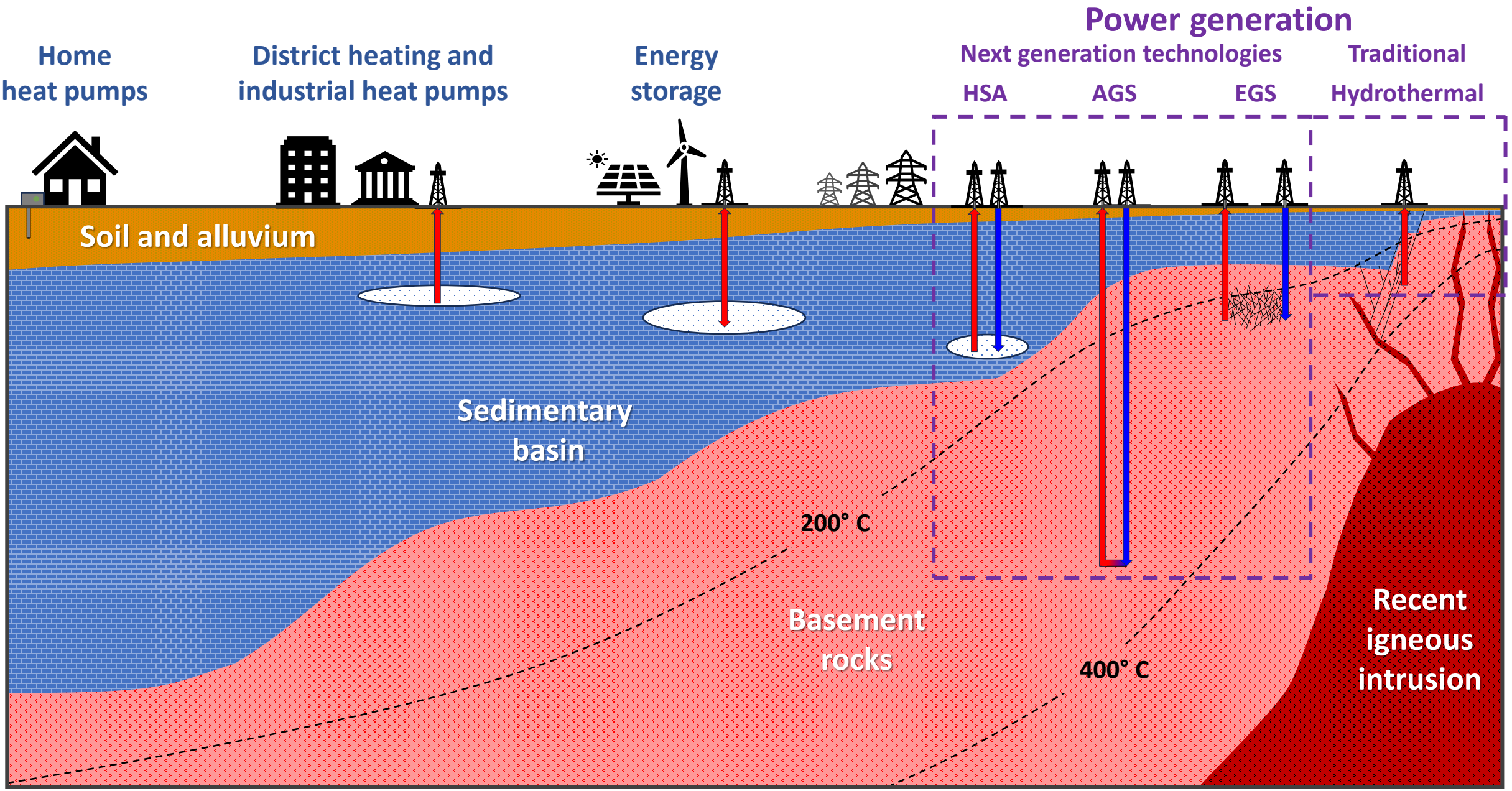
Oil & Gas Technologies Supercharge Geothermal Power Generation Economics

Greg Leveille

May 15, 2025

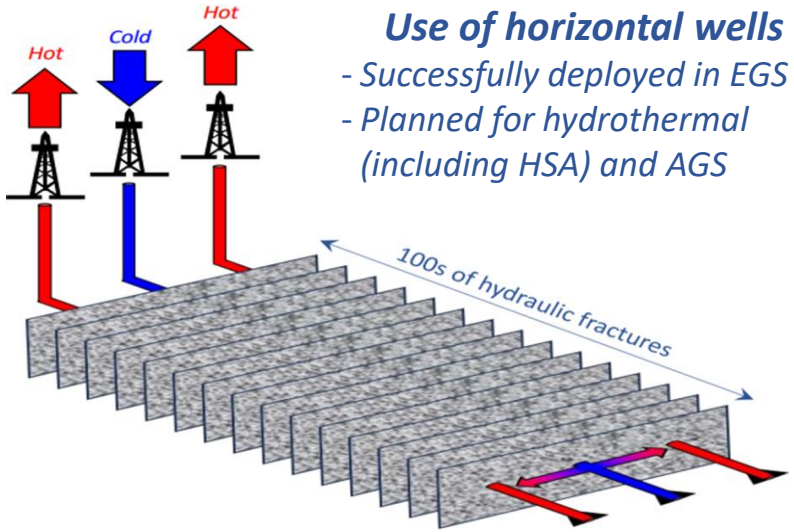
All forms of geothermal power generation are benefitting from O&G technology transfer



Cross section view; not to scale; depiction of geothermal systems are greatly simplified; O&G = Oil and Gas; HSA = Hot Sedimentary Aquifers; AGS = Advanced Geothermal Systems; EGS = Enhanced Geothermal Systems

O&G technologies are positively impacting many subsurface geothermal elements

Well design

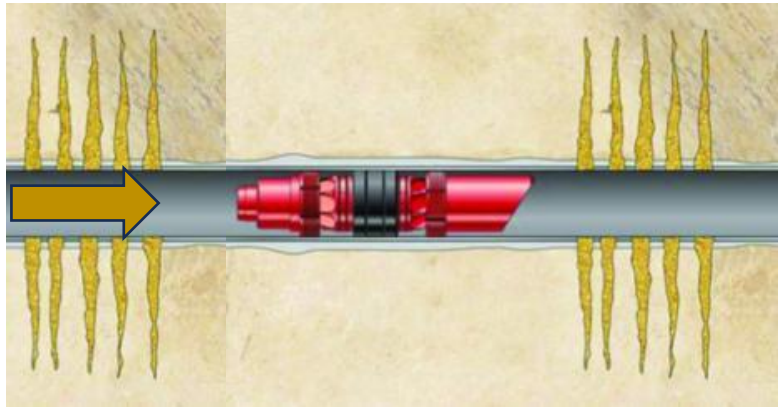


Use of horizontal wells

- *Successfully deployed in EGS*
- *Planned for hydrothermal (including HSA) and AGS*

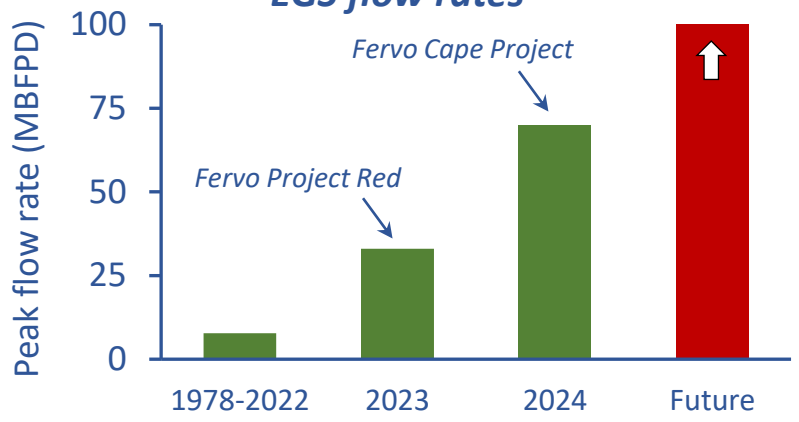
Completion efficiency

Use of plug-n-perf techniques for EGS



Production rates & longevity

EGS flow rates



Enablers – large wellbores, long laterals

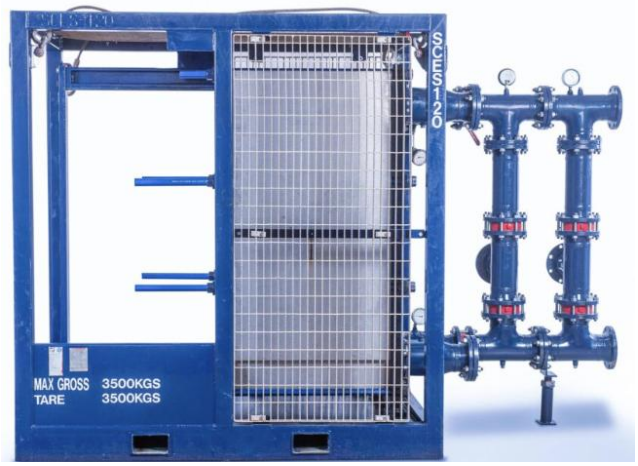
Drilling performance

Modern drilling rigs

PDC bits

Result = 1/10th the time; 1/3rd the cost

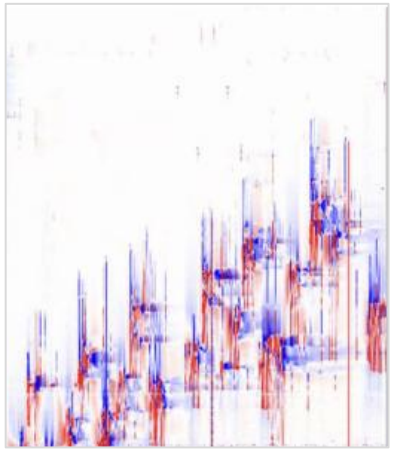
Maximum operating temp.



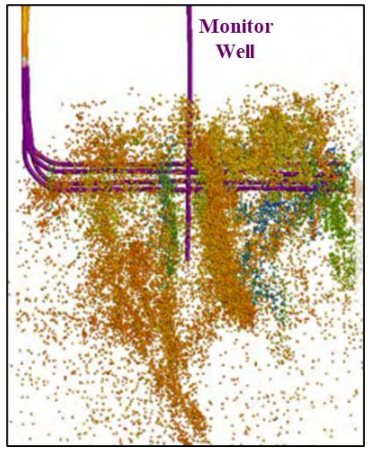
Mud coolers enable operating at higher temps.

