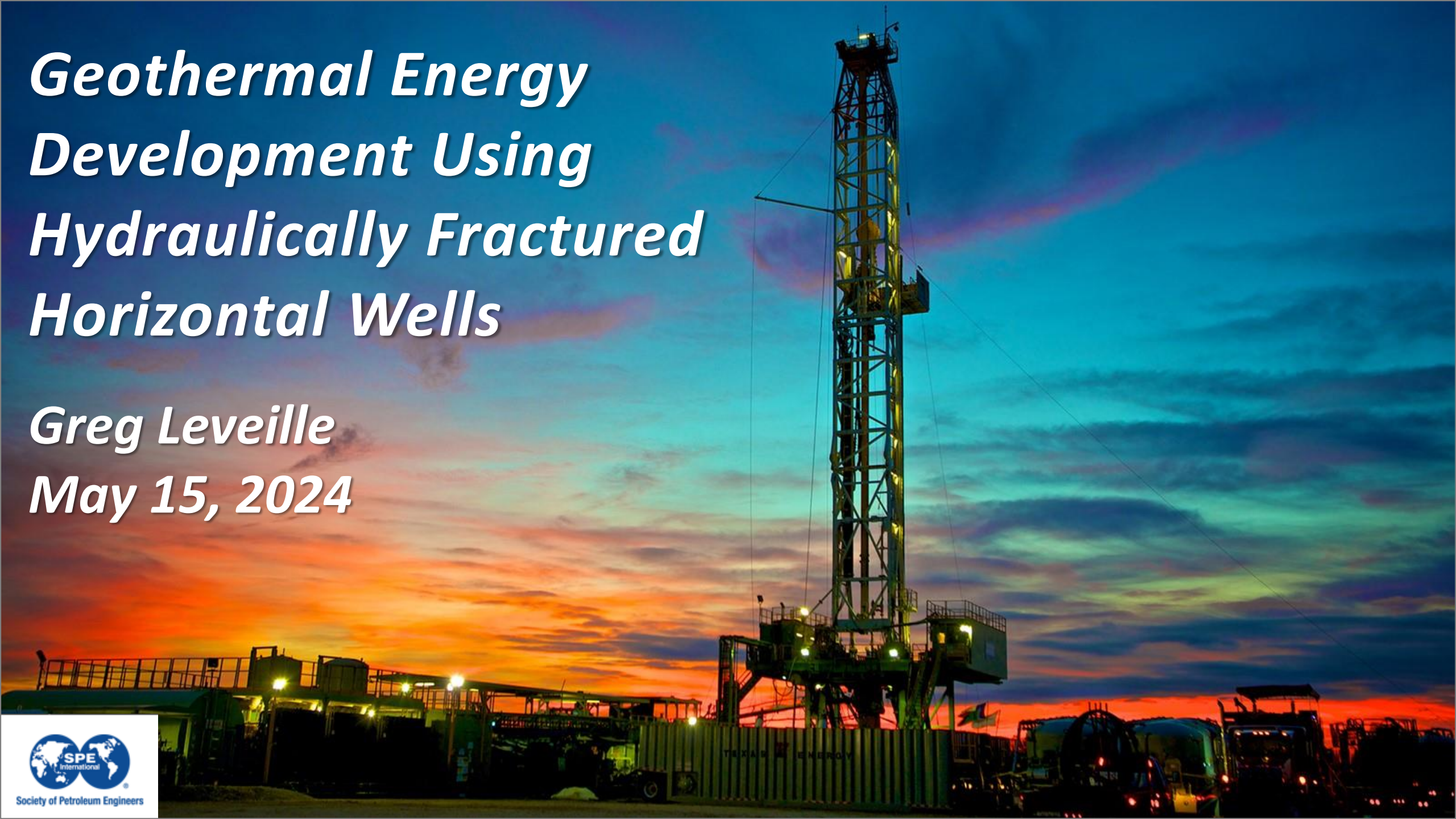


Geothermal Energy Development Using Hydraulically Fractured Horizontal Wells

*Greg Leveille
May 15, 2024*

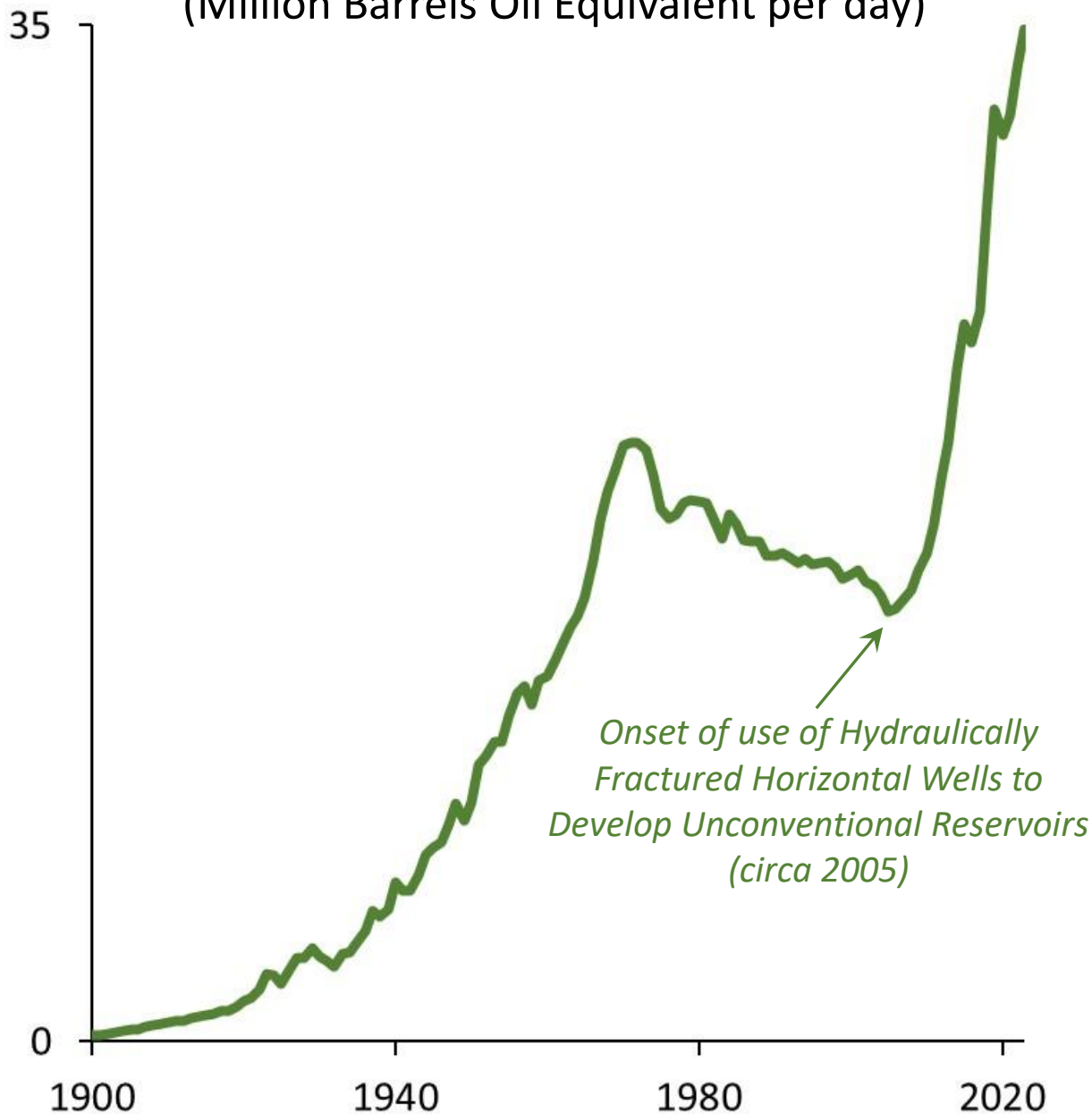


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U.S. Hydrocarbon Production

(Million Barrels Oil Equivalent per day)



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

The U.S. is the World's Largest O&G Producer:

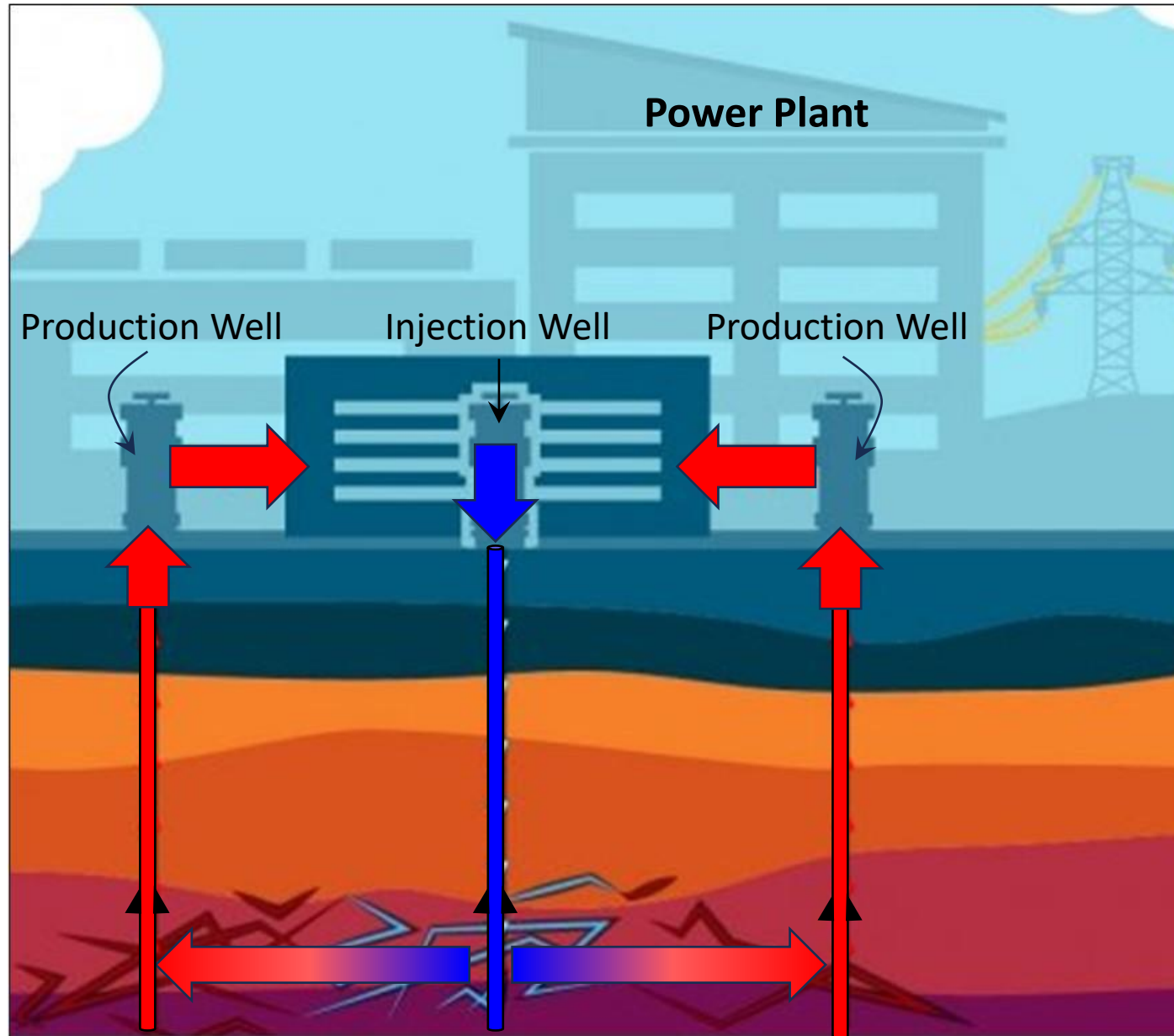
- Oil – Condensate – NGLs – Natural Gas
- > 22% of total global production
- Approaching OPEC's level of output
- ≈ 20 MMBOEPD > Saudi Arabia's output
- ≈ 15 MMBOEPD > Russia's output

America's Unconventional Revolution has:

- Enhanced U.S. energy security
- Invigorated economic growth
- Shrunk America's trade deficit
- Reduced GHG emissions

Hydraulically fractured horizontal wells are what enabled these results to be achieved

