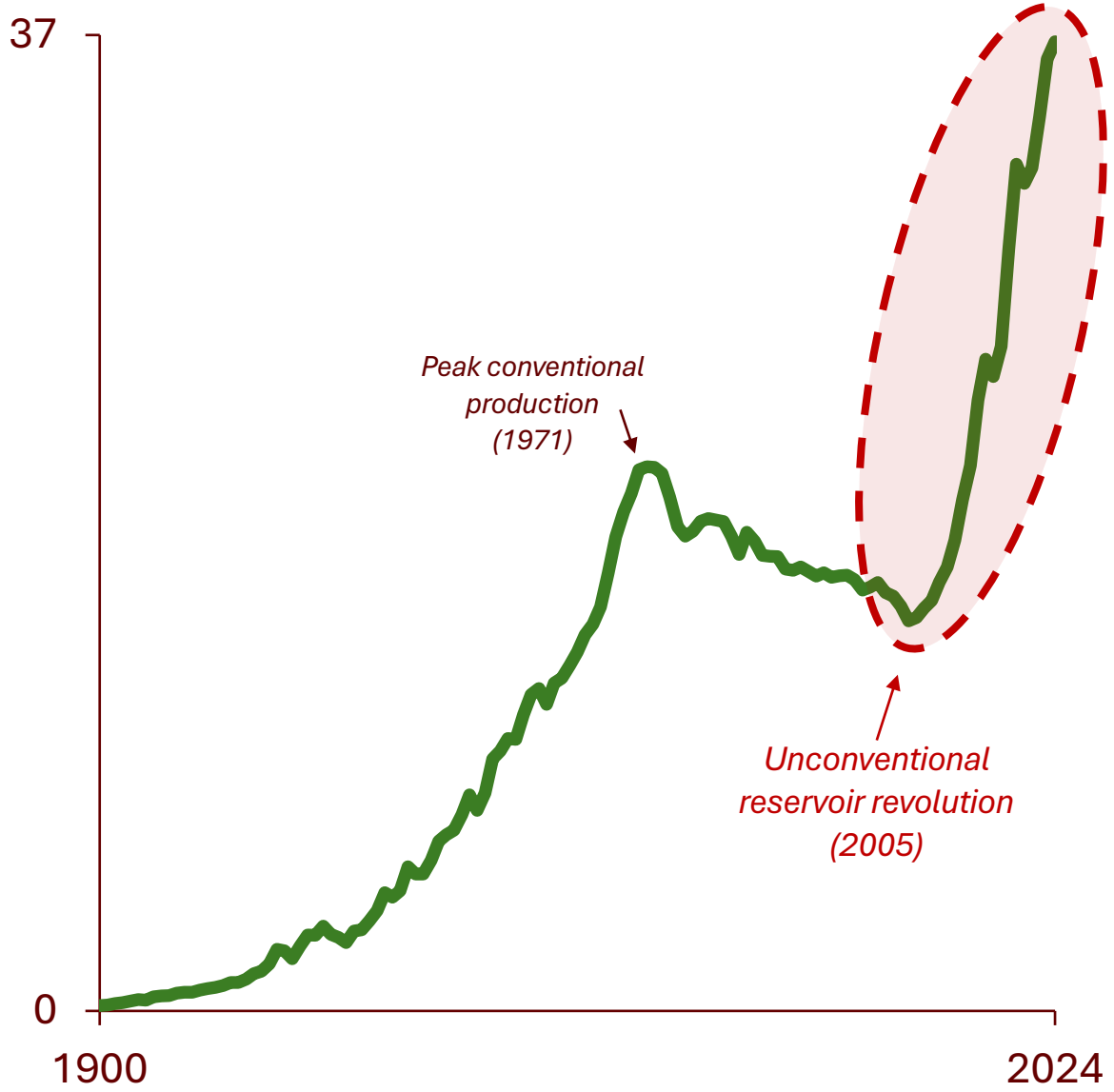
The importance of collaboration for delivering rapid growth in geothermal energy production

Geothermal Rising Conference
October 27, 2025
Greg Leveille

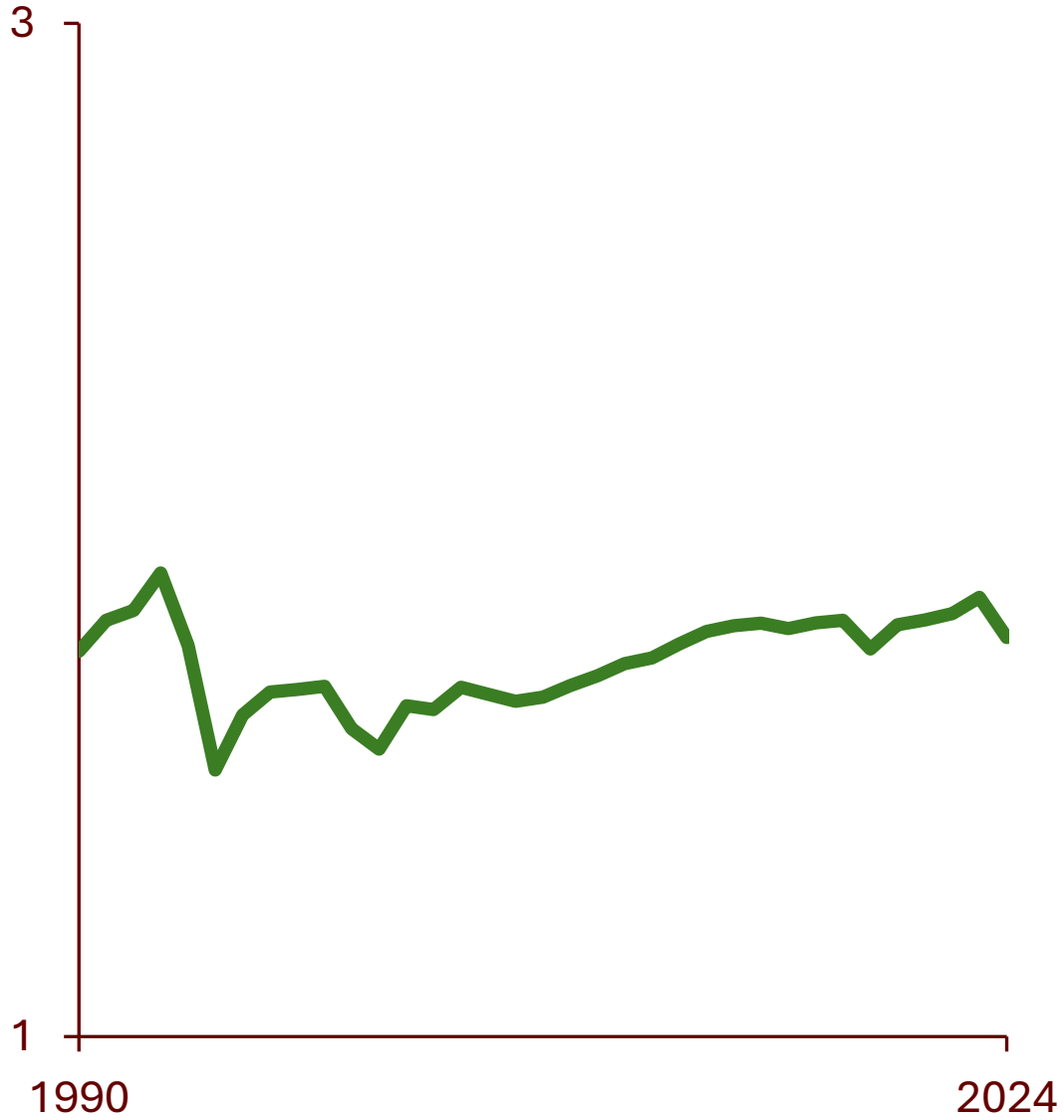
U.S. oil and gas production / U.S. geothermal power output

Million barrels oil equivalent per day



Sources: U.S. EIA and Energy Institute websites; O&G = oil and gas (including condensate and NGLs); MMBOE = million BO equivalent

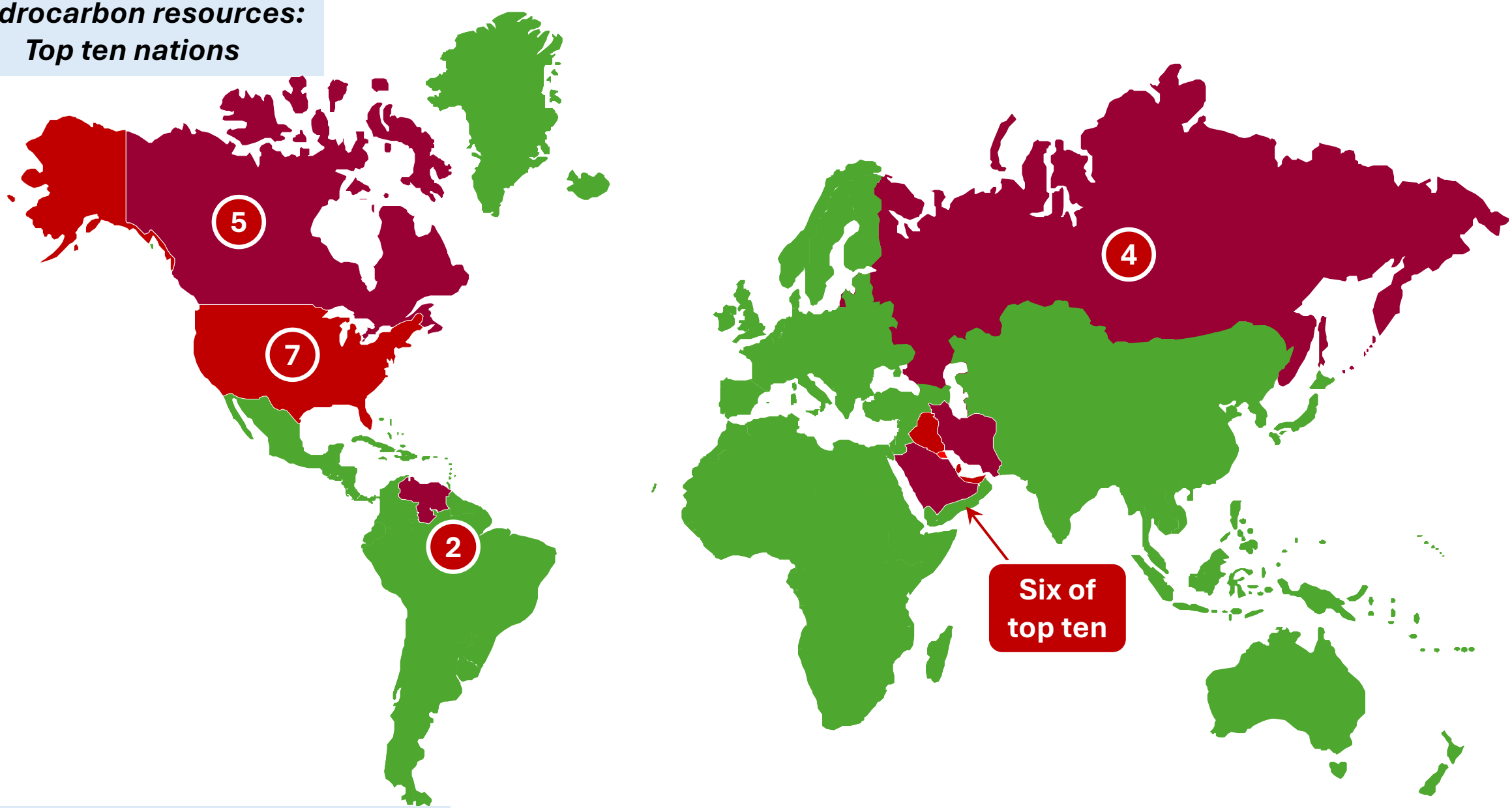
Gigawatts instantaneous generation



Sources: U.S. EIA's website; average instantaneous generation = annual gigawatt hours ÷ 8,760 (i.e., 24 × 365)

America's O&G industry's competitive advantage – It's not the rocks!