Diagnostic tools

Fiber optics

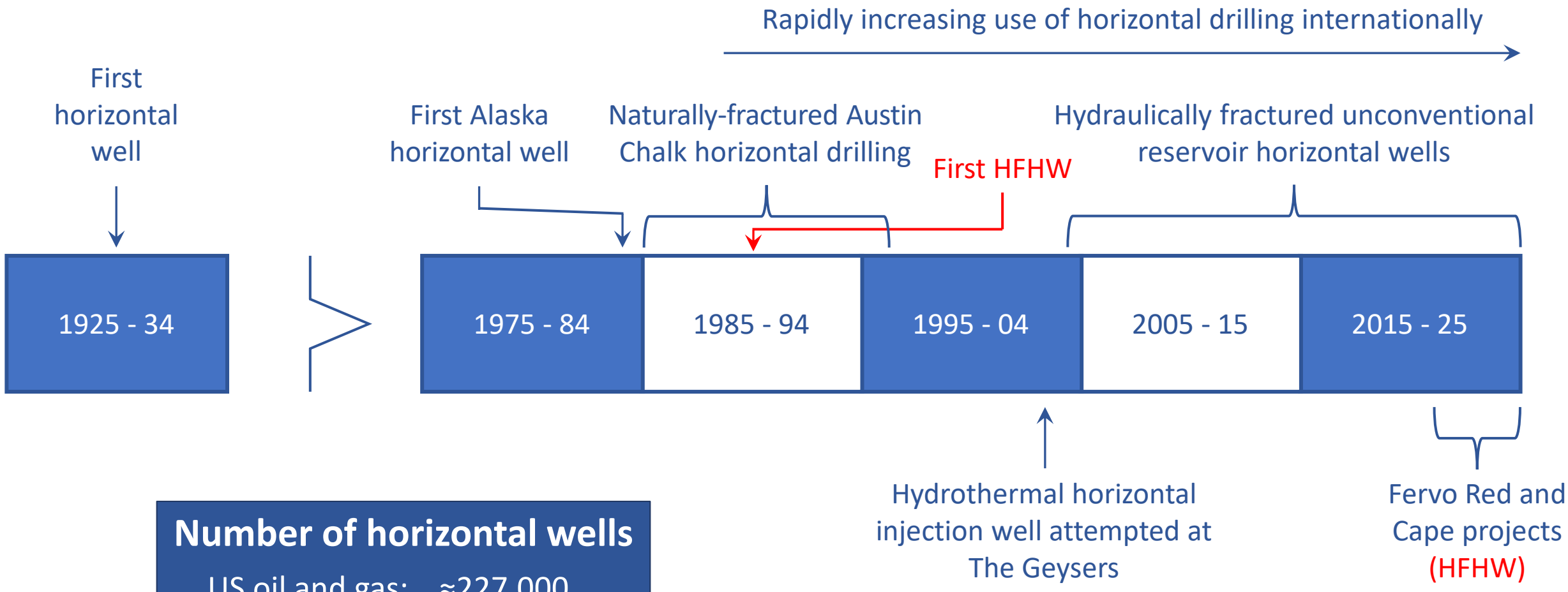


Microseismic



Cross section view

Horizontal wells – Enormous progress over the past 100 years



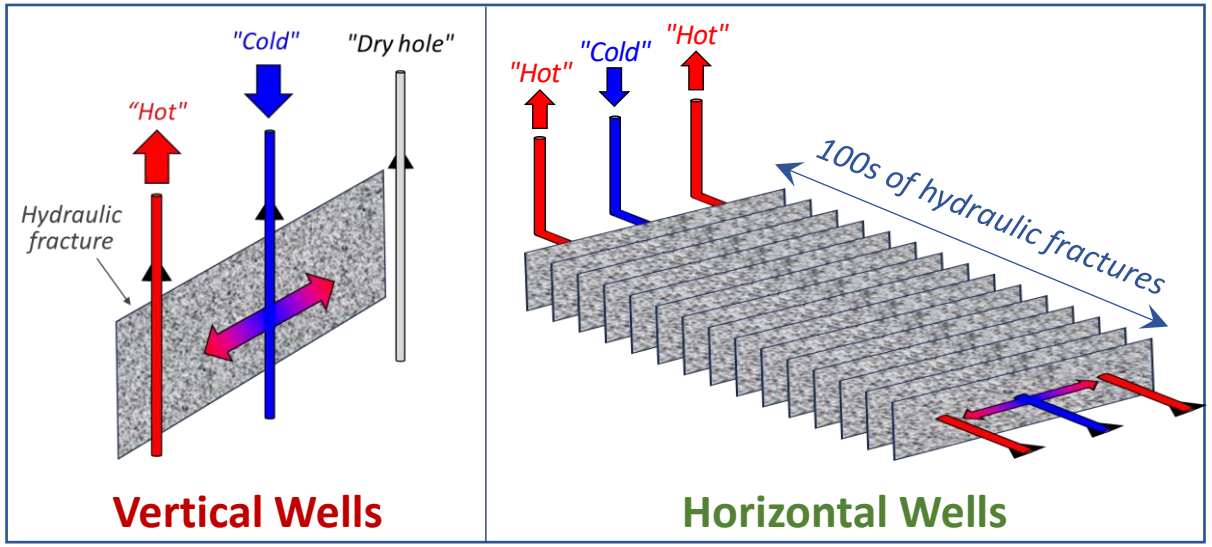
Number of horizontal wells

US oil and gas: ≈227,000

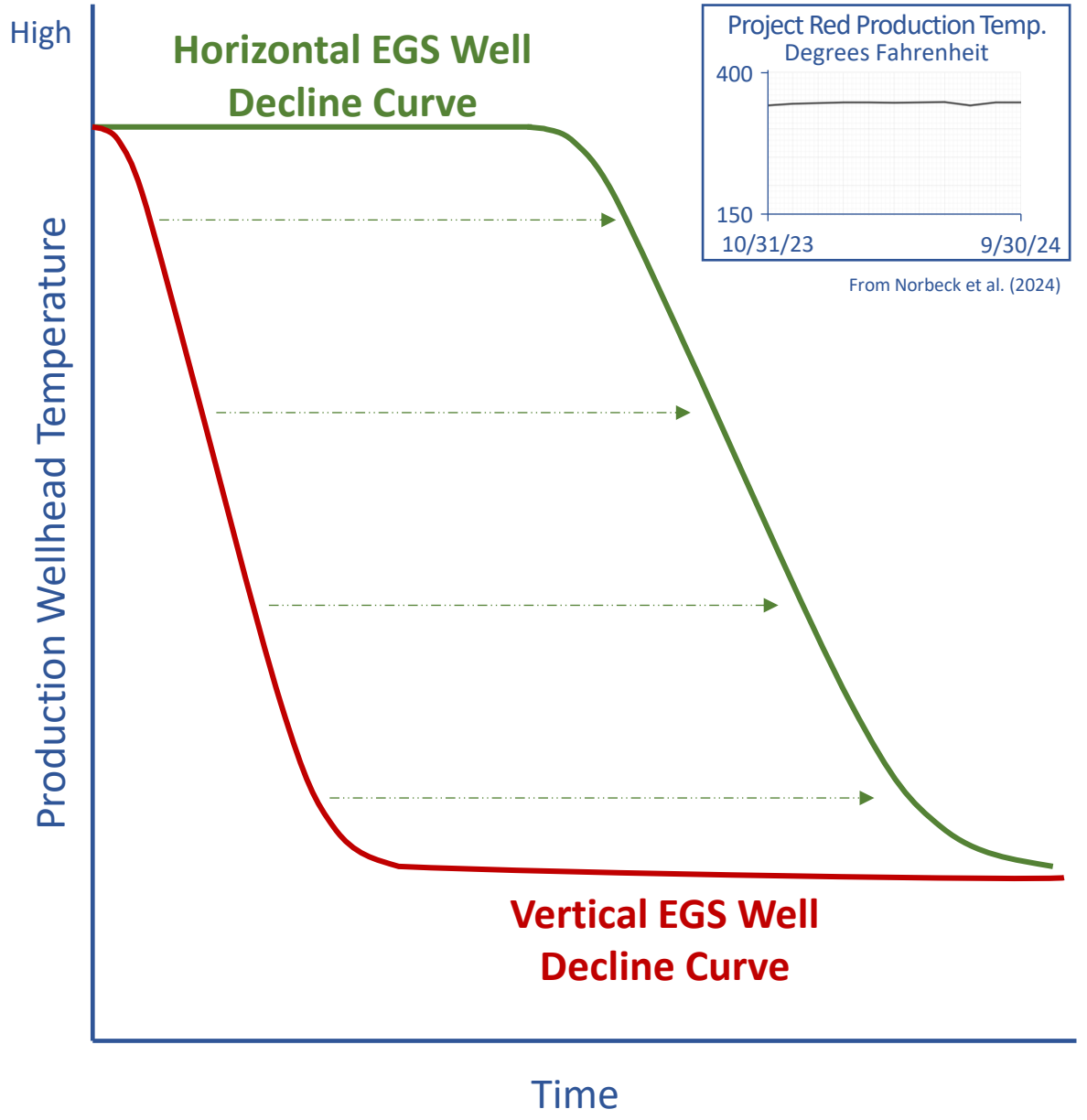
US geothermal: ≈25

Note: For a well to be considered "horizontal", it needs to exceed 80° of deviation from vertical; HFHW = hydraulically fractured horizontal well

The use of hydraulically fractured horizontal wells have transformed EGS economics



Oblique views; not to scale



Diagrammatic depiction modeled after Gringarten et al. (1975); see next slide for model describing the physics driving these outcomes

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

Past = Project is generating power; Present = drilling operations underway; Future = project is in planning stage