Generating Electricity at Scale from Geothermal Resources



Modified diagram from U.S. DOE website

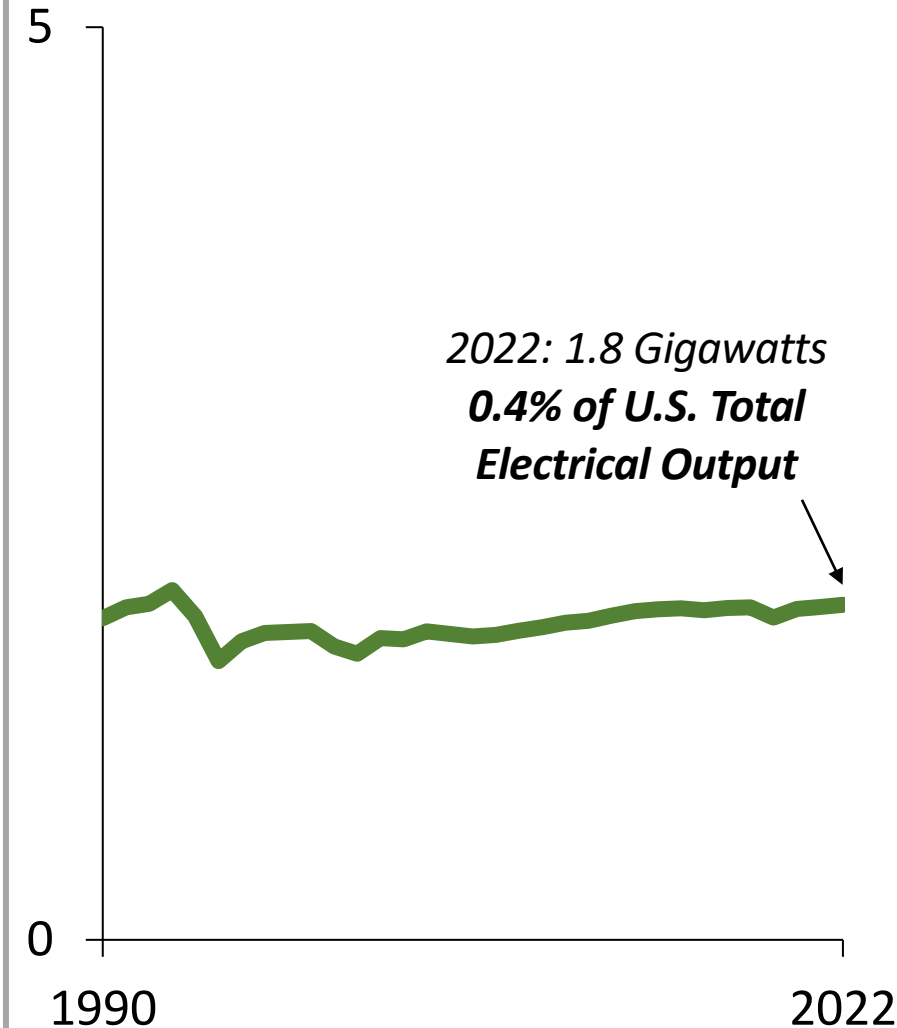
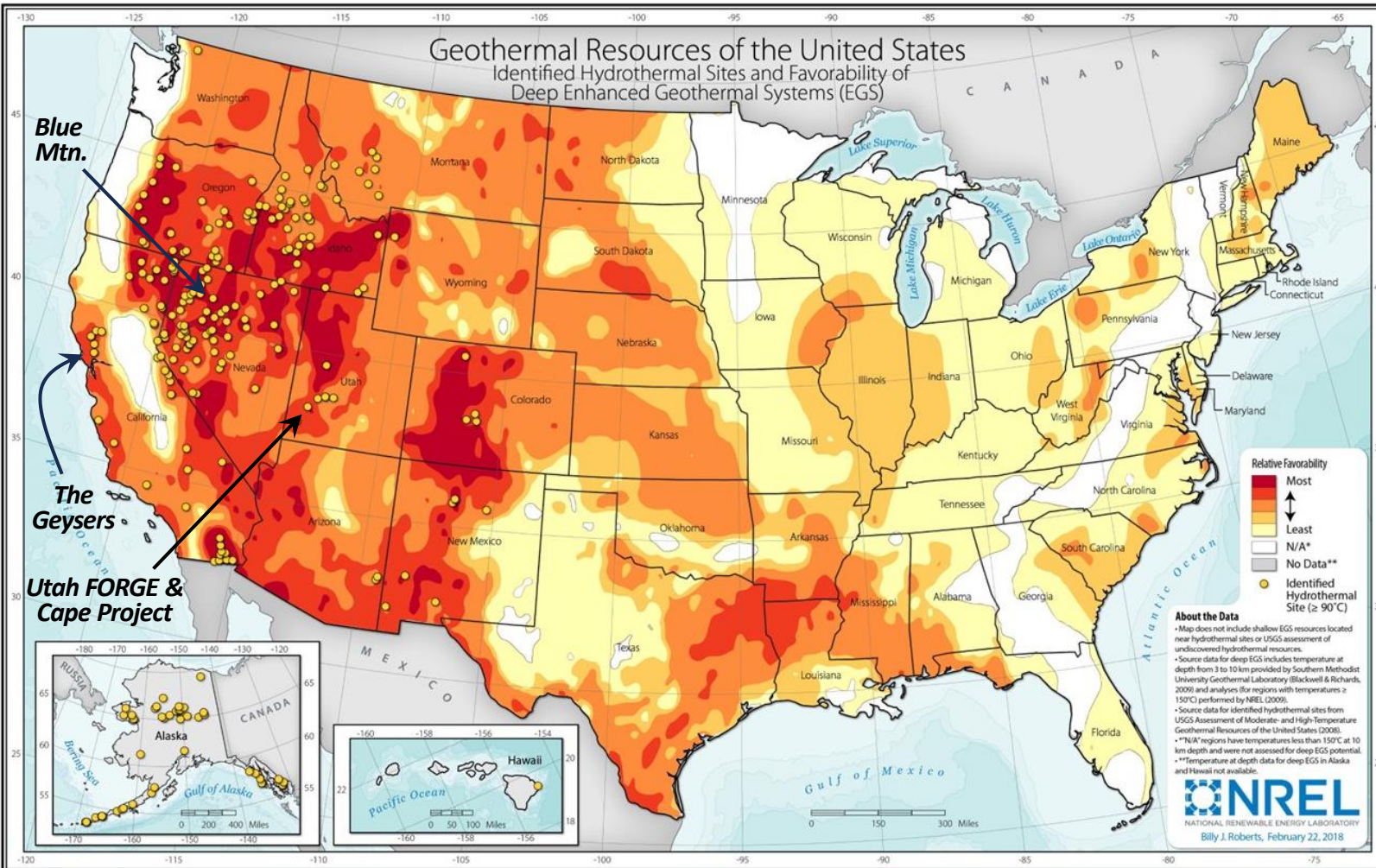
Key Subsurface Components

- Hot Rocks ($>350^{\circ}\text{F}$)
- Large Fracture Surface Area*
- High Fluid Flow Rate