Hydrocarbon resources:
Top ten nations

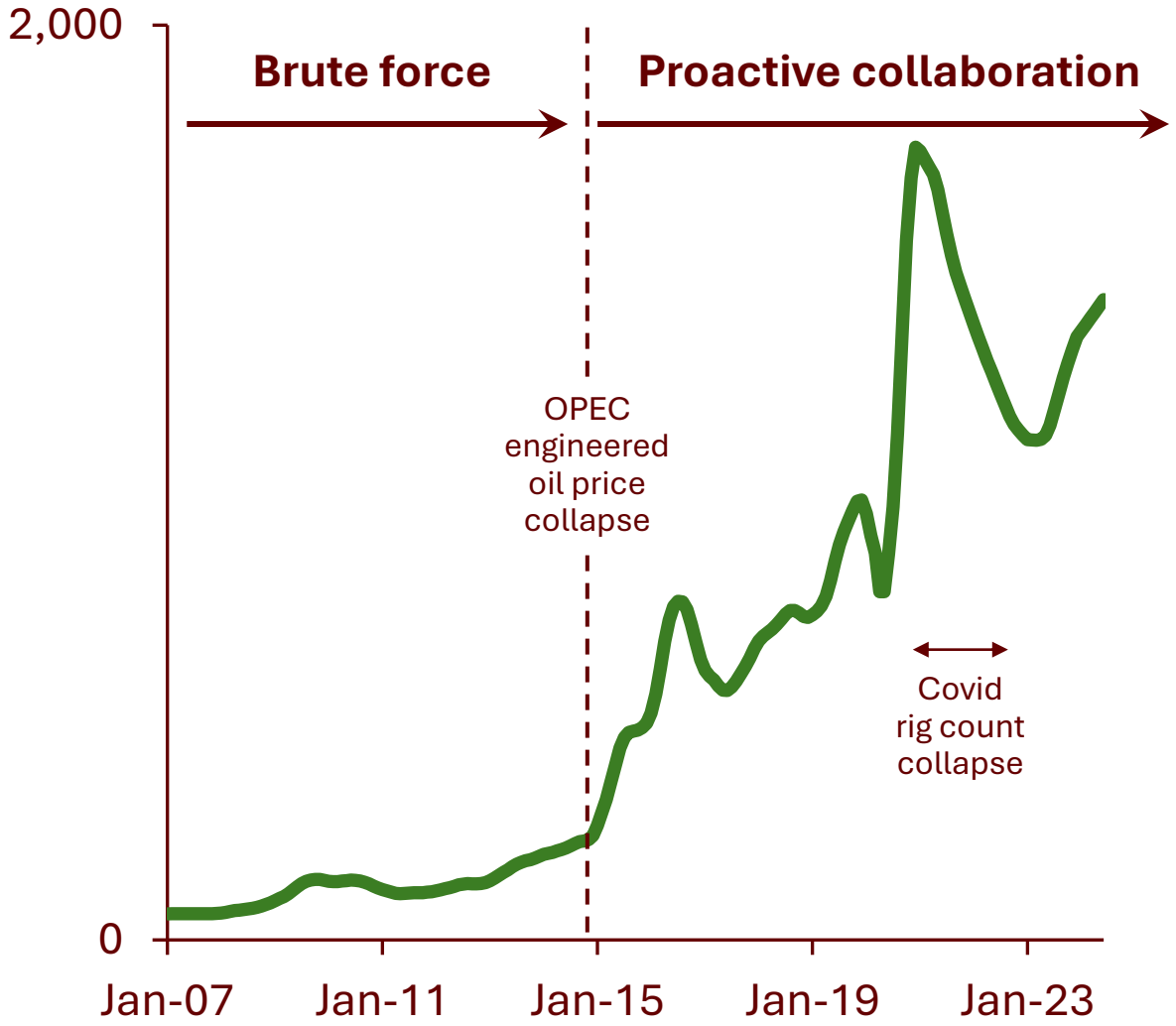


Based on proven reserves data taken from Energy Insights' website in July 2025

Collaboration is critical for delivering breakthroughs of enormous scale

Permian oil output per rig

(barrels of oil per day per rig per month)



U.S. Energy Information Administration Drilling Productivity Report as accessed in April 2025

- The more the better
- Helpful competitors

1

- Partner to share cost
- Share your knowledge

2

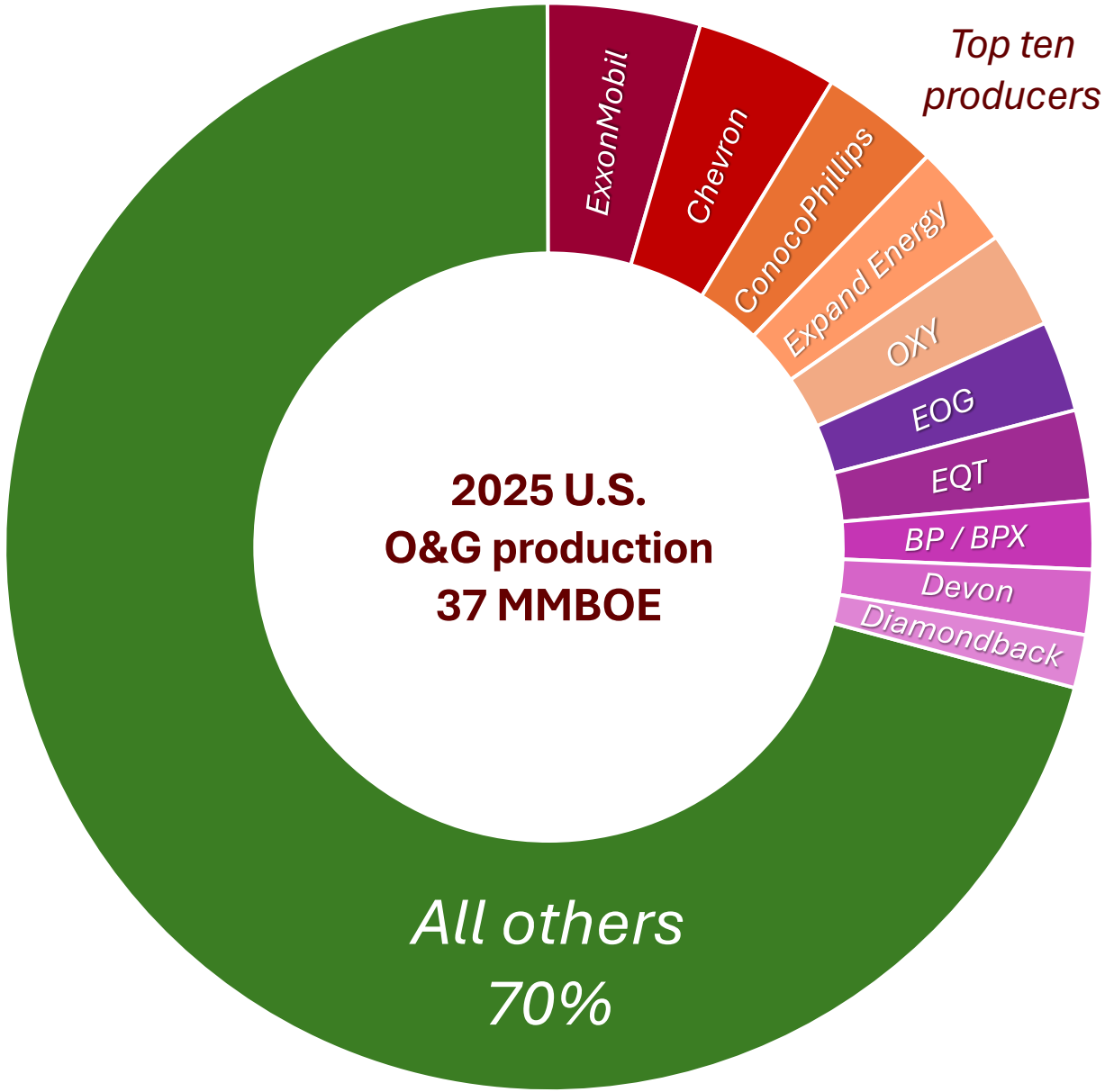
- Broadcast challenges
- Encourage participation