Horizontal wells could also greatly enhance hydrothermal power economics

Identifying faults in basement rocks is difficult

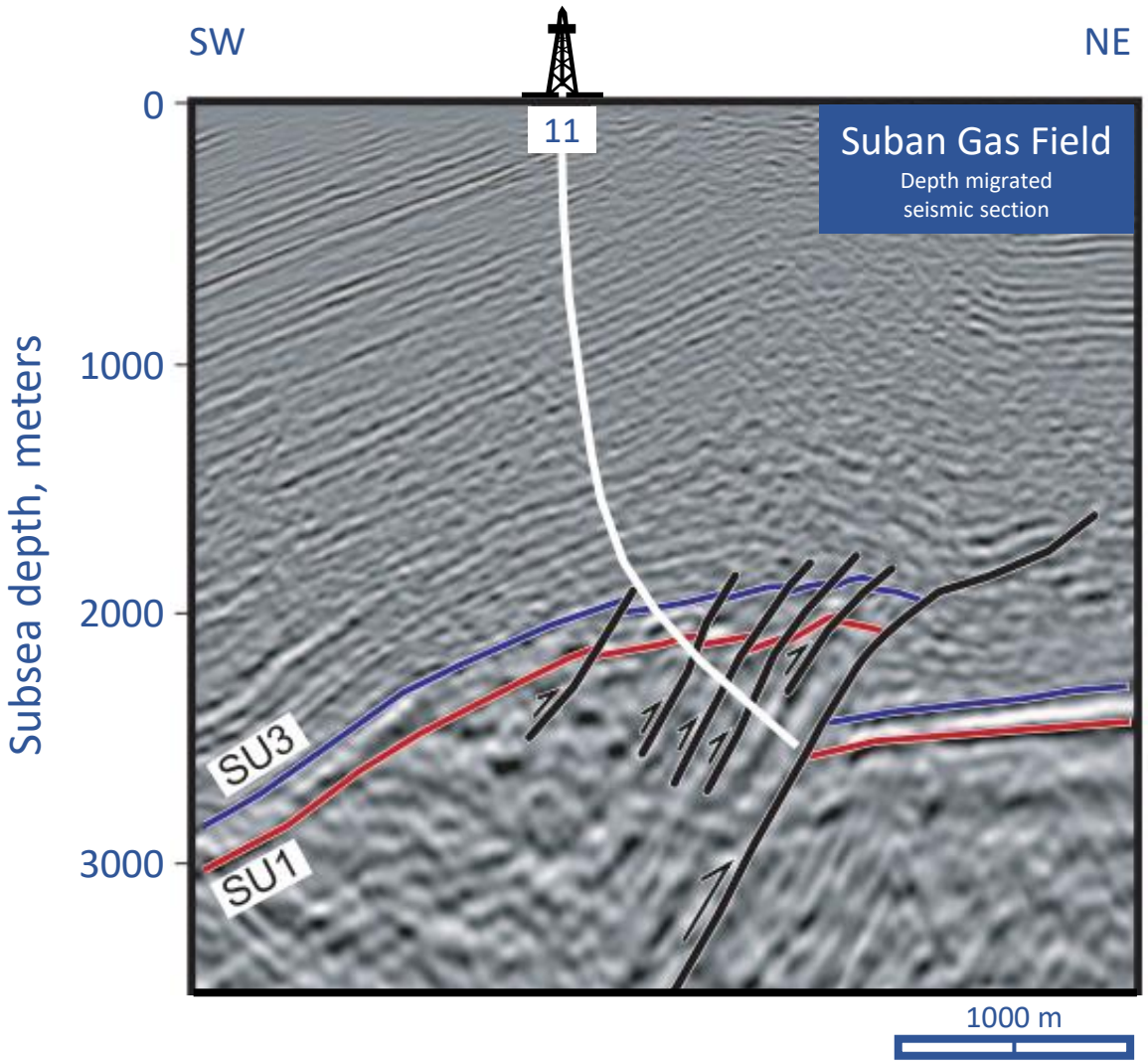


Figure after Hennings et al. (2012). Suban field estimated ultimate recovery = 6 TCFG from fractured basement rocks

To increase flow rates, intersect more fractures

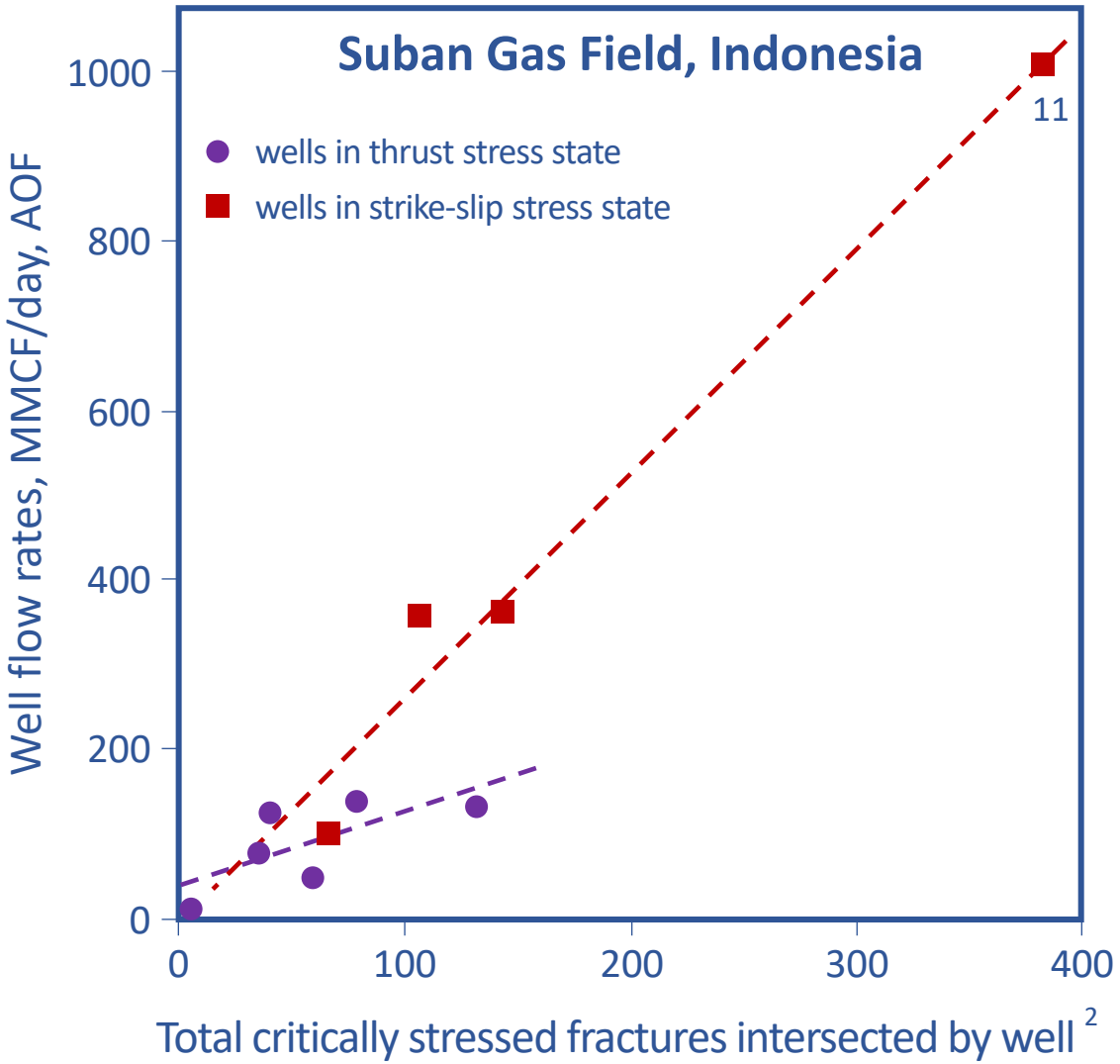


Figure after Hennings et al. (2012). MMCF = million cubic feet; AOF = absolute open flow; [1] critically stressed fractures; [2] from image logs.

Horizontal wells should increase hydrothermal success rates and per well output

Horizontal wells can intersect more fractures

Interpreted fault traces and dilation tendency, Tuscarora geothermal system

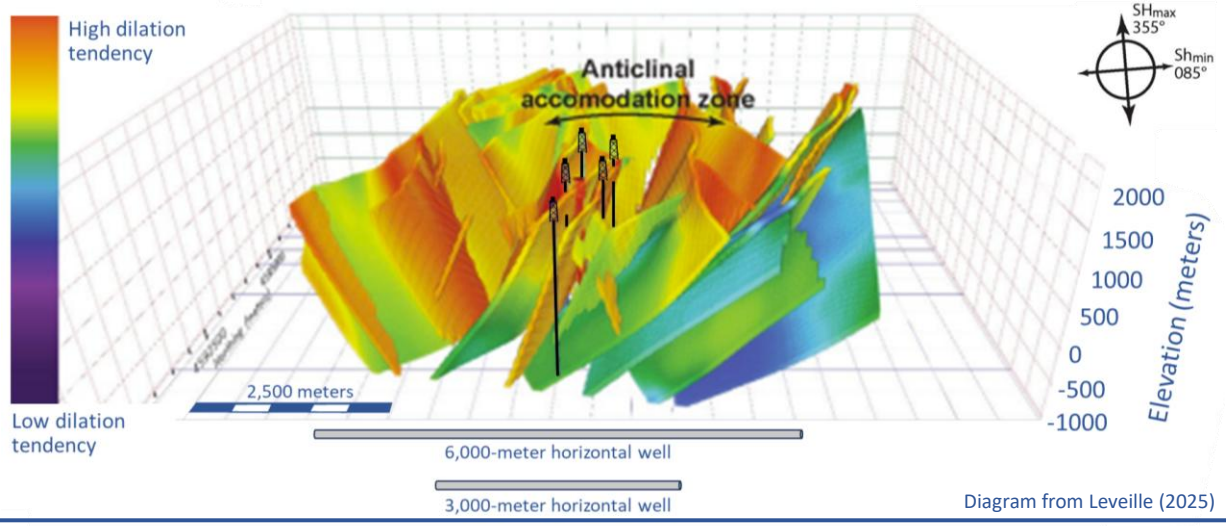


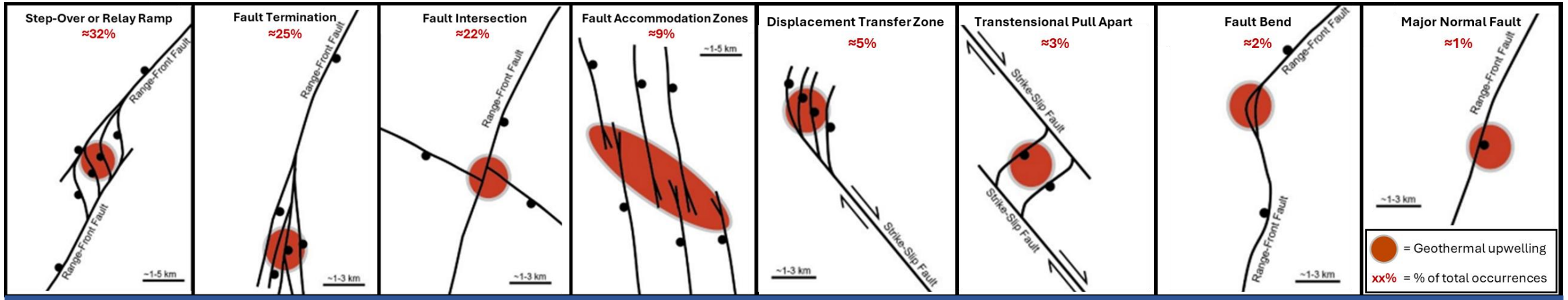
Diagram from Leveille (2025)

