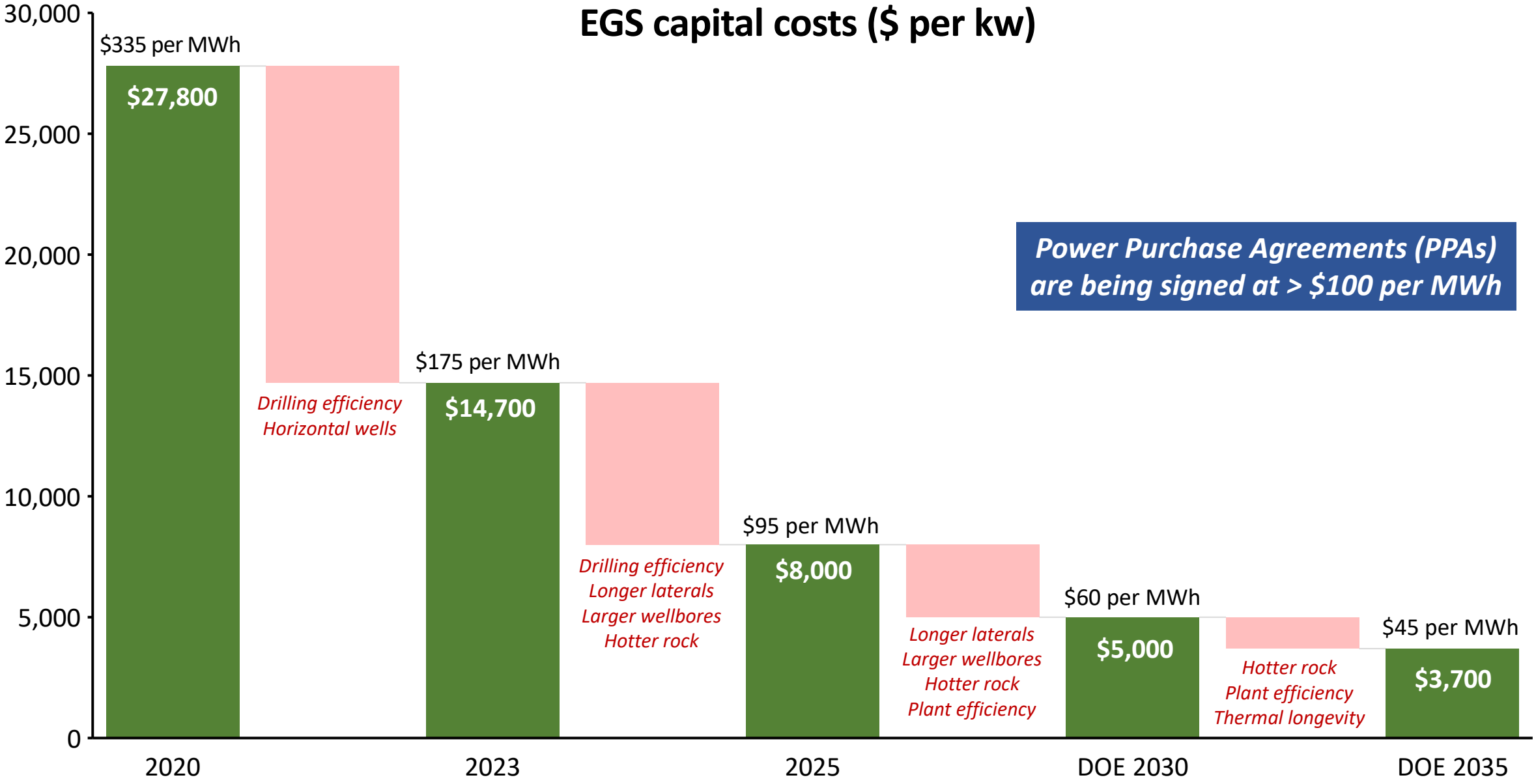


[1]Calculations generated by Mark McClure; graph is for 50,000 barrels per day of produced fluids

Mazama Energy have achieved EGS production at 331° C / 629° F

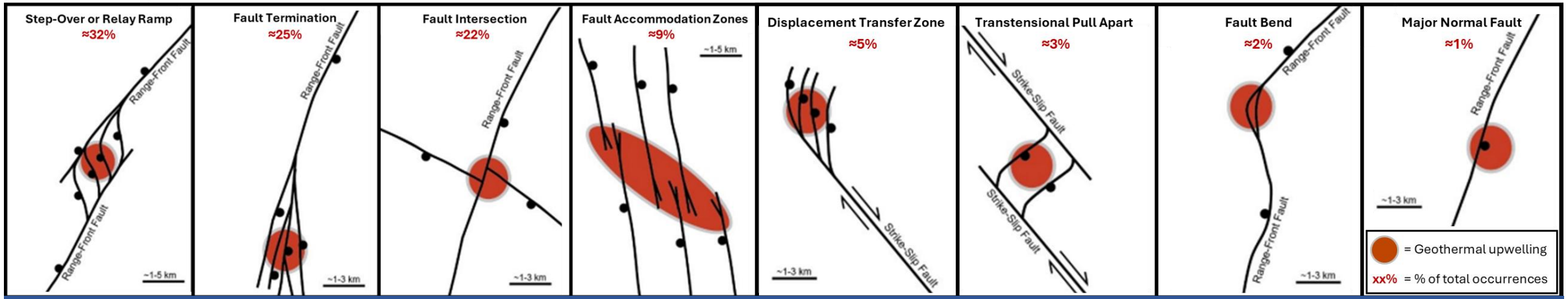
Picture from Mazama Energy's website

EGS capital costs have fallen precipitously over the past five years



All $ per kw numbers from US DOE Next Generation Geothermal Liftoff report except 2025 number, which is estimated. All numbers are unsubsidized. $ per MWh numbers from DOE report or scaled therefrom.