3

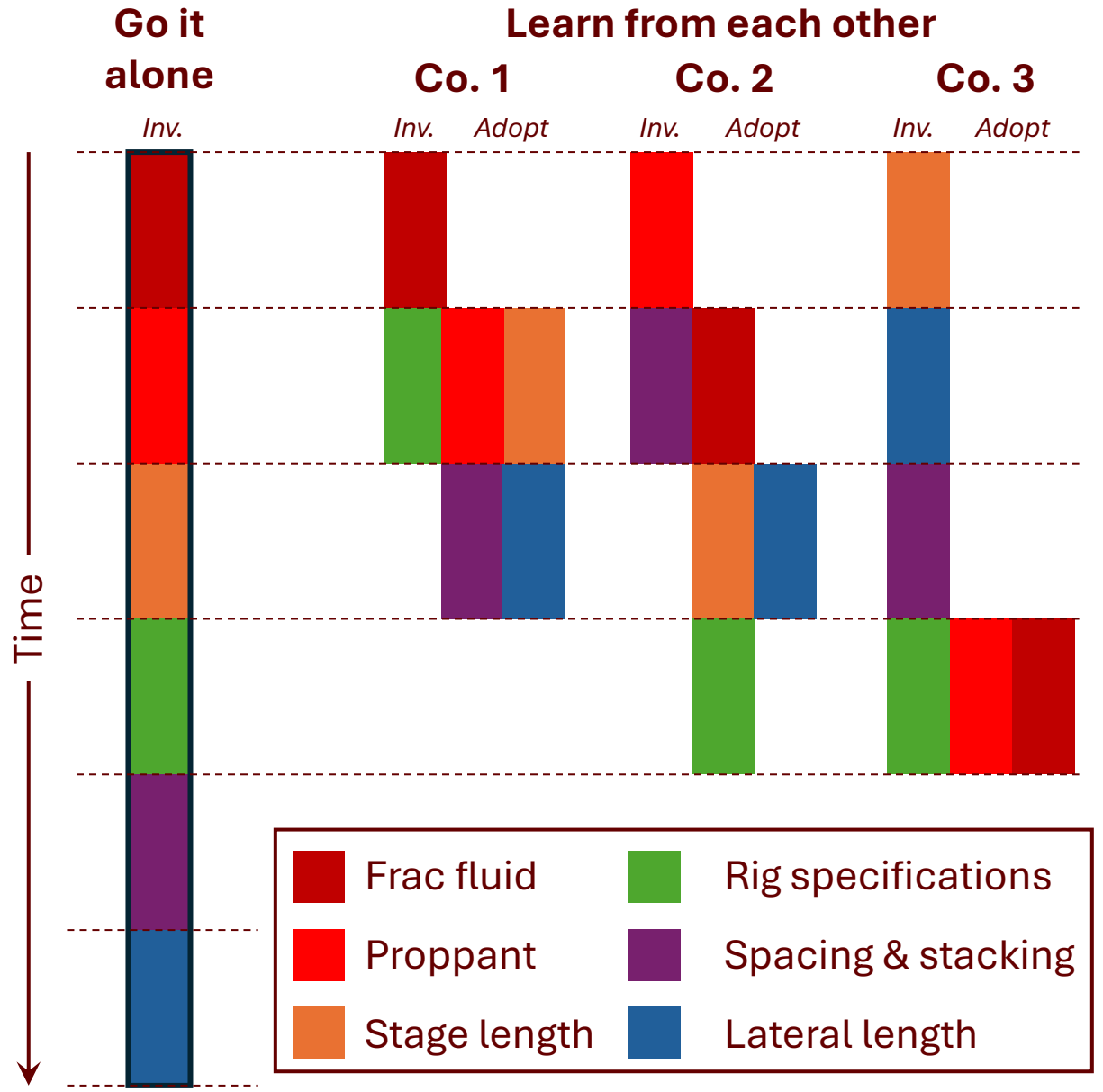
- Spin it out
- Give it away

4

The more the better / Helpful competitors

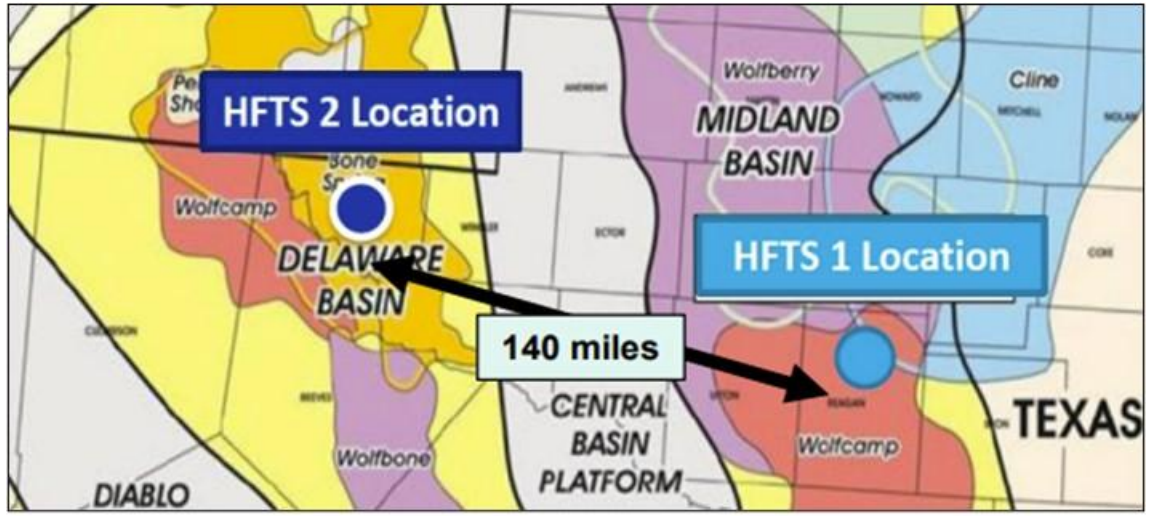


Production data taken from companies' 10-K reports

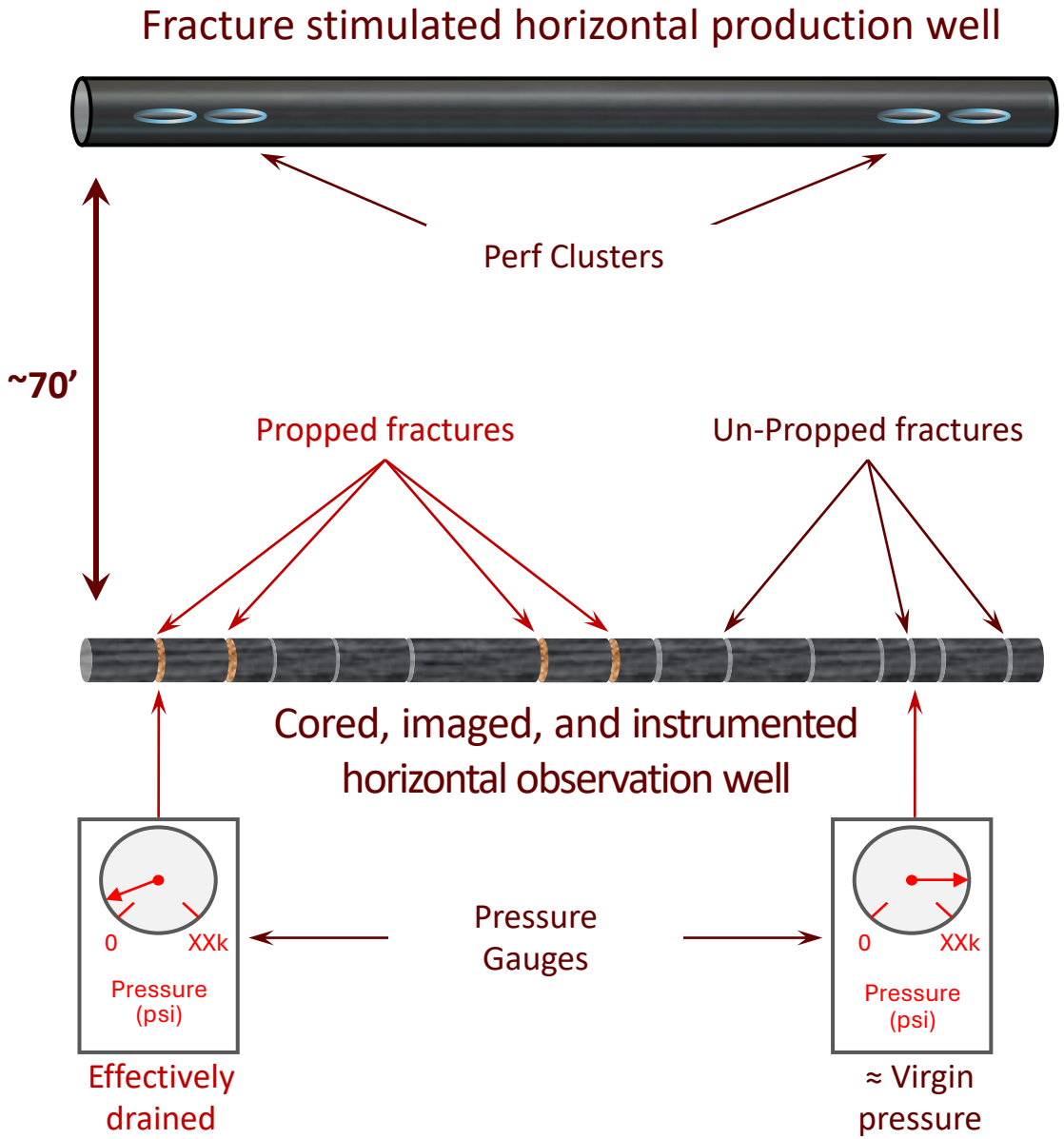


Inv. = Innovate on one's own; Adopt = Adopt better practice from one or more other companies; Co. = Company

Partner to share cost / Share your knowledge



HFTS = Hydraulic fracturing test site; HFTS-1 was operated by Laredo Petroleum; HFTS-2 by OXY



Map View; not to scale; see Raterman et al. 2017 (LINK) and 2019 (LINK) for details

Broadcast challenges / Encourage participation

Casing deformation in hydraulically fractured wells

Society of Petroleum Engineers

SPE-217822-MS

A Comprehensive Review of Casing Deformation During Multi-Stage Hydraulic Fracturing in Unconventional Plays: Characterization, Diagnosis, Controlling Factors, Mitigation and Recovery Strategies

Parent – Child well interactions

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URTeC: 5264

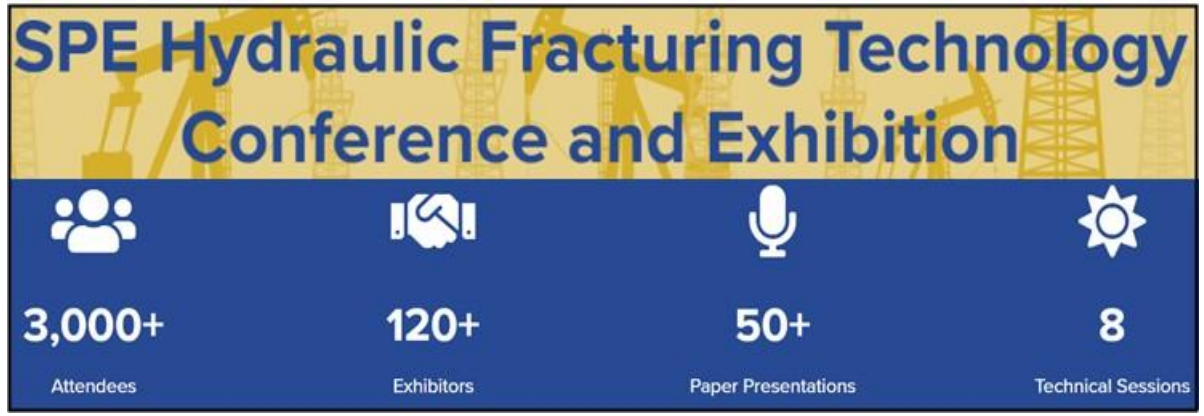
Understanding the Interaction between Parent and Child Using Analytical and Numerical Approaches in Permian Basin – An Operator Perspective

S. Esmaili*, J. Deng, E. Wolfram, V. Muralidharan, I. Harmawan, J. Cassanelli, Occidental

Water management

THE WAY AHEAD
WRITTEN BY AND FOR YOUNG PROFESSIONALS

Balancing Growth and Risk: Why Water Management Is the Permian Basin's Biggest Challenge



Give it away / Spin it out

Publish

URTeC: 2670034

Sampling a Stimulated Rock Volume: An Eagle Ford Example

Kevin T. Raterman[1*], Helen E. Farrell[1*], Oscar S. Mora[1], Aaron L. Janssen[1], Gustavo A. Gomez[1], Seth Busetti[1], Jamie McEwen[1], Michael Davidson[1], Kyle Friehauf[1], James Rutherford[1], Ray Reid[1], Ge Jin[1], Bashali Roy[1], Mark Warren[1]

[1] ConocoPhillips

Abstract

In 2014 ConocoPhillips drilled the first of five deviated wells in DeWitt County, Texas, in order to sample the rock volume adjacent to a horizontal Eagle Ford producer prior to and immediately following hydraulic stimulation. The design, execution and results of the pilot will be described, with particular emphasis on the data acquisition program, which included core, image log, microseismic, DTS/DAS, and pressure data. The observed reservoir state preceding and following hydraulic fracturing will be discussed from an integrated perspective, emphasizing geologic, geophysical, reservoir engineering and completion-related observations.