Remote sensing & ML can improve targeting

Quaternary fault mapping from LIDAR data using deep learning

Diagram from Hermant et al. (2025); ML = machine learning

Geologic studies can be leveraged to identify favorable structural settings



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)

Record setting geothermal drilling results have been achieved by the U.S. DOE funded Utah FORGE project and Fervo Energy's Red & Cape projects

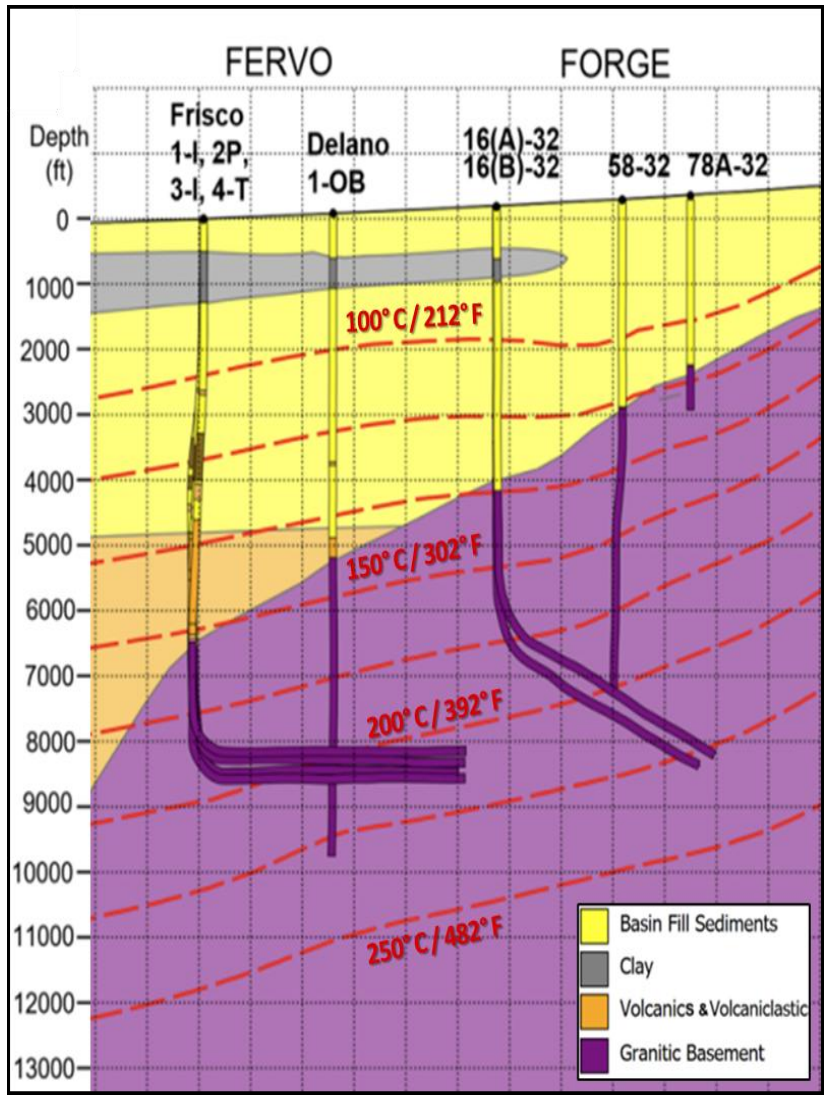


Diagram taken from 2024 paper presented at the 49th Stanford Geothermal Workshop by Fercho et al.

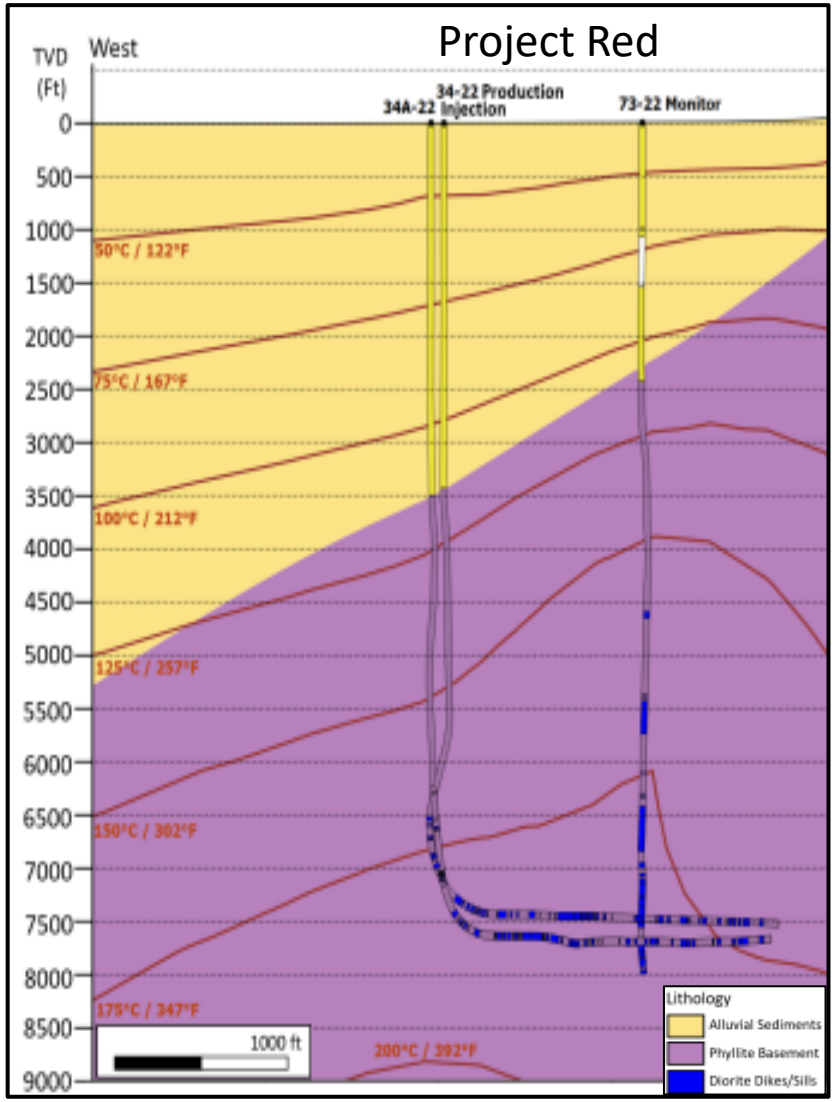
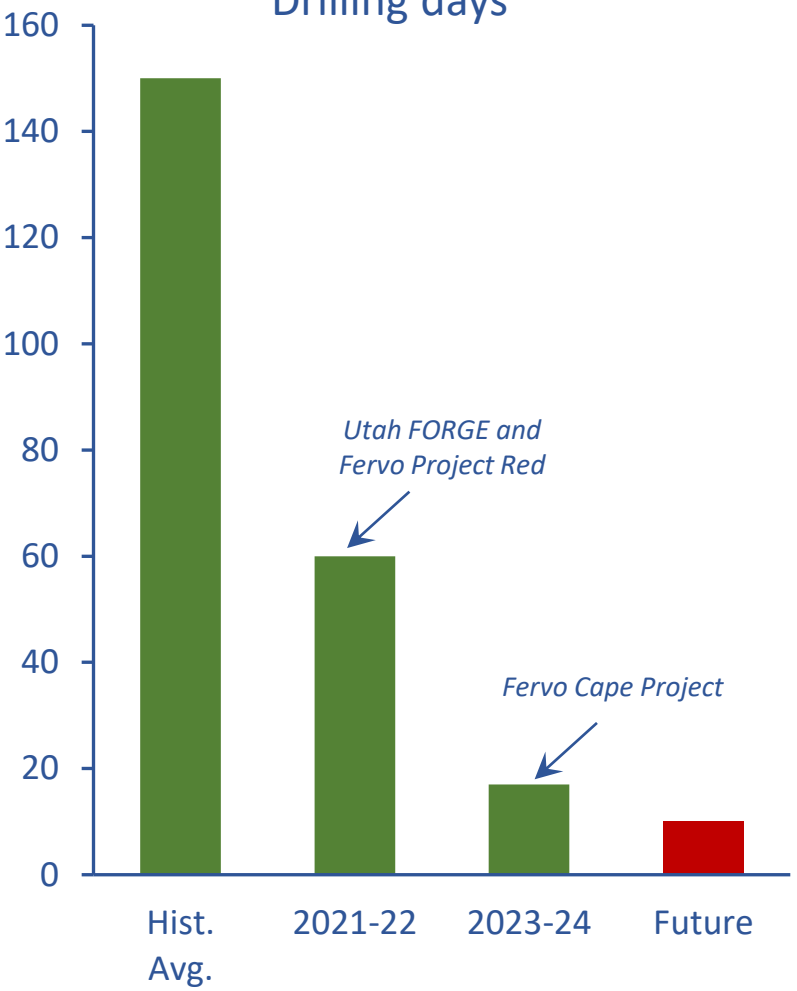


Diagram taken from 2023 by Jack Norbeck and Tim Latimer

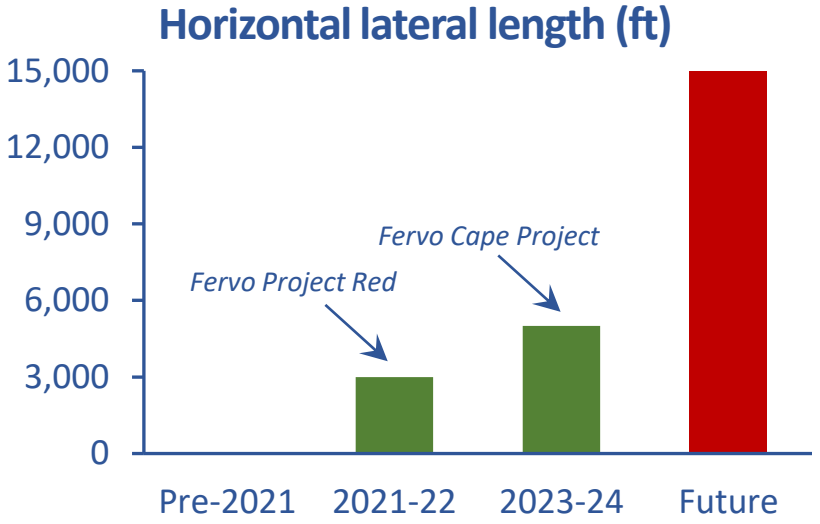
Drilling Performance



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

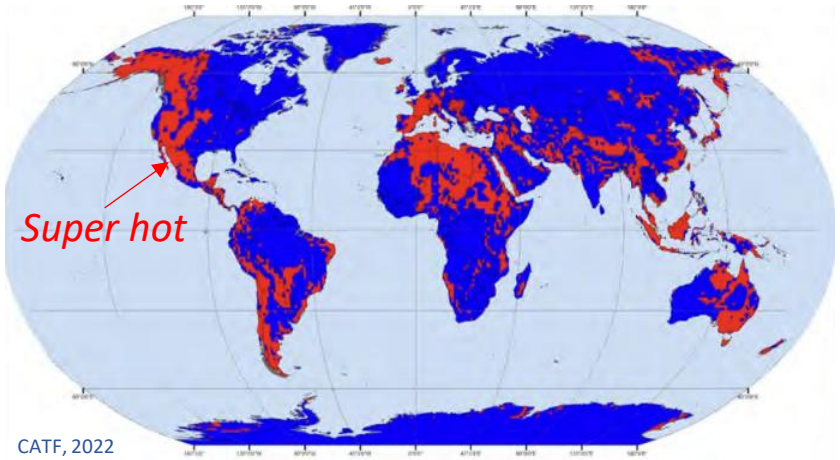
Geothermal power subsurface opportunities and challenges

