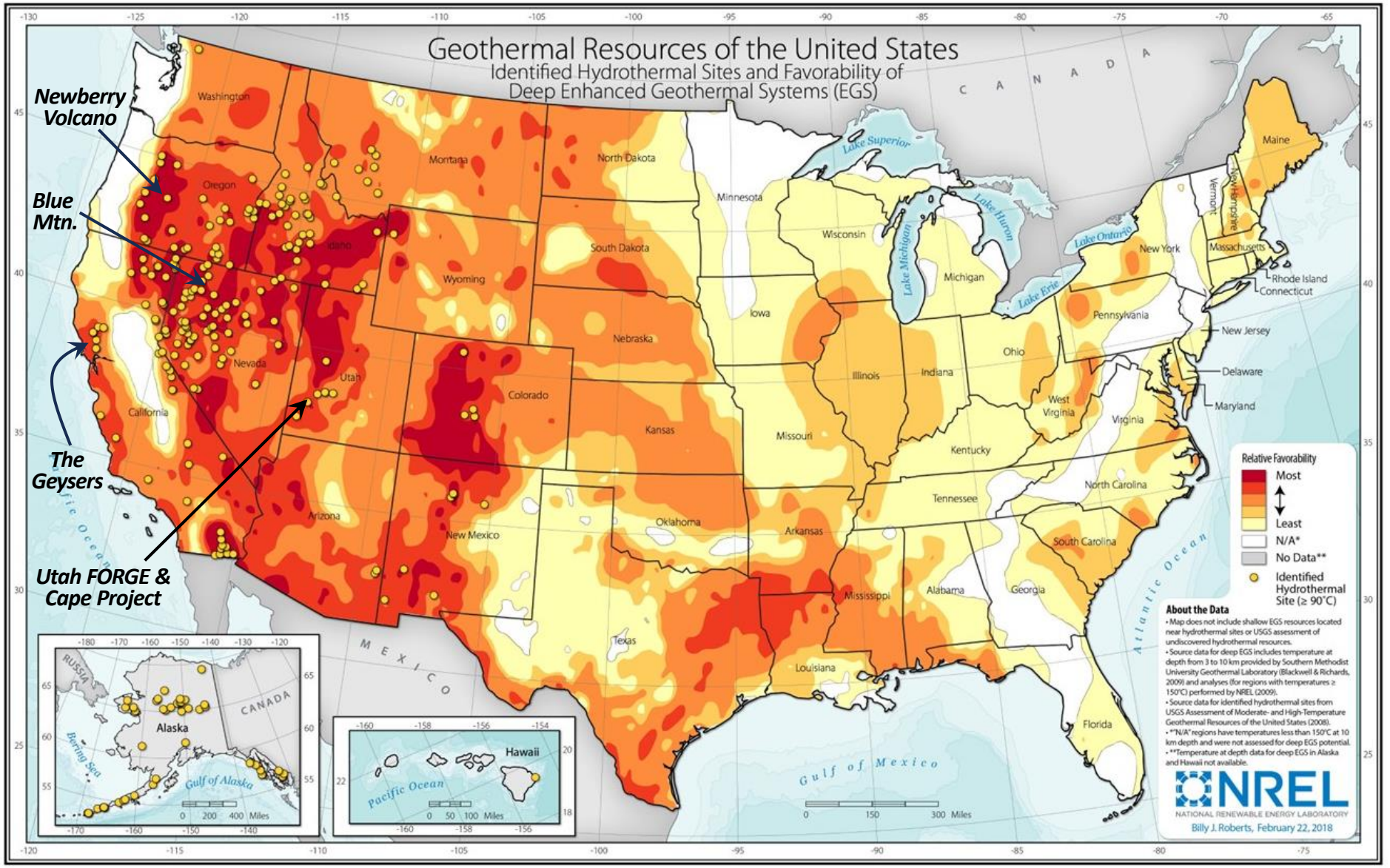
Enhanced Geothermal Systems - Oil & Gas Technology Enabled Breakthroughs

Greg Leveille

November 11, 2024

Electricity generated from geothermal energy holds enormous promise



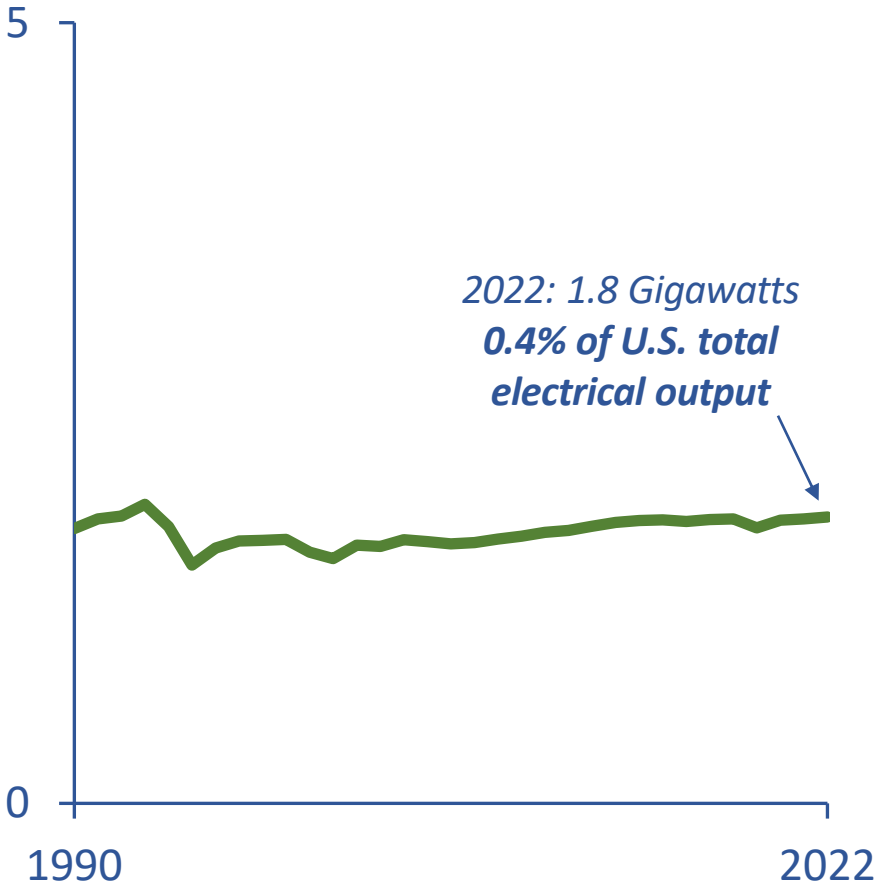
- Near-zero GHG or other emissions
- Firm, dispatchable power (24/7/365)
- Resources sufficient to deliver 1,000s of years of U.S. primary energy consumption
- U.S. is currently the world's largest producer of geothermal power