Introduction

The notion that hydraulic fractures in the subsurface are complex is not new (Maher et al., 1996, Maher, 1999, Cipolla et al., 2008). Fracture complexity has been proposed as one of the causes of high treating pressures and several studies have sampled complex hydraulic fractures. The most notable of these are hydraulic fracture core-throughs (Warpinski et al., 1994, Warpinski et al., 1998, Fisher et al., 2004) and tracer flowback (Rodvelt et al., 2007) endeavors (Warpinski and Teufel, 1987, Warpinski 1991). In these studies, multiple hydraulic fractures were encountered close to each other and fracture deflections and branching at geological heterogeneities, such as natural fractures and bedding surfaces, were described. The observations from mine back data and hydraulically fractured vertical wells indicate that simple bi-wing fractures are not the norm in nature. By extension, this is likely the case for multi-stage horizontal wells completed in shale. Shales are more mechanically anisotropic than the sandstones previously studied and thus should be more likely to develop complex fracturing. With the maturation of microseismic imaging, the premise of complex fracturing has been reinforced (Walker et al., 1998, Fisher et al.,

SPE-217825-MS

Evaluation of Completion Designs and Fracture Heterogeneity via an Instrumented Slant Monitor Well

T. G. Benish, ExxonMobil Upstream Integrated Solutions Company, Spring, TX, US; J. S Brown, ExxonMobil Technology and Engineering Company, Spring, TX, US; S. S. O'Hehir, ExxonMobil Upstream Oil and Gas, Spring, TX, US; K. K. Decker and J. D. Habral, ExxonMobil Technology and Engineering Company, Spring, TX, US; R. Manchanda, ExxonMobil Upstream Oil and Gas, Spring, TX, US; A. Sobrooo, ExxonMobil Technology and Engineering Company, Spring, TX, US; D. S. Vos, ExxonMobil Upstream Oil and Gas, Spring, TX, US

Abstract

Data collected from a passive instrumented monitor well was used to differentiate conductive fracture length and fracture density generated by three different completion designs in the Midland basin. The monitor well was drilled slanting laterally away from a nearby producer and instrumented with fiber optics and a pressure gauge array. The fiber and gauges were monitored during stimulation of the offset well to measure the evolution of created fracture geometry as a function of distance, as well as at various times during production to infer conductive fracture geometries. Integrating the data sets permitted comparison between created fracture geometry and productive dimensions over time while also providing a better understanding of the heterogeneity of conductive fracture lengths within and amongst stages.

Both fiber and pressure measurements complemented each other to discern clear differences in the conductive fracture lengths between the 3 completion designs. The maximum conductive half-length and the distribution of smaller fractures detected by fiber both showed trends in stimulated rock volume between

URTeC: 5866

Multi-well Modeling in the Eagle Ford: An Investigation of Redevelopment, Infill and Refrac Opportunities

Cenet Kamacı[1*], Elif Agarten[1], Phillip Chapman[2], Jon Roberts[2], Dustin Glazier[2], Chet Ozgen[1], 1. NITEC LLC, 2. Devon Energy.

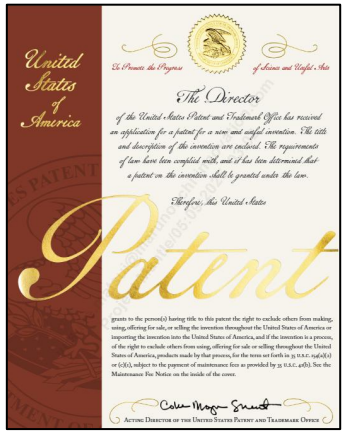
Abstract

As development has matured in Devon's Eagle Ford asset, the focus has shifted from primary development to late life optimization. The optimization options that are considered include: drilling of infill wells in the Lower Eagle Ford Member, drilling of redevelopment wells in the Upper Eagle Ford Member, and refracturing of existing wells. Remaining questions for the upside potential are: 1) What is the right development pattern for these different opportunities? 2) How would infills, redevelopment wells, and refracs interact? and 3) What is the impact of primary depletion in all these scenarios? Multi-well reservoir modeling is suited to answer these questions by considering the full lifecycle, wellbores, and the unit.

This case study focuses on reservoir modeling of two pads in DeWitt County, Texas to investigate the production dynamics of multiple refractured wells and to capture the inter-well connectivity among refractured parents and several redevelopment wells. For this purpose, a history matched simulation model with nine (9) horizontal hydraulically fractured wells was developed. Within the modeled area, five parent wells produced for about 5 years prior to four of them being refractured. The fifth parent well was only repressured prior to the completion of new redevelopment wells. Immediately after the parent wells were refractured, the four redevelopment wells were zipper fractured. Besides the stimulation information, bottomhole pressure gauge data from multiple wells was available for model calibration.

A 3D static reservoir model that integrates multi-disciplinary data from geology, petrophysics, geomechanics and engineering was utilized. A fully implicit dual-porosity reservoir simulator with special geomechanical features was used for the calibration, in which the temporal change in mean stress for each grid cell is implicitly solved together with pressure and the other flow variables using poro-elastic information. This simulator dynamically solves for fracture generation (rock deformation) and dilation of tensile fractures, as well as the subsequent fracture closure upon depletion and re-dilation of fractures as a function of net stress. The calibration effort consisted of matching the performance of all wells during the hydraulic fracturing, flow back, and depletion periods, including daily historical oil, gas, and water production rates together with the bottomhole pressure data. Predictive runs were performed to examine different development scenarios and to provide decision support for pattern optimization.

Patent



United States of America

To Promote the Progress of Science and Useful Arts

The Director

of the United States Patent and Trademark Office has received an application for a patent for a new and useful invention. The title and description of the invention are enclosed. The requirements of law have been complied with, and it has been determined that a patent on the invention shall be granted under the law.

Therefore, this United States

Patent

grants to the person(s) having title to this patent the right to exclude others from making, using, offering for sale, or selling the invention throughout the United States of America or importing the invention into the United States of America, and if the invention is a process, of the right to exclude others from using, offering for sale or selling throughout the United States of America, products made by that process, for the term set forth in 35 U.S.C. 154(a)(1) or (c)(1), subject to the payment of maintenance fees as provided by 35 U.S.C. 41(b). See the Maintenance Fee Notice on the inside of the cover.

Acting Director of the United States Patent and Trademark Office

A portfolio of patents

United States of America

Patent

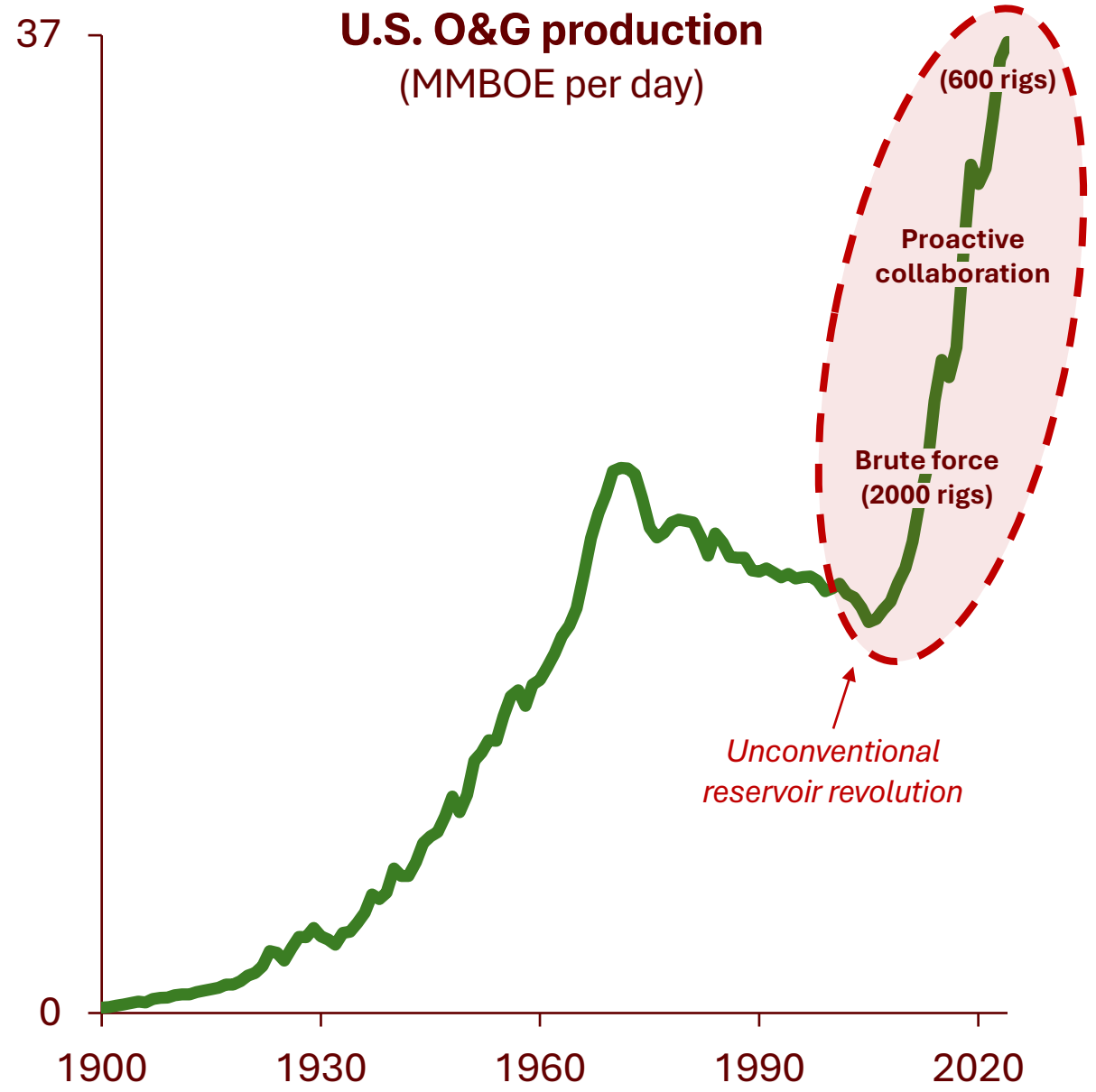
+

Insufficient funding to develop patented ideas

≠

Value creation

Collaboration was critical for delivering rapid U.S. production growth



Sources: U.S. EIA and Energy Institute websites; O&G = oil and gas (including condensate and NGLs); MMBOE = million BO equivalent