Hydrothermal exploration and production has been revitalized



Key uncertainties: Location of faults, dilation tendency, recency of fault movement, degree of mineralization

Diagram showing the geologic setting for fault-system-related hydrothermal upwellings in The Great Basin, western USA in map view. Diagram modified after Faulds and Hinz (2015)

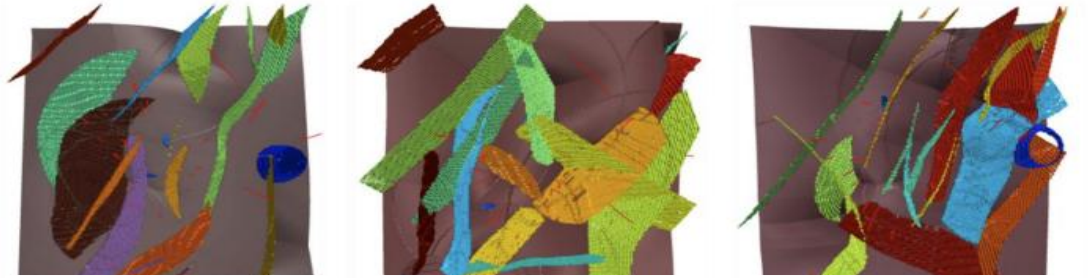
Remote sensing / Seismic imaging

Quaternary fault mapping from LIDAR data using deep learning

Diagram from Hermant et al. (2025)

Machine learning / AI

Model 1 (map view) Model 2 (map view) Model 3 (map view)



Model 1 (side view) Model 2 (side view) Model 3 (side view)

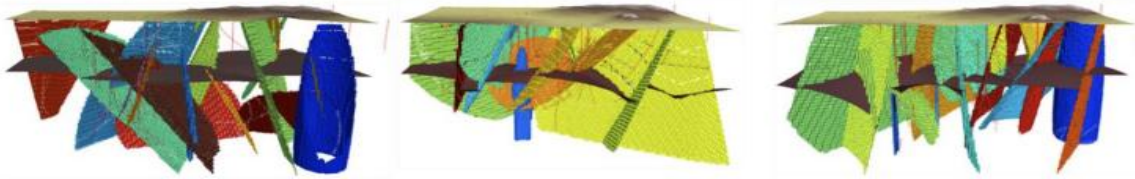


Diagram from Pollock (2020)