Map taken from U.S. NREL website

However, to date, U.S. geothermal power output growth has been negligible

U.S. Geothermal Power Output

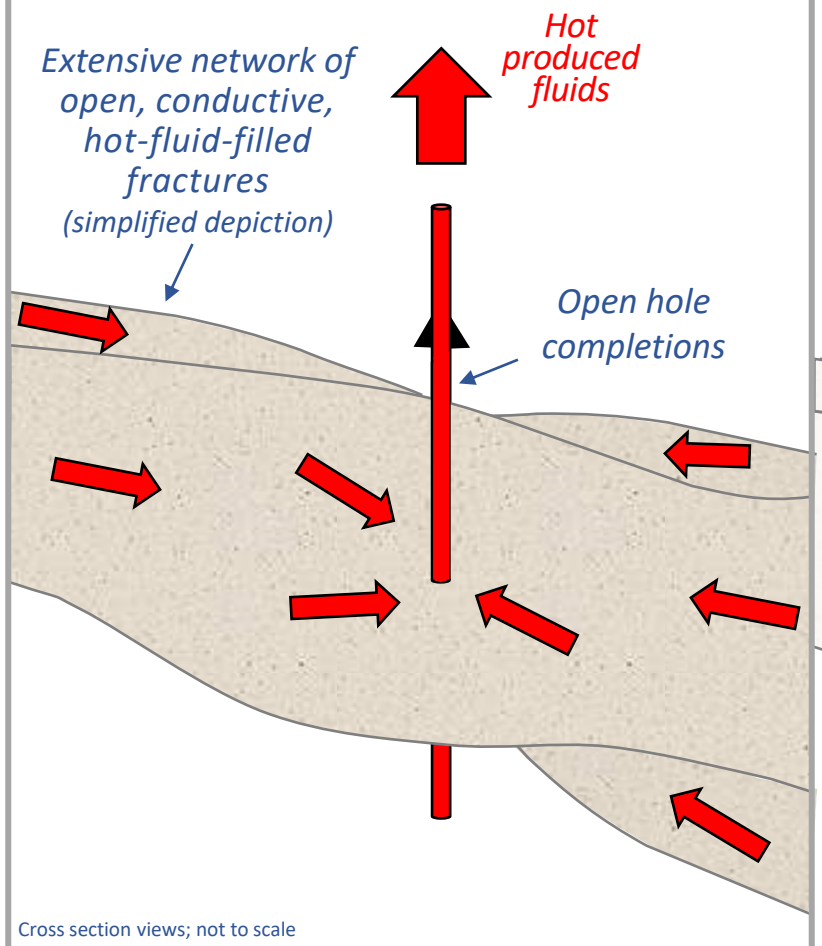
(Average annual GW of instantaneous output)



