Geothermal Power Production – An Oil and Gas Technology Enabled Revolution Currently Underway in the USA

Greg Leveille

May 8, 2025

Picture from Fervo Energy's website

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

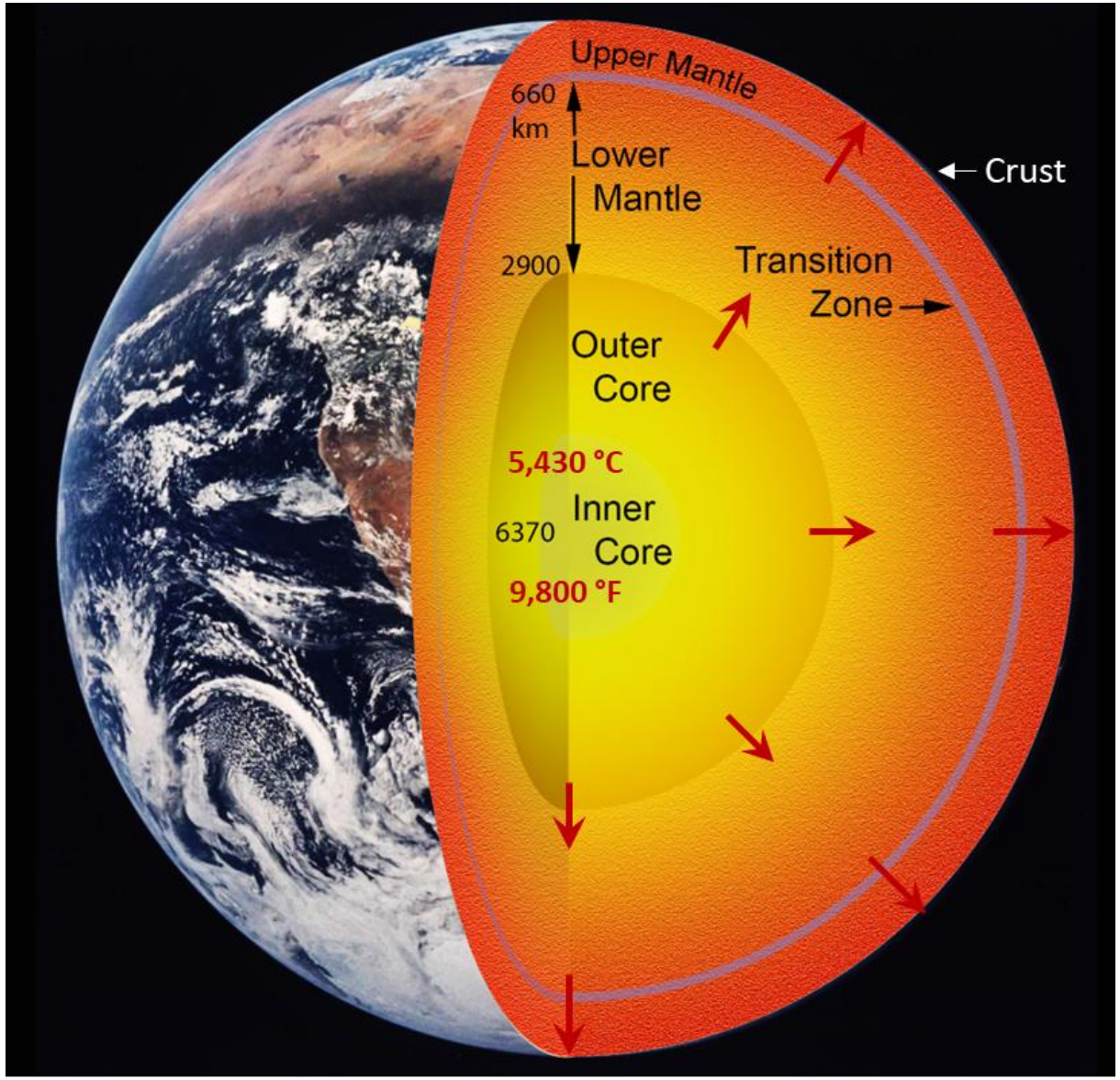
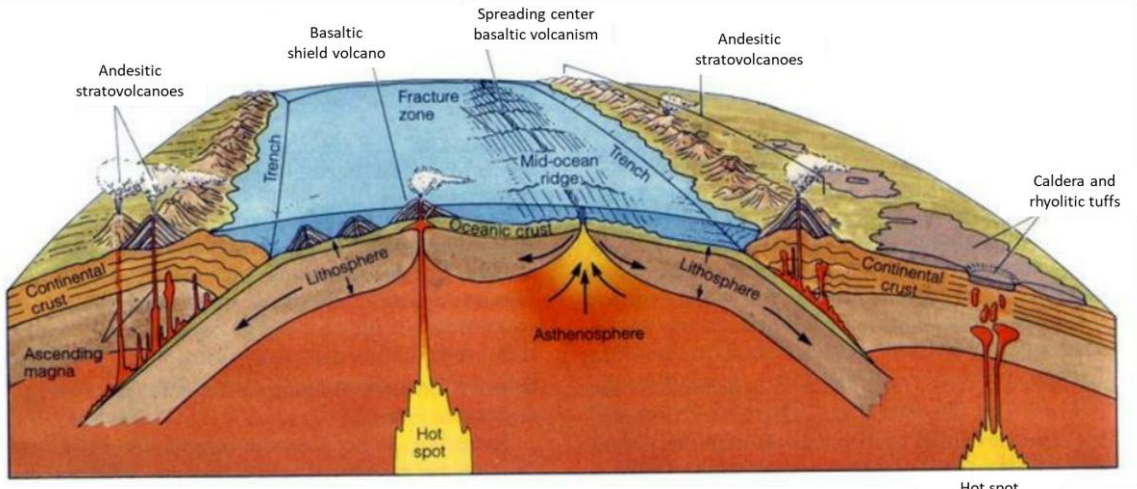
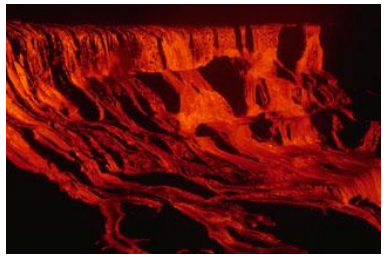


Diagram modified after Steve Jacobsen, Department of Earth, Environmental, and Planetary Sciences, Northwestern University

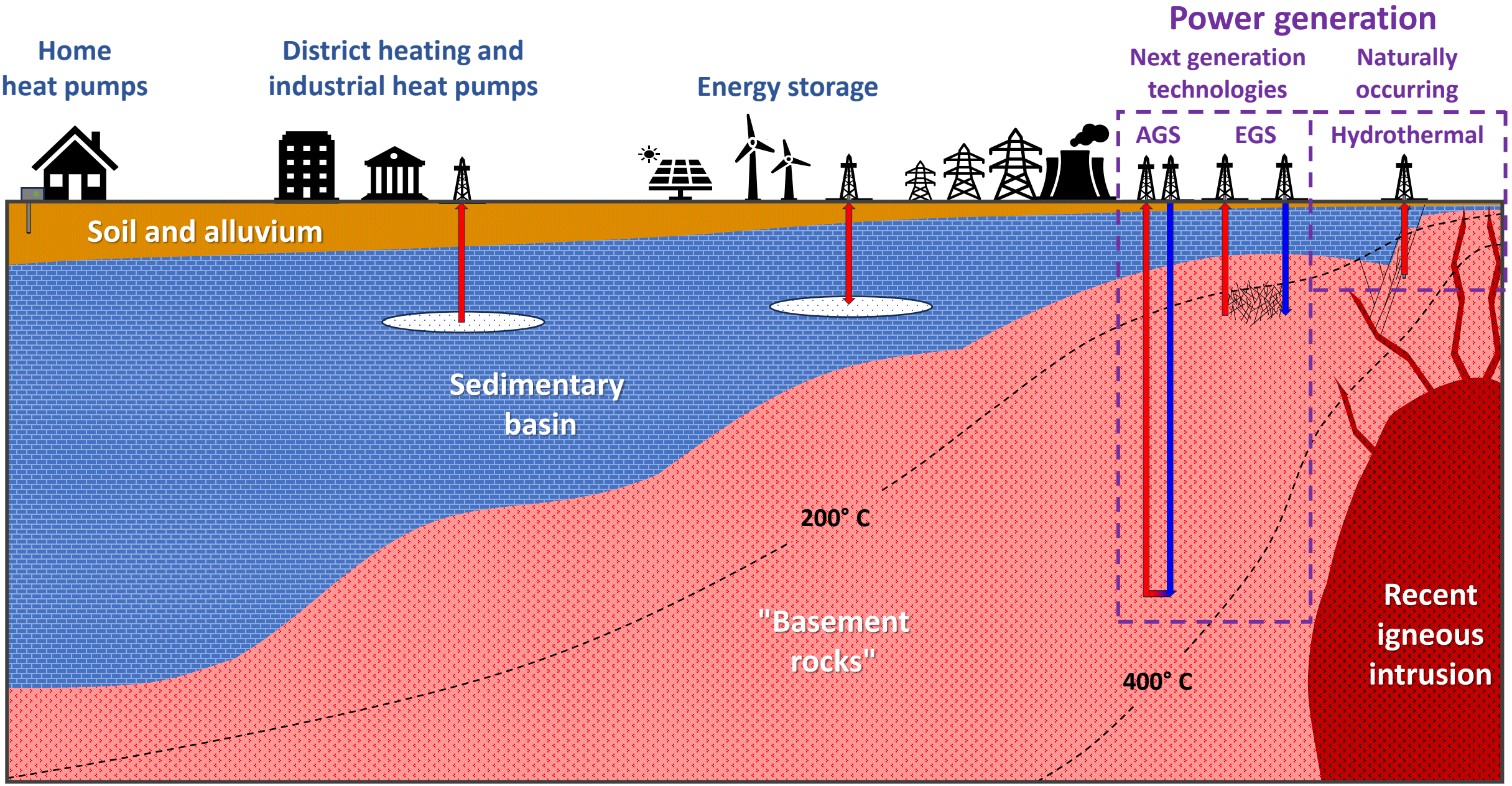


Picture taken from Rice University "Discovering Plate Boundaries" online presentation



Pictures taken from Smithsonian Institute Global Volcanism program website

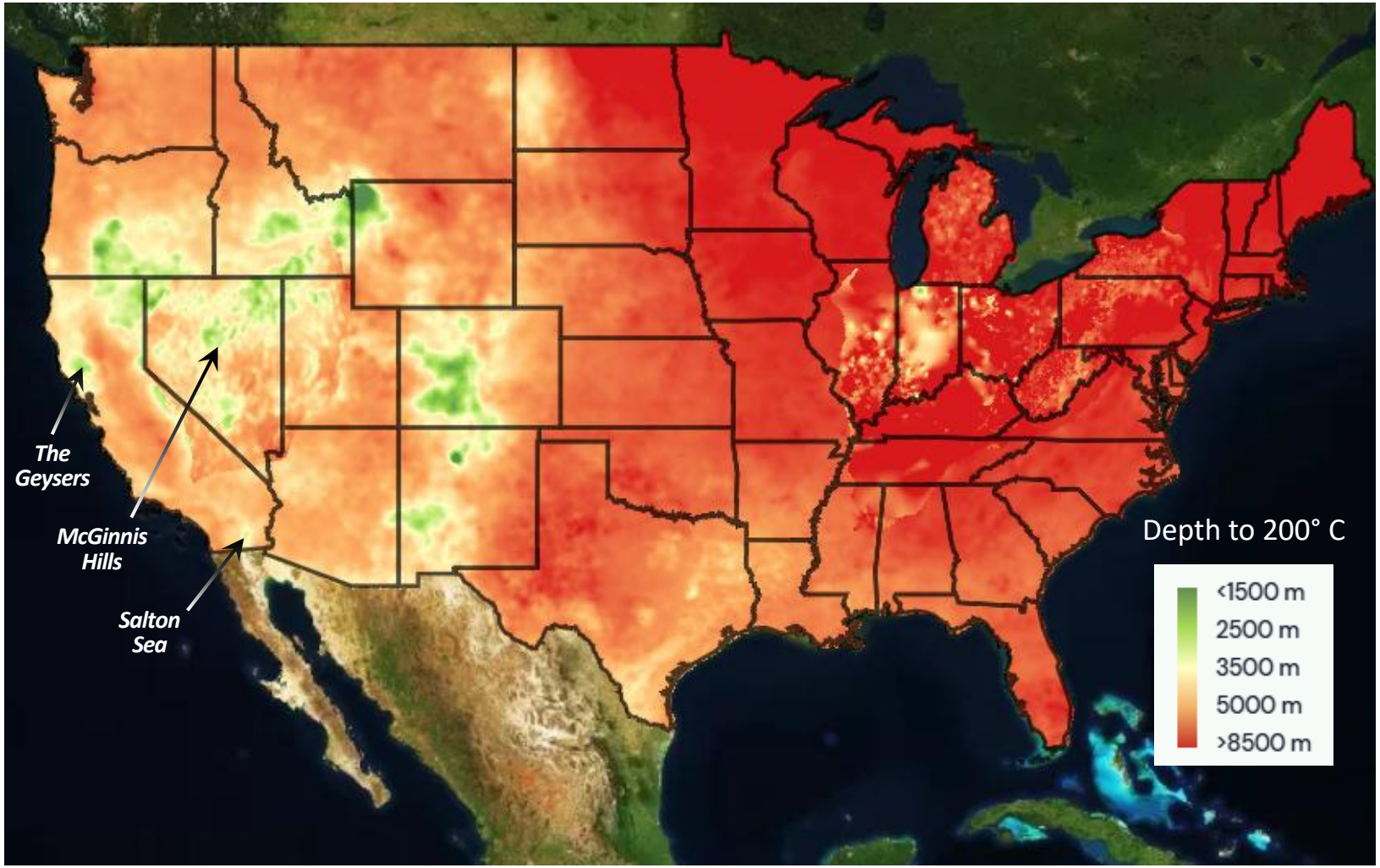
There are many ways in which mankind can use heat for useful purposes