Horizontal wells could also greatly enhance hydrothermal power economics

Identifying faults in basement rocks is difficult

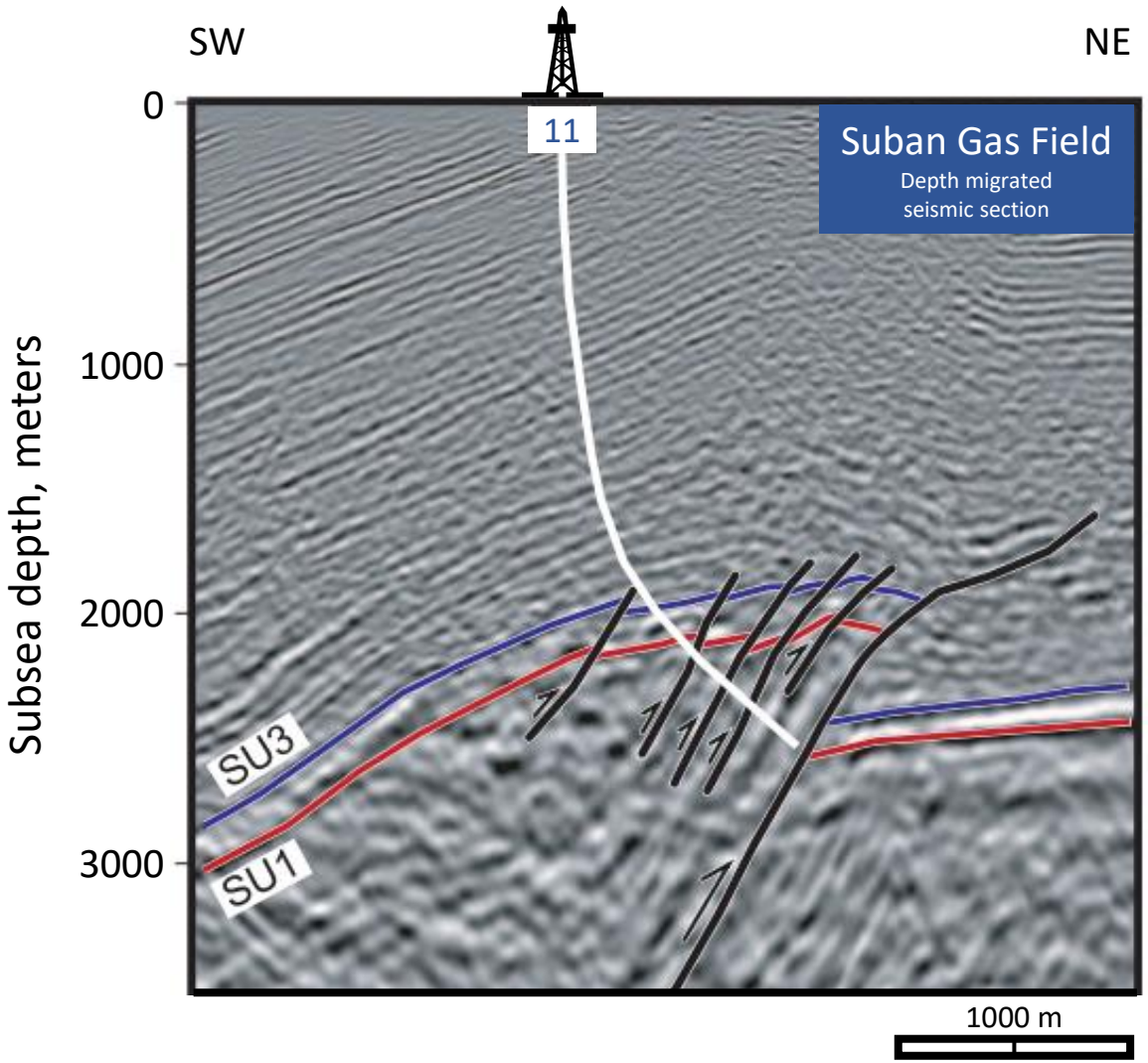


Figure after Hennings et al. (2012). Suban field estimated ultimate recovery = 6 TCFG from fractured basement rocks

To increase flow rates, intersect more fractures

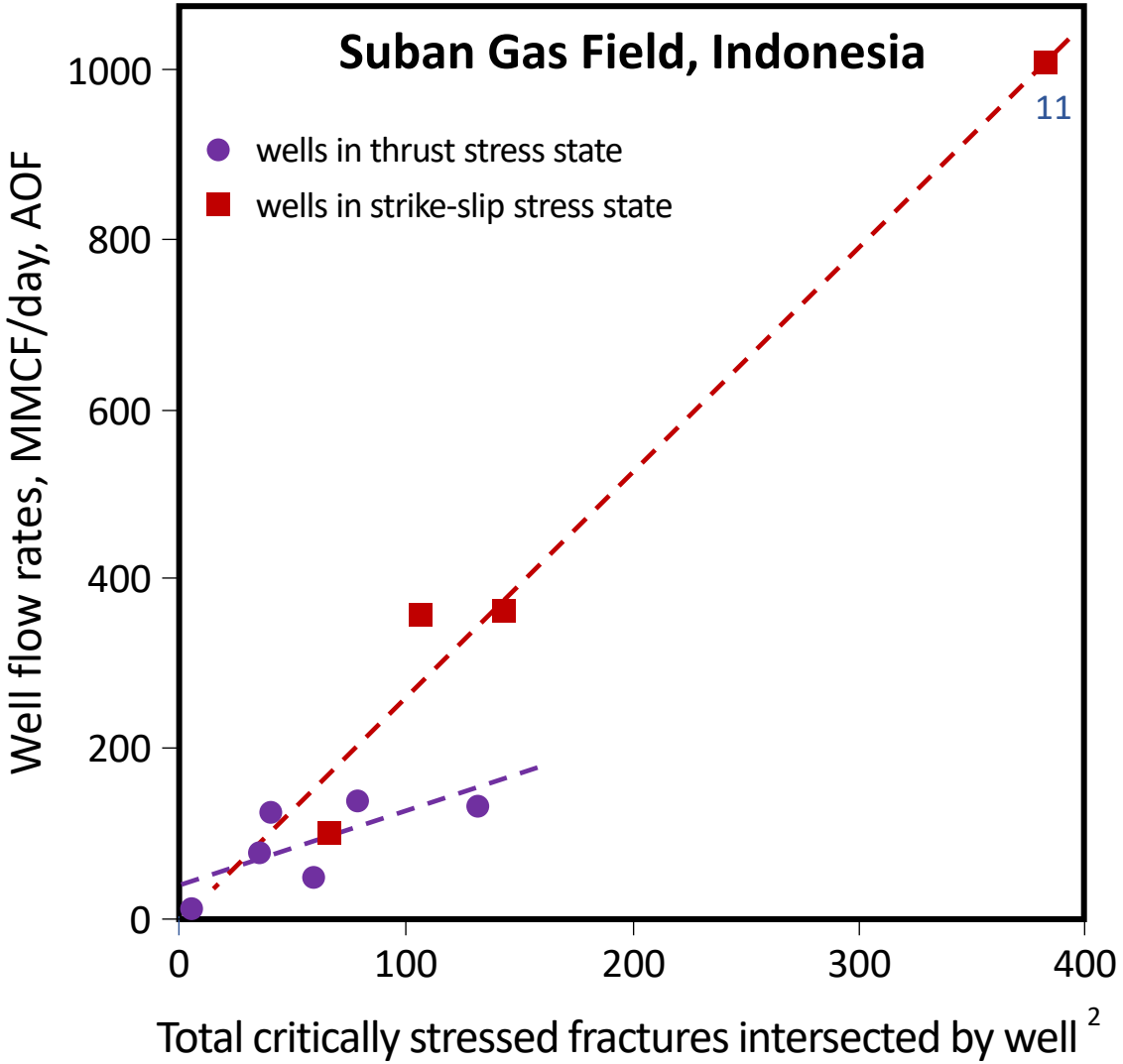


Figure after Hennings et al. (2012). MMCF = million cubic feet; AOF = absolute open flow; [1] critically stressed fractures; [2] from image logs.