Source: U.S. EIA ; plot shows annual average instantaneous electricity output

NEGLIGABLE GROWTH DESPITE CONSIDERABLE INVESTMENT

Hydrothermal Systems

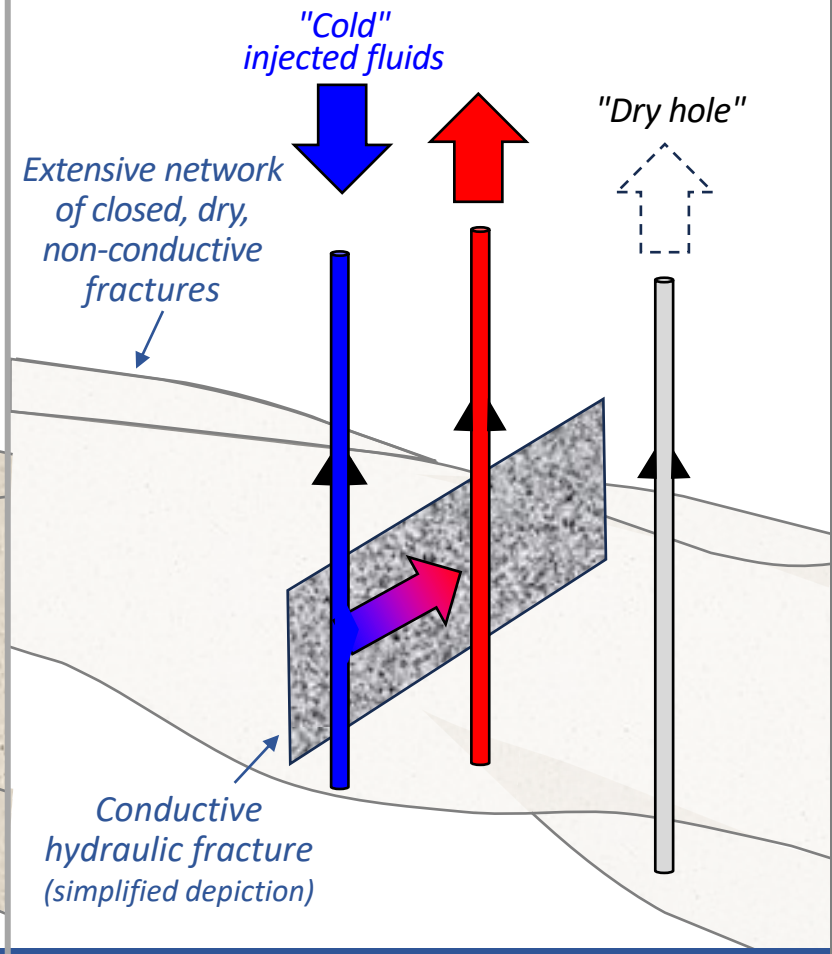


Cross section views; not to scale

EXCEEDINGLY RARE

Example: The Geysers, California

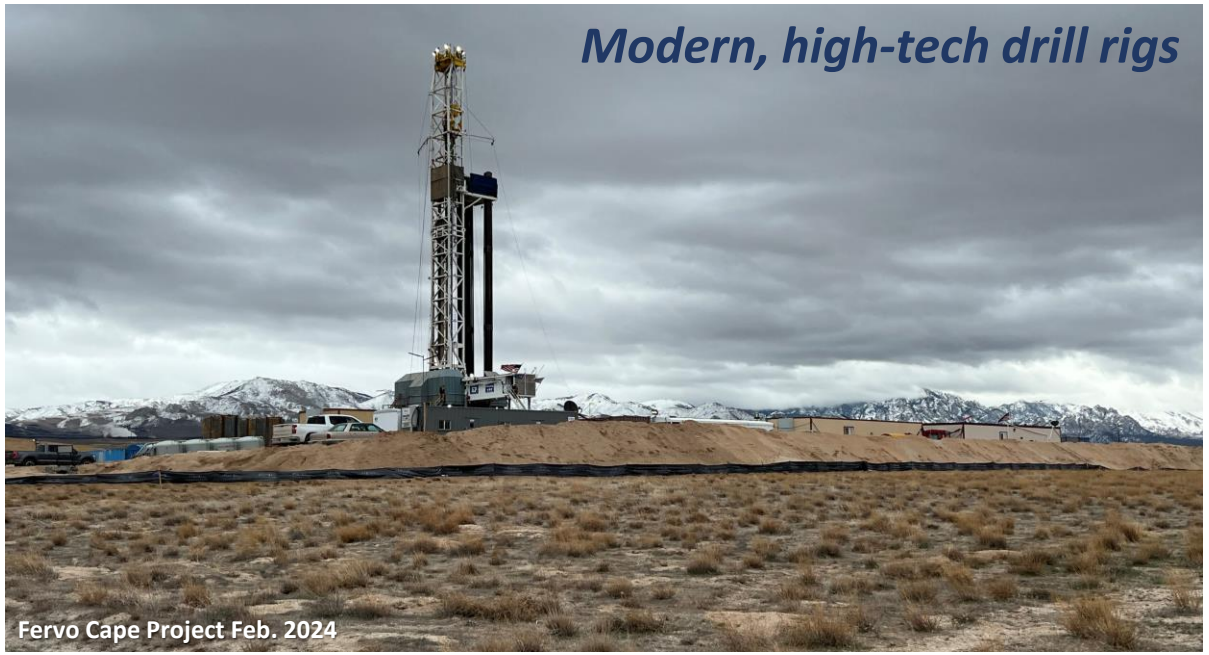
Old Style EGS



EXCEEDINGLY DISAPPOINTING

Example: Most EGS projects 1970-2023

Technology transfer from the oil & gas industry is transforming EGS economics



Drill bit design

Roller Cone

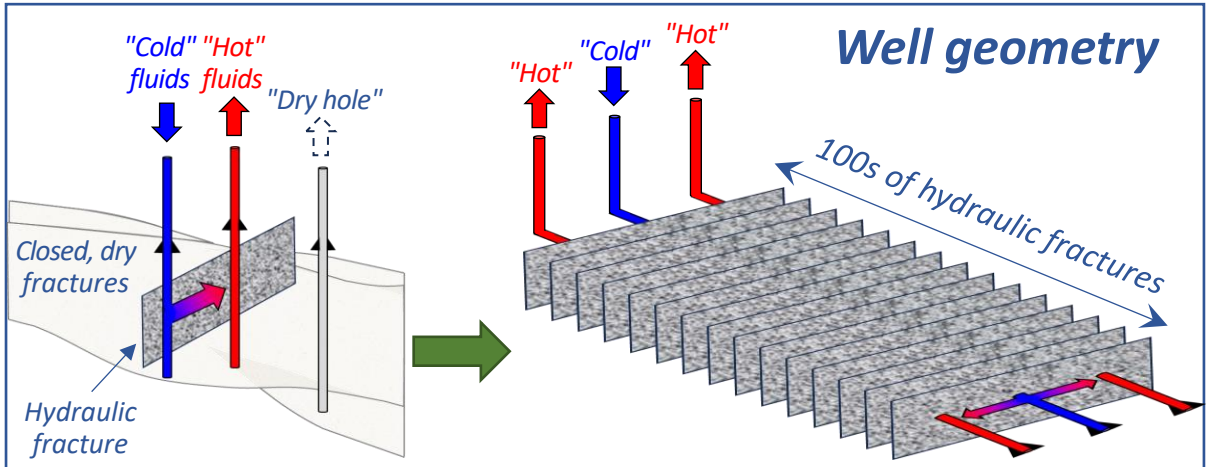
PDC

Physics-based drilling

Fred Dupriest
& Sam Noynaert