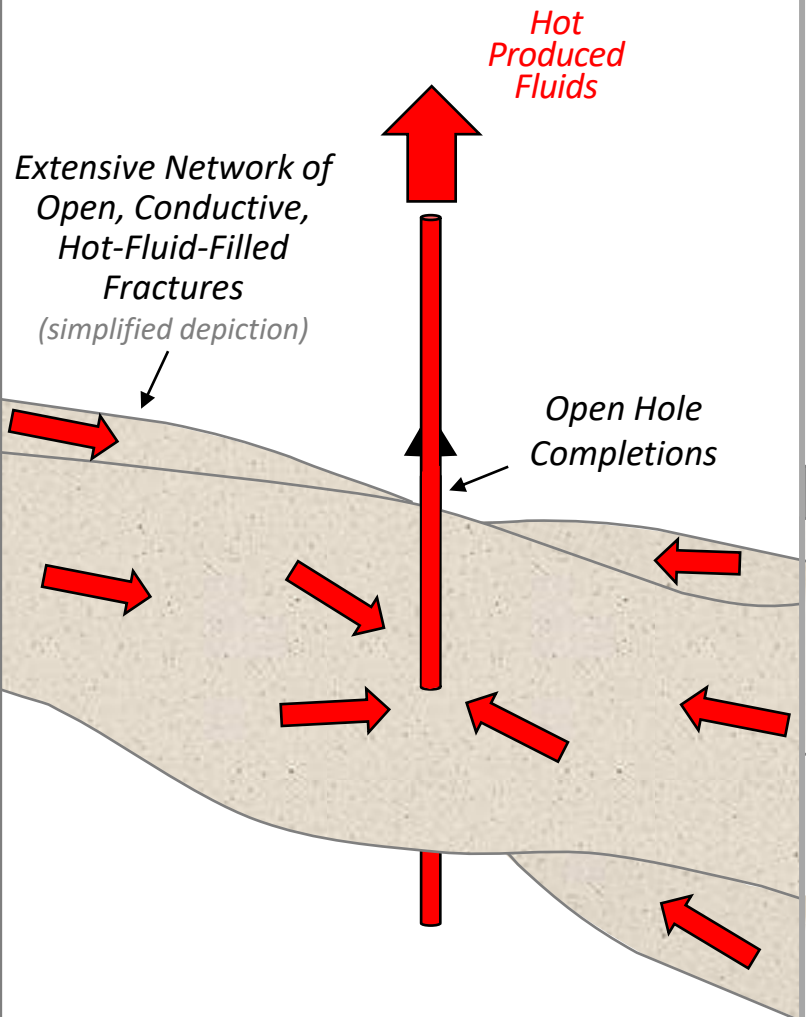
* Some companies are also pursuing closed-loop systems and flow through sedimentary rocks with high porosity and permeability.

Geothermal Resources Represent a Nearly Inexhaustible Supply of Energy

But U.S. Electricity Output from Geothermal is Negligible



Hydrothermal Systems



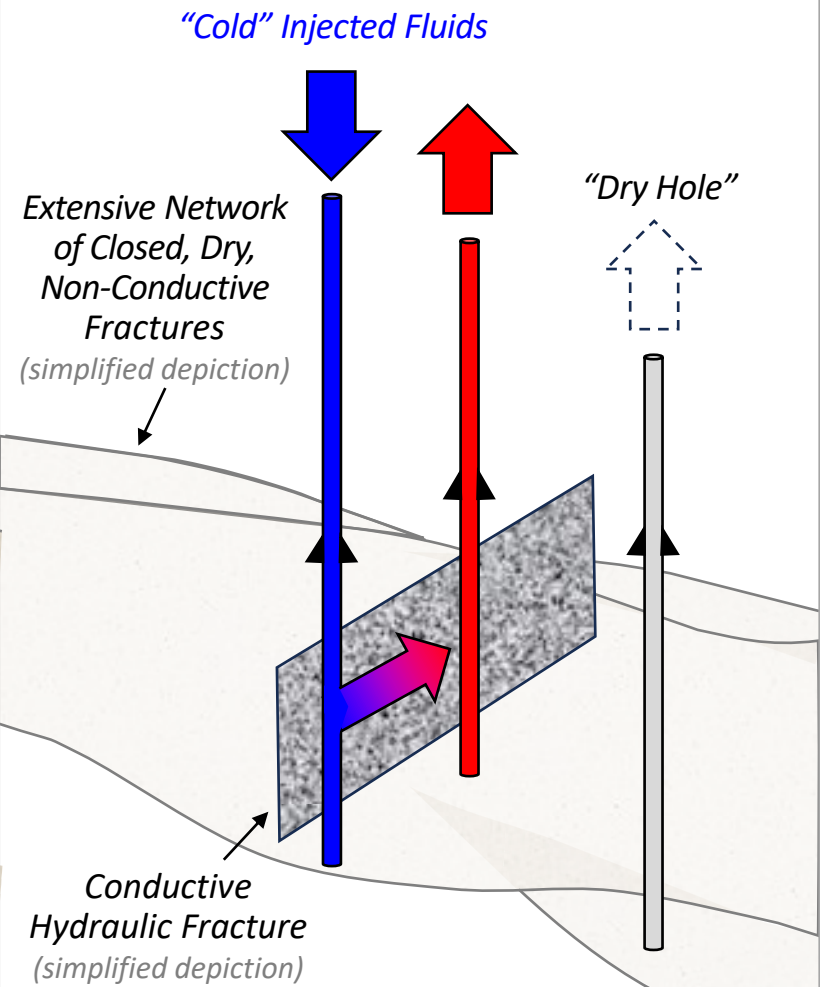
Cross section views; not to scale

EXCEEDINGLY RARE

Example: The Geysers, California

Enhanced Geothermal Systems (EGS)