Pressure geothermal systems can both store and generate power

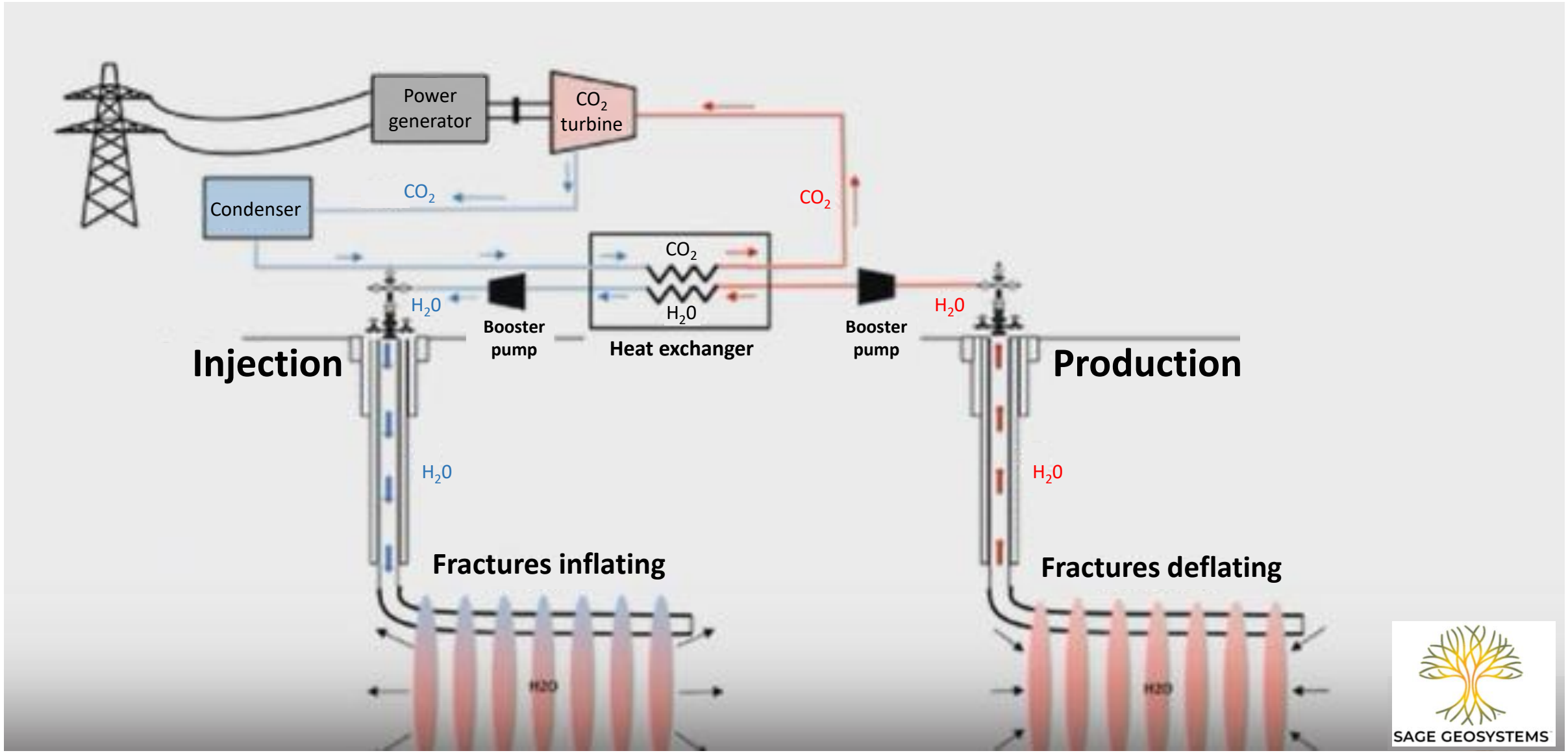
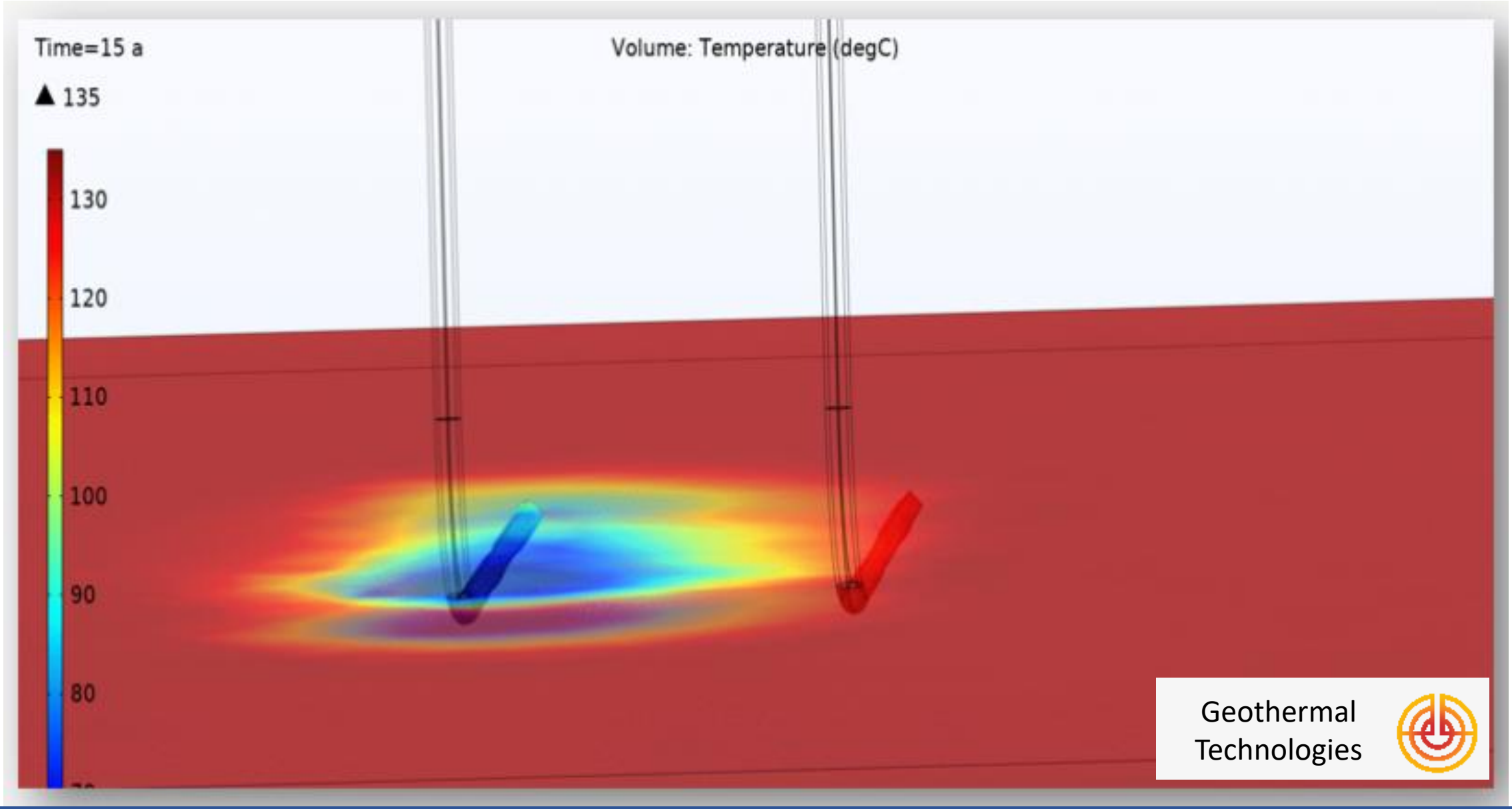