Texas A&M University

Well geometry



Vertical Wells

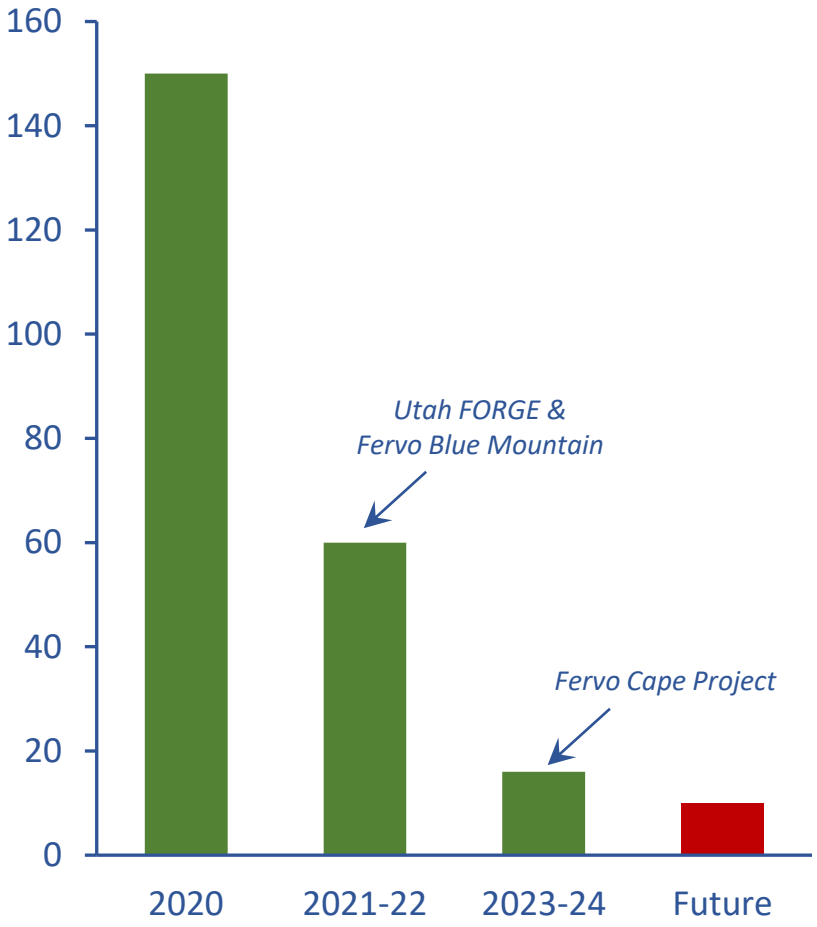
Horizontal Wells

Oblique views; not to scale

O&G technological innovations have delivered game changing results

Spectacular drilling performance improvements

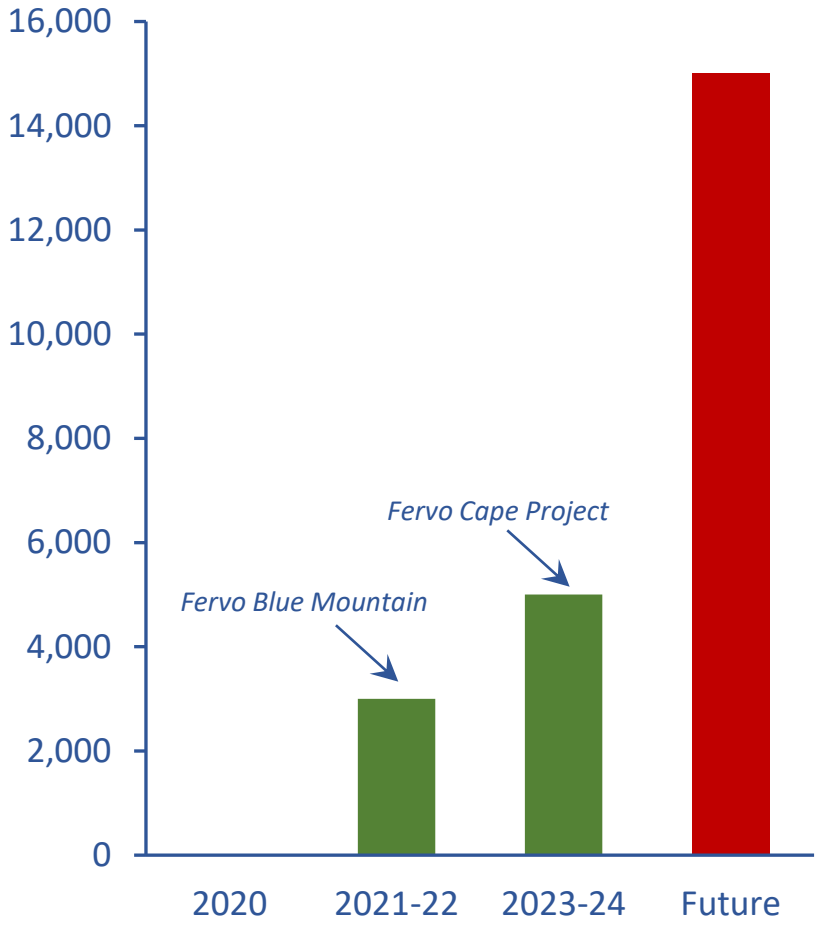
Drilling days to 12,000’ MD



Sources: El-Sadi et al, 2024, Review Of Drilling Performance In A Horizontal EGS Development; Winkler and Swearingen, 2021, Summary of Drilling Activities, Well 16A(78)-32 (Utah FORGE)

Ability to D&C horizontal laterals in basement rocks

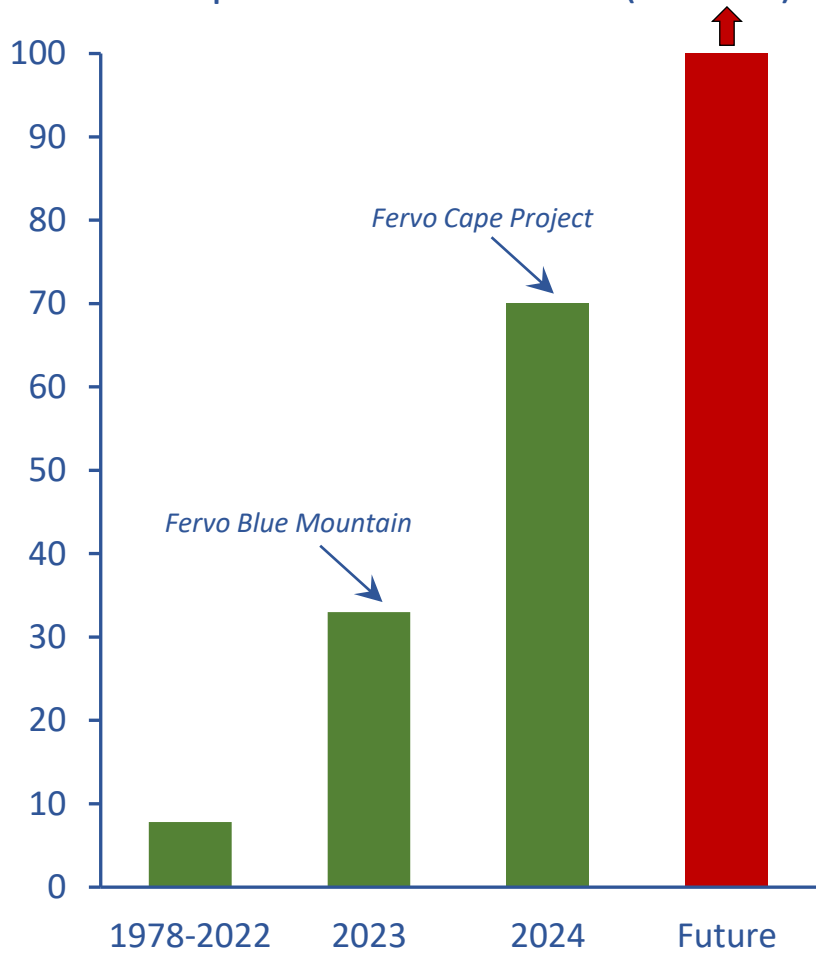
Lateral length (feet)