Increase contacted surface area



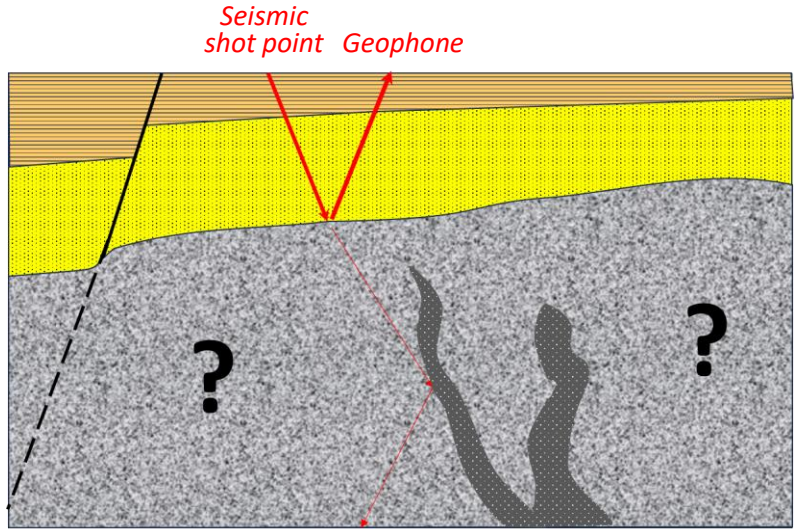
Super hot rocks (>375°C)

Super hot rock < 10 km below surface

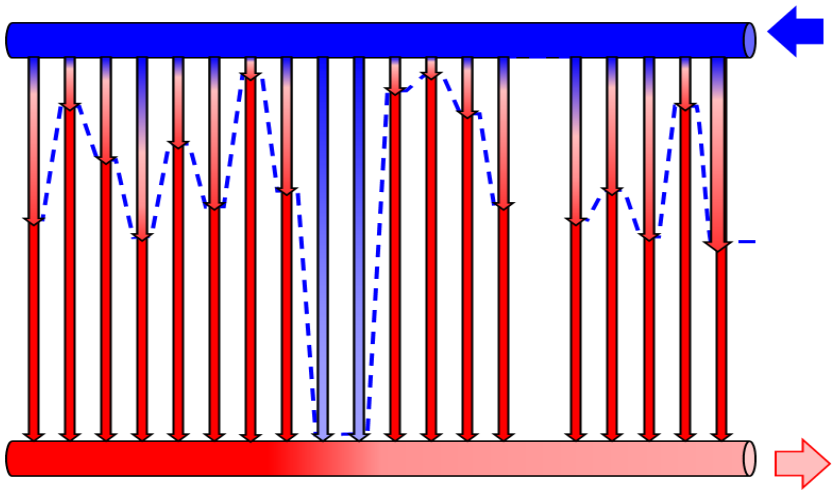


CATF, 2022

Fault identification in basement



Thermal longevity



Map view, Not to scale

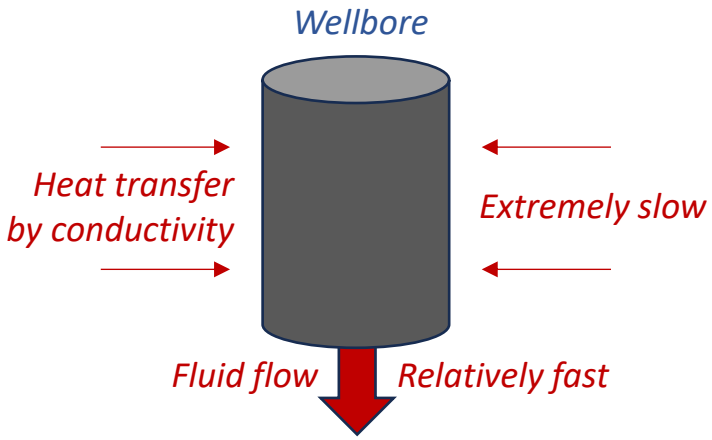
Remediating conformance issues

- Mechanical devices, plugging agents, chemical treatments
- Pre-installed or deployed later
- Inflow, outflow, or both

Scaling and corrosion

Pictures from Anne Pluymaker, EGU Blogs, 2019

Solving the AGS (closed loop) thermal longevity challenge



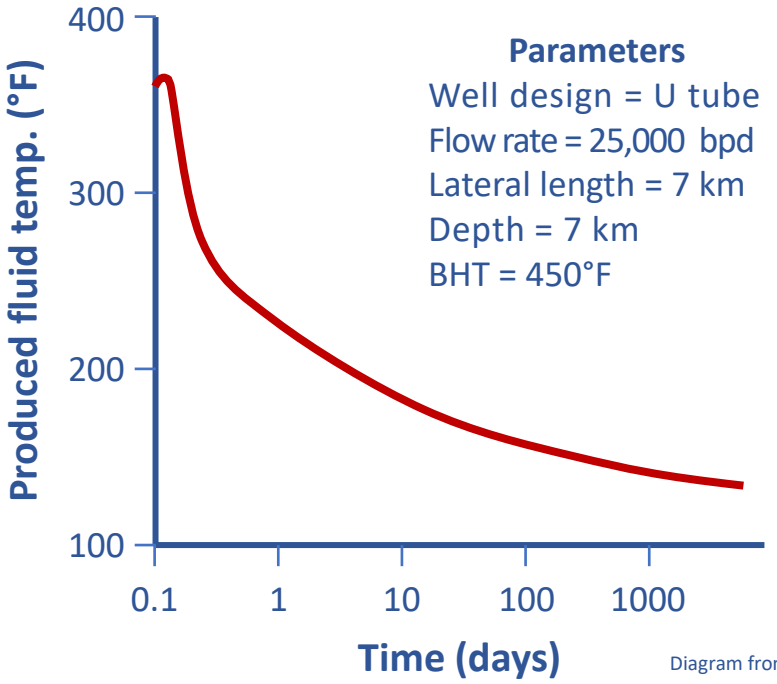
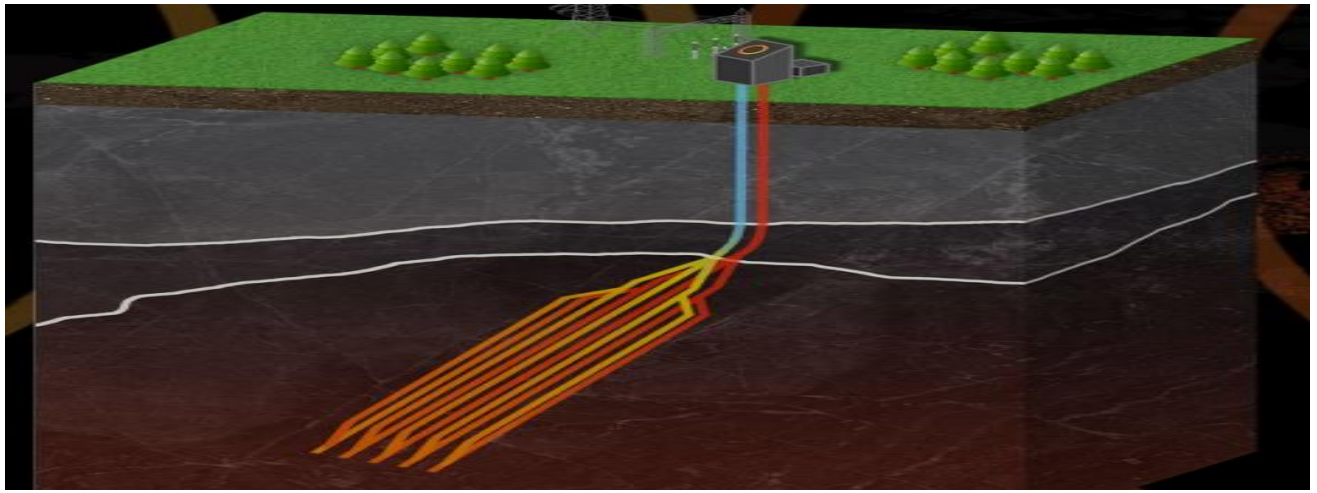
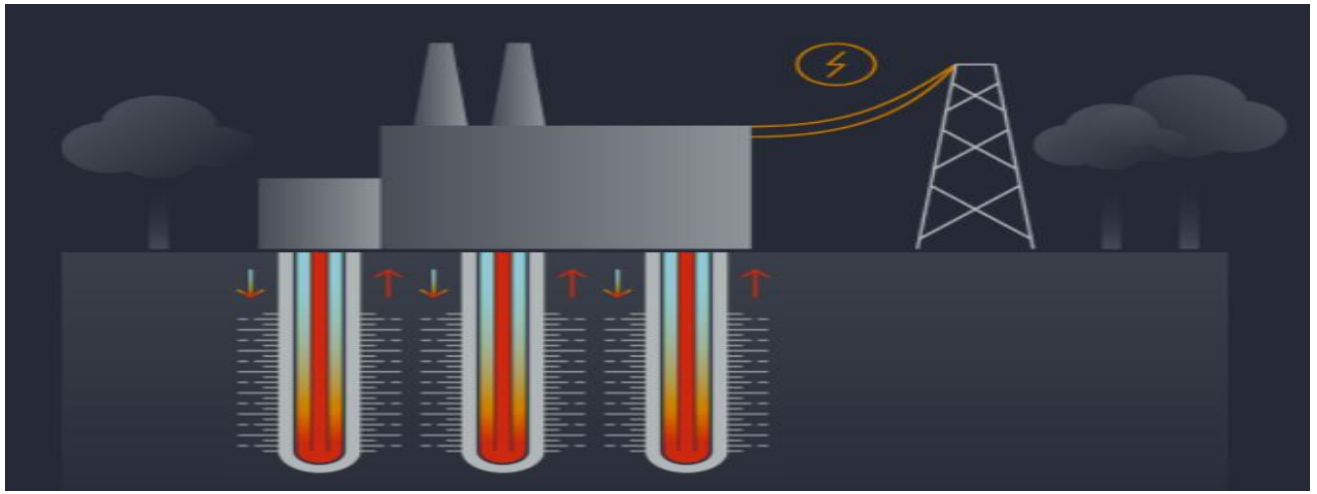