Cross section view; not to scale; depiction of geothermal systems are greatly simplified; Hydrothermal includes HSA; HSA = Hot Sedimentary Aquifers; EGS = Enhanced Geothermal Systems; AGS = Advanced Geothermal Systems.

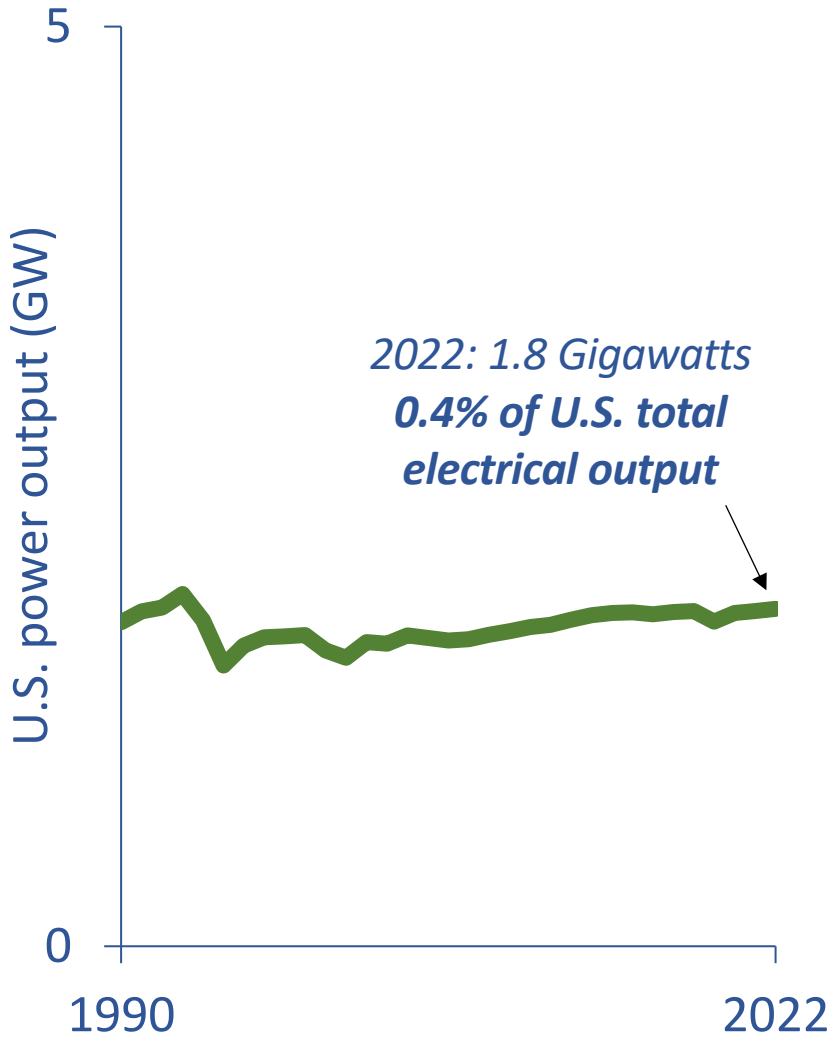
America possesses abundant heat resources that could be converted to power

The US has hot rocks at relatively shallow depths in many areas



Map copied from Project Innerspace's website, February 2025

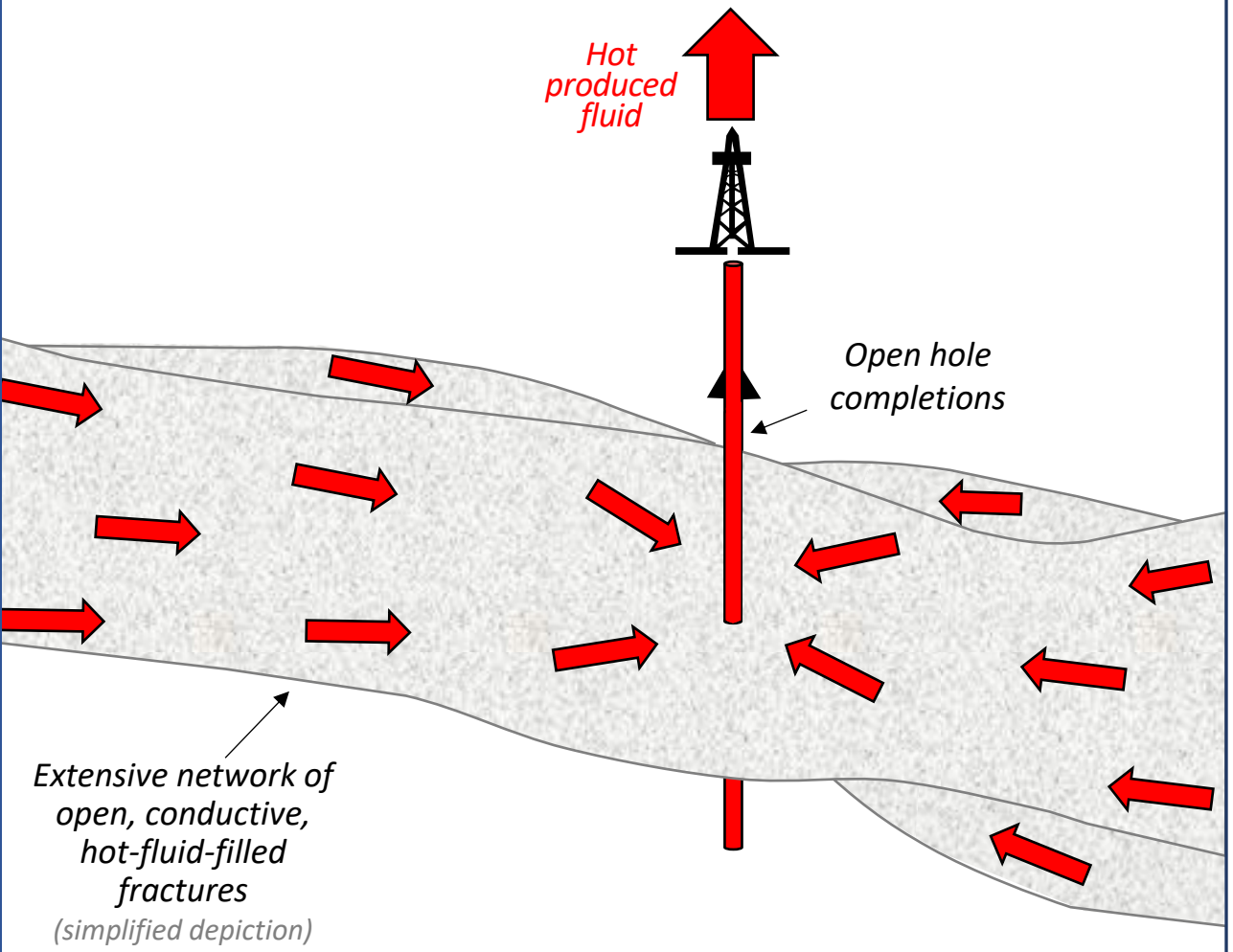
But U.S. power output is trivial



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

Past approaches to extracting heat for power production have met with limited success