- The more the better
- Helpful competitors
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- Share your knowledge
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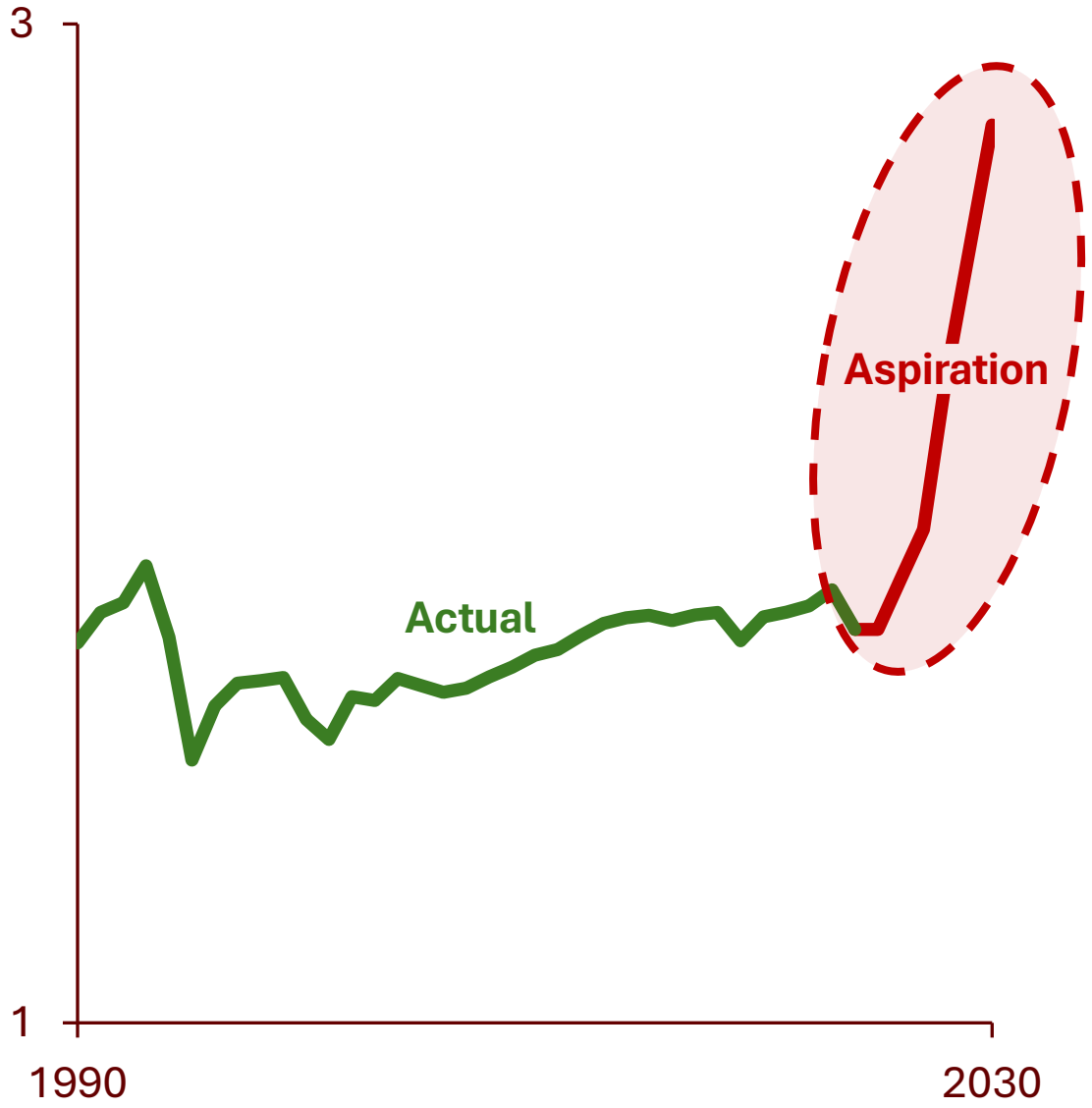
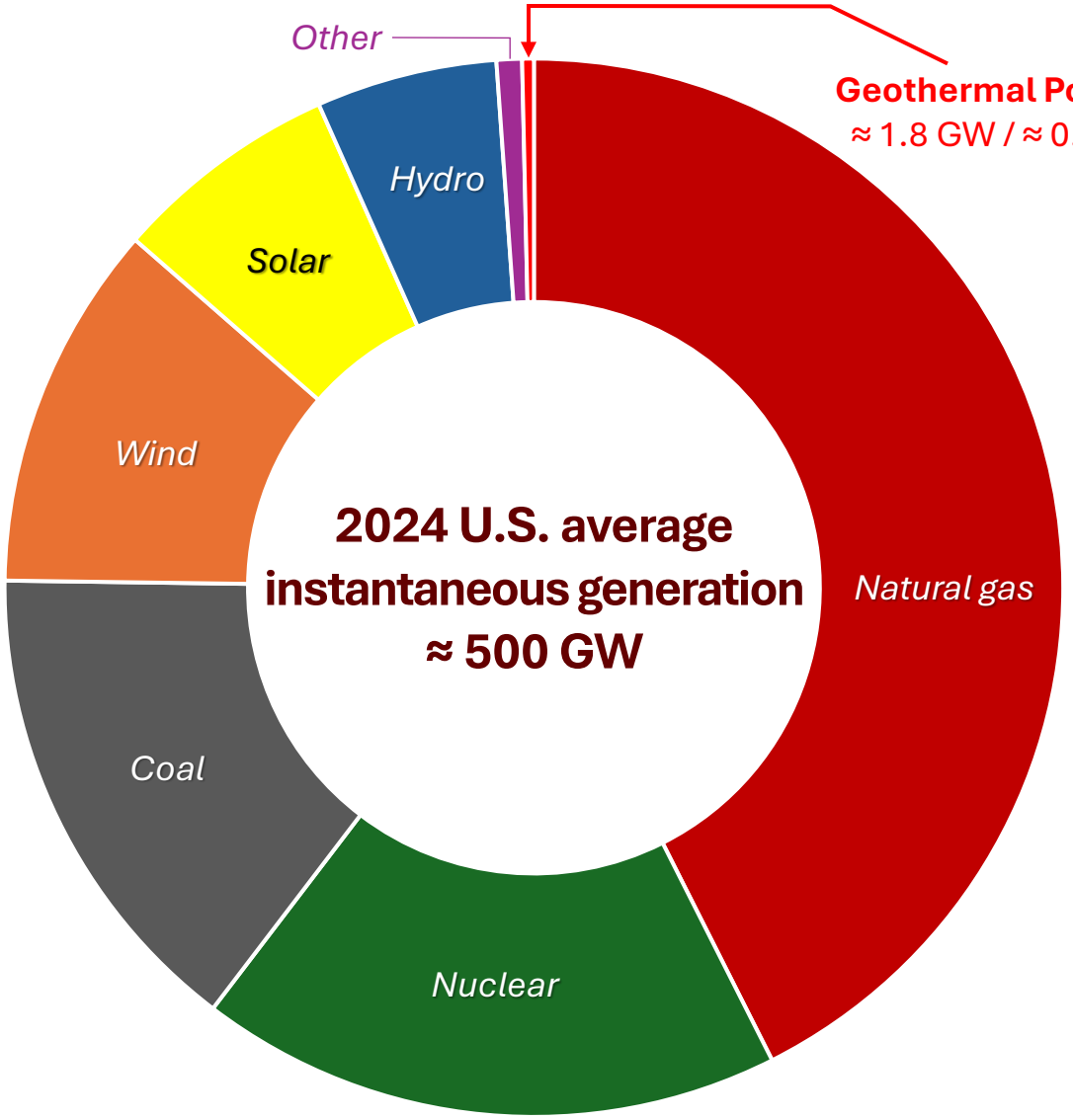
Collaboration will be crucial if we are to rapidly grow geothermal power output

Gigawatts instantaneous generation



Sources: Actual data was taken from the U.S. EIA's website; average instantaneous generation = annual gigawatt hours ÷ 8,760 (i.e., 24 × 365)