Diagram from McClure 2021

Eavor multi-lateral closed loop "radiator" design



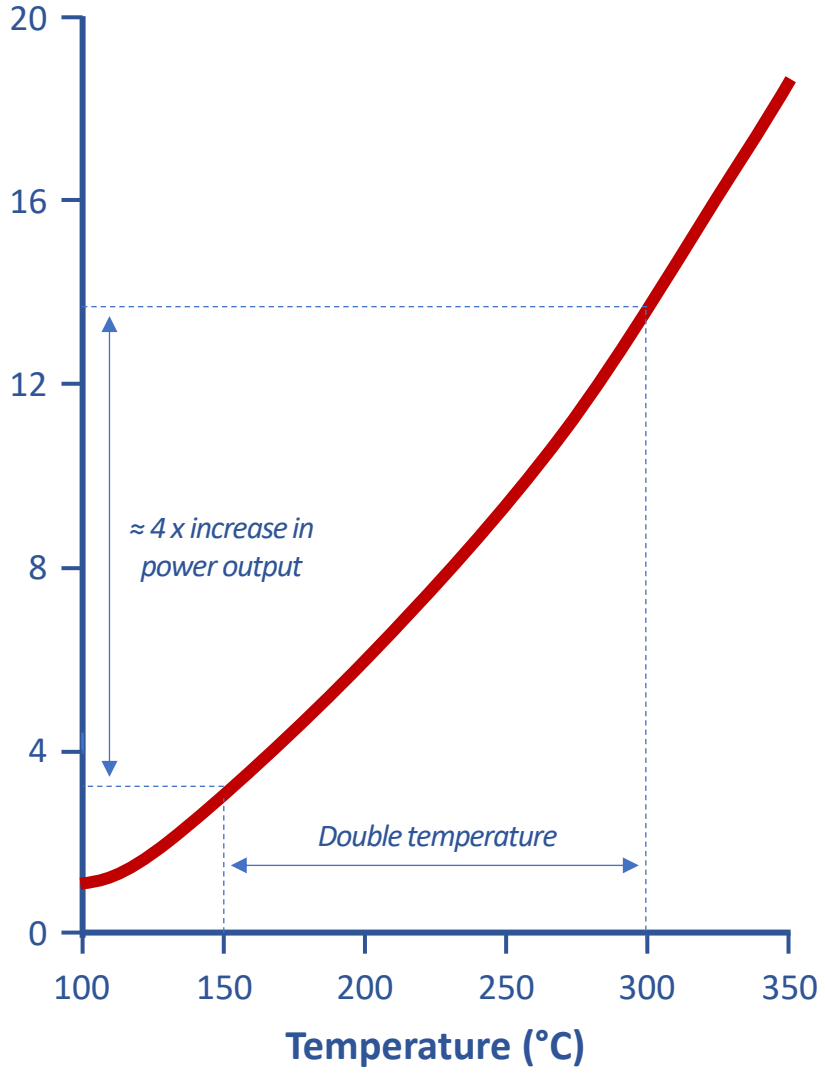
XGS enhanced-conductivity combined inj./prod. well



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

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

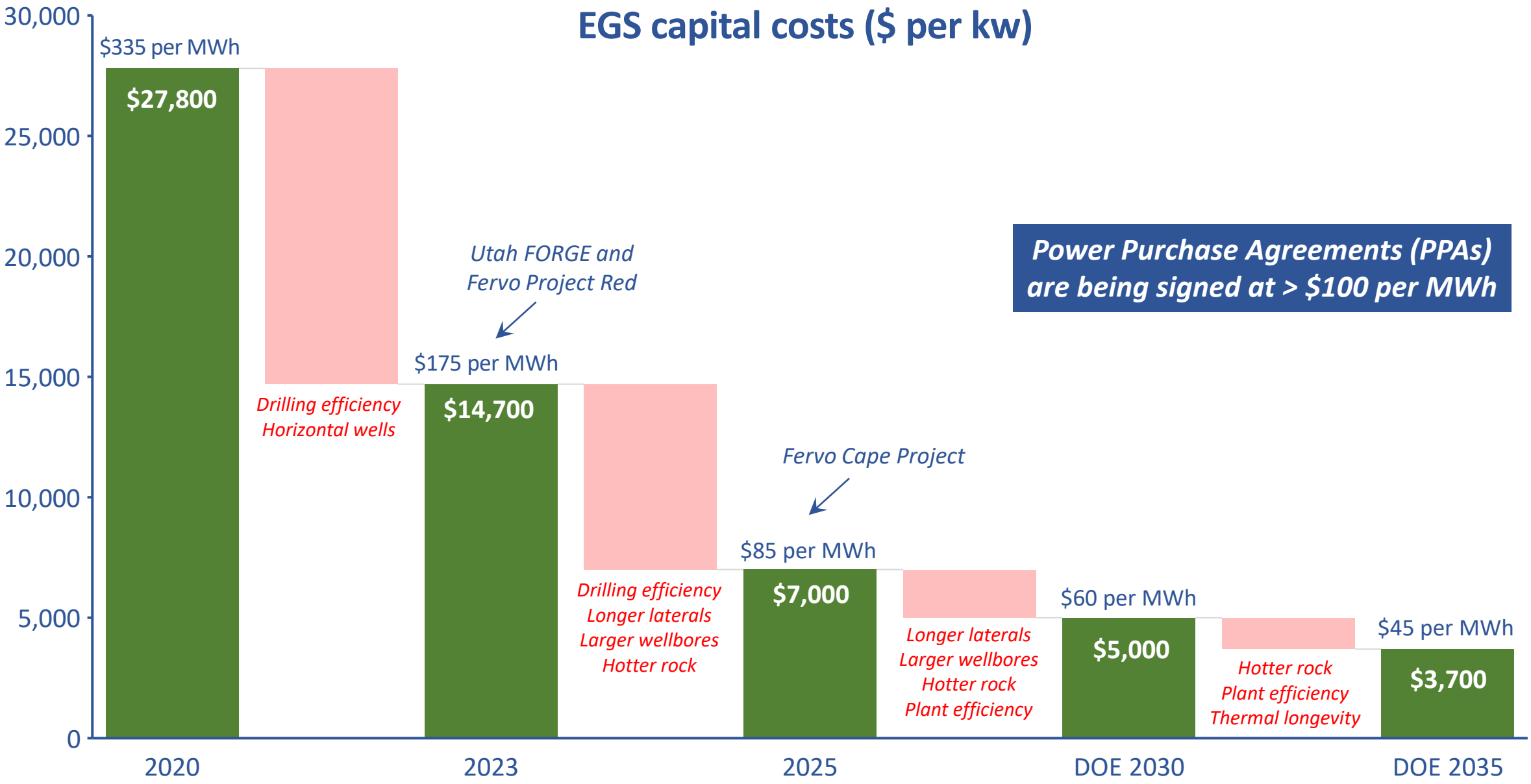
Power generation (MWe)[1]



[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

EGS capital costs have fallen precipitously over the past five years

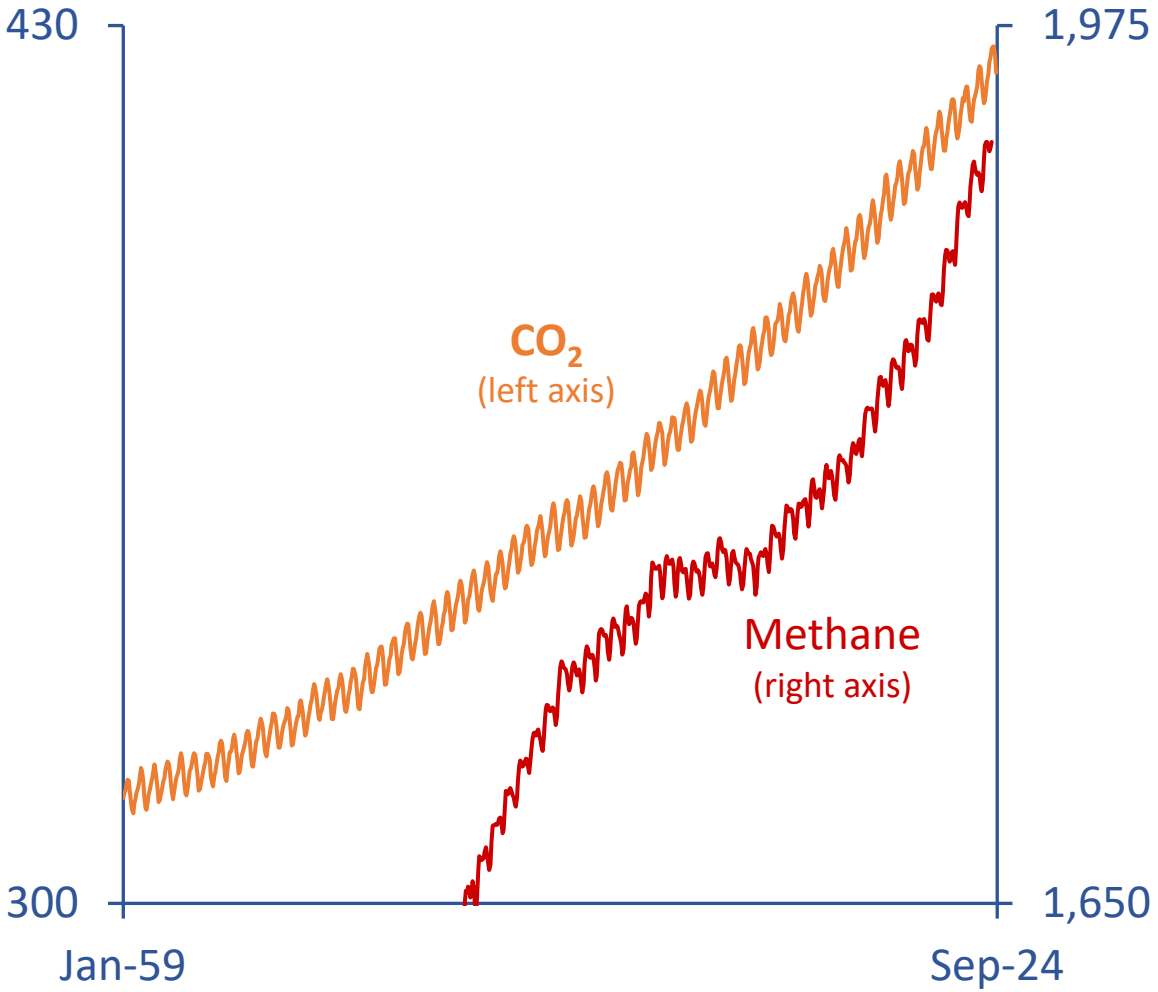


All $ per kw numbers from US DOE Next Generation Geothermal Liftoff report except 2025 number, which is estimated. All numbers are unsubsidized. $ per MWh numbers from DOE report or scaled therefrom.