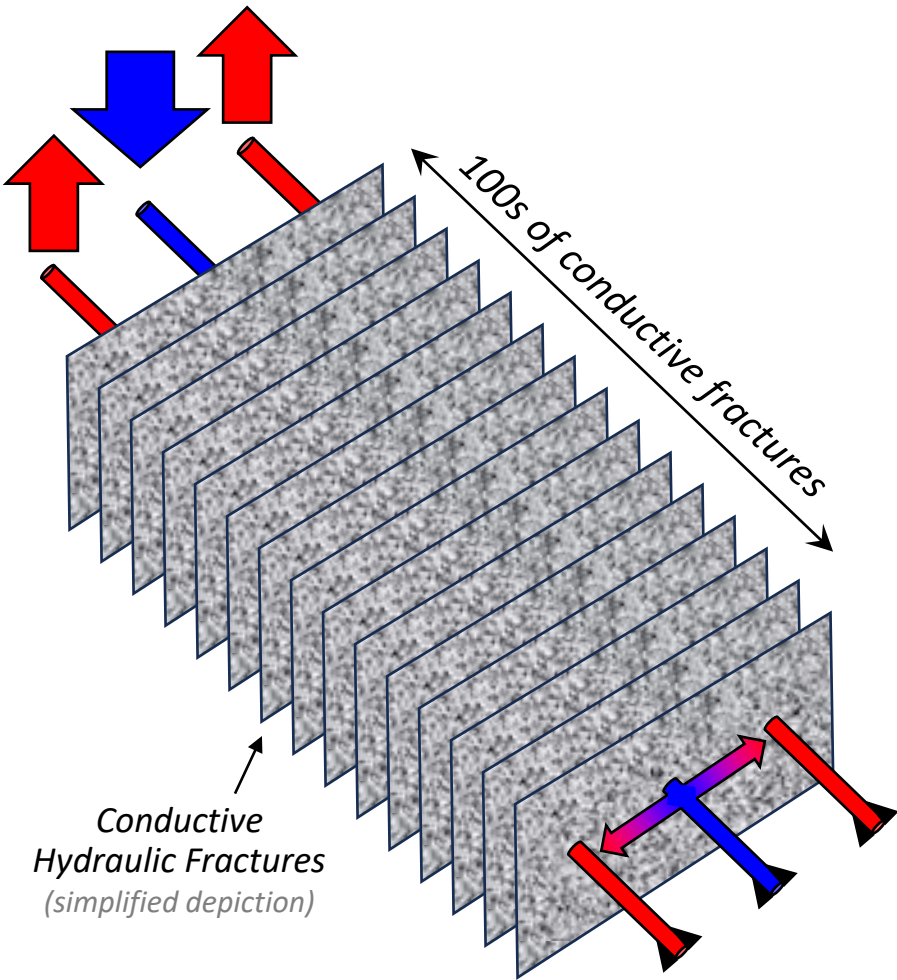
Vertical Wells



EXCEEDINGLY DISAPPOINTING

Example: Most EGS projects 1970-2023

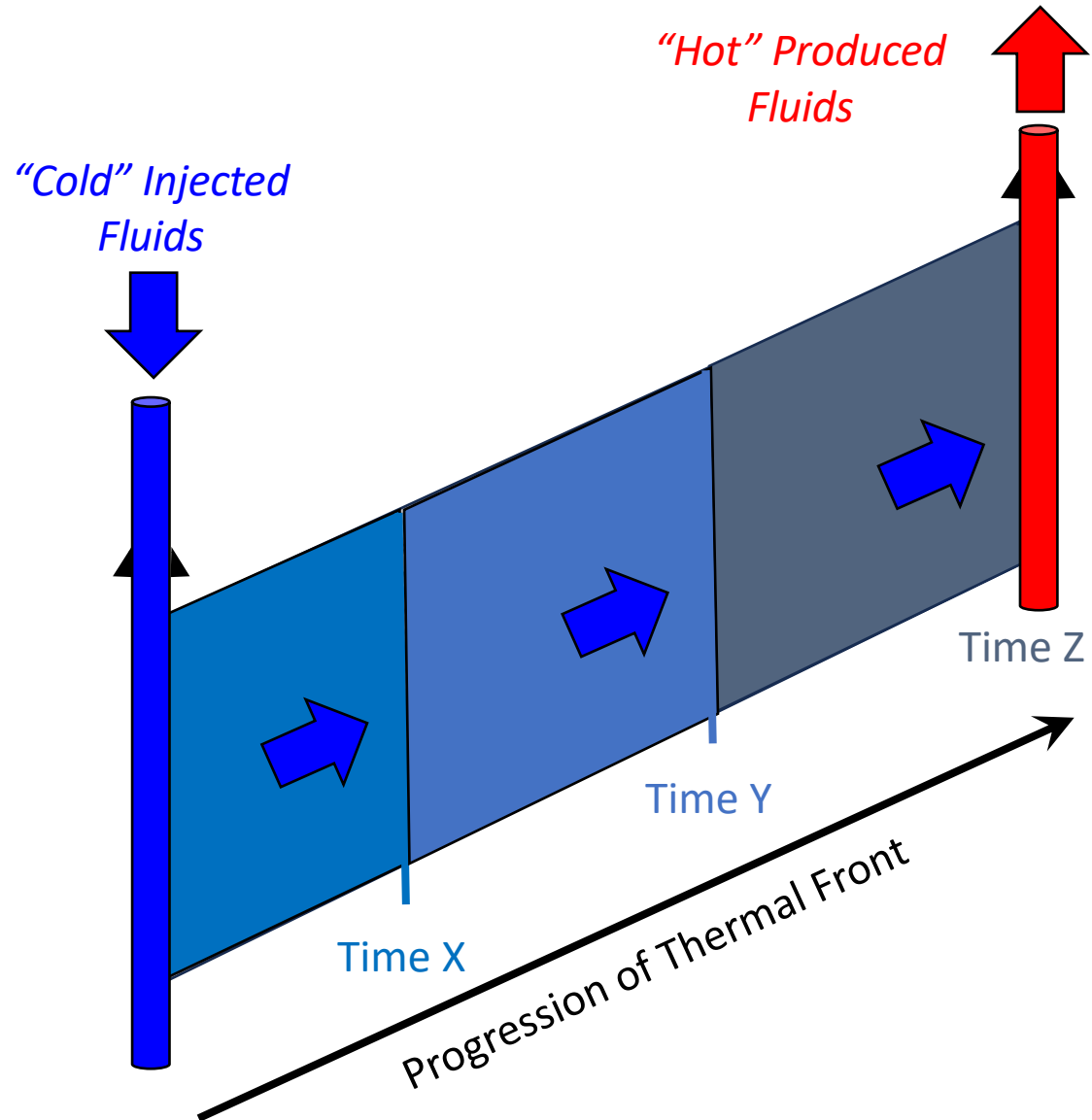
Horizontal Wells



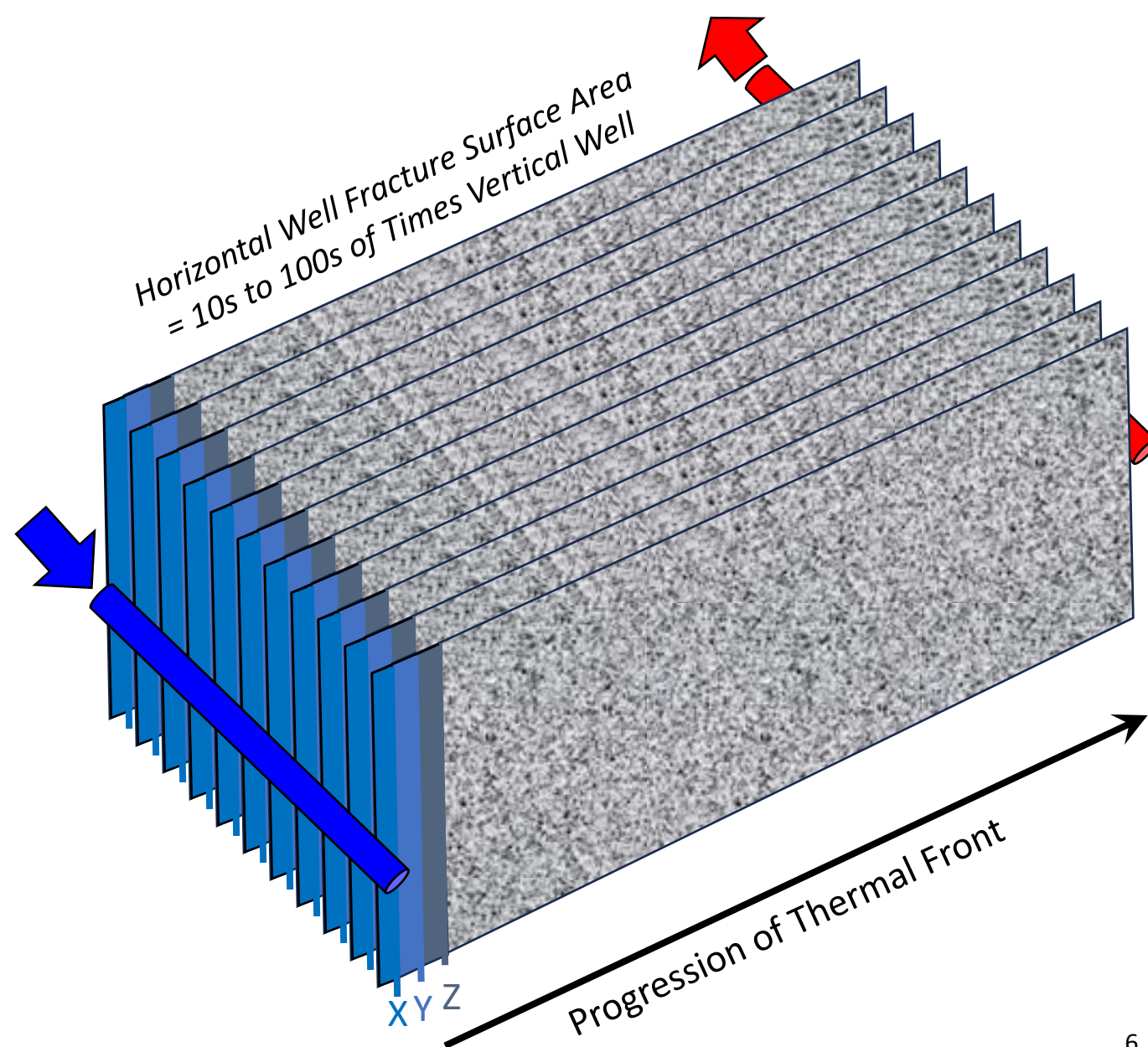
THE RIGHT TOOL FOR THE JOB

Examples: Fervo and Utah FORGE

EGS with Vertical Wells



EGS with Horizontal Wells



Fervo Blue Mountain Nevada Demonstration Project

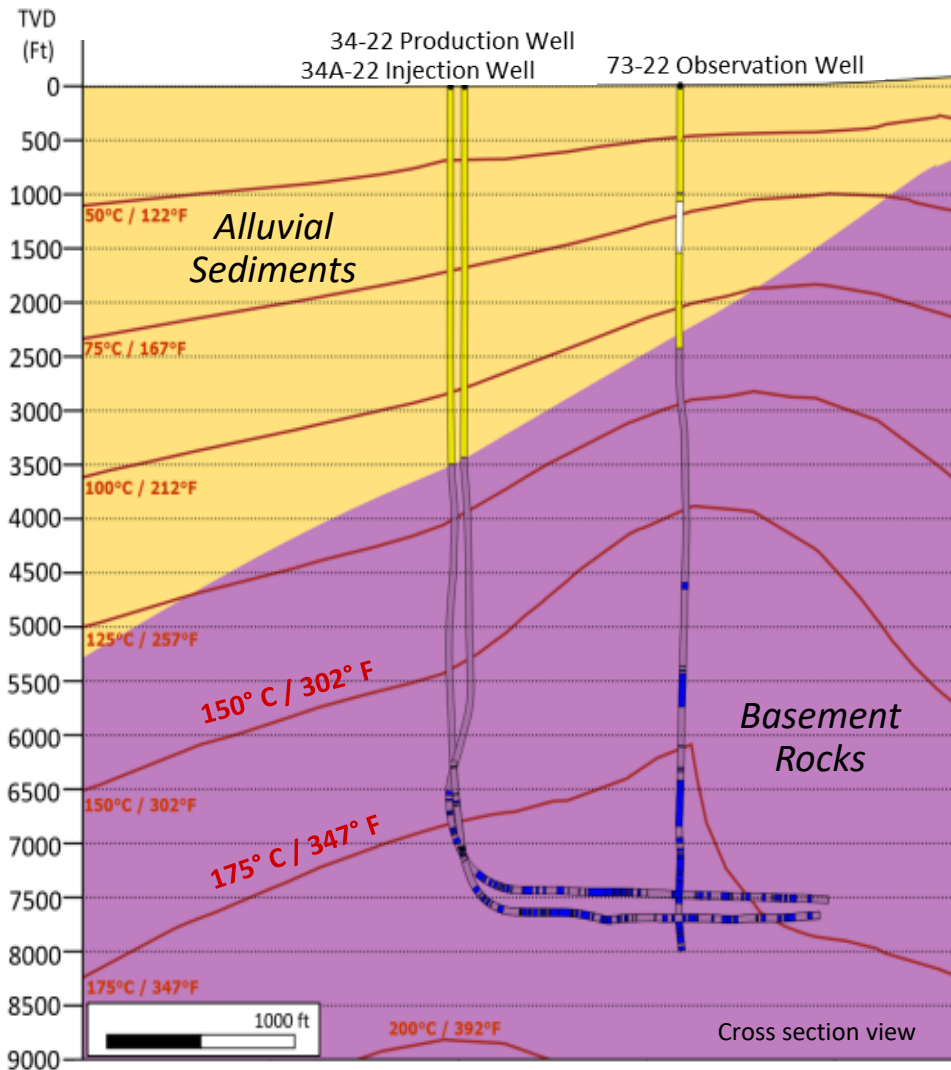


Diagram taken from 2023 paper by Jack Norbeck and Tim Latimer

Fervo & Utah FORGE Accomplishments to Date¹

- Ability to drill horizontally in hot, hard rocks
- Drilling time: from ≈ 150 days to < 25 days²
- Viability of plug & perf completions at $> 400^\circ \text{F}$
- Establishment of connectivity between horizontal injectors and producers
- Record setting EGS production rates
- Consistent placement of injected fluid across $> 3,000'$ of horizontal section
- Numerous sources suggest thermal longevity greater than a decade in duration is achievable