U.S. power production market share



Source: U.S. EIA website Electric Power Annual

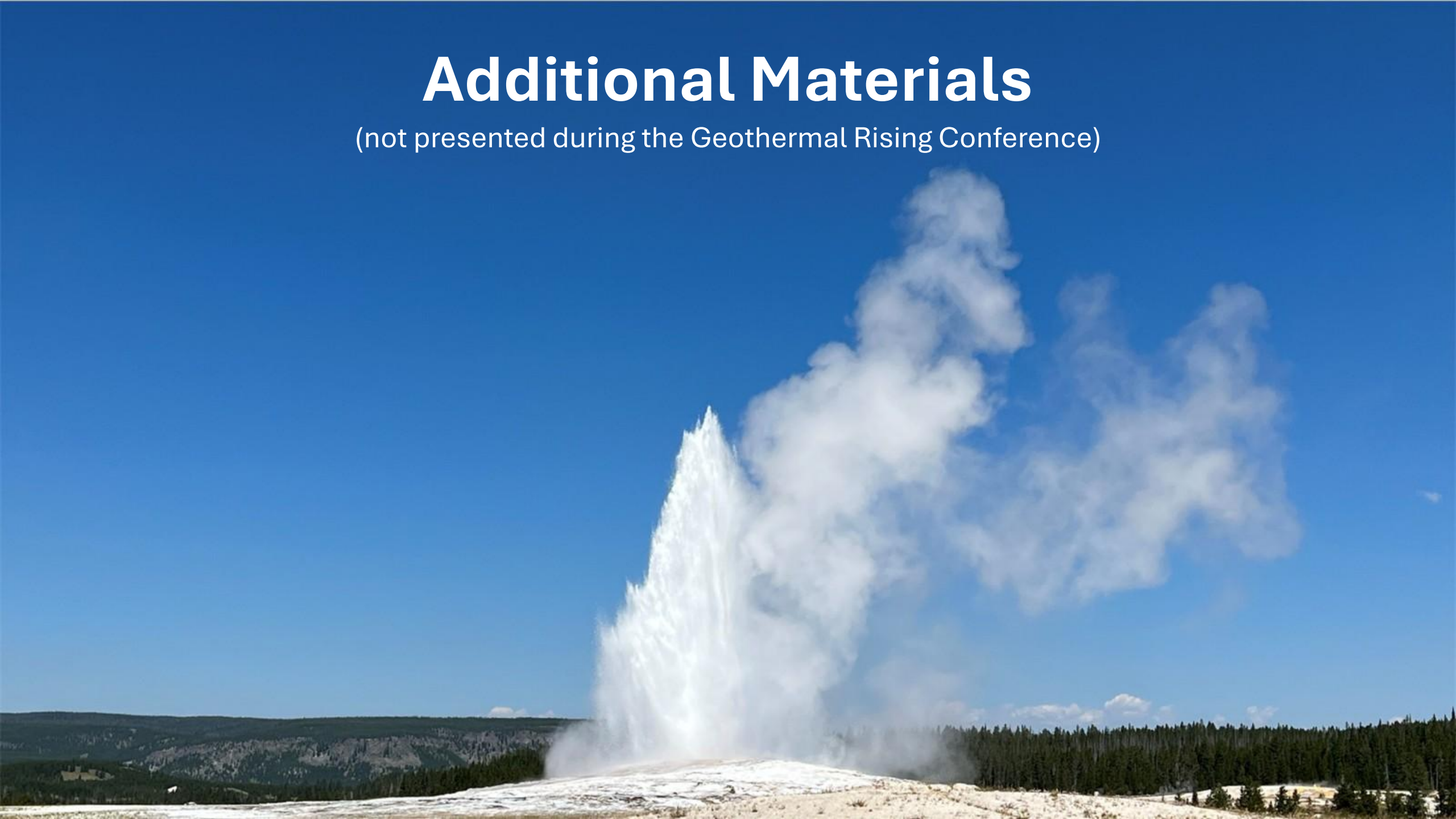
The importance of collaboration for delivering rapid growth in geothermal energy production

You can access a copy of this slide deck at:
www.tidalwavetechnologies .com

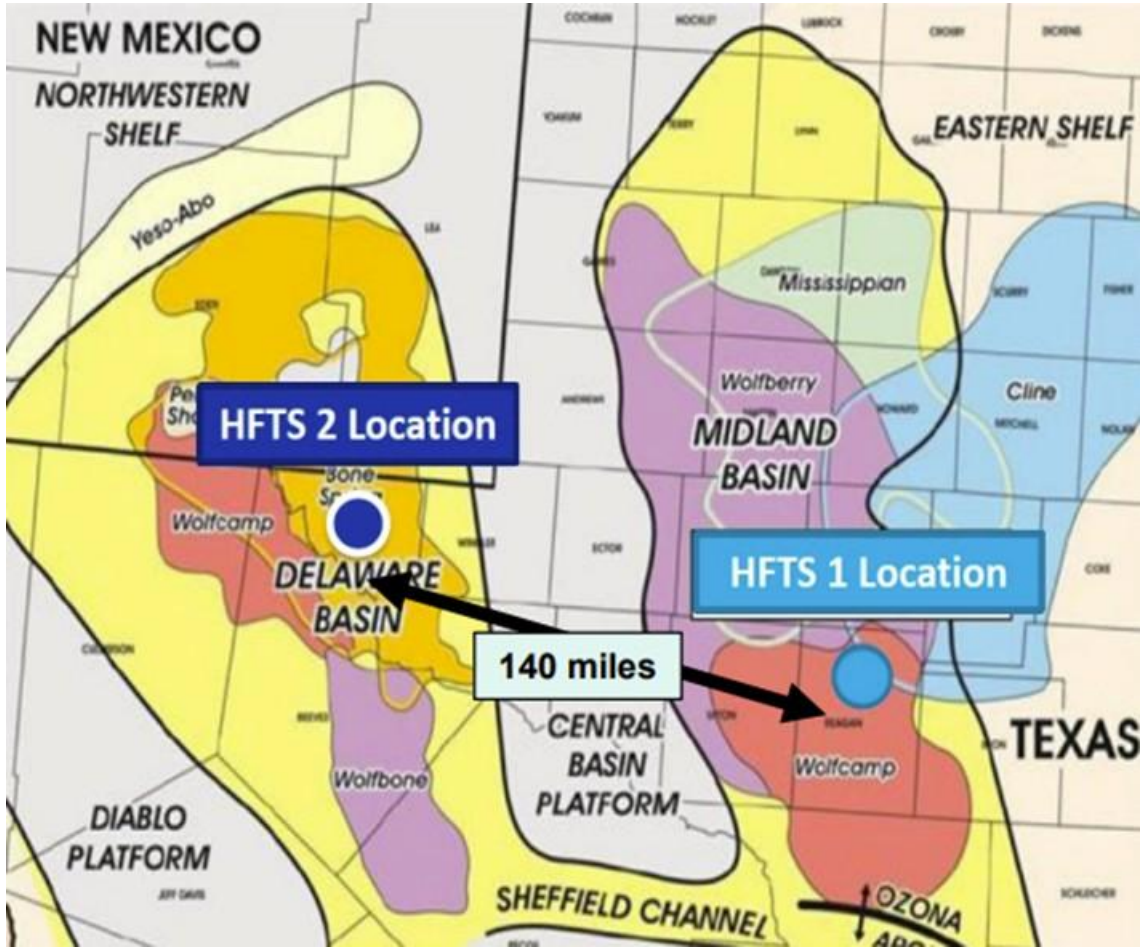
Geothermal Rising Conference
October 27, 2025
Greg Leveille

Additional Materials

(not presented during the Geothermal Rising Conference)



Joint O&G industry-government-academia demonstration projects



Project	Duration	DOE $	Industry $	Total $
HFTS 1	2014-23	21.5	22.7	44.2
HFTS 2	2018-22	7.8	12.6	20.4

- Hydraulic Fracturing Test Sites 1 and 2 were excellent examples of field-based, high-impact, joint industry-government-academia demonstration projects
- Both projects had a lead operator on whose acreage the projects were executed
- Other operators and government entities provided funding and expertise; academia provided R&D capabilities (e.g., UT; Stanford; Texas A&M)

Figures from HFTS 1 Project Summary by Jordan Ciezobka, GTI Energy (presented at NETL Resource Sustainability Project Review Meeting, October 2022)

Experimentation focus areas that could further improve EGS economics

Potentially Significant "Upsides"

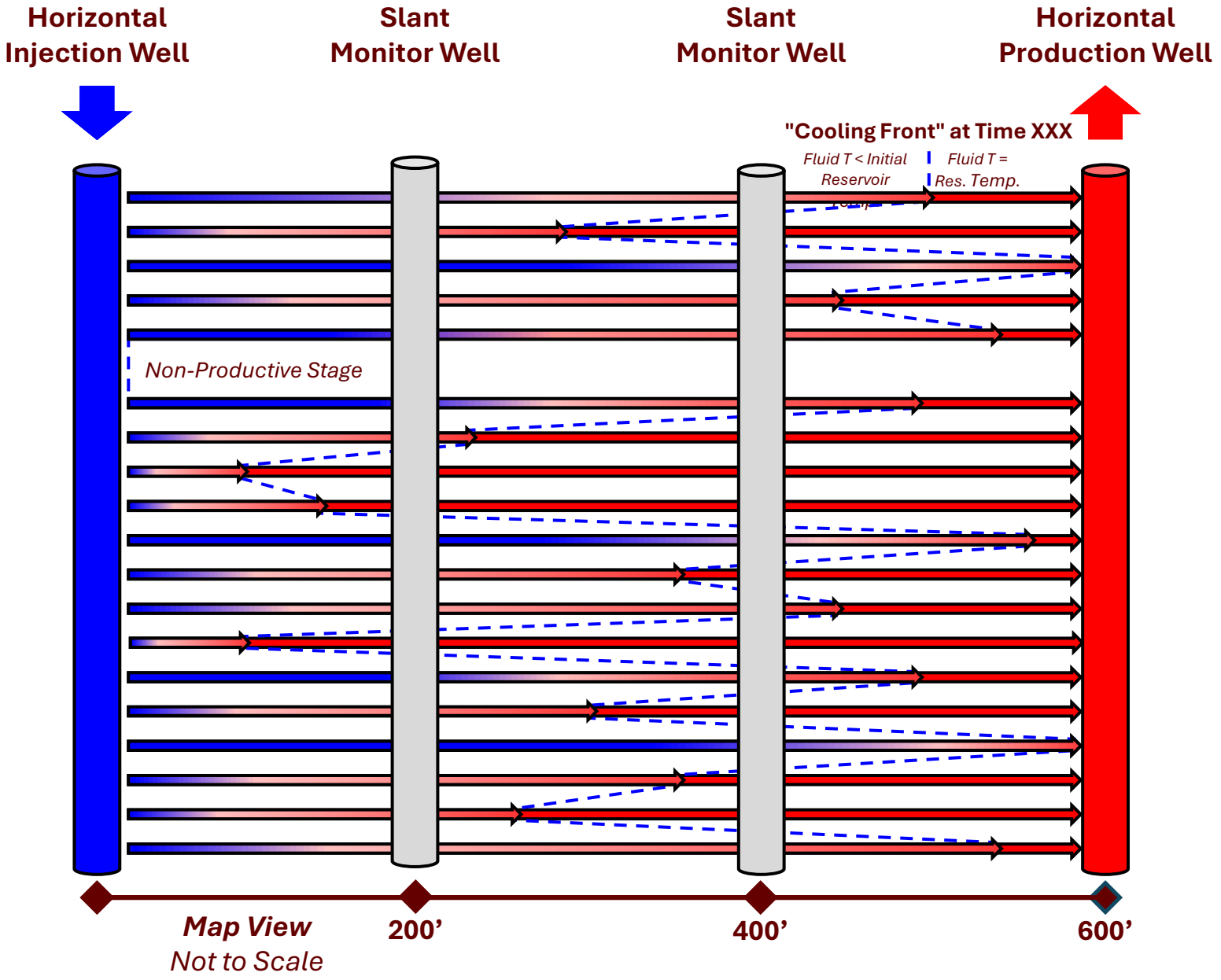
Improved Conformance	*Greater Surface Area*	*Super Hot Rocks*	*Higher Flow Rates*	*"Open Hole" Producers*[3]	*One Plant / Deeper Layers*
• Well placement • Completion design • Operating practices • Remediation options	• Longer laterals • Wider well spacing • LL: 3M → 5M → 15M ft. • WS: 300' → 600' → __	• Blue Mtn. ≈ 375° F • Cape 400° to 435° F • SHR target 705° F[1] • ≈ 1 MW per 25° F[2]	• Larger casing = >rate • > Fracture conductivity • Project Red 25M bfpd • Cape design 70M bfpd	• $5 MM or more per well cost reduction • Uncertain flow rate impact, but could yield higher rates	• Synergy with Super Hot Rocks progress • Reuse as much of plant as possible after initial wells die
>Thermal Longevity	***>Thermal Longevity***	***> Thermal Output***	***> Thermal Output***	***Less D&C Cost***	***Less Plant Cost***