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

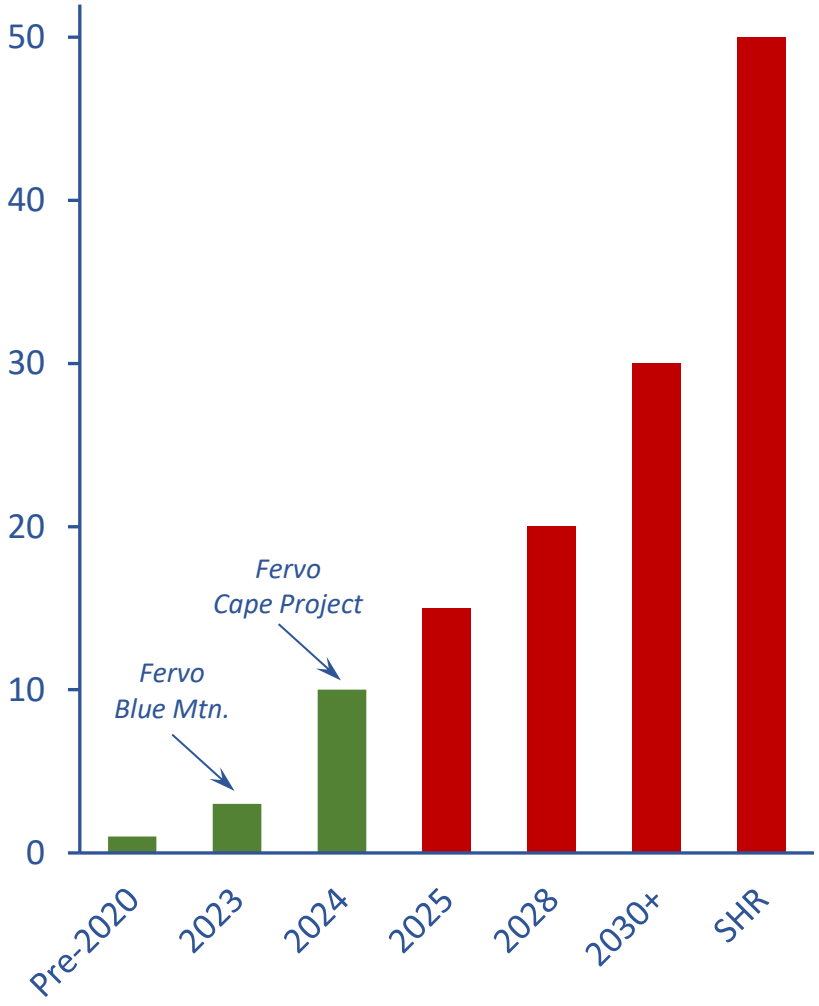
Peak production flow rate (MBFPD)



Note: 1978 – 2020 data from 11 projects; average peak flow rate shown (7,800 bfpd); range was from 2,700 to 16,300

Technological innovations have vastly improved EGS project outcomes

Per well power output (MW)



SHR = Super hot rocks

Science & engineering efforts underway to further improve results

Higher Flow Rates

- Larger casing = >rate
- > Fracture conductivity
- Blue Mtn. 25M bfpd
- Cape design 70M bfpd

> Thermal Output

> Fracture Surface Area

- Longer laterals
- Wider well spacing
- LL: 3M → 5M → 15M ft.
- WS: 300’ → 600’ → __

>Thermal Longevity

One Plant / Deeper Layers

- Synergy with Super Hot Rocks progress
- Reuse as much of plant as possible after initial wells die

Lower Plant Cost

Super Hot Rocks

- Blue Mtn. ≈ 375° F
- Cape 400° to 435° F
- SHR target 705° F[1]
- ≈ 1 MW per 25° F[2]