Hydrothermal (naturally occurring) systems

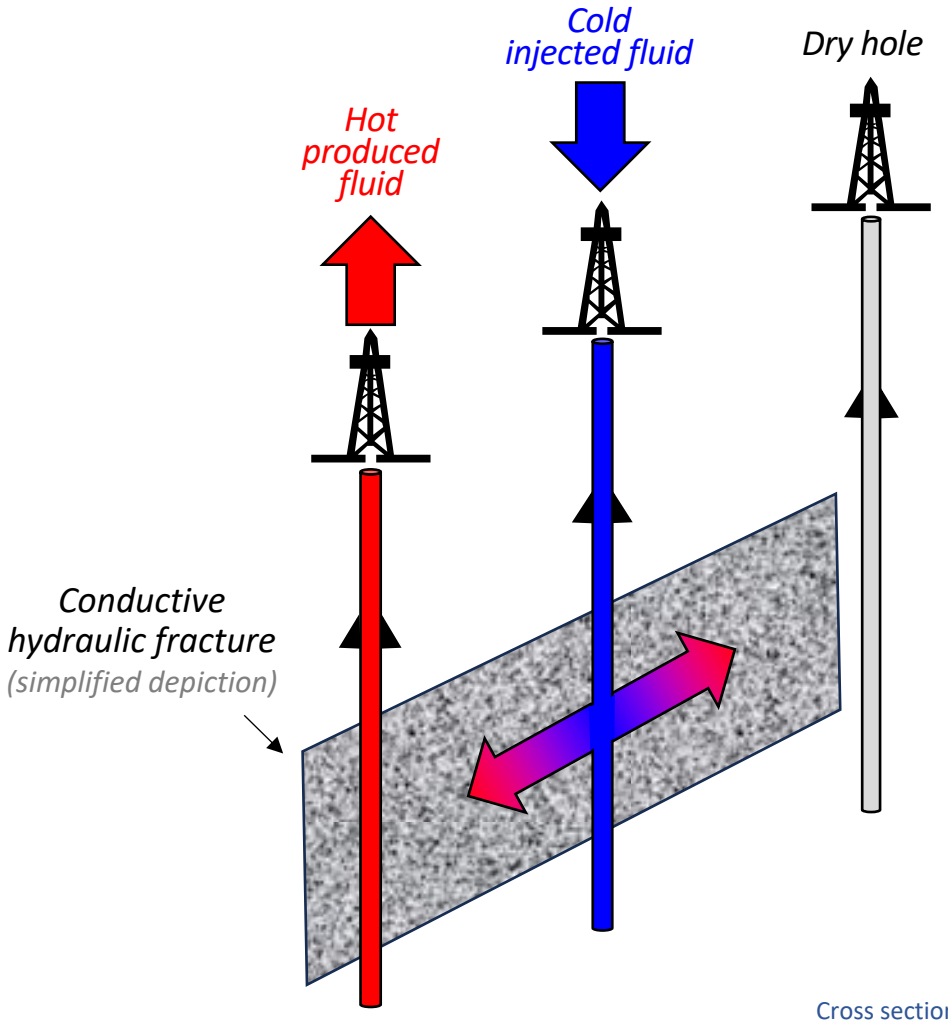


Cross section view; not to scale

RELATIVELY RARE AND/OR HARD TO FIND

Examples: The Geysers, California; McGinnis Hills, Nevada

Enhanced geothermal systems with vertical wells



Cross section view; not to scale

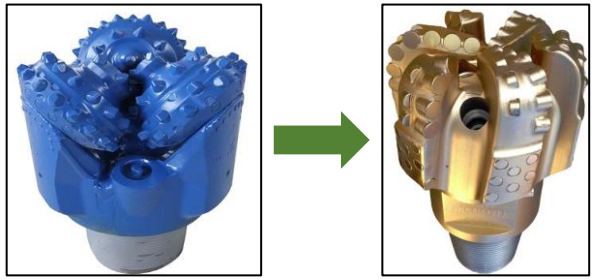
EXCEEDINGLY DISAPPOINTING

Examples: Most EGS projects between 1970-2023

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

Latest oil and gas drilling technologies

Drill bit design



Roller Cone → PDC

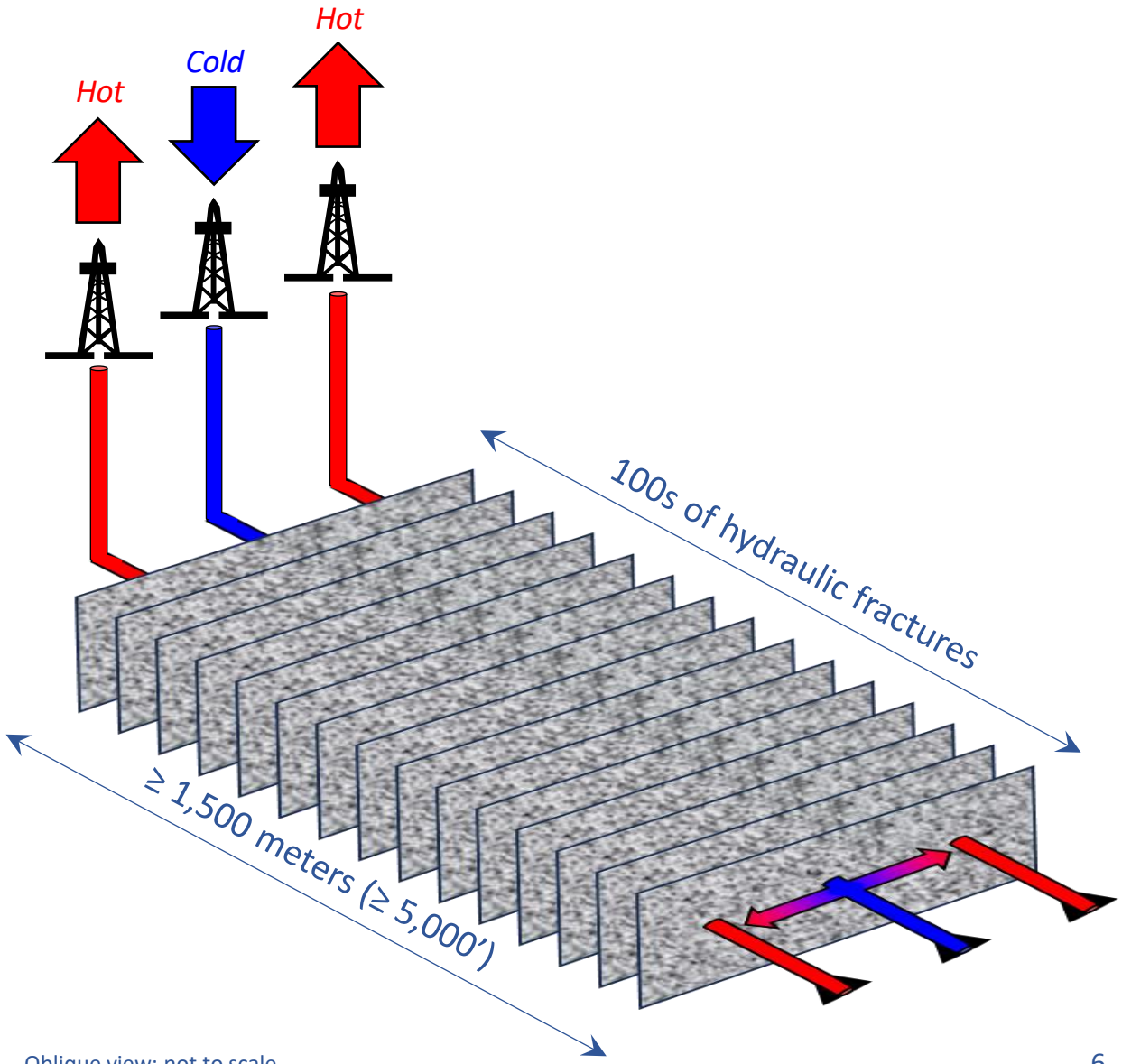
Physics-based drilling

Fred Dupriest
& Sam Noynaert

Texas A&M University

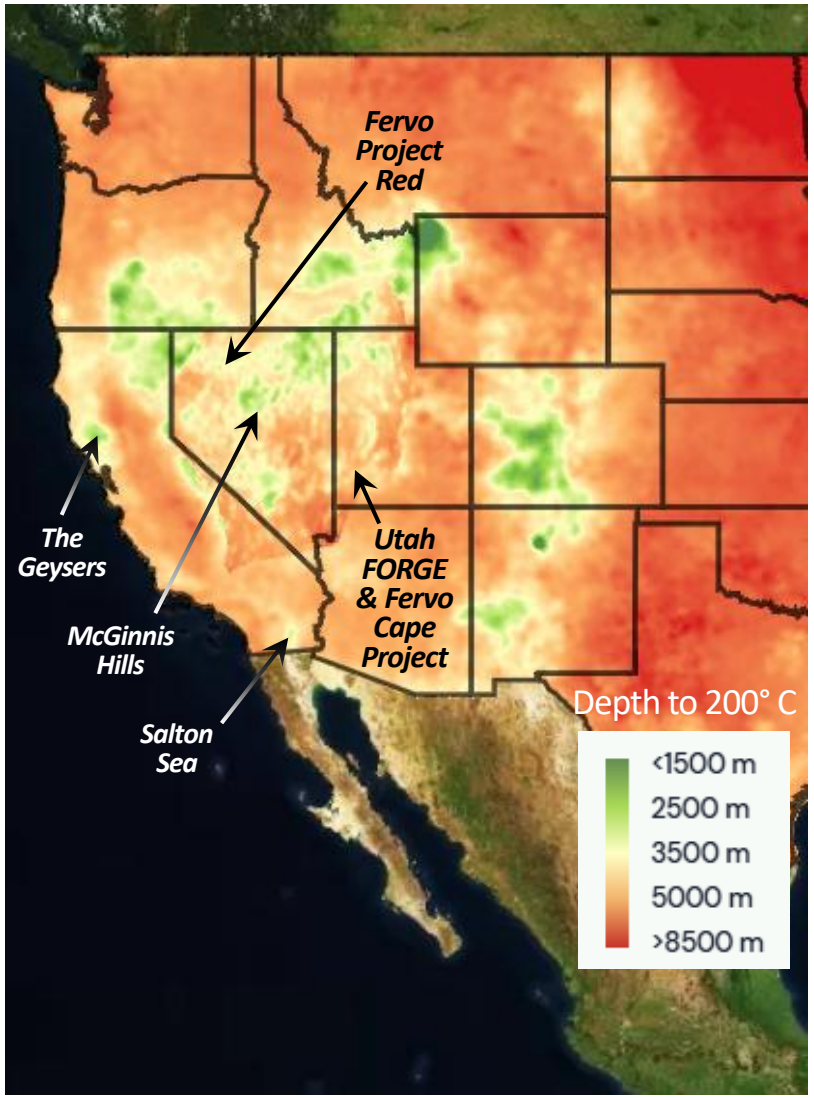
EGS = Enhanced geothermal systems; PDC = Polycrystalline diamond compact (bits)

Hydraulically fractured horizontal wells

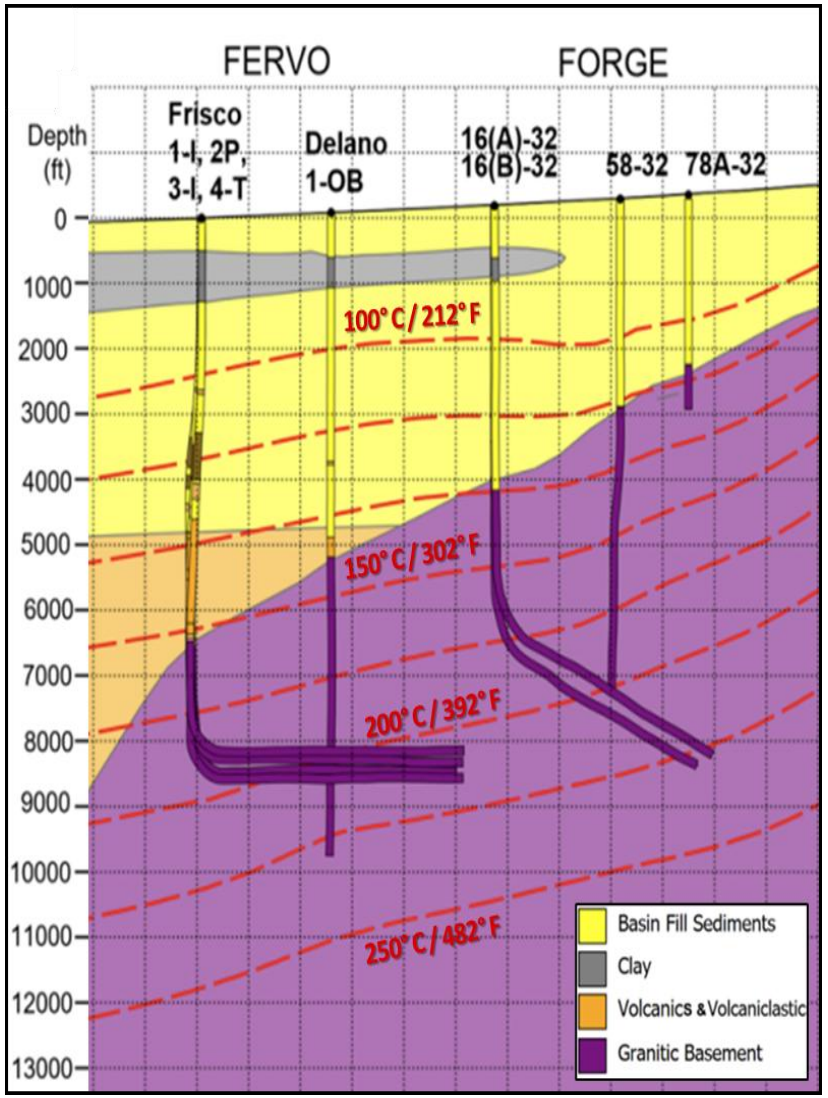


Oblique view; not to scale

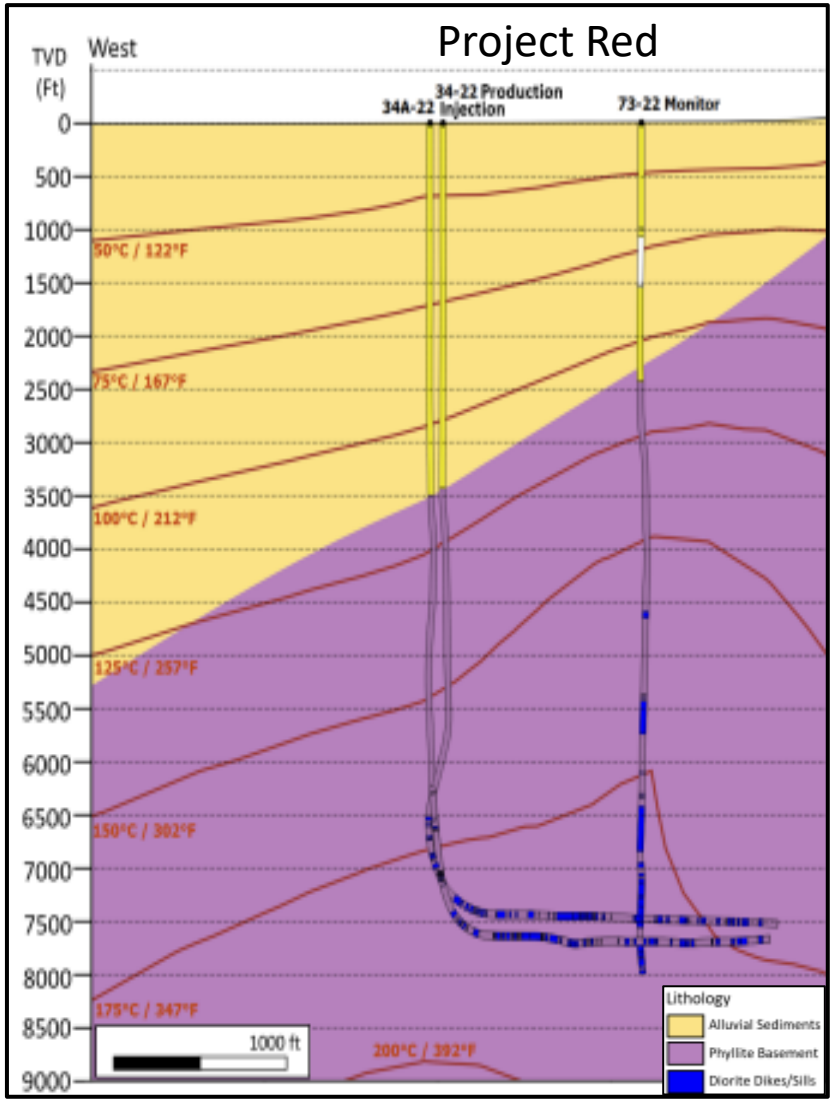
Cutting edge oil and gas industry technologies were first deployed at the U.S. DOE funded Utah FORGE project and Fervo Energy's Red and Cape projects



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.