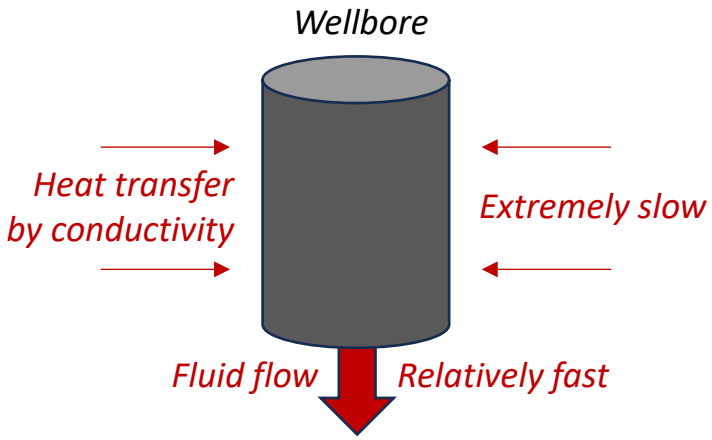
Figure from Sage Geosystems presentation at Petrobras sponsored 1st Brazilian Workshop on Geothermal Energy, November 2024

Sedimentary geothermal systems flow fluids through pore space in permeable formations



Occlusion of porosity and permeability at temperatures conducive for large scale power production is largest challenge