> Thermal Output

Improved Conformance

- Well placement
- Completion design
- Operating practices
- Remediation options

>Thermal Longevity

Scaling Management

- Robust scaling characterization and treating programs
- Same for corrosion

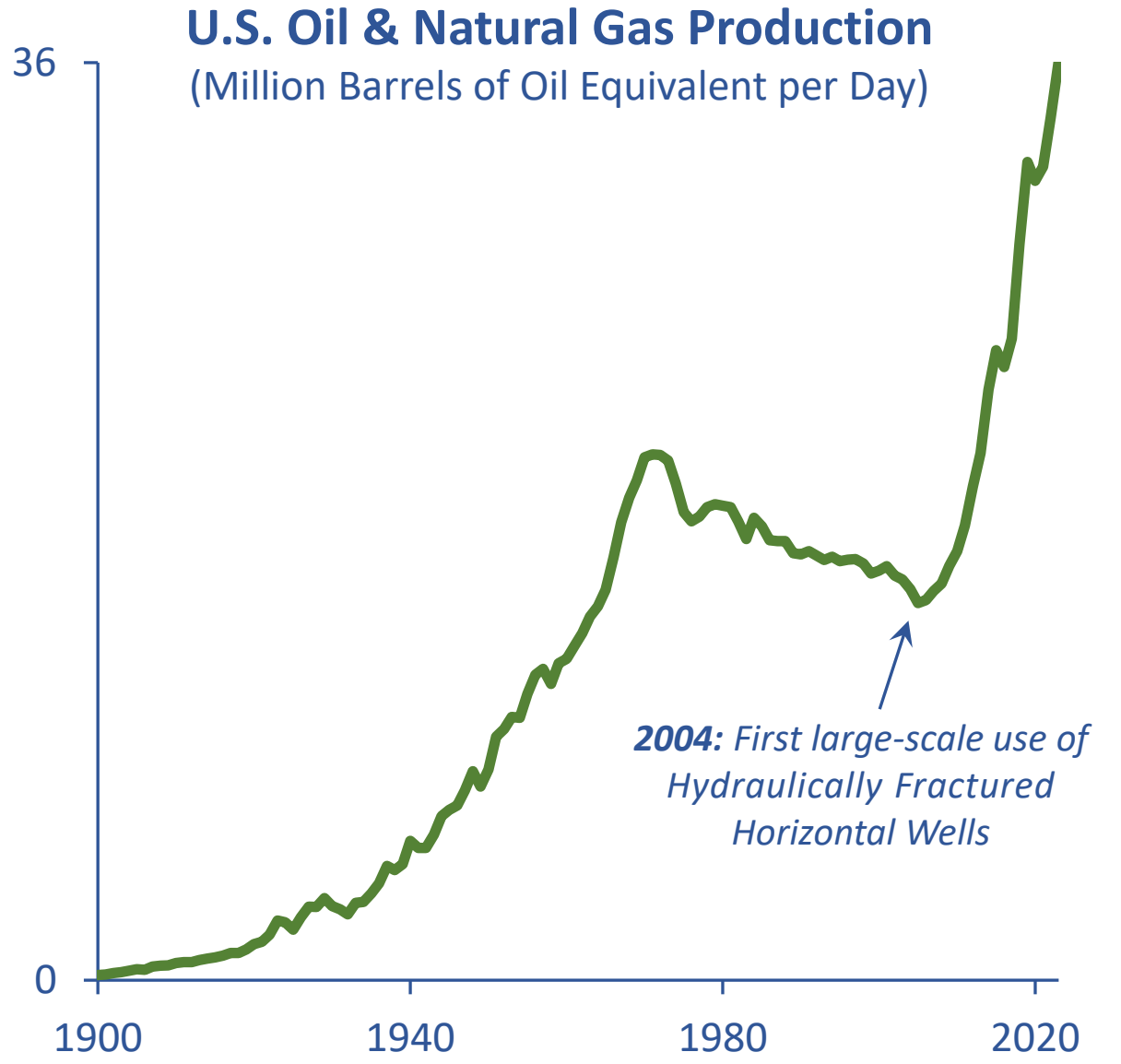
Plant & OPEX Cost

Not an exhaustive list; [1] 374° C; [2] at 50,000 bfpd flow rate

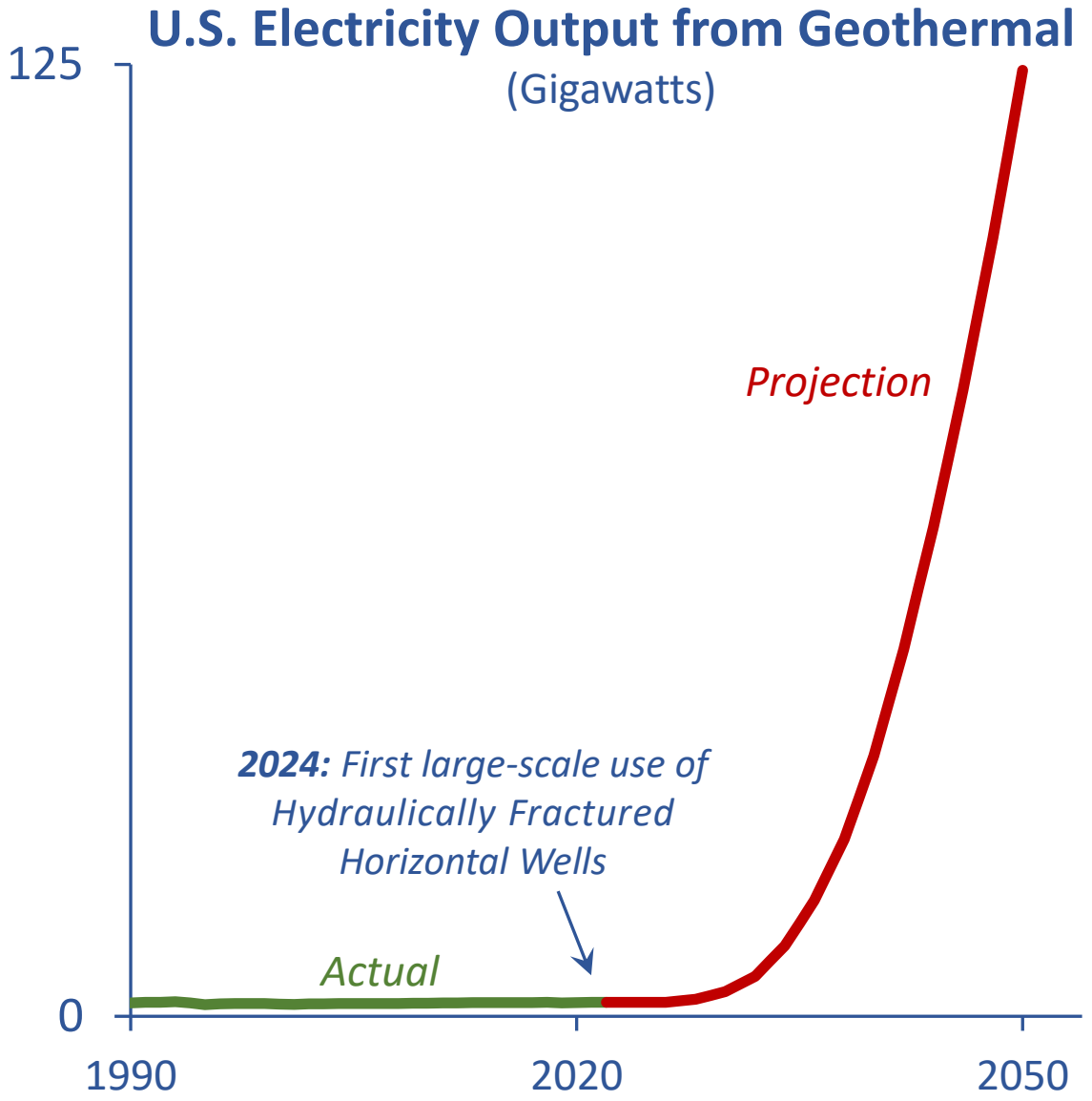
Using horizontal wells to develop EGS projects also greatly reduces project risk

Hydrothermal systems	Enhanced Geothermal Systems (EGS)	
Vertical wells	Vertical wells	Horizontal wells
• High subsurface temperature	• High subsurface temperature	• High subsurface temperature
• Pervasively fractured rocks	• Pervasively fractured rocks	
• Overpressured, fluid-filled, conductive fractures		***"Minimally fractured rocks" preferable to reduce the likelihood of thermal breakthrough, excessive leakoff, and induced seismicity***
• Pressure recharge mechanism		
EXCEEDINGLY RARE	***EXCEEDINGLY DISAPPOINTING***	***RIGHT TOOL FOR THE JOB***
Example: The Geysers, California	Example: Most EGS projects 1970-2023	Examples: Cape Project & Utah FORGE