Potentially Significant "Downsides"[4]

Thermal Breakthrough	*Fluid Leakoff*	*Induced Seismicity*	*Loss of Fracture Conductivity*	*Scaling*	*Corrosion*
• Well length, spacing & stacking, flow rates • Completion design • Operating practices • Remediation options	• Avoiding tectonically stressed localities • Completion design • Operating practices • Remediation options	• Avoiding tectonically stressed localities • Completion design • Operating practices • Remediation options	• Proppant placement best practices • Proppant and frac fluid selection • Operating practices	• Robust scaling characterization and treating programs	• Robust corrosion characterization and treating programs • Materials selection
Thermal Longevity	***Plant & OPEX Cost***	***License to Operate***	***Thermal Longevity***	***Plant & OPEX Cost***	***Plant & OPEX Cost***

[1] 374° C; [2] at 50,000 bfpd flow rate; [3] Wells could be completed open hole or with a slotted liner; [4] Downsides that could be mitigated

Conformance experiment: Multiple monitor wells between injector & producer

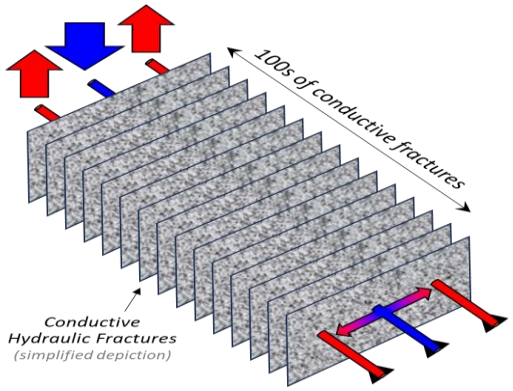


Simplified depiction of a complex physical phenomenon; Depiction of cooling characteristics are for demonstration purposes only; they are not based on actual data

- **Concept:** Place multiple slant monitor wells between injector and producer to learn how "cooling front" migrates over time
- **Execution:** Drill and fracture stimulate injector and producer; assess data indicating location of fractures; place monitor wells at optimal locations
- **Benefits:** Learning how front moves through fracture system in 3D space will help with optimizing placement of future wells; learning from a project like this will be far more effective from a value optimization perspective than learning from trying different placements of producers relative to injectors; likely to also help with completion designs (e.g., stage & perf cluster spacing)
- **Approximate Cost:** $15 to $30 MM depending on the number of monitor wells
- **Requirements:** Must be done in producing field

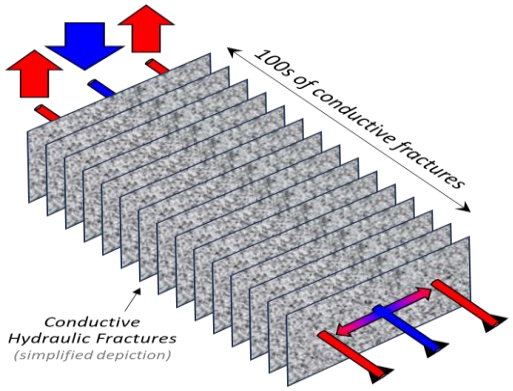
Super hot rocks experiments: Increase thermal output per barrel of fluid pumped

Current EGS Developments
Maximum Reservoir Temperatures
400 to 450° F



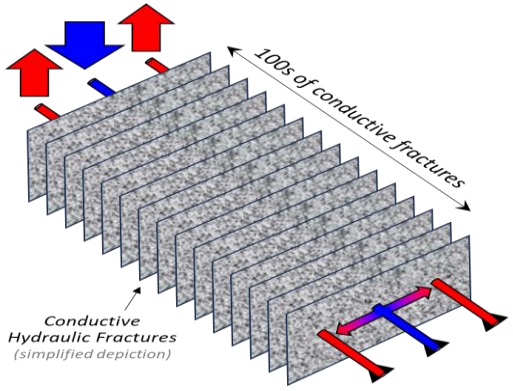
Power per Producer ≈ 10 MW [1]

"Project Mercury"
Target Reservoir Temperature
525° F



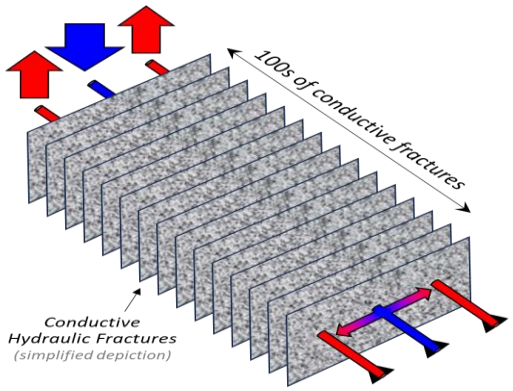
Power per Producer ≈ 15 MW [1]

"Project Gemini"
Target Reservoir Temperature
600° F



Power per Producer > 20 MW [1]

"Project Apollo"
Target Reservoir Temperature
705° F



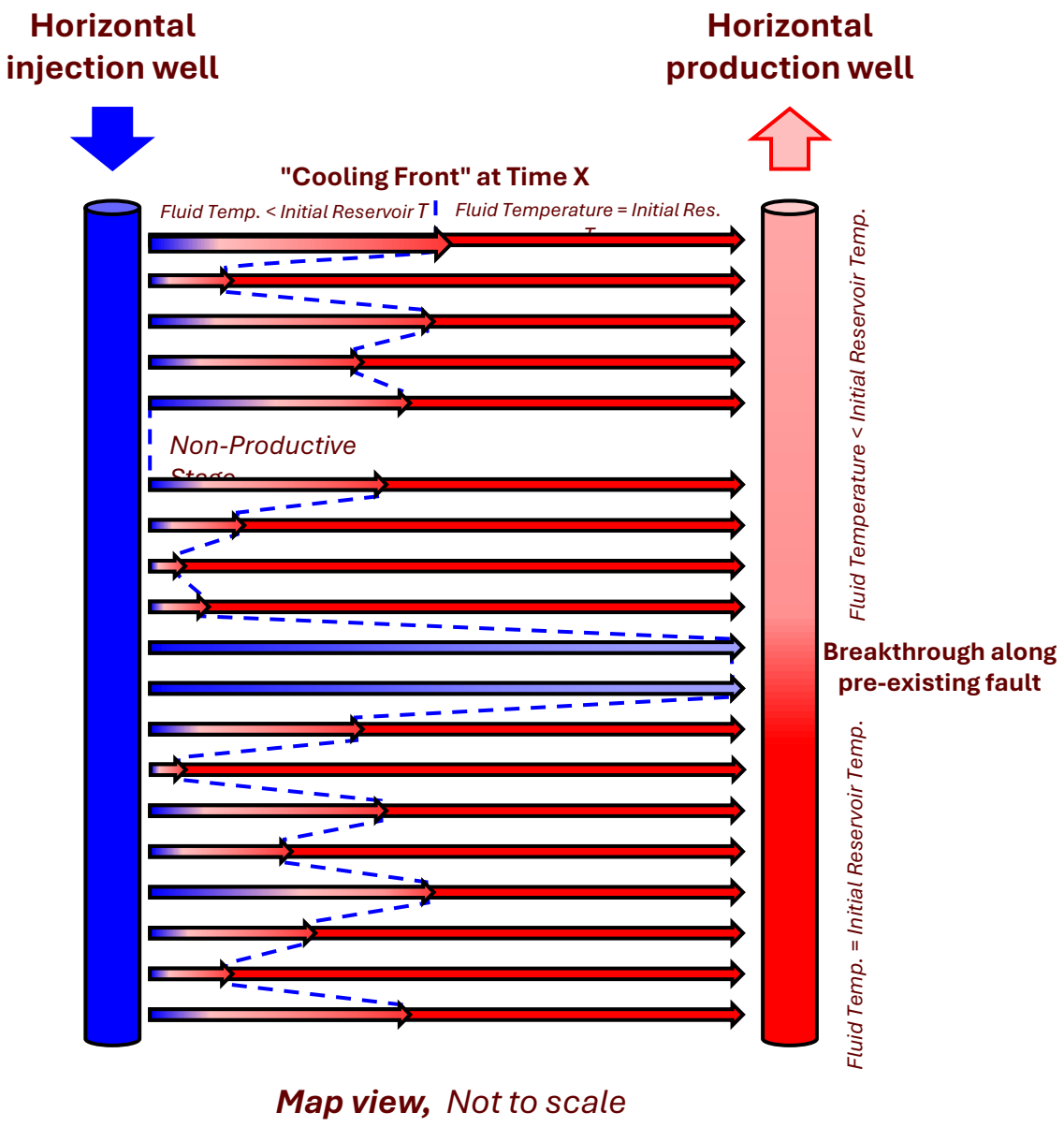
Power per Producer >> 30 MW [1]

- **Concept:** Much as NASA did in the 1960s to land men on the moon and safely return them to Earth[2], this effort would involve a series of projects designed to step up the industry's ability to drill, complete, and operate horizontal EGS wells at significantly higher temperatures to increase power output per producer
- **Execution:** Drill, complete, and operate one or more well pairs or triplets at 75 to 100 degree jumps in reservoir temperature
- **Benefits:** There is significant economic advantage to being able to operate EGS projects at temperatures above current 400 to 450° F range, especially in areas with exceptionally high heat flow gradients
- **Approximate Cost:** $50 - 75 MM per project phase
- **Requirements:** Must be able to produce wells to a facility capable of handling high temperature fluids; will require considerable collaboration between operators, service companies, government labs, and universities

[1] Power output levels calculated for a 70,000 bfpd flow rate

[2] NASA analogy used to emphasize phased approach to reaching goal, not importance of the objective