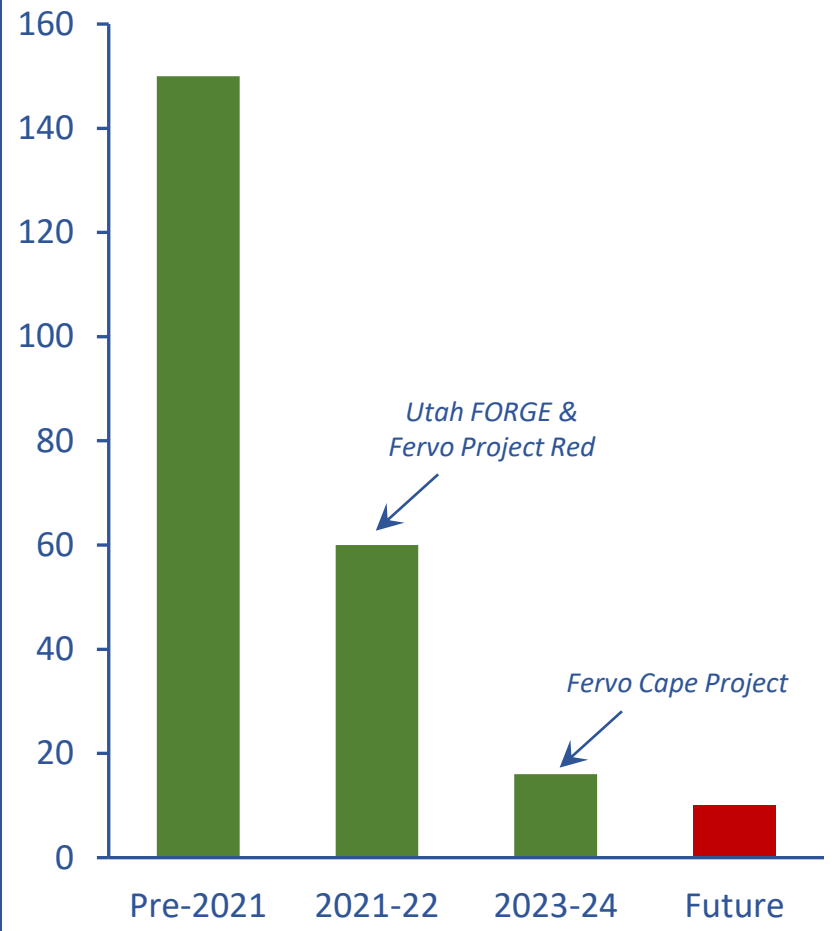


Cross section view parallel to horizontal lateral direction taken from 2023 by Jack Norbeck and Tim Latimer

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

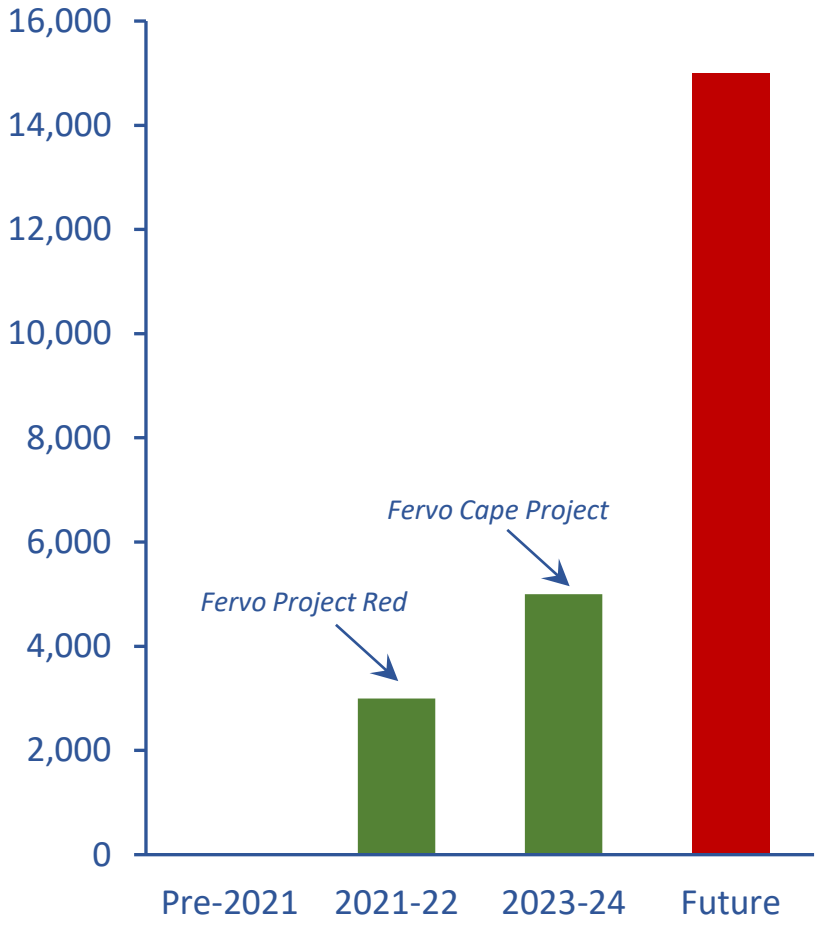
Drilling days to 12,000' MD (≈ 3,600 m)



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

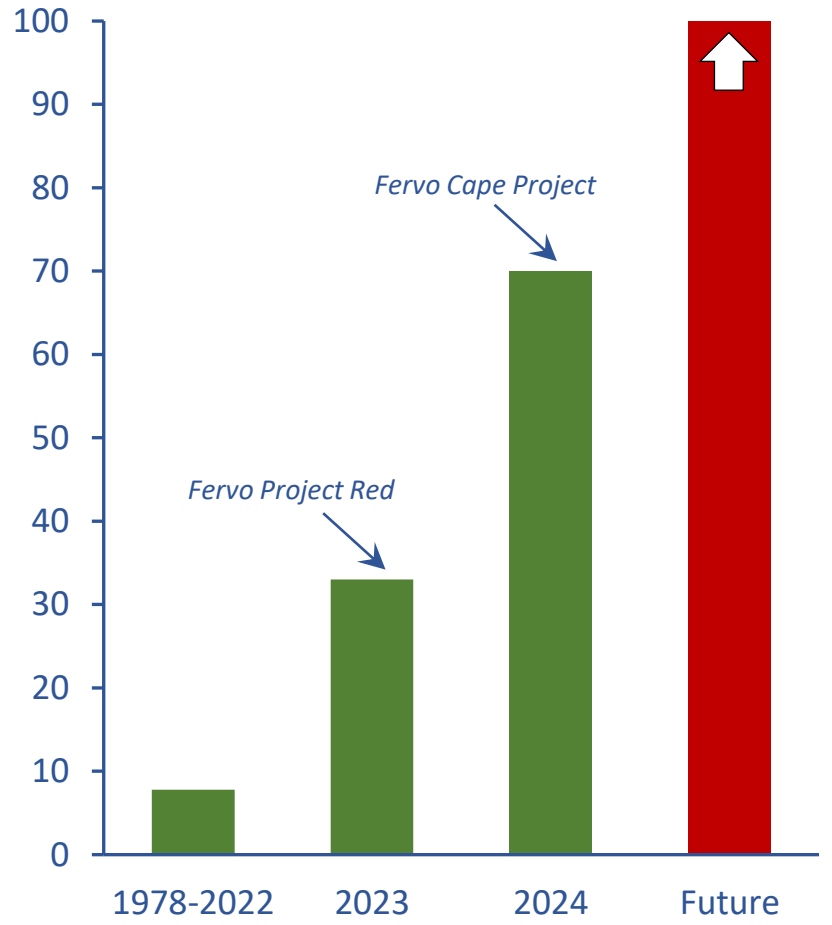
Lateral length (feet)



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

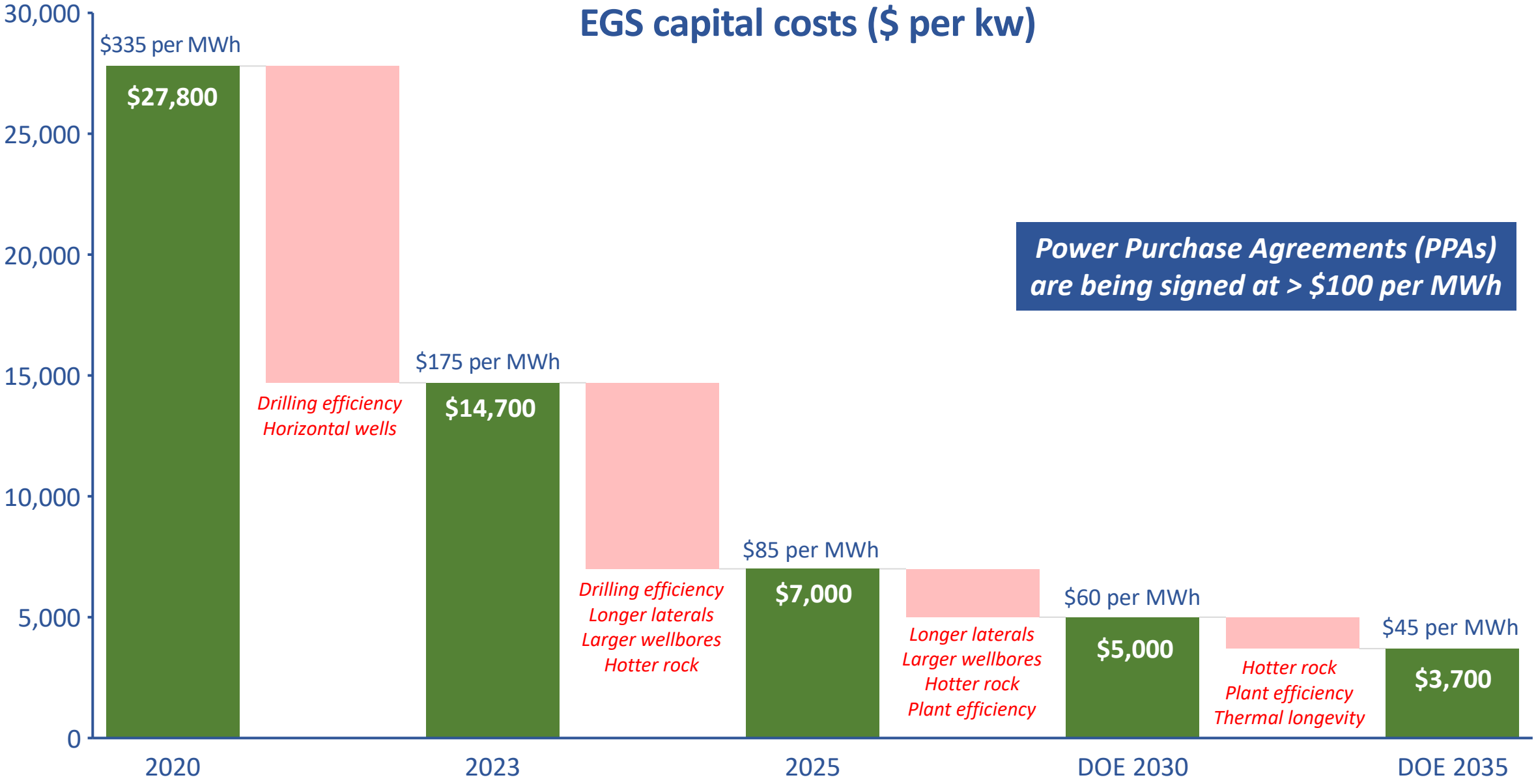
Near order-of-magnitude increase in per well production