¹ Includes results from both Fervo's Blue Mountain Nevada demonstration project and their Cape Project commercial development in SW Utah

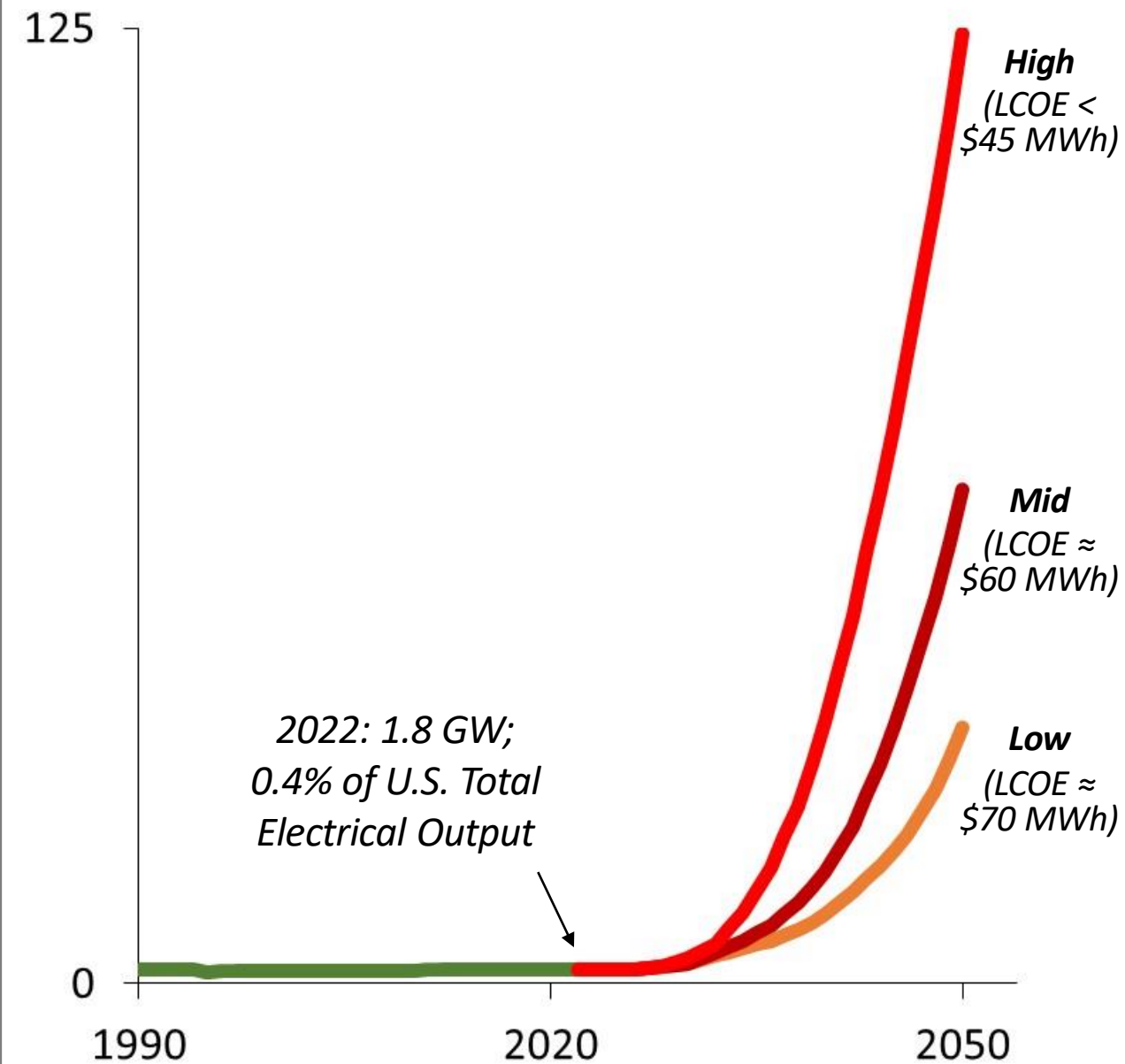
² For a 10,000' MD well drilled predominantly through hot, hard, abrasive basement rocks

O&G Industry Technologies will be Critical for the Success of EGS



U.S. Electricity Output from Geothermal

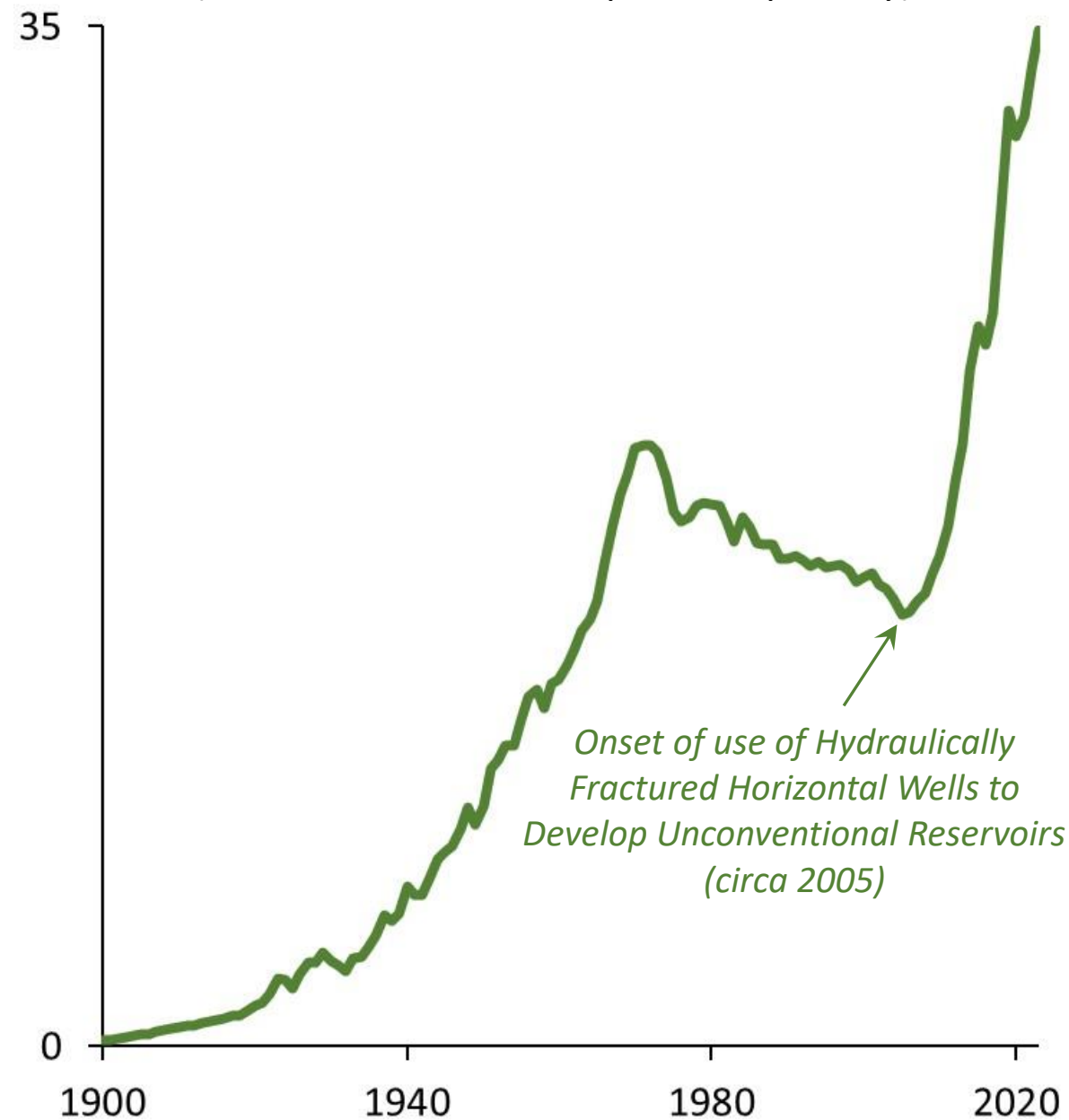
(Gigawatts)