In the U.S., O&G technologies are poised to enable a geothermal power breakthrough like that achieved in U.S. unconventional O&G reservoirs



Sources: U.S. EIA, Energy Insights, and BP 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

EGS breakthrough – Today in the U.S., soon in many places across the globe

Key Take-Away Messages

- Oil and gas technologies are dramatically improving EGS economic outcomes
- EGS can provide abundant, affordable, firm, clean power
- The skills and knowledge possessed by oil and gas operators like Petrobras will be crucial for rapidly growing power production using enhanced geothermal systems

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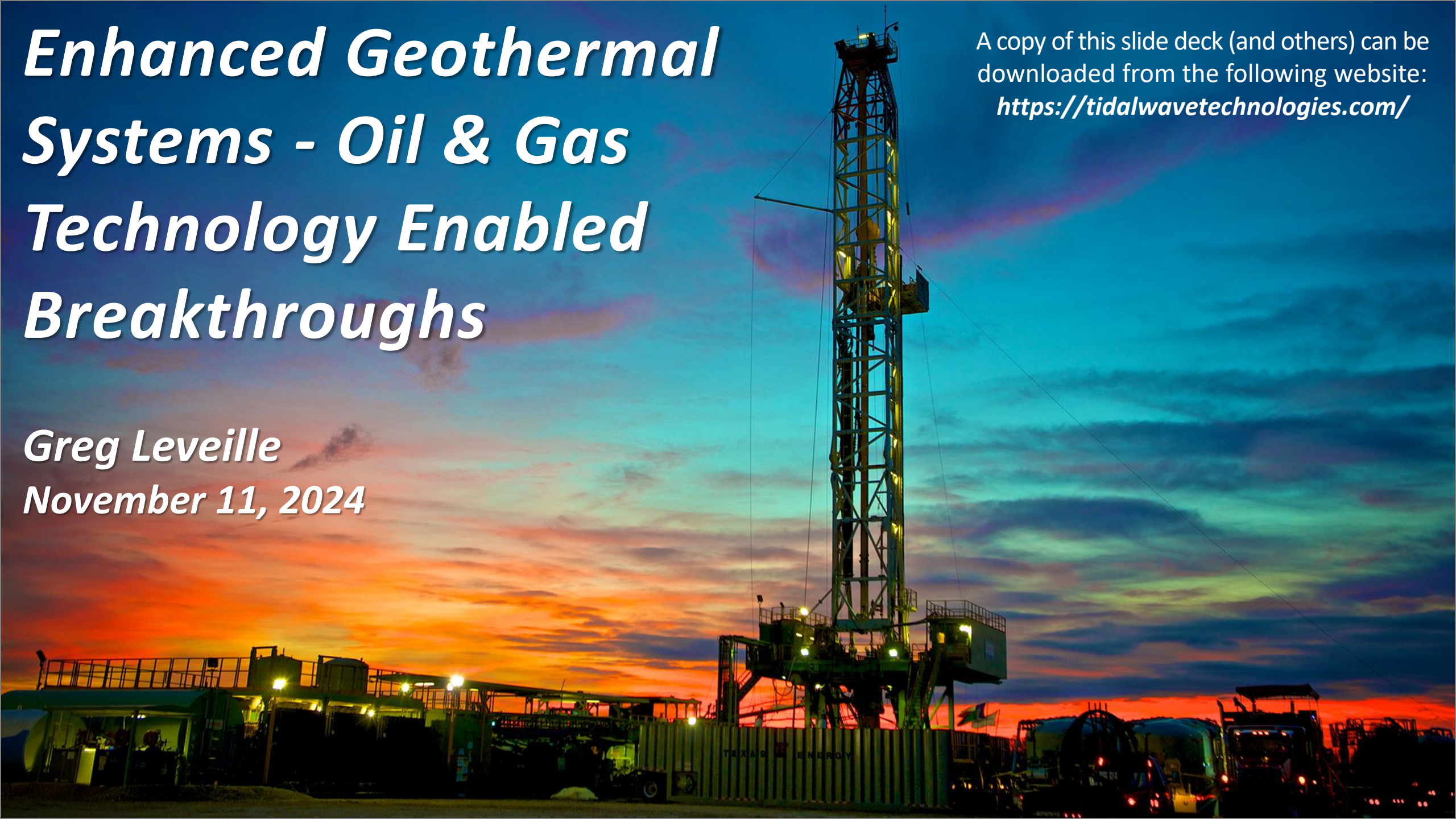
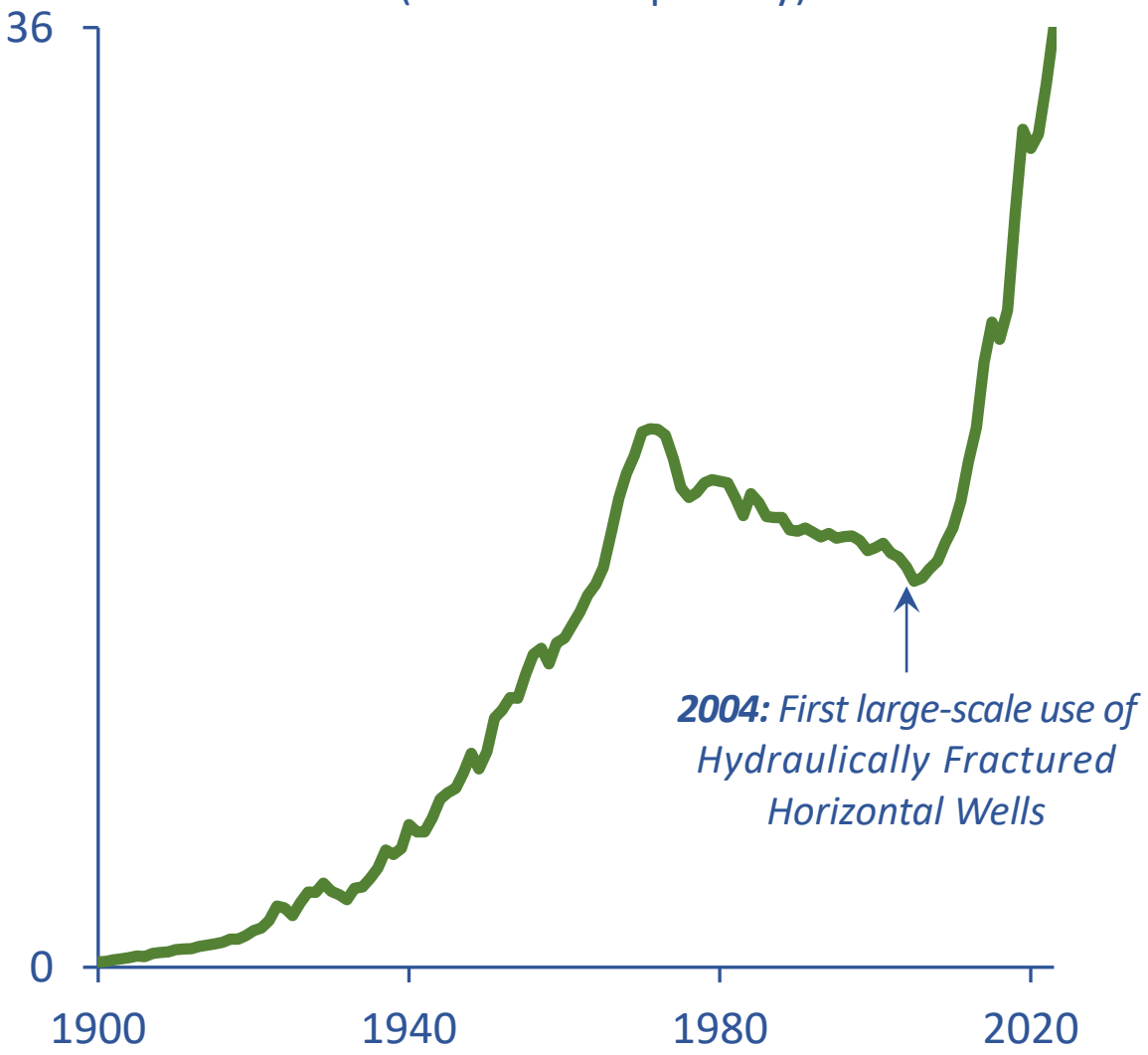
https://tidalwavetechnologies.com/