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

EGS capital costs have fallen precipitously over the past five years

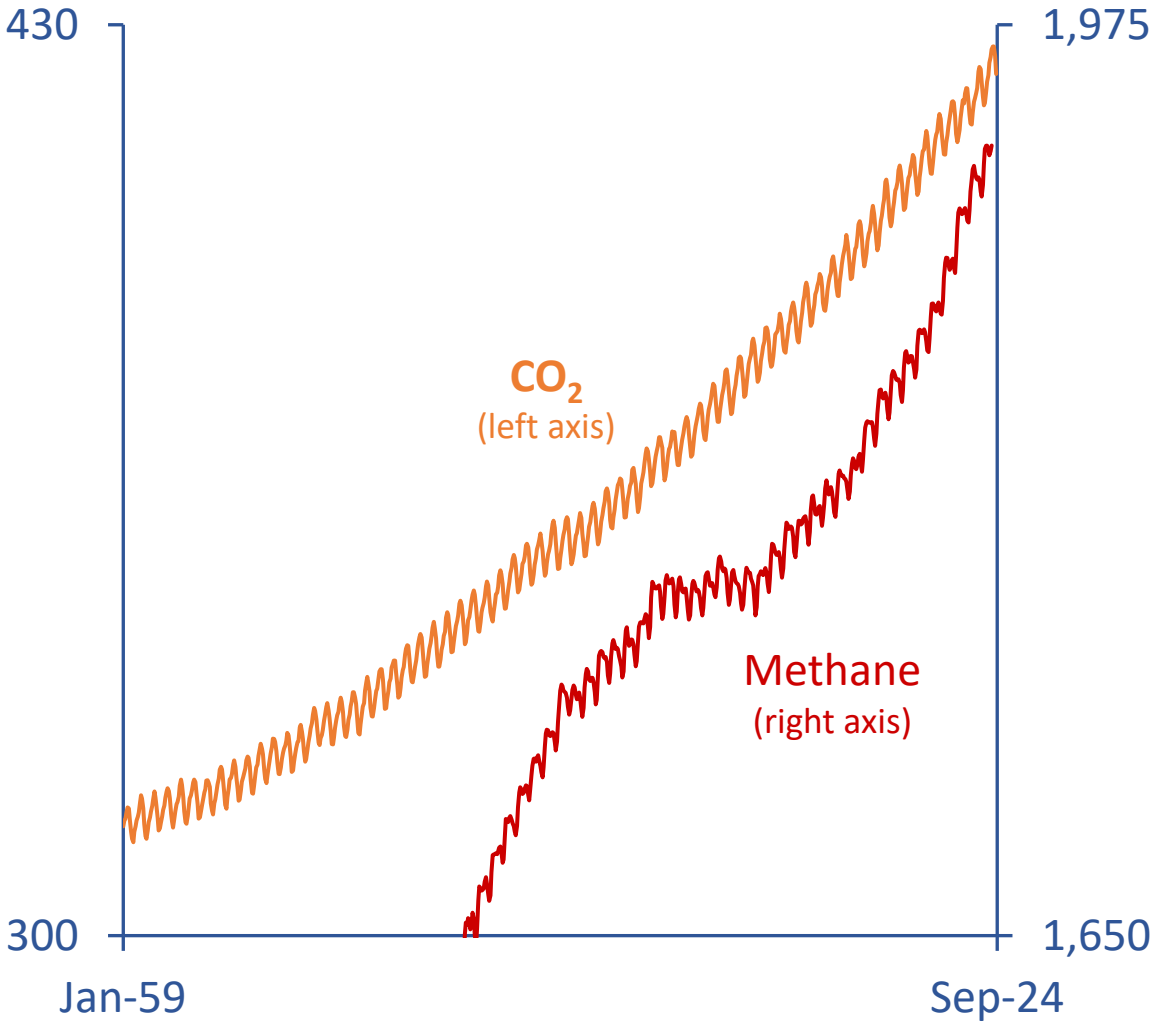


All $ per kw numbers from US DOE Next Generation Geothermal Liftoff report except 2025 number, which is estimated. All numbers are unsubsidized. $ per MWh numbers from DOE report or scaled therefrom.

High PPA pricing driven by climate change concerns and rapid power demand growth

Atmospheric GHG levels are increasing

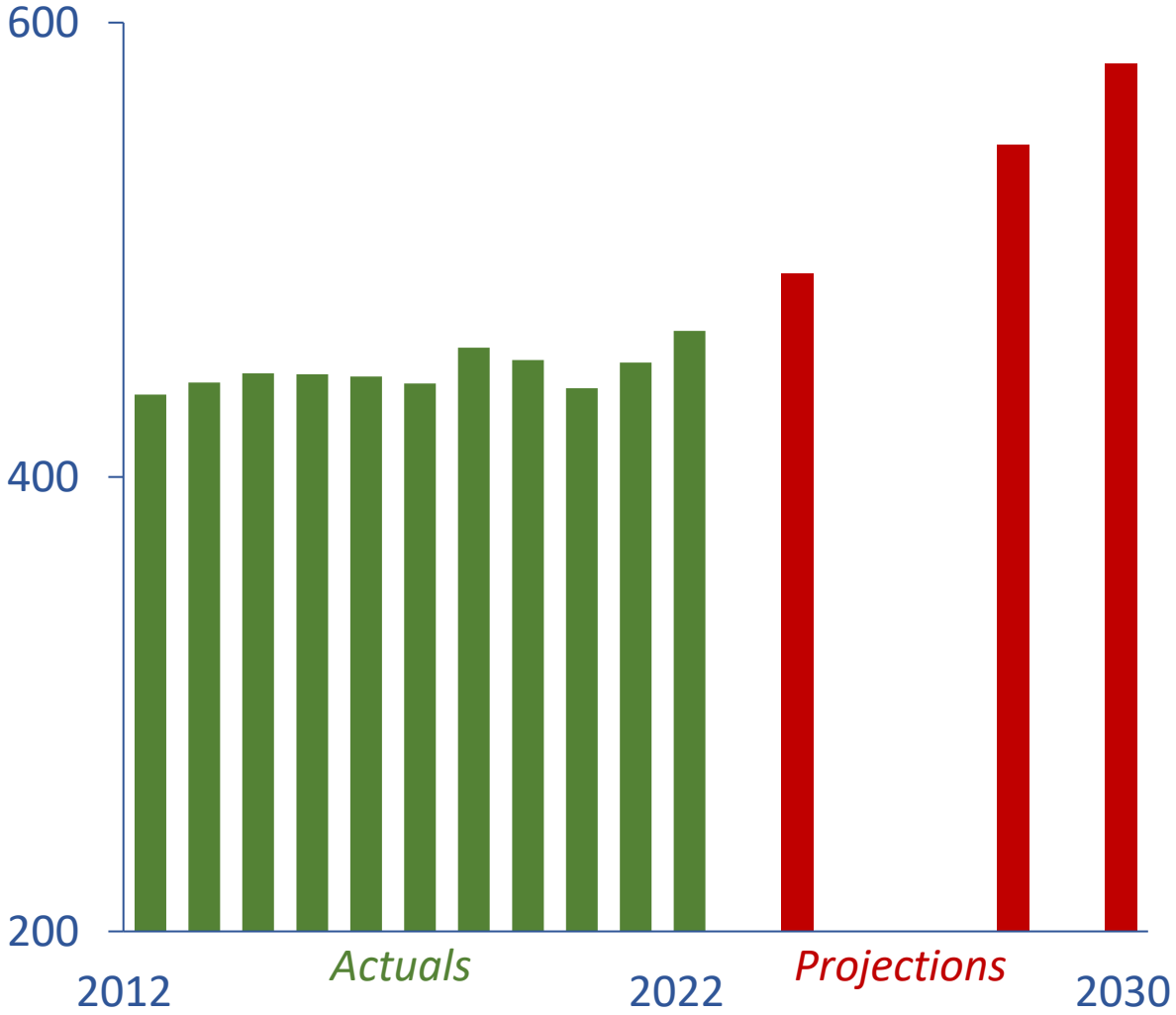
Monthly average atmospheric CO_2 (ppm) and methane (ppb)



Source: NOAA Global Monitoring Laboratory, Earth System Research website; September 2024

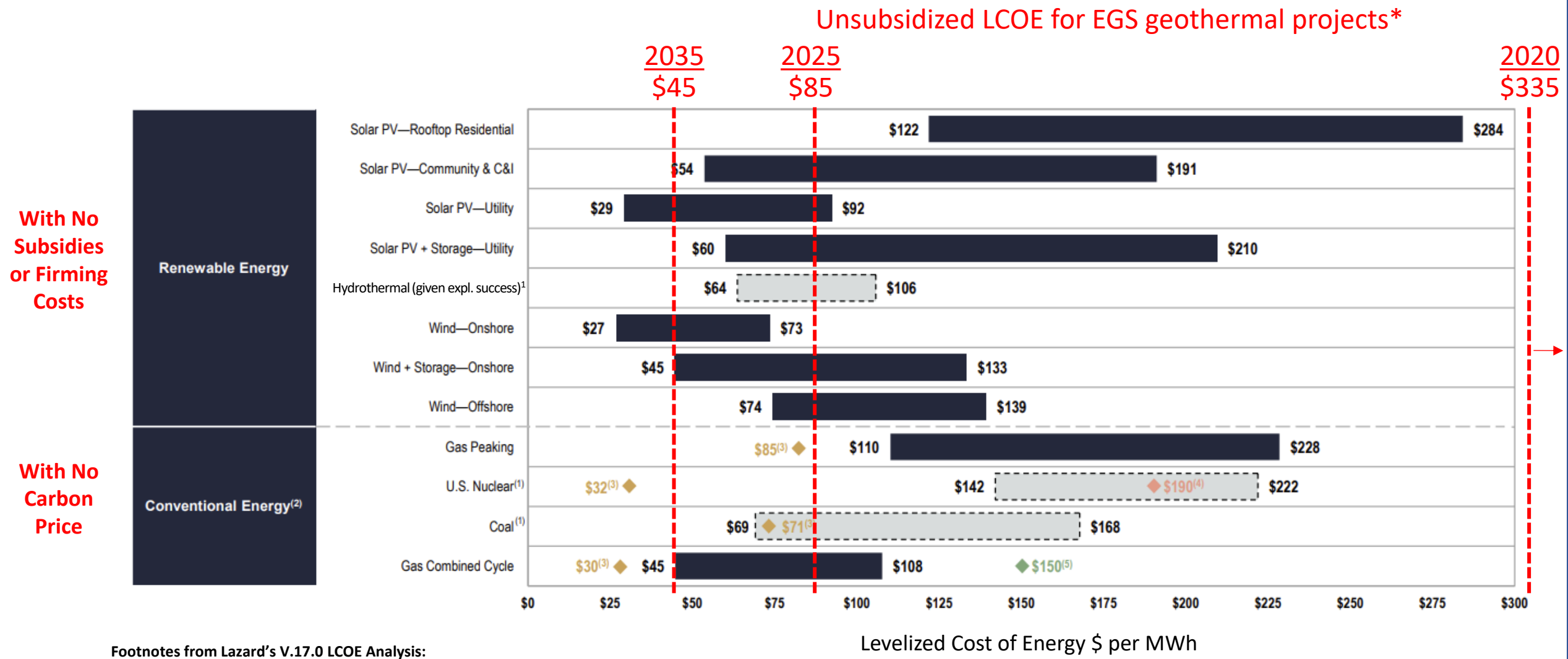
U.S. power consumption is growing rapidly

Annual average gigawatts of power consumed



Sources: 2012 to 2022 U.S. EIA; 2024, 2028, and 2030 NERC projections modified by BCG; Annual output in TWh converted to GWs to allow easy comparison to available capacity

The world therefore needs abundant, affordable, firm, low-carbon energy like what geothermal could provide given further technology advancements



Footnotes from Lazard's V.17.0 LCOE Analysis:

All LCOE assessments assume 60% debt at an 8% interest rate and 40% equity at a 12% cost of capital.