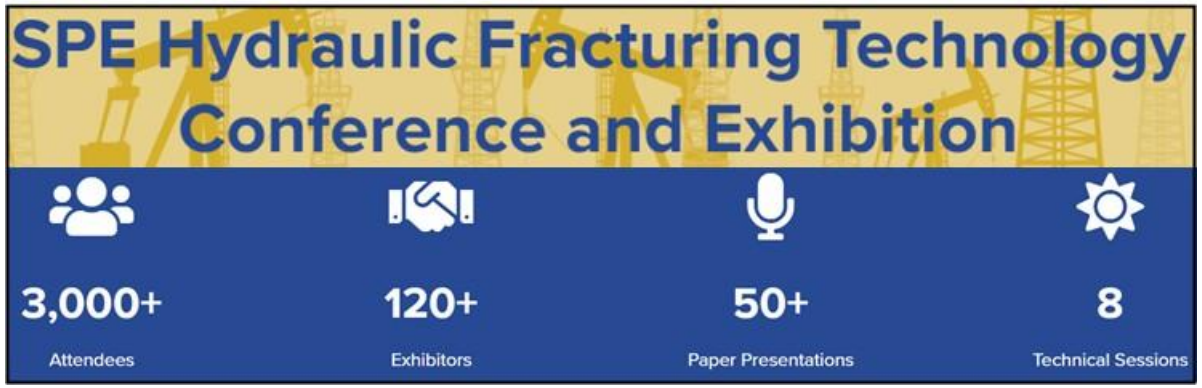
Remediating conformance related issues experiments



Simplified depiction of a complex physical phenomenon; Depiction of cooling characteristics are for demonstration purposes only; they are not based on actual data

- **Concept:** Develop technologies that would enable an operator to shut-off fractures that act as fluid-flow "superhighways" between injectors and producers, thereby extending the effective life of EGS production wells by shutting off cold, high-flow rate pathways. Tools and techniques should also be applicable for shutting off fractures that enable excessive leakoff or are contributing to unacceptable levels of induced seismicity via interaction with pre-existing geologic features.
- **Execution:** Field testing will be dependent upon the nature of the technologies developed and the availability of EGS wells in which a technology can be tested. For technologies that would be deployed after a problem is identified in wells that have been placed on production, testing could be coupled with the experiments described in slide six or done on an opportunistic basis in an existing field.
- **Benefits:** Limiting thermal breakthrough, excessive leakoff, and induced seismicity greatly enhances project economics and preserves an operators "license to operate".
- **Approximate Cost:** Millions to tens of millions (tech dependent)
- **Requirements:** Will want sufficiently robust data gathering capabilities to be able to characterize cause of problems and experimental results

Examples of operating companies being willing to release results and share knowledge via publications and participation in conferences



- Significant support of conferences from operators in the form of sponsorship, approval for SMEs to submit papers, and encouraging employee attendance
- URTeC Executive Advisory Board[1] circa 2020:
  - BP
  - Chevron
  - Concho
  - ConocoPhillips (chair)
  - Devon
  - Hess
  - OXY
  - Pioneer
  - Saudi Aramco
  - Shell

[1] URTeC's Executive Advisory Board has been and still is comprised of CTOs and other very senior technology leaders from E&P opertaors

Examples of knowledge shared by O&G companies

ExxonMobil

SPE International
Society of Petroleum Engineers

SPE-217825-MS

Evaluation of Completion Designs and Fracture Heterogeneity via an Instrumented Slant Monitor Well

T. G. Benish, ExxonMobil Upstream Integrated Solutions Company, Spring, TX, US; J. S Brown, ExxonMobil

HESS

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URTeC: 4044071

The Perfect Frac Stage, What's the Value?

Craig Cipolla*[1], Ankush Singh[2], Mark McClure[2], Michael McKimmy[1], John Lassek[1].
1. Hess Corporation, 2. ResFrac Corporation.

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ConocoPhillips

URTeC: 2670034

Sampling a Stimulated Rock Volume: An Eagle Ford Example

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[1] ConocoPhillips

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ConocoPhillips

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URTeC: 263

Analysis of a Drained Rock Volume: An Eagle Ford Example

Kevin T. Raterman*[1], Yongshe Liu[1], Logan Warren[1]; 1. ConocoPhillips.

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devon

URTeC: 5066

Multi-well Modeling in the Eagle Ford: An Investigation of Redevelopment, Infill and Refrac Opportunities

Caner Karacaer*[1], Elif Agartan[1], Philip Chapman[2], Jon Roberts[2], Dustin Glazier[2], Chet Ozgen[1],
1. NITEC LLC, 2. Devon Energy.

Examples of geothermal energy conferences focused on technical knowledge sharing

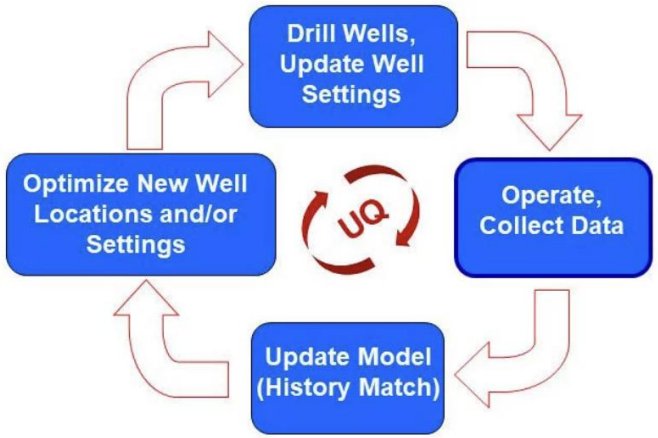
Stanford University

WGC 2026
FORGING GEOTHERMAL INNOVATION
JUNE 8 - 11, 2026 | CALGARY, CANADA

Examples of academia-led, O&G industry-focused consortiums

MEWBOURNE COLLEGE OF EARTH AND ENERGY
WELL CONSTRUCTION TECHNOLOGY CENTER
The UNIVERSITY of OKLAHOMA

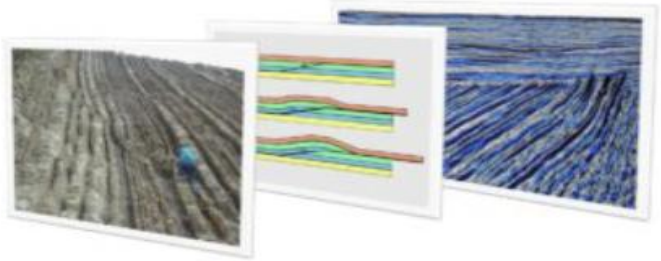
Stanford | Doerr School of Sustainability
Smart Fields Consortium
Energy Science & Engineering



TEXAS A&M UNIVERSITY
Engineering
CRISMAN INSTITUTE

EGI Energy & Geoscience Institute
THE UNIVERSITY OF UTAH

UTAH FORGE U.S. Department of Energy



PETROLEUM SYSTEMS & GEOCHEMISTRY

GEOPHYSICS

RESERVOIR GEOMECHANICS

GIS & SATELLITE ANALYSIS

SHALE CHARACTERIZATION

CHRONOSTRATIGRAPHY

- 50-year history
- >$1 billion in research delivered
- Databases of reports/data

TEXAS
RAPID RIG AUTOMATION
Performance Improvement in Drilling

Spin it out example / Give it away example

JPT JOURNAL OF PETROLEUM TECHNOLOGY

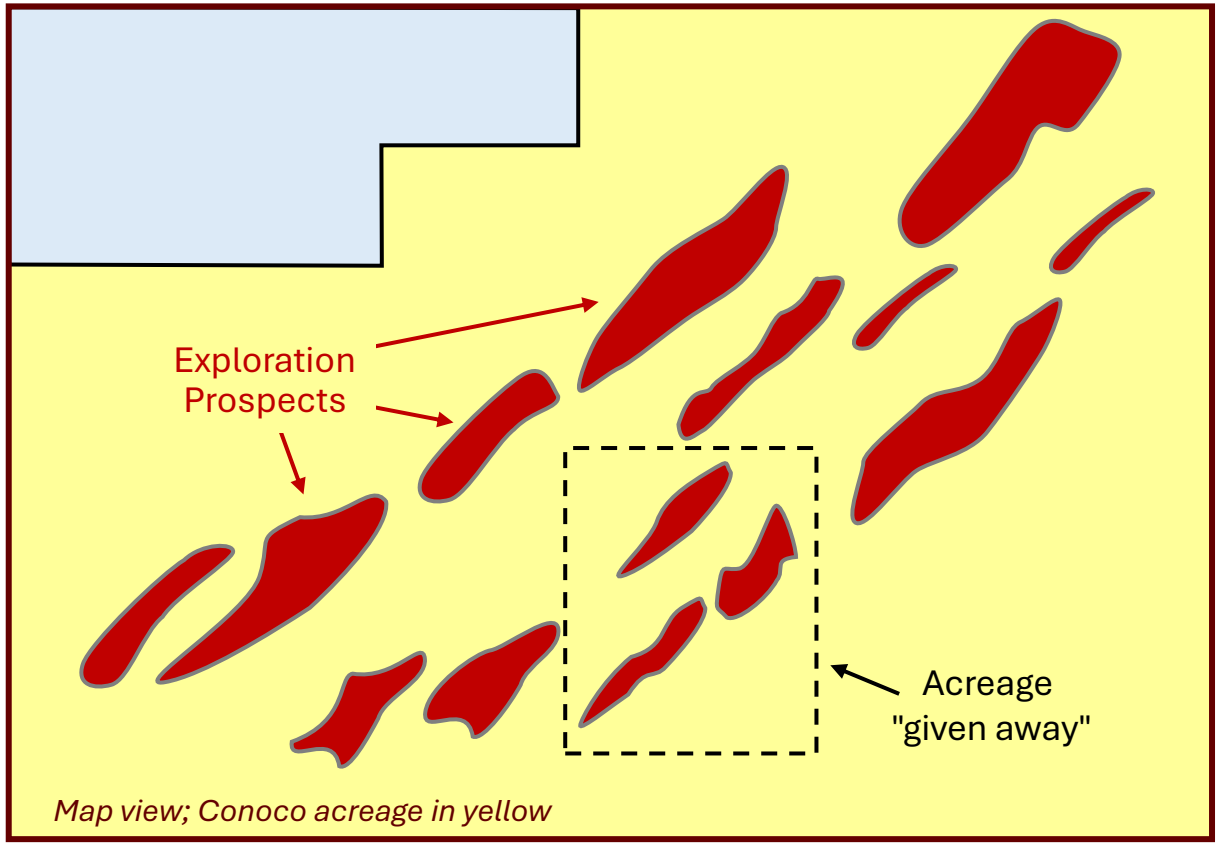
FRACTURING/PRESSURE PUMPING

Devon Makes Sealed Wellbore Pressure Monitoring Available to Entire Shale Sector

Developed by the large shale producer, its new way to monitor interactions between horizontal wells is now available as a commercial software. The concept is considered a stepping stone toward real-time fracture design.

WellData Labs CHATWDL COMPLETIONS FRACTURE DIAGNOSTICS

The revolution has arrived: Sealed Wellbore Pressure Monitoring

Conoco new basin value maximization (early 1950s)

- Acquire large lease position in unexplored areas
- Give away a portion of the acreage to another operator
- Require operator to execute work program & share data
- Other operator gets free acreage; derisks play for Conoco