Solving the closed loop thermal longevity challenge



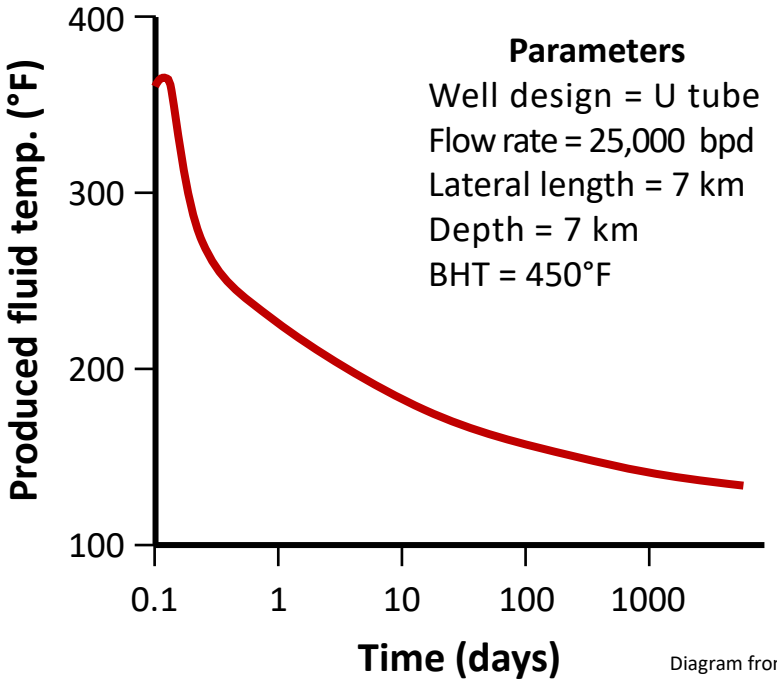
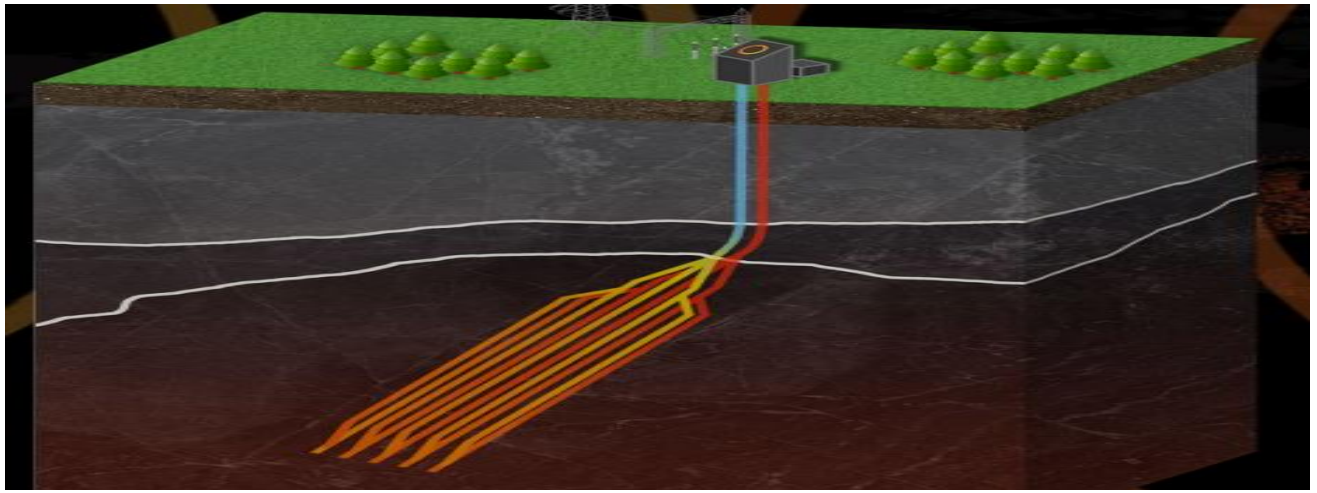
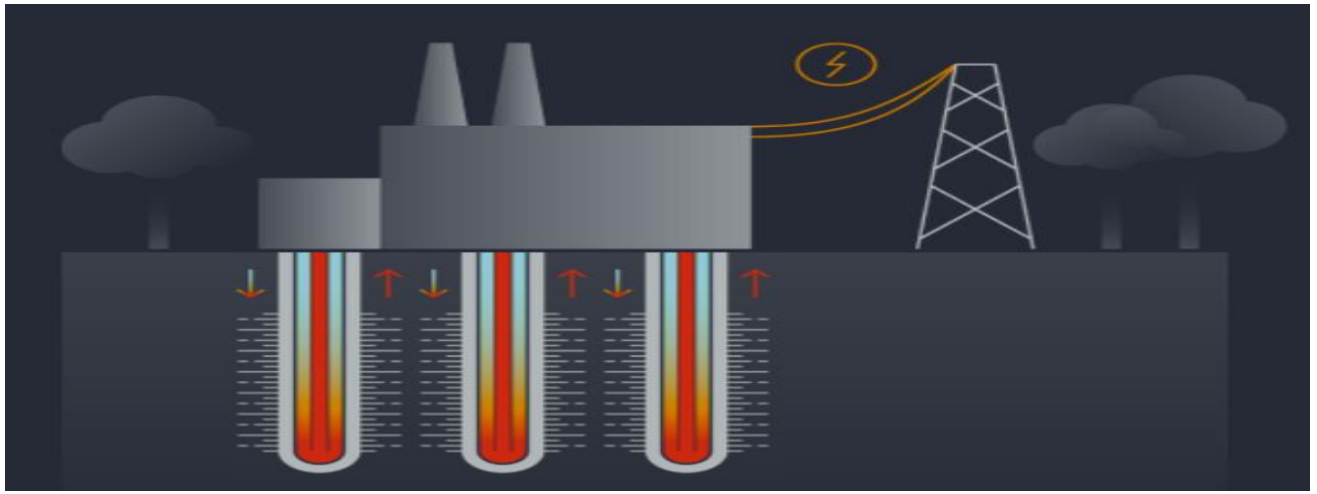


Diagram from McClure 2021

Eavor multi-lateral closed loop "radiator" design



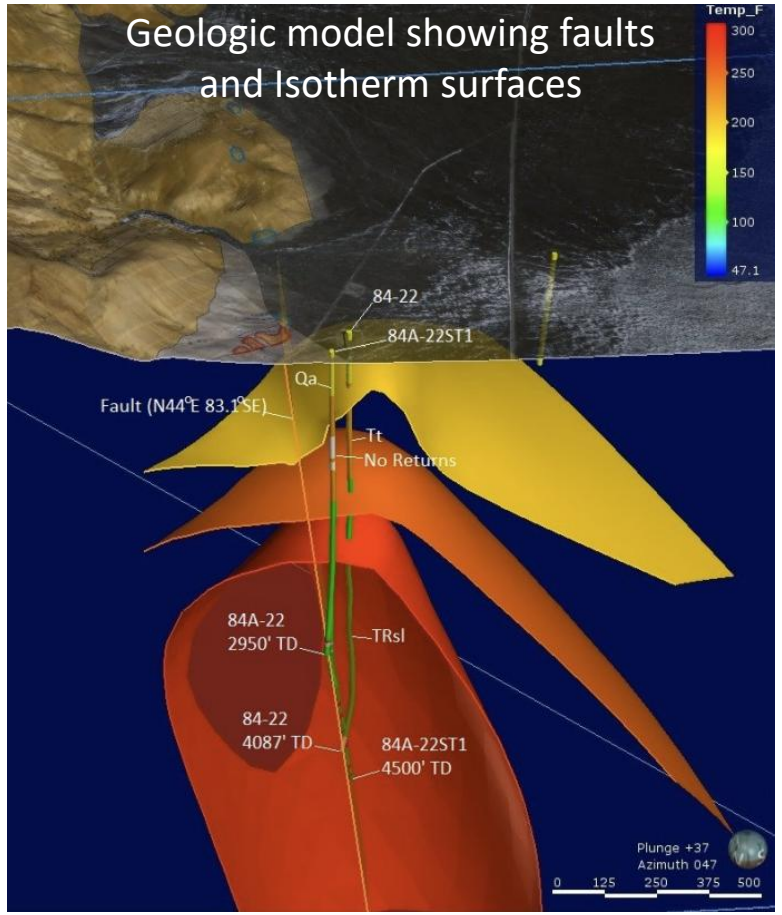
XGS enhanced-conductivity combined inj./prod. well



Potential solutions: increase flow loop surface area at depth; insulate upper portion of flow loop; target higher temperatures