[1] Given the limited public or observable data available for new build geothermal, coal, and nuclear projects, the LCOE presented herein reflects Lazard's LCOE V.14.0 results adjusted for inflation. Coal LCOE does not include the cost for transportation & storage.

[2] The fuel cost assumptions for Lazard's LCOE analysis for natural gas generation, coal generation, and nuclear generation are $3.45 per MMBTU, $1.87 per MMBTU, and $0.85 per MMBTU, respectively

* See slide nine for path to $45 per MWh LCOE. It is reasonable to expect at this early stage of technology deployment a considerable range of uncertainty in both current and 2035 LCOE due to both uncertainty in the ultimate level of performance achieved and local variations that impact LCOE.

Past, present, and future hydraulically fractured horizontal well EGS projects

Horizontal wells could also greatly enhance hydrothermal power economics

Identifying faults in basement rocks is difficult

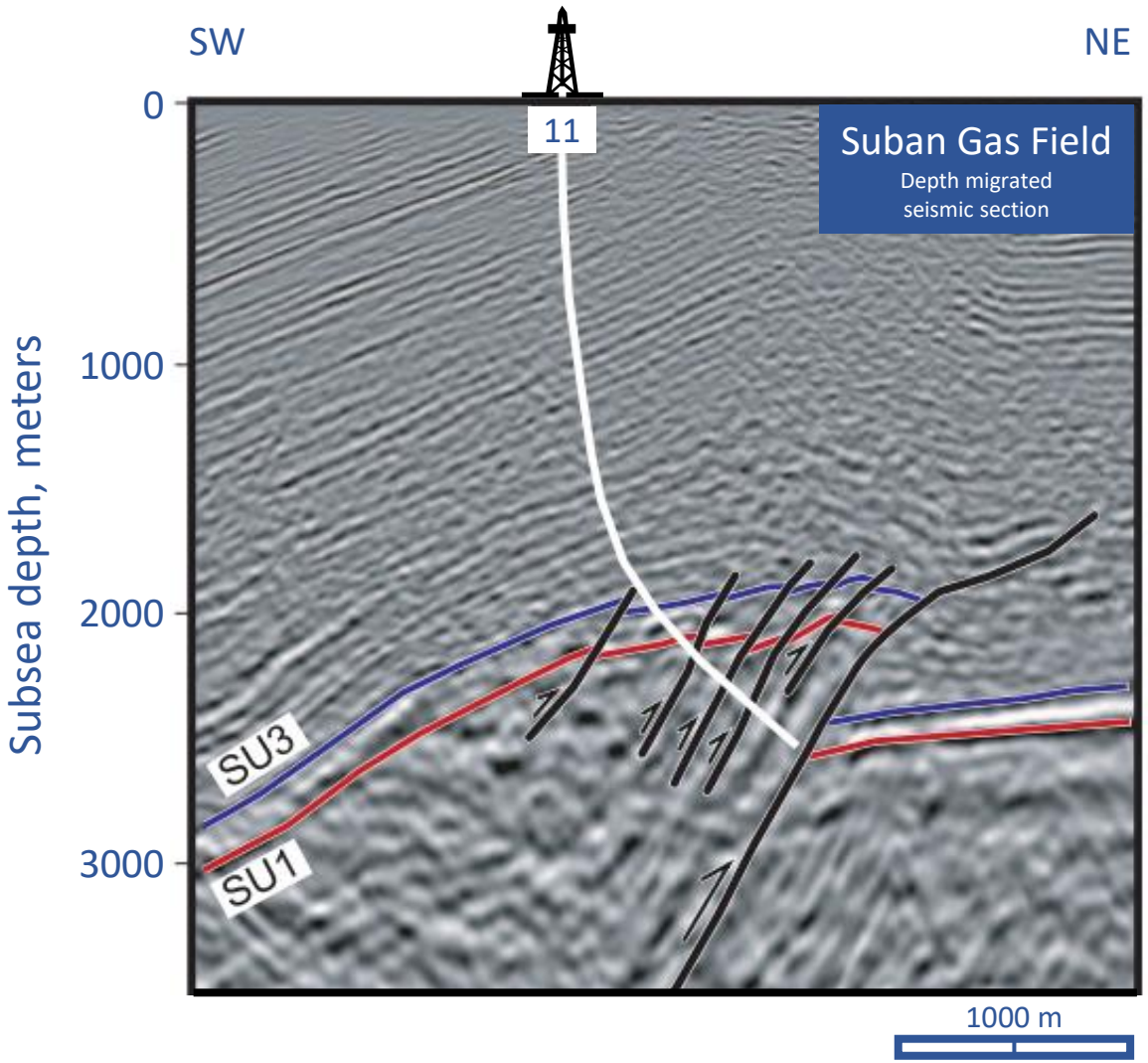


Figure after Hennings et al. (2012). Suban field estimated ultimate recovery = 6 TCFG from fractured basement rocks

To increase flow rates, intersect more fractures

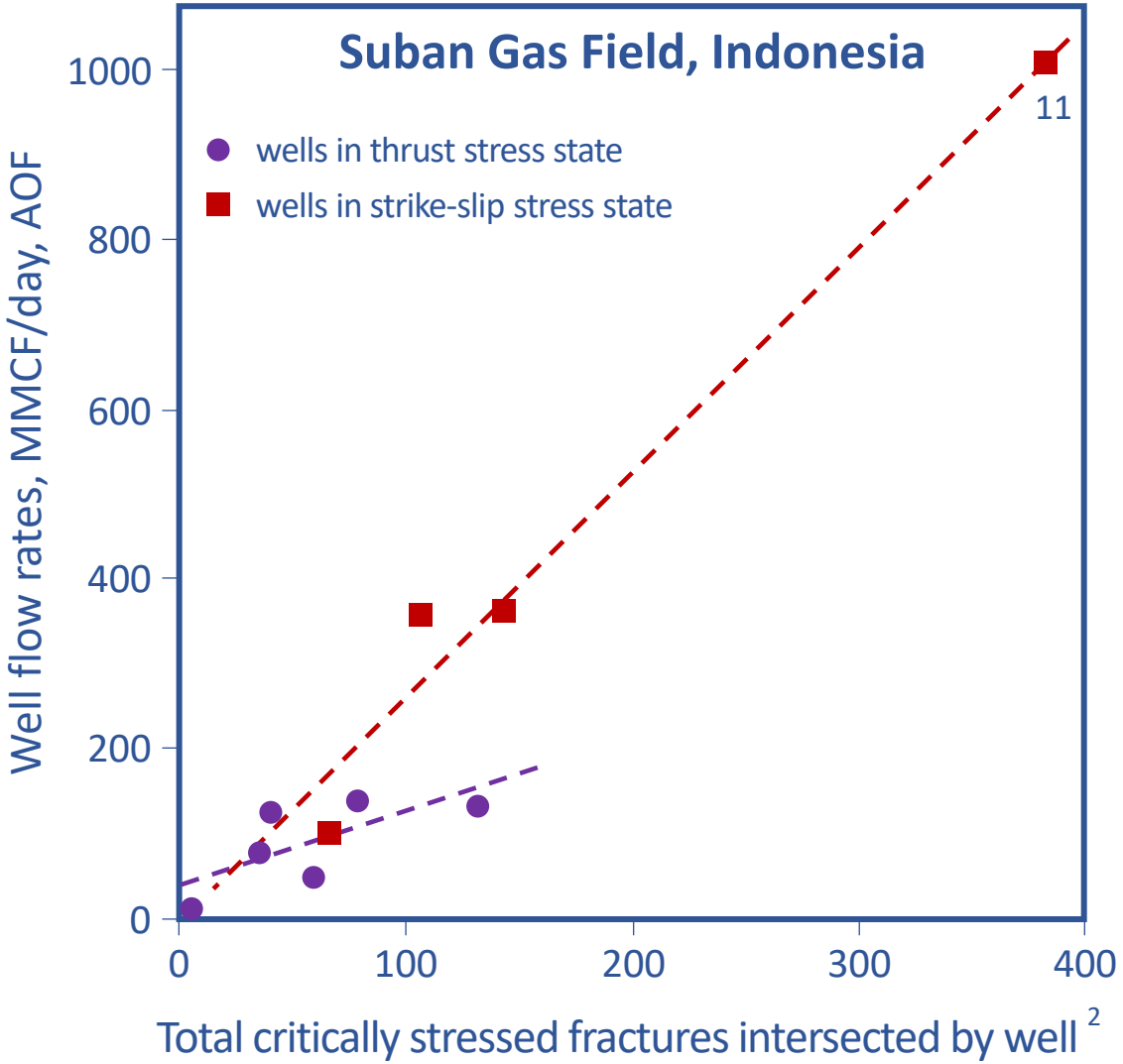
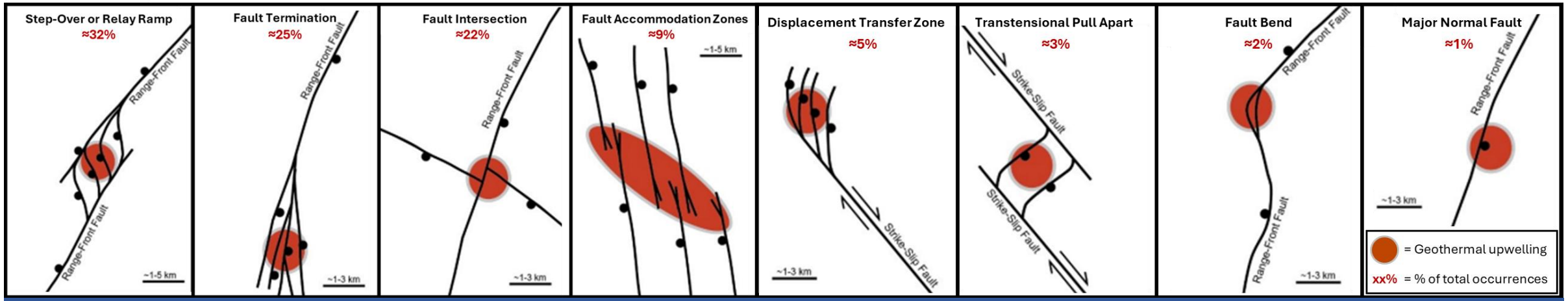


Figure after Hennings et al. (2012). MMCF = million cubic feet; AOF = absolute open flow; [1] critically stressed fractures; [2] from image logs.

Increasing hydrothermal success rates and output per well



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)