Recent geothermal projects have received premium pricing due to climate change concerns

Atmospheric GHG levels are increasing rapidly

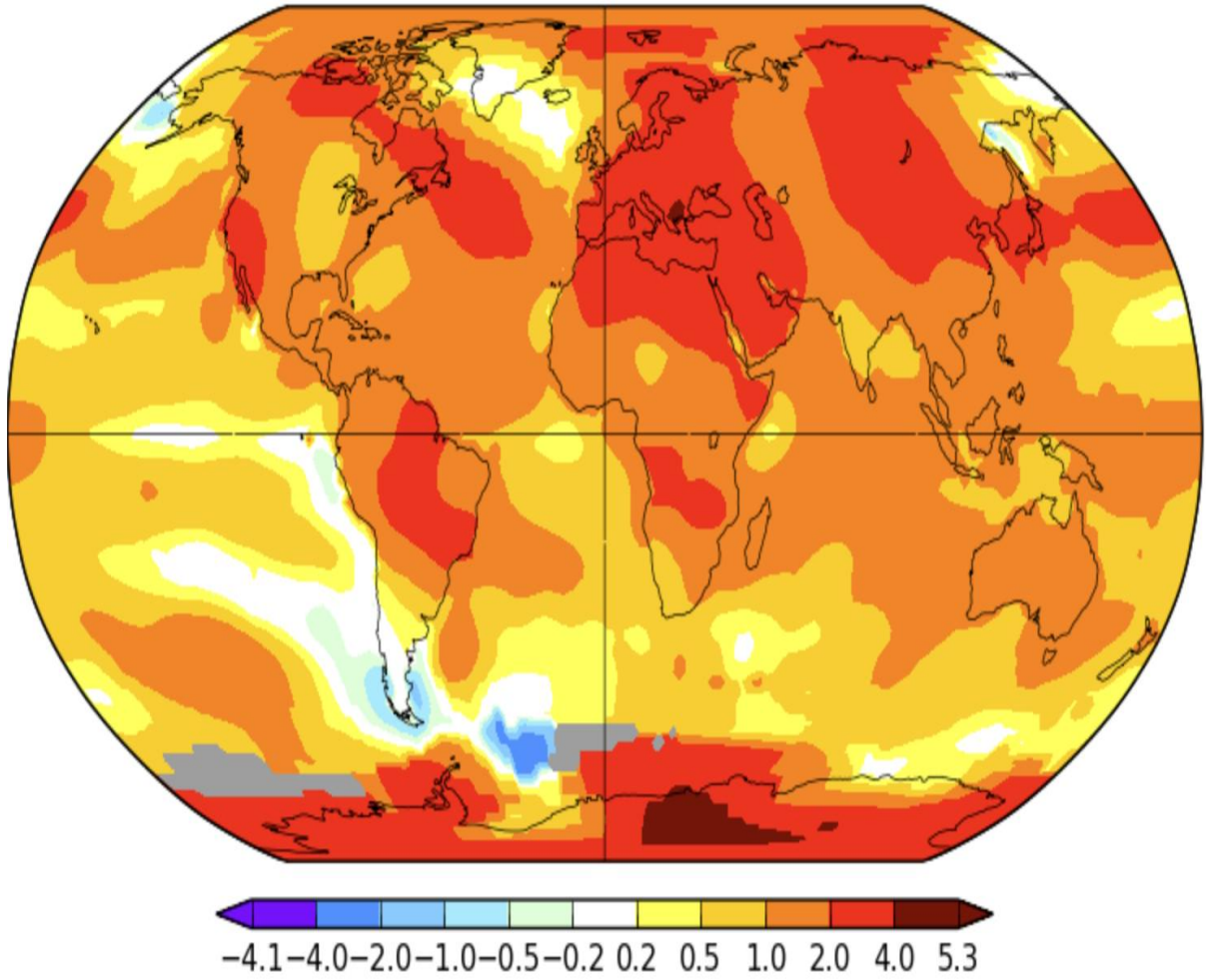
Monthly average atmospheric CO_2 and methane levels
(CO_2 ppm; Methane ppb)



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

Surface air temperatures are rising

Summer 2024 compared to 1951-1980 summer mean
(Delta degrees Celsius)



Source: NASA Goddard Institute for Space Studies; GISS Surface Temperature Analysis (v4); September 2024

In the near-term, premium pricing will likely be localized, but long-term…

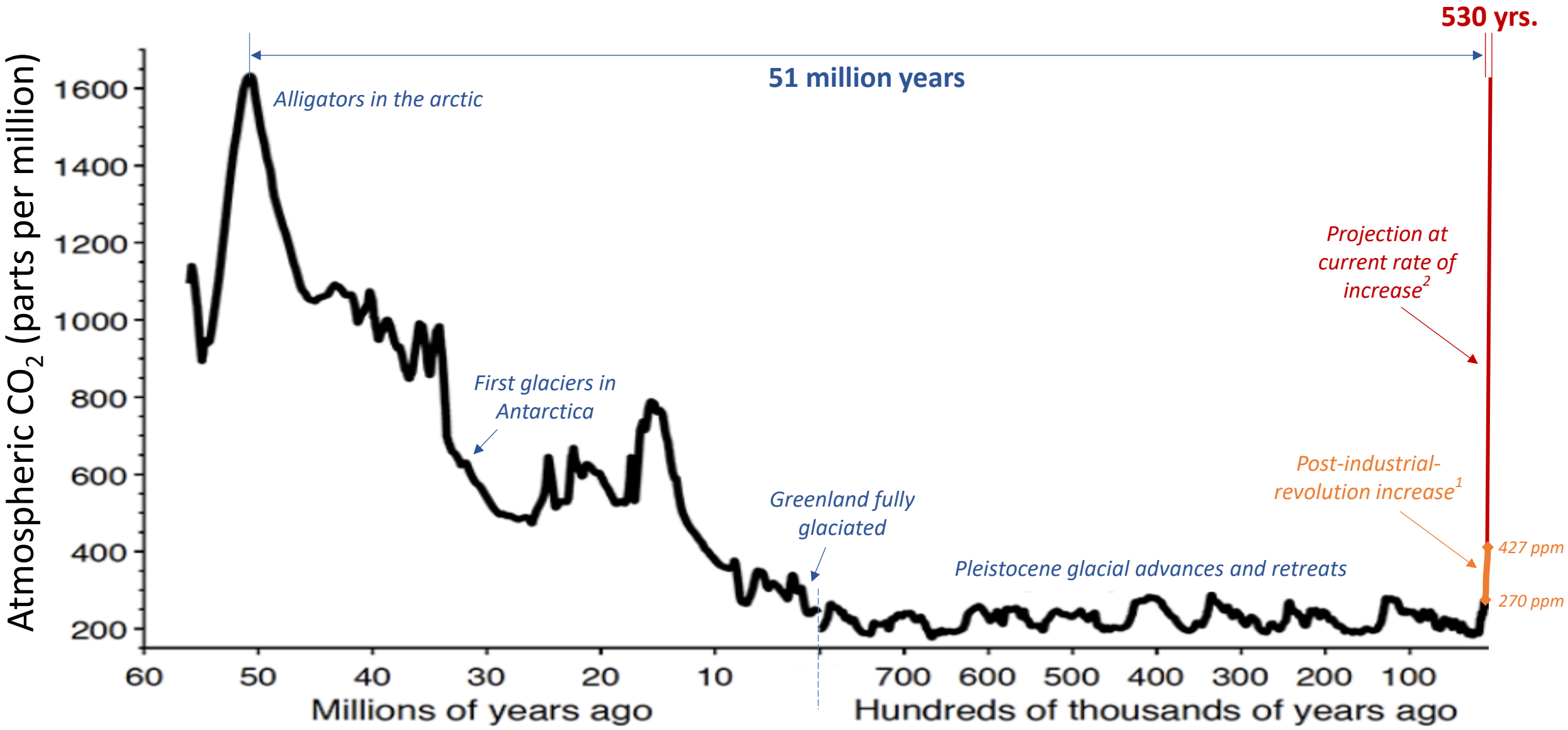
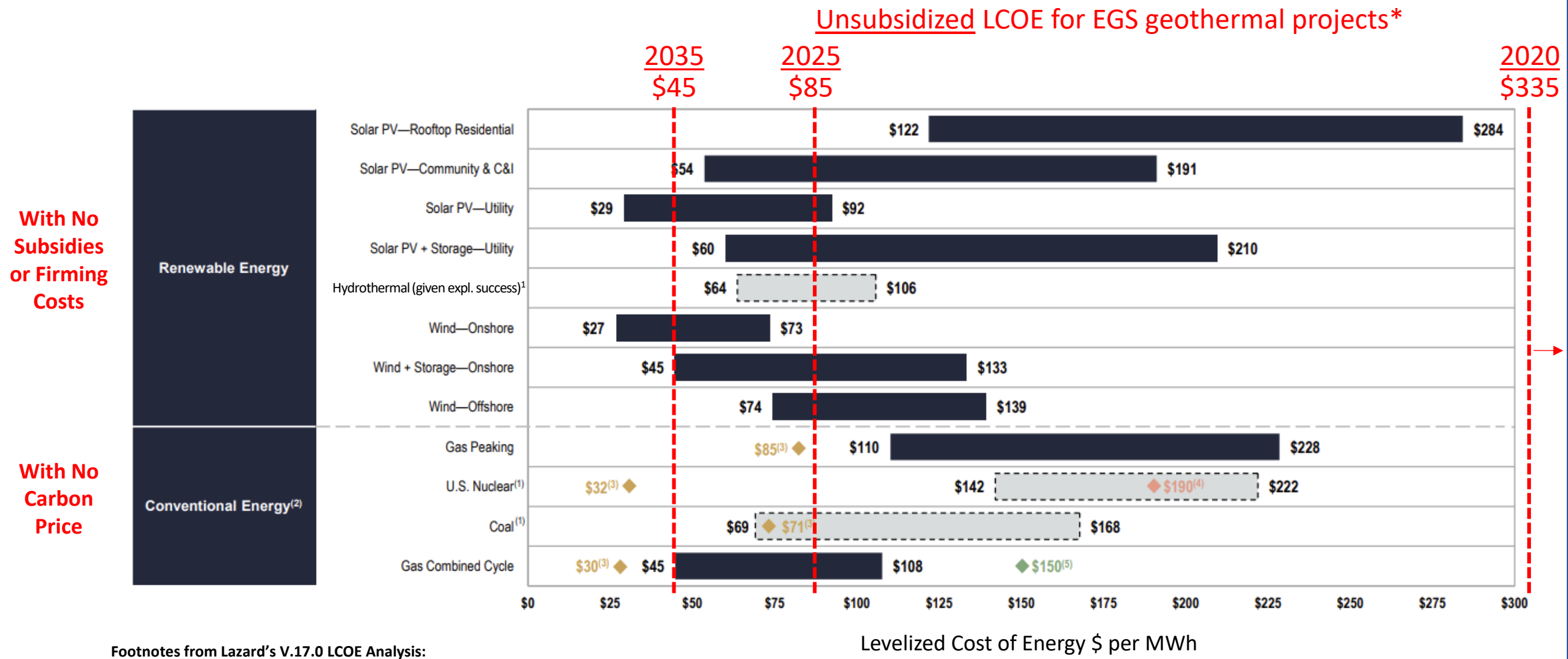


