Rapid Experimentation and Sharing of Knowledge - Factors Critical for Delivering Breakthroughs of Enormous Scale

Greg Leveille

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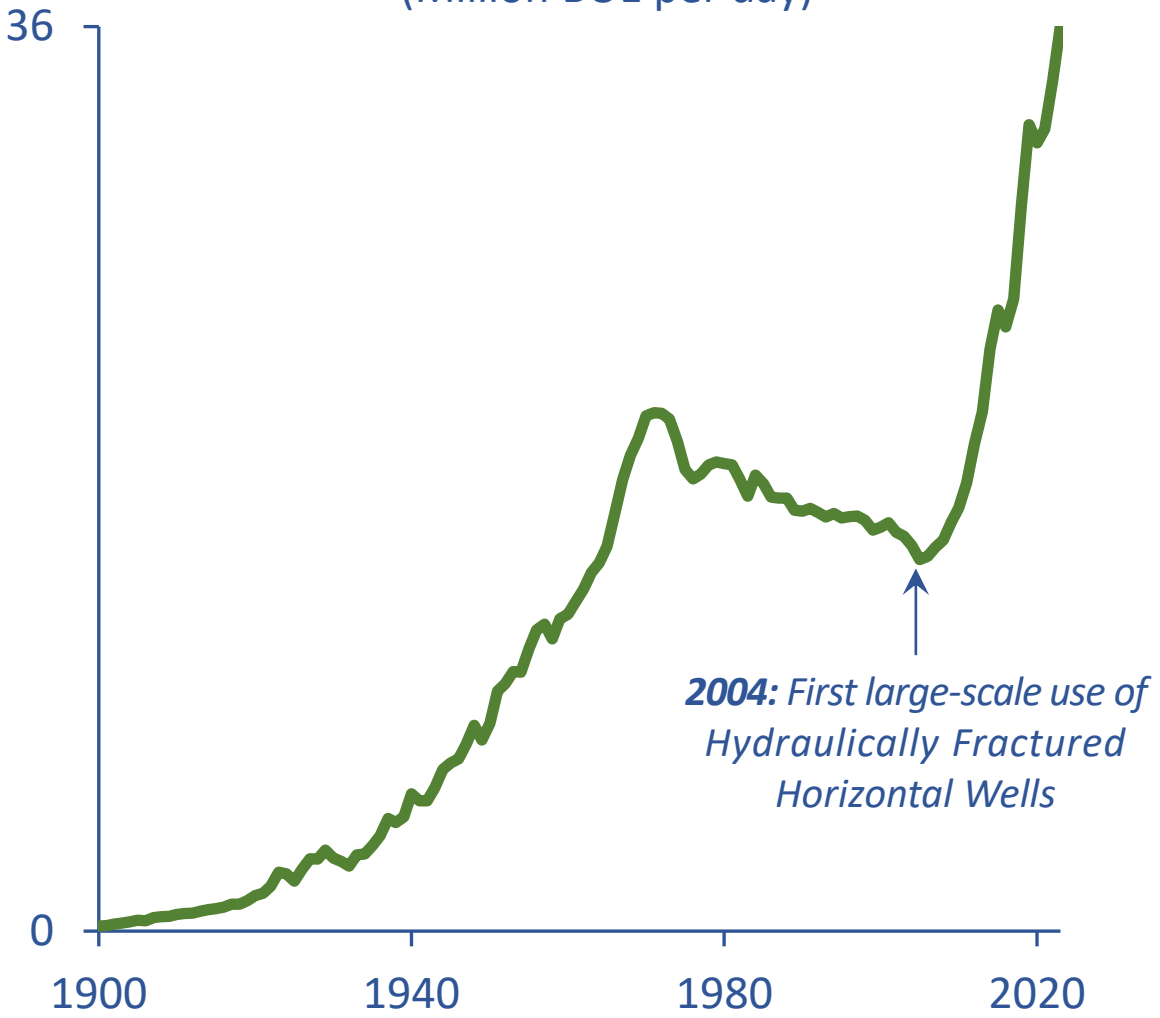
Since 2004, the U.S. O&G industry has delivered astonishing production growth – an outcome made possible by rapid experimentation and sharing of knowledge