Horizontal wells

Interpreted fault traces and dilation tendency, Tuscarora geothermal system

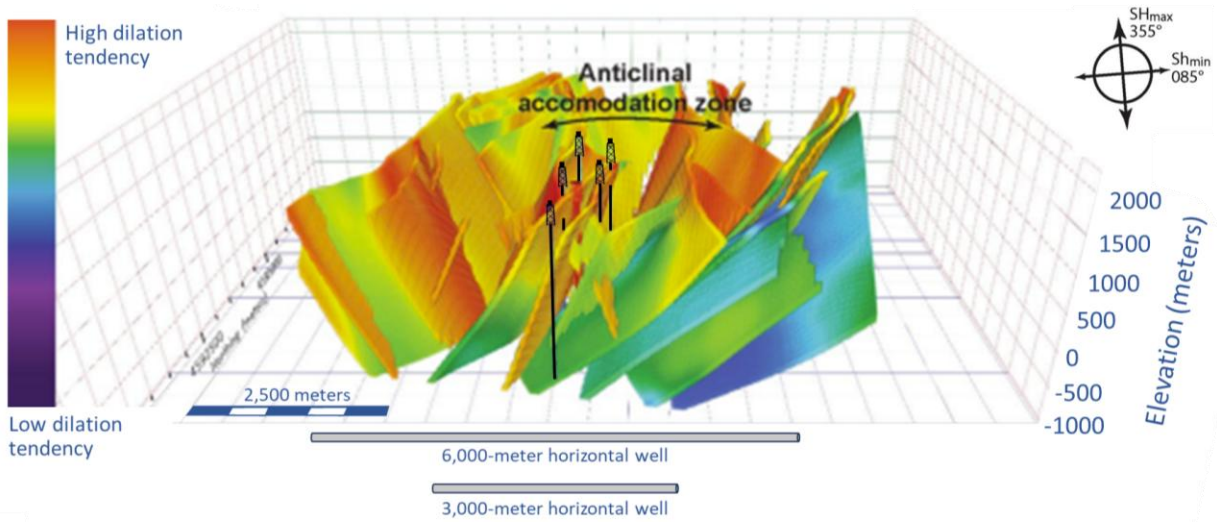
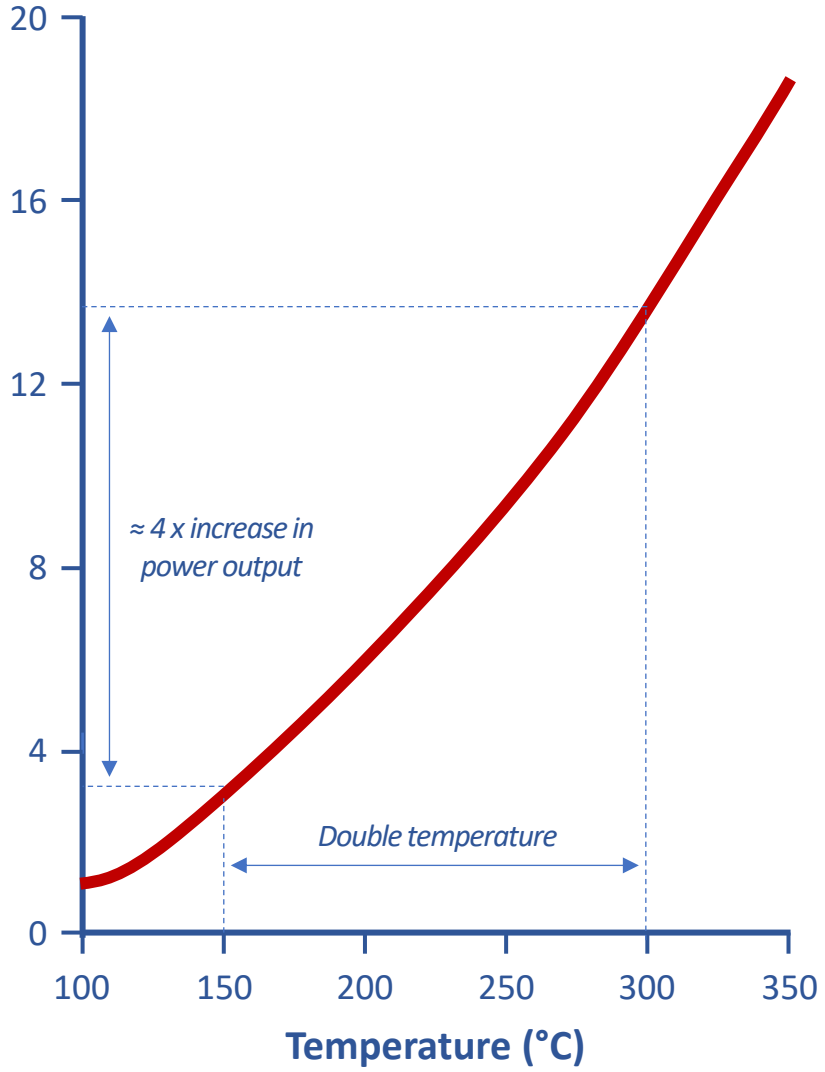


Diagram from Leveille and Zoback (2025)

Super hot rocks – when achieved, the economic payoff will be immense

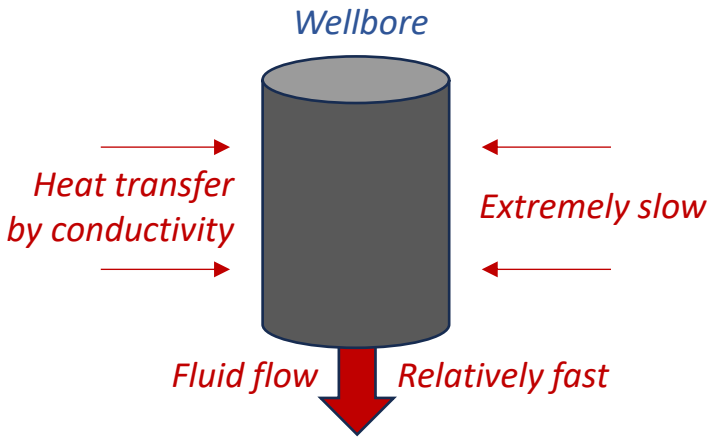
Power generation (MWe)[1]



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

Efforts are underway to achieve super hot rock power production

Solving the AGS (closed loop) thermal longevity challenge



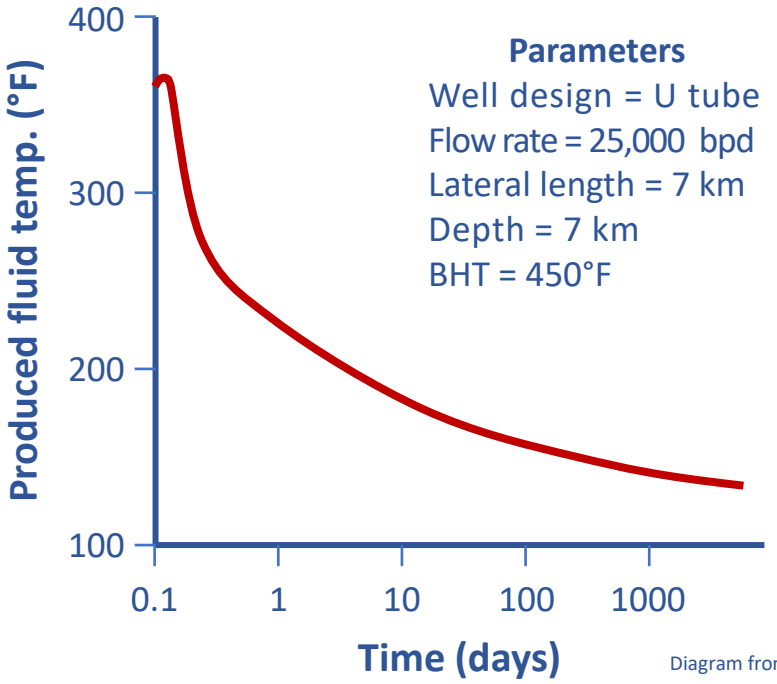
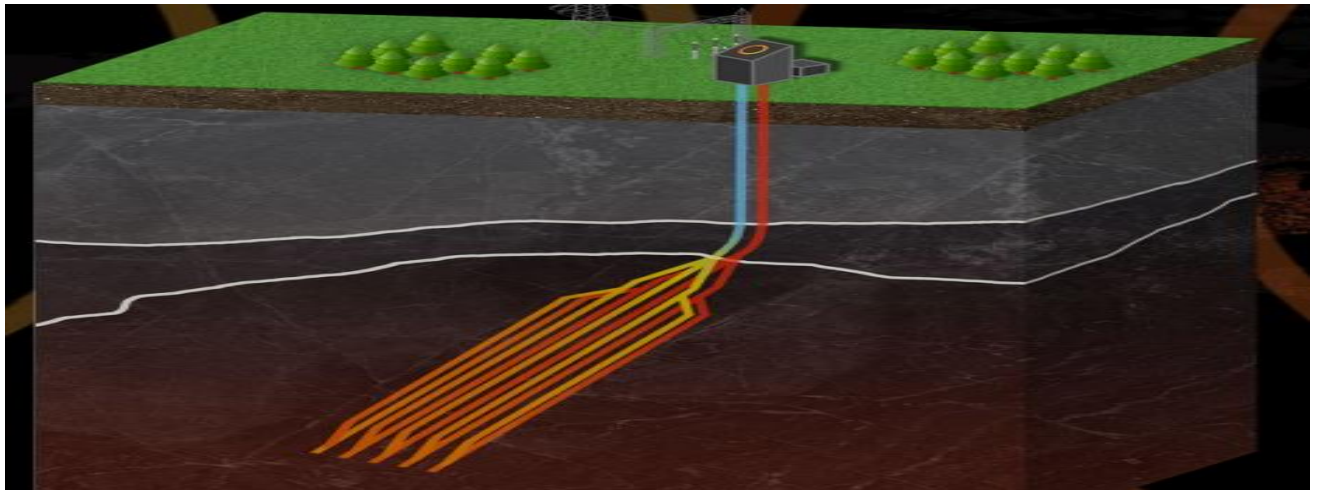
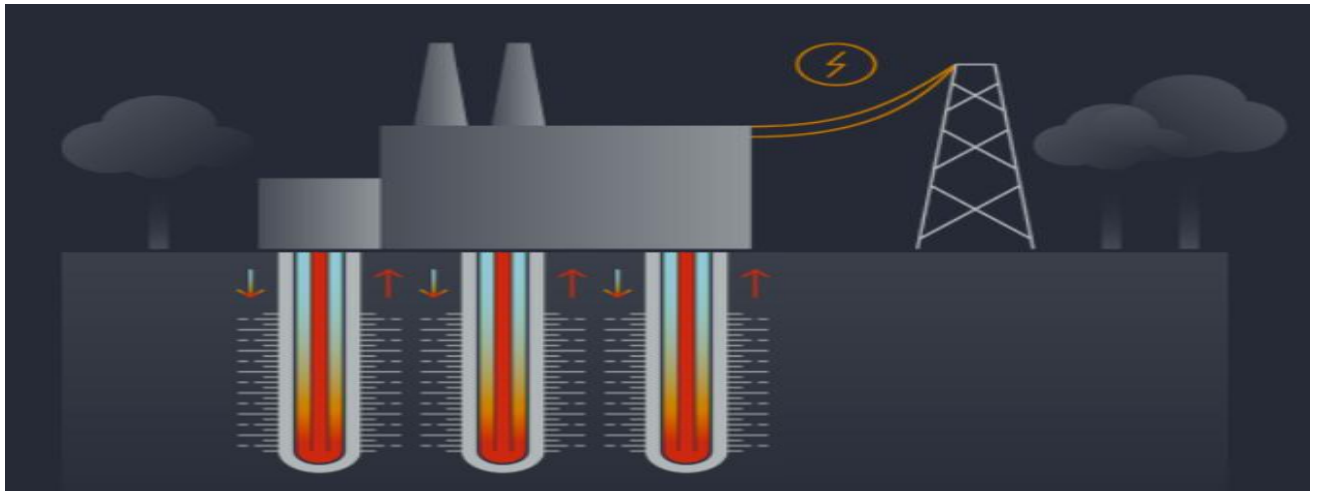