Just as with unconventional reservoirs, there will be unexpected & underappreciated challenges to overcome

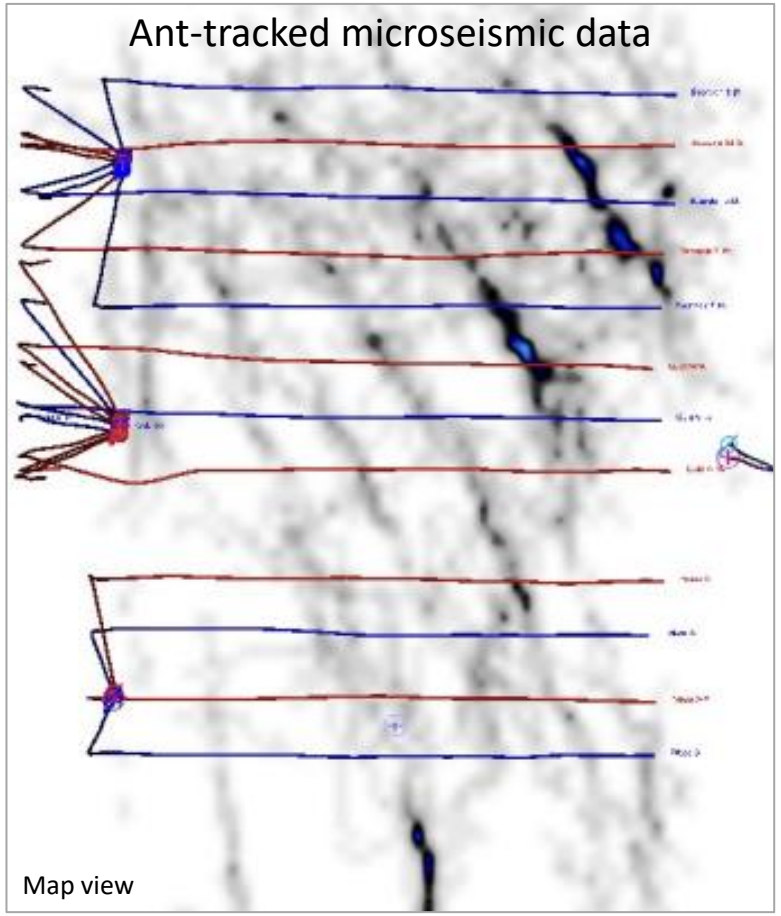
Hydrothermal systems



- Determining fault geometries and characterizing fluid flow pathways
- Challenges: placing injectors to provide pressure support but avoid breakthrough

Source: Successful Deployment of a Multi-Crossing Directional Drilling Method at Ormat's New Tungsten Mountain Geothermal Field in Churchill County, Nevada, Delwiche (2018)

Enhanced geothermal systems (EGS)



- Managing challenges created by pre-existing faults and fractures
- Challenges: thermal degradation, water losses, casing deformation

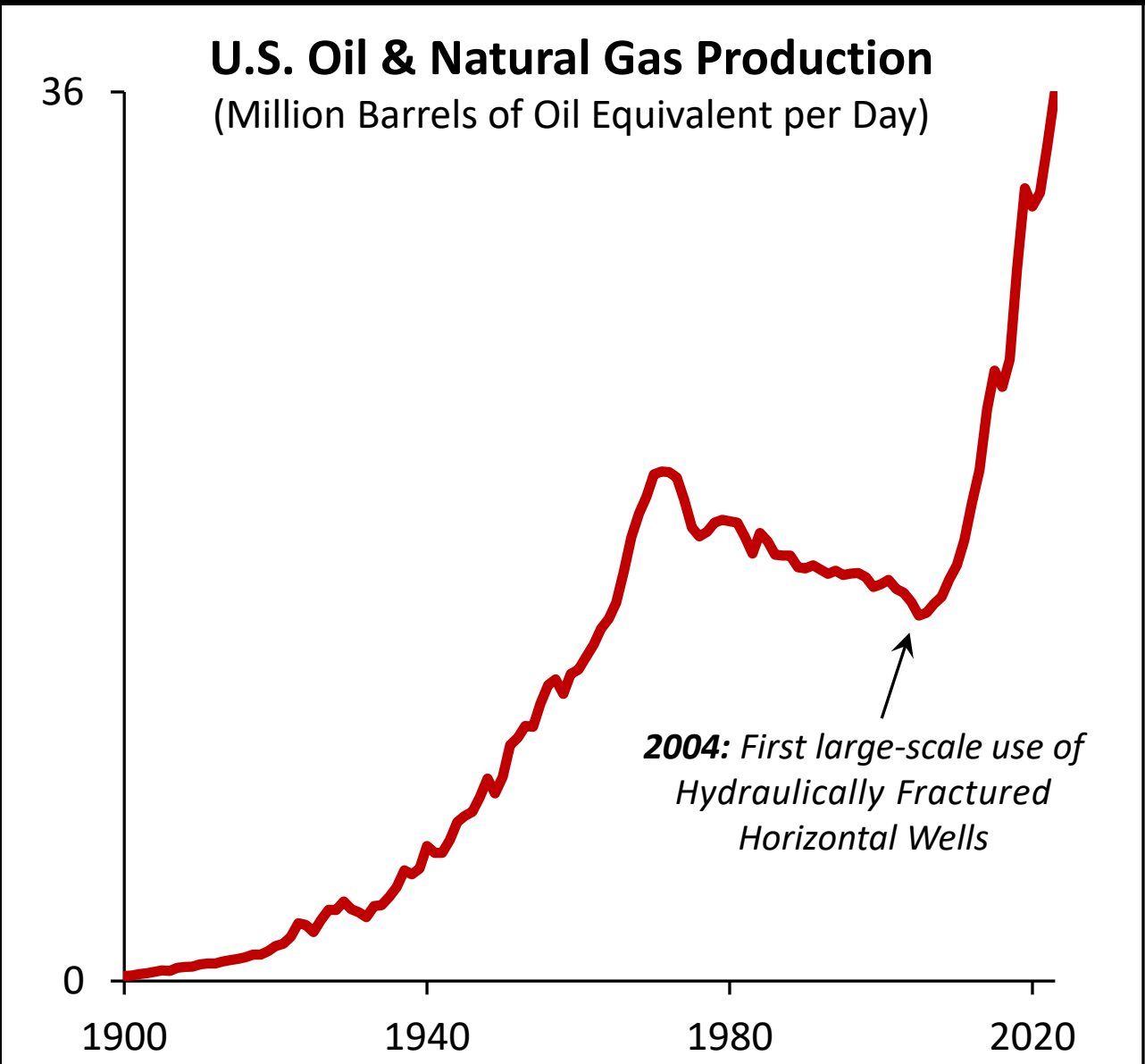
Source: Insights from Microseismic Monitoring of Enhanced Geothermal Systems: Case Study from Cape Modern, Utah, USA, Dadi (2025)