Diagram modified after Zhang, Y. and Liu, X., 2021. [1] From 270 ppm pre-industrial revolution to 427 ppm on April 17, 2025. [2] Rate of increase over the past 25 years has been 2.2 ppm per annum. PPM = Parts per million.

The world 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.

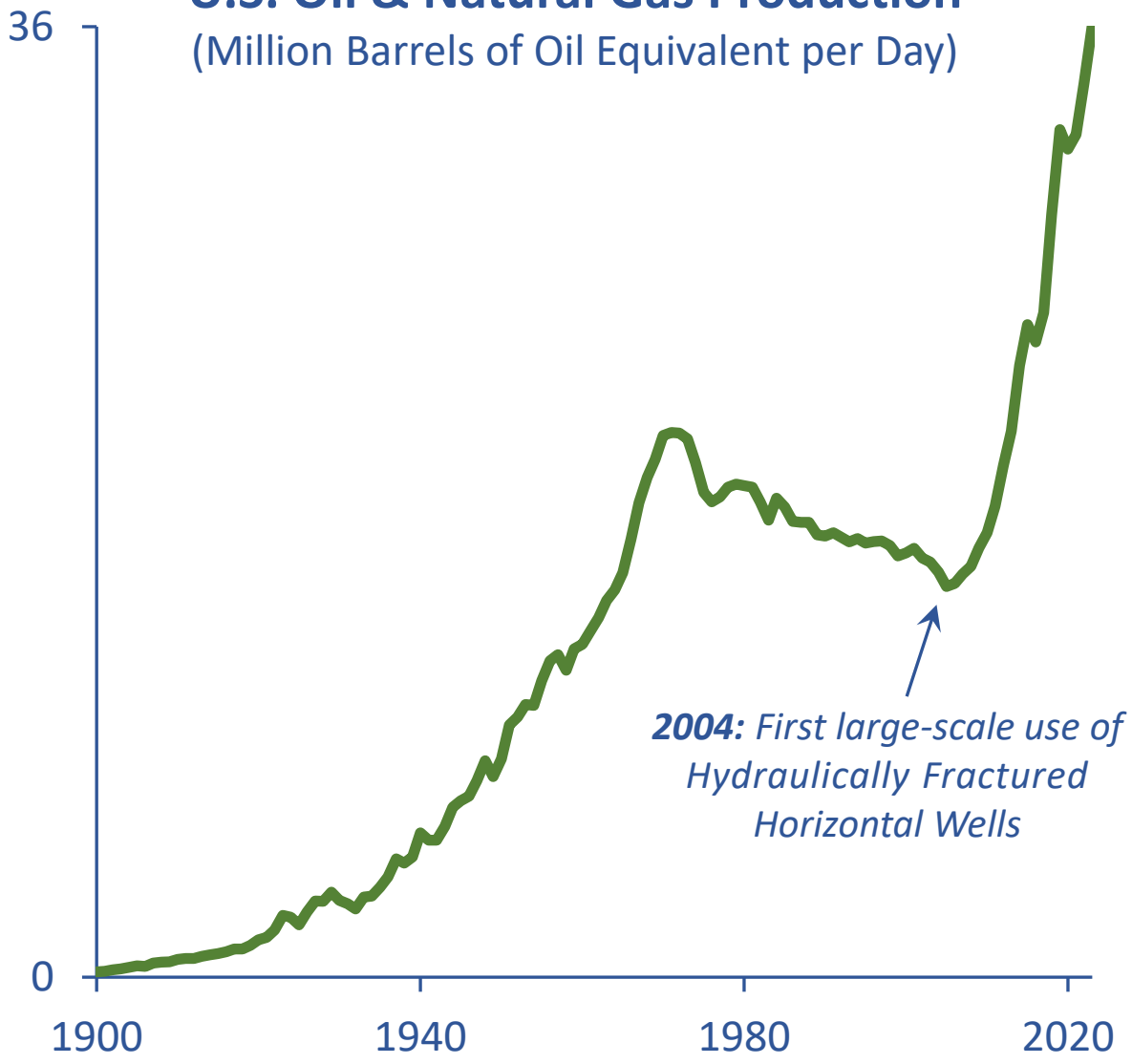
[1] Given the limited public or observable data available for new build geothermal, coal, and nuclear projects, the LCOE presented herein reflects Lazard's LCOE V.14.0 results adjusted for inflation. Coal LCOE does not include the cost for transportation & storage.

[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.

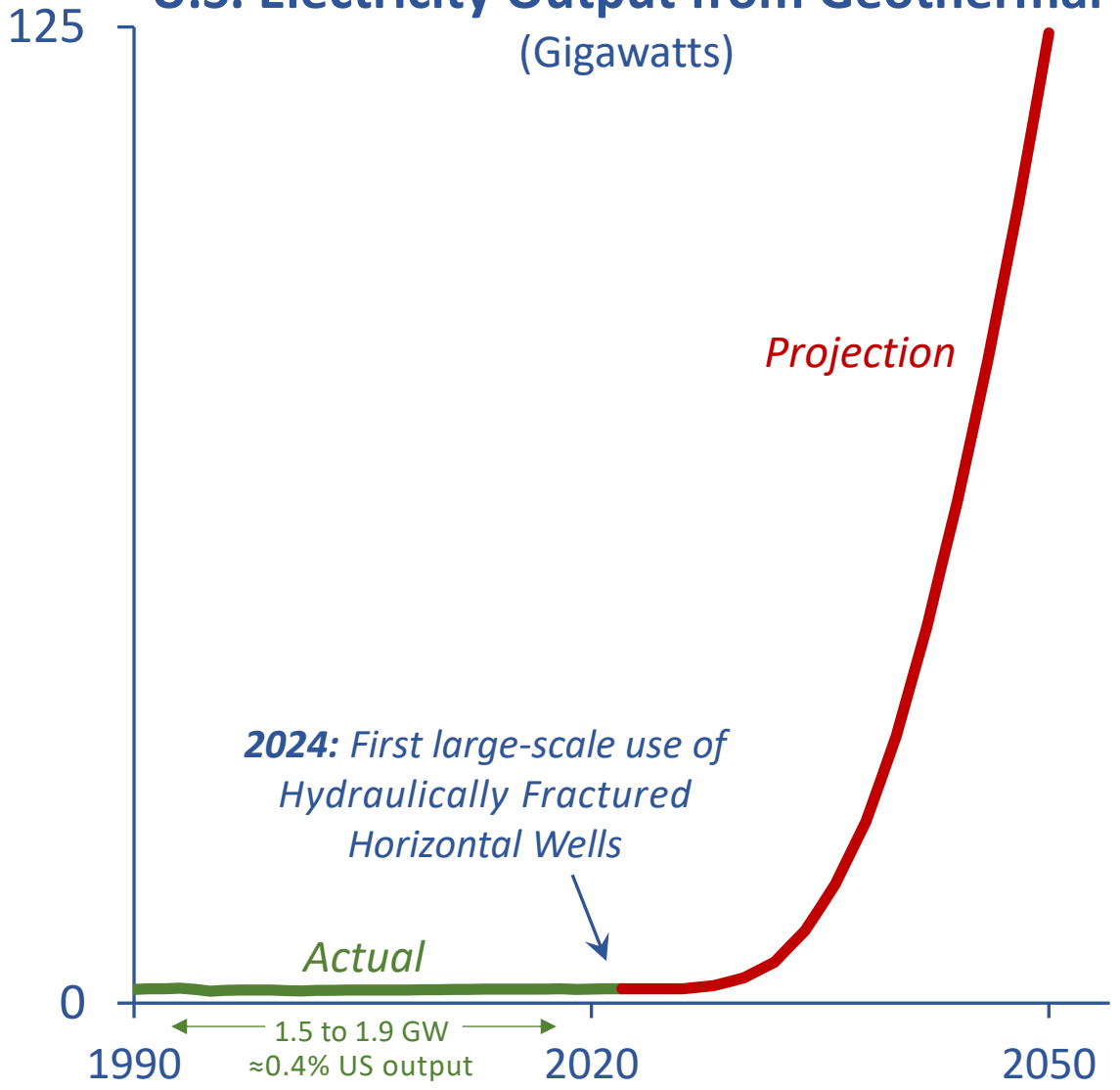
O&G technologies are poised to enable a geothermal power breakthrough like that achieved in U.S. unconventional O&G reservoirs

U.S. Oil & Natural Gas Production



Sources: U.S. EIA and Energy Institute websites

U.S. Electricity Output from Geothermal



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

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A copy of this slide deck can be downloaded at:

https://tidalwavetechnologies.com/

Picture from Fervo Energy's website

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- 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)
- Zhang, Y. and Liu, X., 2021, ***Ancient Deepsea Shells Reveal 66 Million Years Of Carbon Dioxide Levels*** (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)
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- 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)
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Other selected key references (page 2 of 2)

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- 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)