Diagram from McClure 2021

Eavor multi-lateral closed loop "radiator" design



XGS enhanced-conductivity combined inj./prod. well

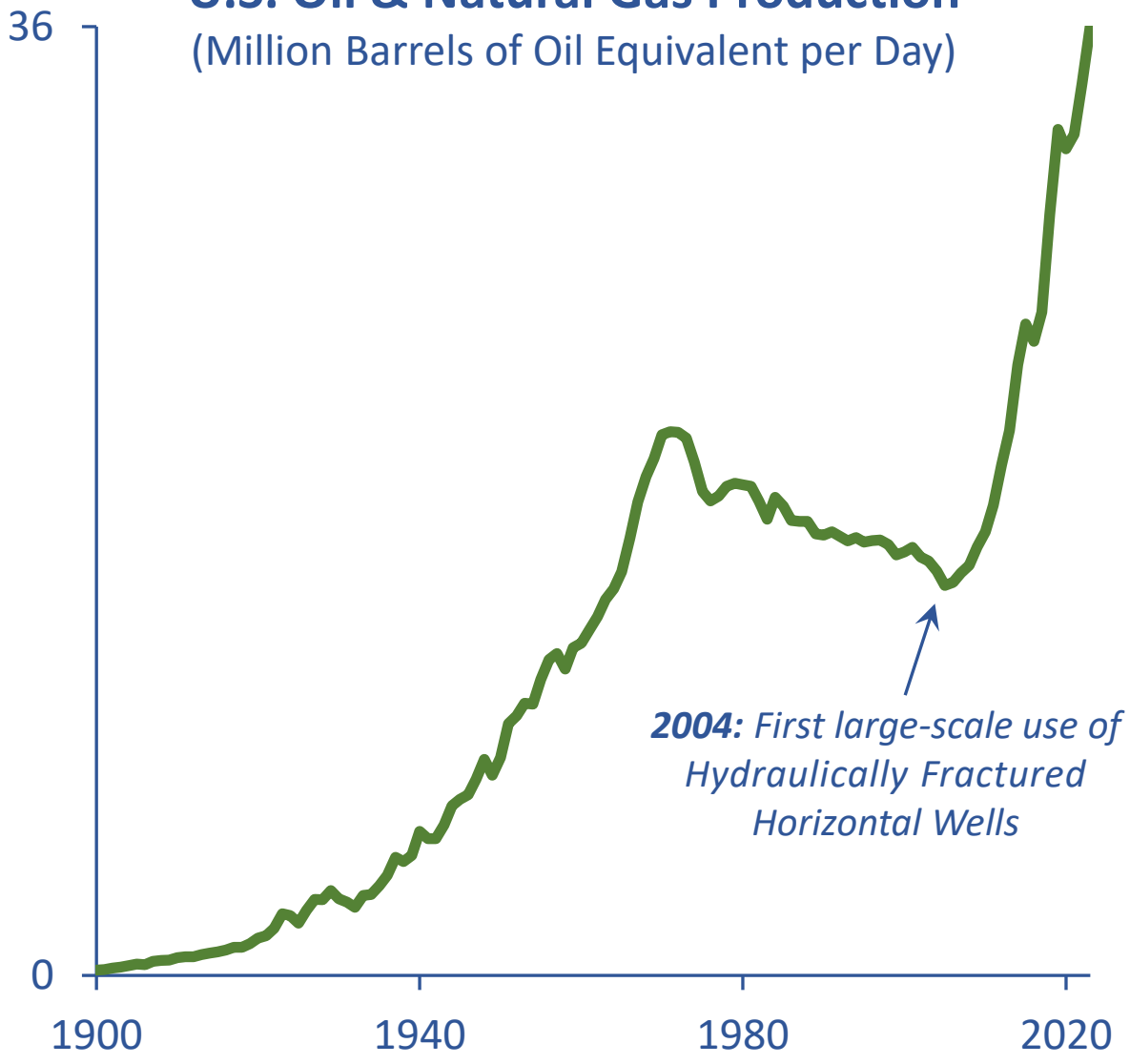


Potential solutions: increase flow loop surface area at depth; insulate upper portion of flow loop; target higher temperatures

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

U.S. Oil & Natural Gas Production

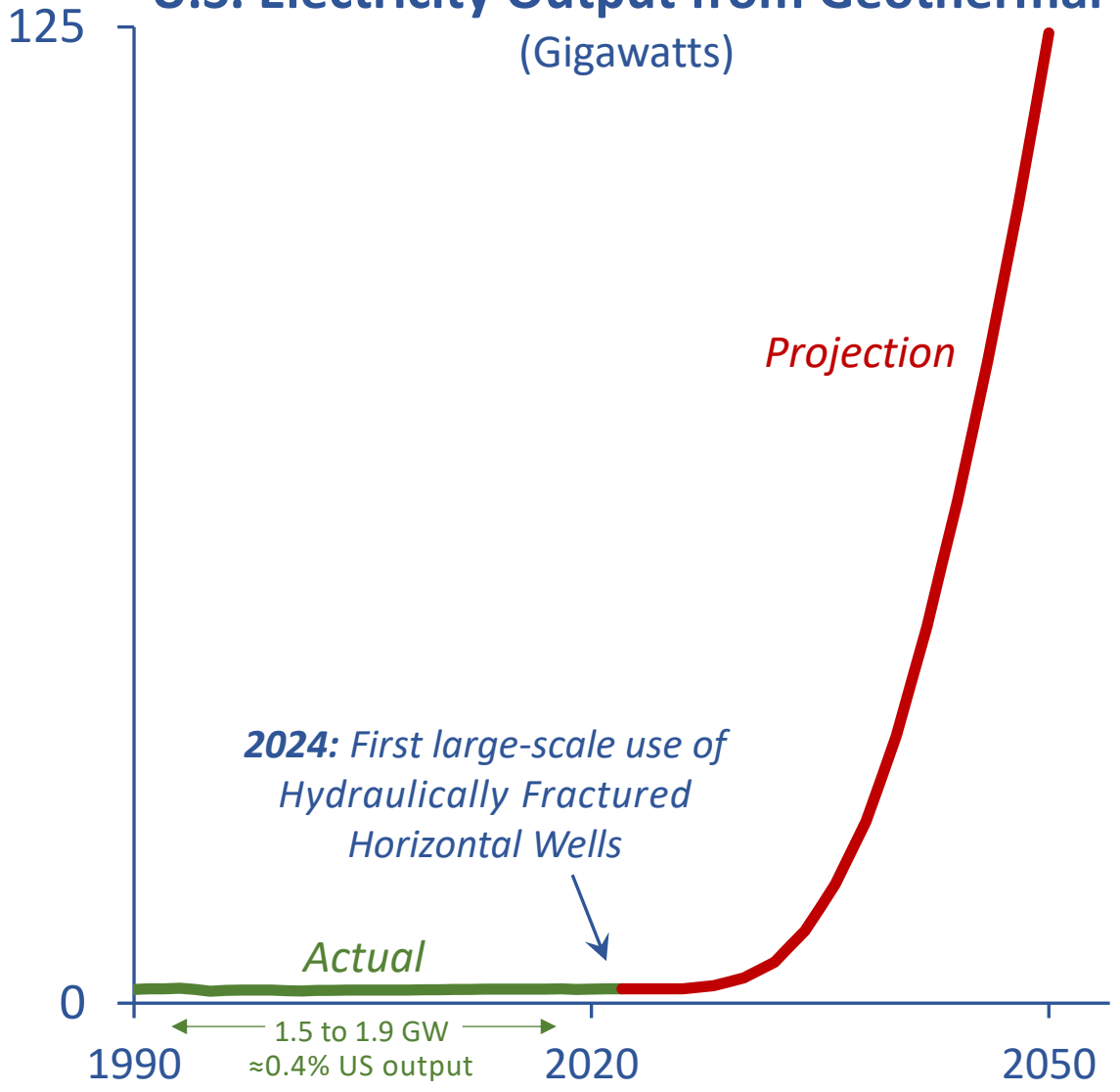
(Million Barrels of Oil Equivalent per Day)



Sources: U.S. EIA and Energy Institute websites

U.S. Electricity Output from Geothermal

(Gigawatts)



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

Fervo's Cape Project will increase US geothermal power output by > 25%

0.5 GW of power output
Phase 1 start-up in 2026
Phase 2 start-up in 2028

Areal photo of Fervo Cape Phase 1 project; April 2025. Picture from Fervo Energy's website

Geothermal Power Production – An Oil and Gas Technology Enabled Revolution Currently Underway in the USA

Greg Leveille

May 8, 2025

A copy of this slide deck can be downloaded at:

https://tidalwavetechnologies.com/

Picture from Fervo Energy's website

References for materials used in this presentation

- CATF, 2022, ***Superhot Rock Energy - A Vision for Firm, Global Zero-Carbon Energy*** (LINK)
- CATF, 2024, ***Gaps, Challenges, and Pathways Forward for Superhot Rock Energy Summary Report*** (LINK)
- Energy Institute, 2024, ***Statistical Review of World Energy*** (LINK)
- Geothermal Technologies Office, 2024, ***Pathways to Commercial Liftoff: Next-Generation Geothermal Power***, (LINK)
- Hermant, B., Kiersnowski, L., and Bellanger, M., 2025, ***Using Deep Learning to Map Quaternary Faults in Western USA*** (LINK)
- Lazard, 2024, ***Levelized Cost of Energy Comparison*** (LINK)
- Leveille, G., 2025, ***Horizontal Hydrothermal Wells: An Idea Whose Time Has Come*** (LINK)
- McClure, M., 2021, ***Why Deep Closed-Loop Geothermal Is Guaranteed To Fail*** (LINK)
- NOAA Global Monitoring Laboratory, 2025, ***Trends in CO2 and CH4*** (LINK)
- Norbeck, J., Gradl, C. and Latimer, T., 2024, ***Deployment of Enhanced Geothermal System technology leads to rapid cost reductions and performance improvements*** (LINK)
- Norbeck, J. and Latimer, T., 2023, ***Commercial-Scale Demonstration of a First-of-a-Kind Enhanced Geothermal System*** (LINK)
- Project Innerspace, 2025, ***The Geothermal Exploration Opportunities Map Beta*** (GeoMap™) (LINK)
- United States Department of Energy, 2024, ***Pathways to Commercial Liftoff: Next-Generation Geothermal Power*** (LINK)
- United States Energy Information Administration, 2025, ***Crude Reserves and Production*** (LINK) ***& Natural Gas Gross Withdrawals and Production*** (LINK) ***& Electricity Net Generation by Energy Source*** (LINK)

Other selected key references (page 1 of 2)

Horizontal EGS Demonstration Project Results

- Jack Norbeck & Tim Latimer, 2023, ***Commercial-Scale Demonstration of a First-of-a-Kind Enhanced Geothermal System*** (LINK)
- Mark McClure, 2023, ***Fervo Energy's 'Project Red' Results are a Historical Breakthrough for Geothermal – What Comes Next*** (LINK)
- Kareem El-Sadi, Brittany Gierke, Elliot Howard, Christian Gradl, 2024, ***Review Of Drilling Performance In A Horizontal EGS Development*** (LINK)
- Deniz Ertas, 2025, ***EGS Reservoir Characterization Through Injectivity and Steady-State Circulation Tests*** (LINK)
- Steven Fercho et al., 2025, ***Update on the Geology, Temperature, Fracturing, and Resource Potential at the Cape Geothermal Project Informed by Data Acquired from the Drilling of Additional Horizontal EGS Wells*** (LINK)
- Joe Moore, 2024, ***Current Activities at Utah FORGE*** (LINK)
- Duane Winkler and Leroy Swearingen, 2021, ***Summary of Drilling Activities: Well 16A(78)-32***, Utah Forge website (LINK)
- Fred Dupriest and Sam Noynaert, 2022, ***Drilling Practices and Workflows for Geothermal Operations*** (LINK)

Fully Coupled Hydraulic Fracturing and Reservoir Simulation Key Insights

- Mark McClure, 2023, ***Thermoelastic fracturing and buoyancy-driven convection – Surprising sources of longevity for EGS circulation*** (LINK)
- Mark McClure, 2023, ***Technical barriers for deep closed-loop geothermal*** (LINK)

U.S. Department of Energy Geothermal Publications

- Lawrence Berkeley National Laboratory, 2023, ***Characterizing the Geothermal Lithium Resource at the Salton Sea***, (LINK)
- Geothermal Technologies Office, 2023, ***U.S. DOE Enhanced Geothermal Shot***, (LINK)

Other selected key references (page 2 of 2)

Demand for Clean Firm Electricity and High-Tech Companies' Net Zero Goals

- Scientific American, 2023, ***The AI Boom Could Use a Shocking Amount of Electricity*** (LINK)
- Sam Altman, 2024, ***Age of AI will require an 'energy breakthrough'*** (LINK)
- Microsoft, 2020, ***Microsoft will be carbon negative by 2030*** (LINK)
- Google, 2024, ***Google Commitment to net-zero carbon*** (LINK)
- Google, 2024, ***A new initiative with Microsoft and Nucor to accelerate advanced clean electricity technologies*** (LINK)
- Meta, 2024, ***Climate: We commit to reaching net zero emissions across our value chain in 2030*** (LINK)
- Amazon, 2024, ***Amazon's Climate Pledge – Net zero by 2040*** (LINK)
- Nvidia, 2024, ***NVIDIA Corporate Responsibility Report - Fiscal Year 2023*** (LINK)

Insights from Oil & Gas Horizontal Well Hydraulic Fracturing Characterization Projects

- Kevin T. Raterman et al., 2017, ***Sampling a Stimulated Rock Volume: An Eagle Ford Example***, URTeC paper 2670034 (LINK)
- Kevin T. Raterman, Yongshe Liu, and Logan Warren, 2019, ***Analysis of a Drained Rock Volume: An Eagle Ford Example***, URTeC paper 2019-263-MS, (LINK)
- Caner Karacaer et al., 2021, ***Multi-well Modeling in the Eagle Ford: An Investigation of Redevelopment, Infill and Refrac Opportunities***, URTeC paper 2021-5066-MS (LINK)
- Greg Leveille and Mark Zoback, 2025, ***Impacts of Shear Zones on Enhanced Geothermal Systems (EGS): Best Practices for Avoiding Induced Seismicity, Premature Thermal Breakthrough, and Excessive Leakoff*** (LINK)