Super hot production

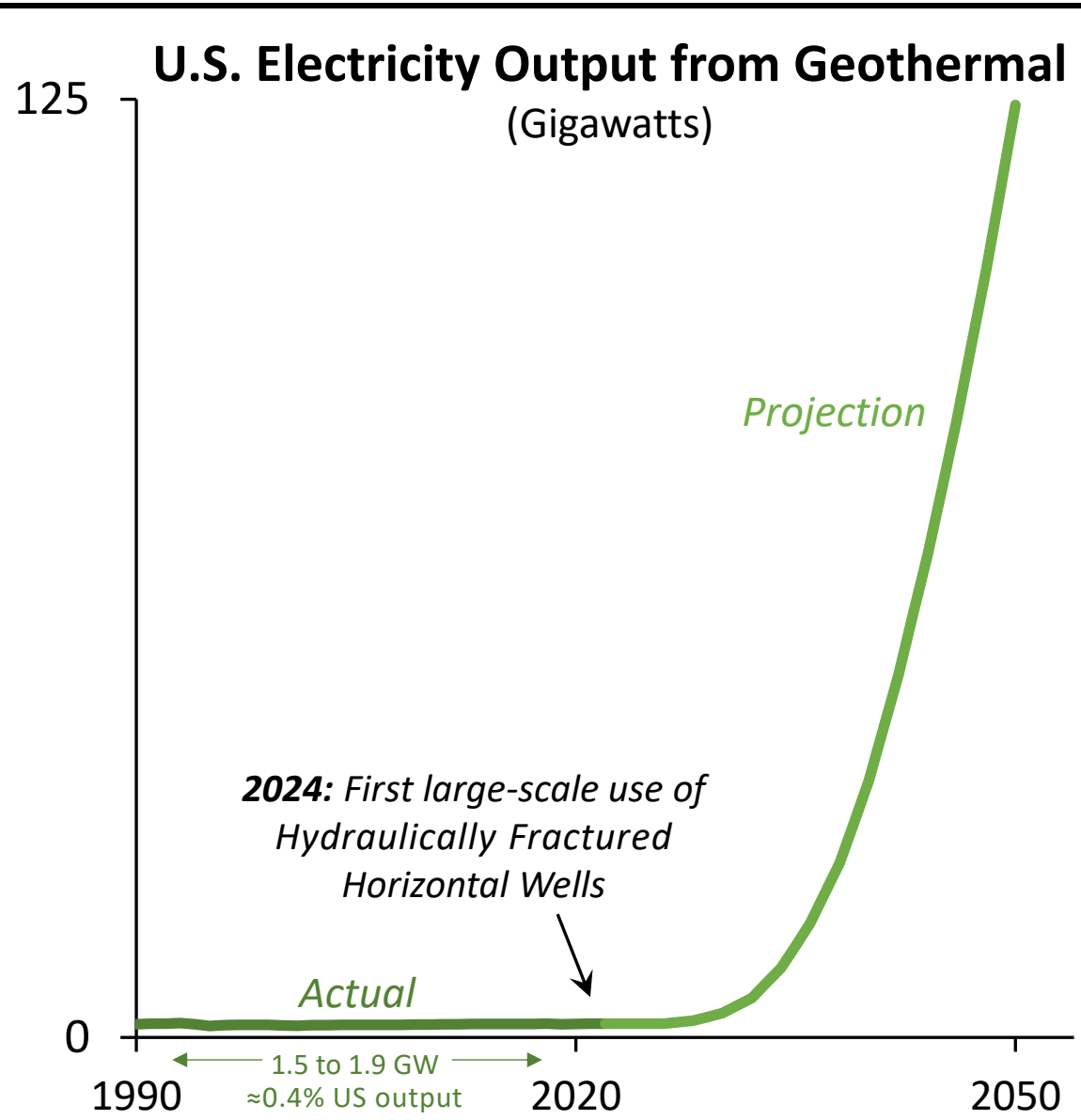
- Managing challenges created by high temperatures and reactive fluids
- Challenges: proppant dissolution, equipment failures, scaling, corrosion

Source: CATF website (LINK)

Geothermal power production is poised to achieve a breakthrough like that achieved in U.S. unconventional O&G reservoirs



Sources: U.S. EIA and Energy Institute websites



Sources: U.S. EIA for 1990 to 2022; 2022 average output = 1.8 GW (0.4% of U.S. total); Author projection from 2023 to 2050

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Picture from Fervo Energy's website