It is possible that EGS could replicate unconventional O&G learning curve

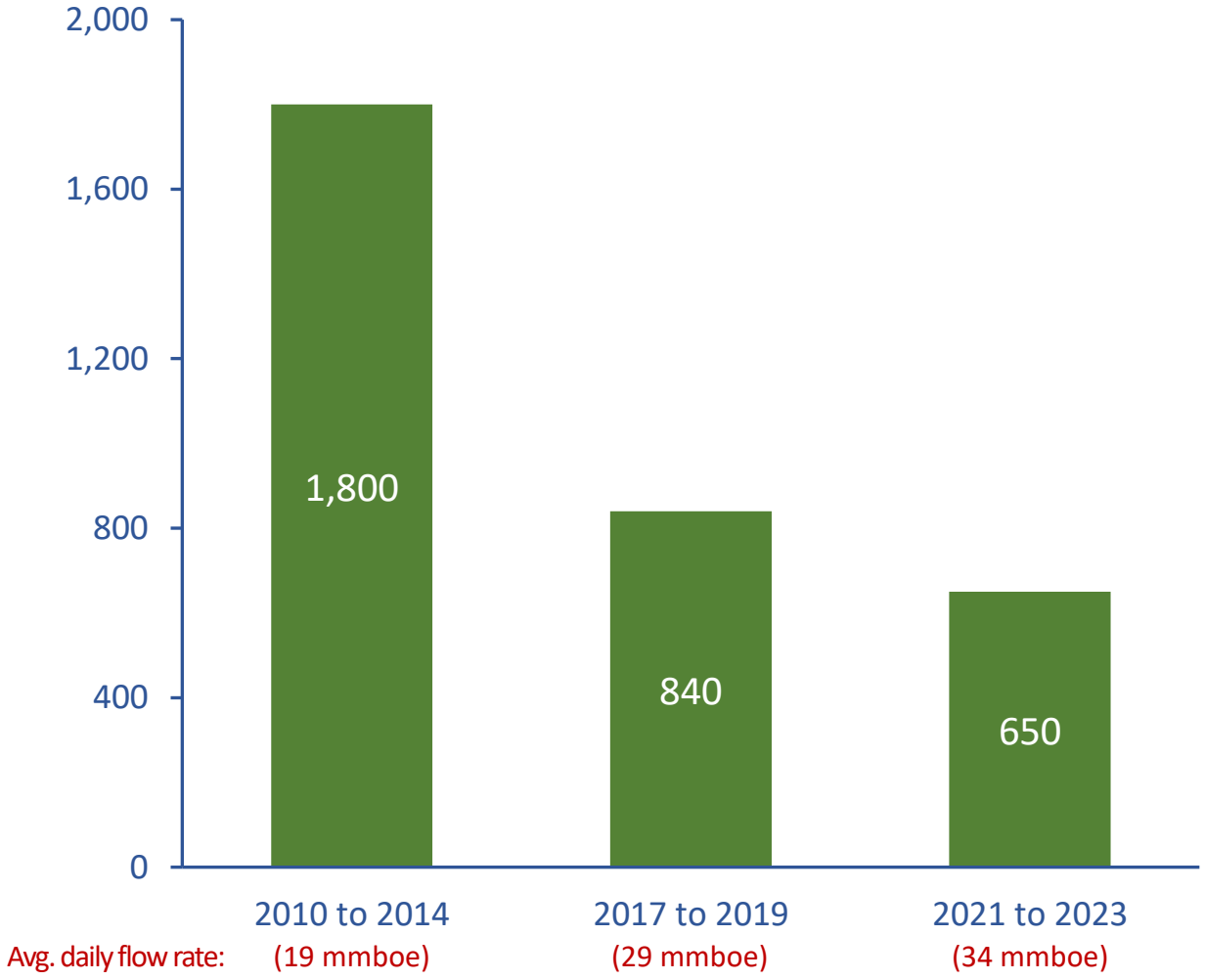
U.S. Oil & Gas Production

(Million BOE per day)



Source: Post 1965 from World Energy 2024 report; Pre-1965 oil production from EIA; Pre-1965 gas volumes estimated from multiple sources

U.S rig count needed to grow annual production by > 1,000,000 BOE per day



Sources: U.S. production = U.S. EIA, Energy Insights, and BP websites; Rig count = Baker Hughes; BOE = Barrels of oil equivalent; natural gas converted at 6 mcf per barrel of oil. mmboe = million barrels of oil equivalent