Sources: U.S. EIA for 1990 to 2022; Author projections from 2023 to 2050; Total U.S. Consumption 2022 = 482 GW; 2050 DOE Estimate = 630 GW

U.S. Oil & Natural Gas Production

(Million Barrels of Oil Equivalent per Day)



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

The Need for Abundant, Affordable, Clean Firm Electricity is Skyrocketing

Microsoft will be carbon negative by 2030



Microsoft and Open AI to commission \$100 billion “Stargate” artificial intelligence supercomputer by 2028



Operating on 24/7 Carbon-Free Energy by 2030.

With new geothermal project, it’s full steam ahead for 24/7 carbon-free energy

Amazon to reach net-zero emissions by 2040



The Dawn of a New Industrial Revolution

Key Take-Away Messages

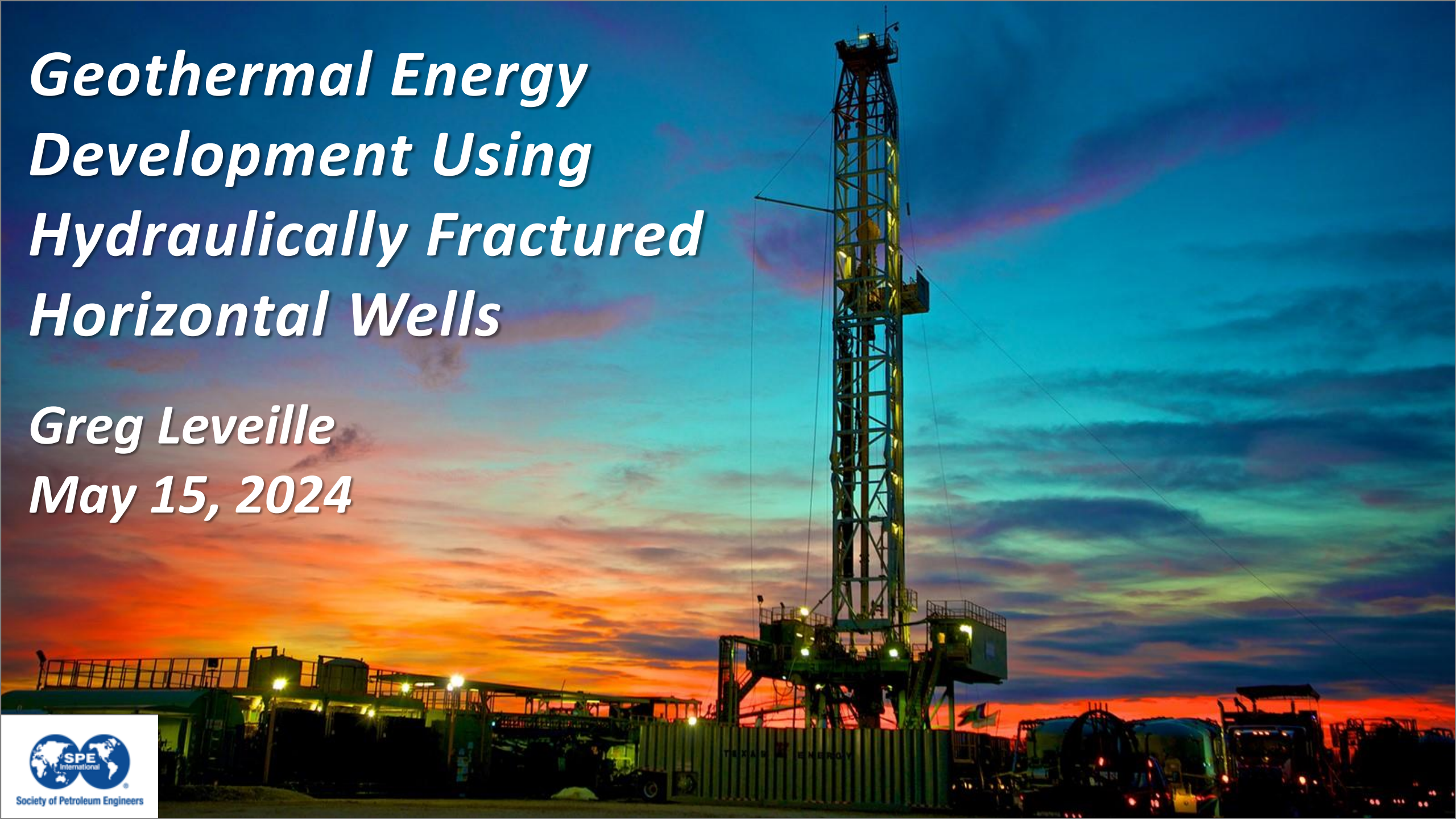
- The use of hydraulically fractured horizontal wells has more than doubled U.S. hydrocarbon output since 2005
- This has produced enormous benefits for the U.S. O&G industry, America, and humankind
- The same skills, equipment, and people who achieved this result will be needed to optimize EGS development
- By delivering dramatic improvements in EGS performance, the O&G industry will once again positively impact our nation's and our planet's future

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Society of Petroleum Engineers



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- Mark McClure, 2023, *Fervo Energy's 'Project Red' Results are a Historical Breakthrough for Geothermal – What Comes Next* ([LINK](#))
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- Google and Fervo Energy, 2023, *A first-of-its-kind geothermal project is now operational* ([LINK](#))
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- 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](#))