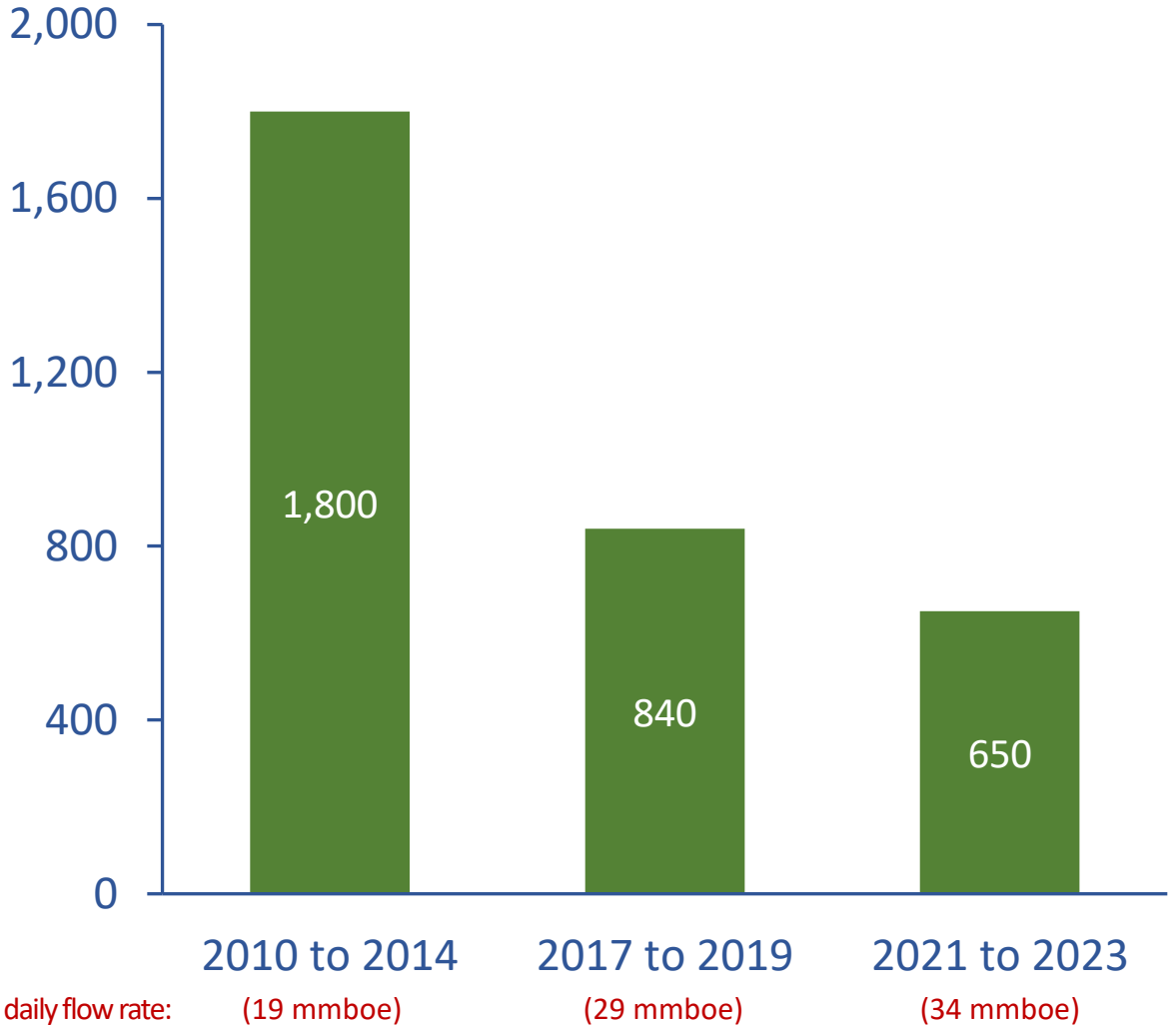
U.S. Oil & Gas Production

(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 > one million BOE per day

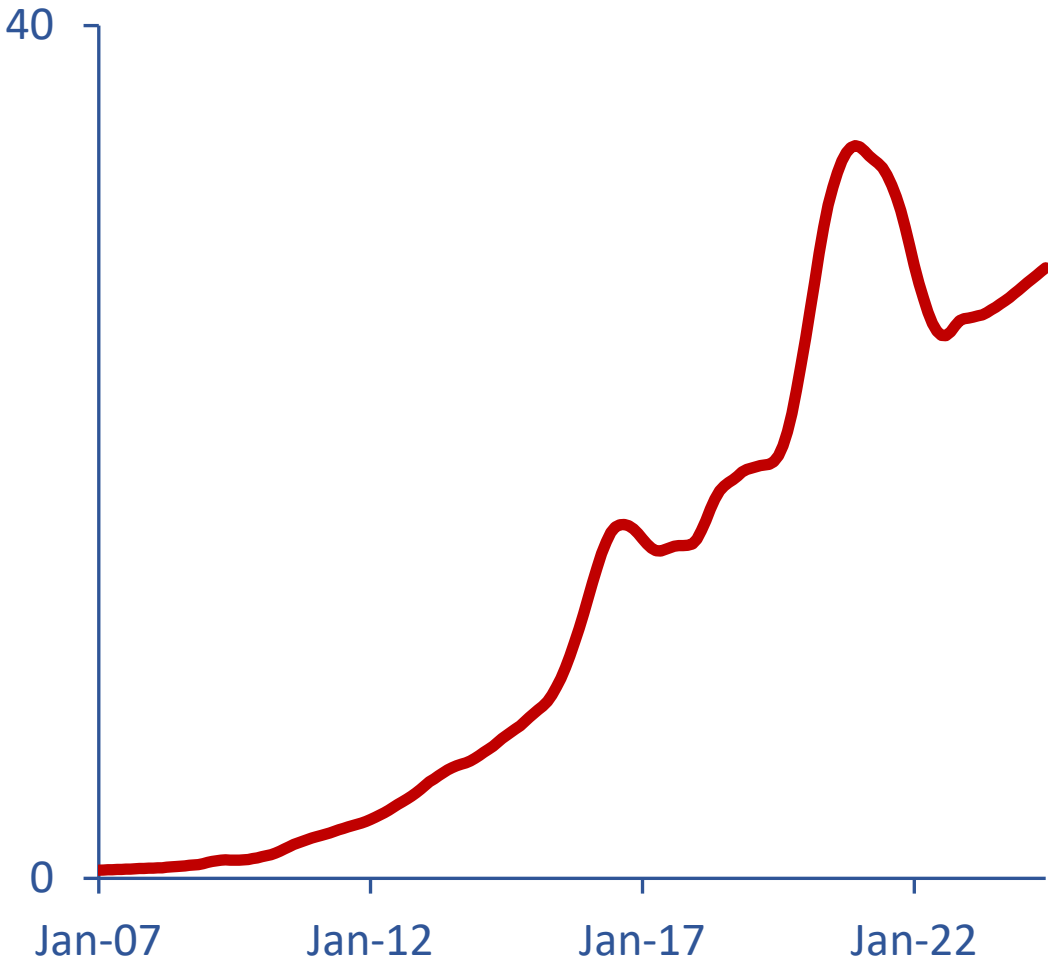


Sources: U.S. production = U.S. EIA, Energy Insights, and BP websites; Rig count = Baker Hughes

Rapid experimentation and the willingness to share knowledge drove dramatic increases in per well production and massive cost reductions

Marcellus / Utica "new gas" output per rig

(million cubic feet per day)



U.S. Energy Information Administration Drilling Productivity Report as accessed in November 2024

Well construction and development plan elements considerably improved since 2004

- Drilling rig and frac fleet equipment
- Downhole drilling tools (e.g., directional drilling)
- Tools for multi-stage fracture stimulation
- Proppant types and proppant sizing
- Coupled reservoir and fracture modeling tools
- Fracturing logistics (e.g., zipper fracs)
- Lateral lengths; well spacing and stacking
- Refracture stimulation techniques
- Enhanced oil recovery

Not a complete list of improvements achieved; EUR = enhanced oil recovery

Why share knowledge?

- Sharing greatly increases the pace of progress and reduces company-specific and overall industry cost of experimentation
- No company has the full range of knowledge or skills necessary to optimize development of a particular resource type
- For resource extraction industries, the only durable "patent" is rights to explore and develop high quality acreage
- Knowledge sharing provides the transparency needed to attract outside investment
- Within the energy industry, it is competition between sources of energy that is most important, not competition within a given segment

Sharing mechanisms that worked for O&G

- Diffusion of ideas from the use of the same suite of service companies by all operators (i.e., lack of operator vertical integration)
- Operating companies being willing to share knowledge through company-to-company data trades and other forms of interaction
- Enable data aggregators to gain access to enough useful data to deliver economically viable services
- Operating companies being open to sharing results via publications and participation in conferences and workshops
- Joint industry-government-academia demonstration projects

Focus for the remainder of this presentation

Enable data aggregators to gain access to enough useful data to deliver economically attractive services

ENVERUS

Haynesville operators calculate remaining growth

12.5 years of sub-$3.00/mcf inventory remains in key natural gas basin

Enverus: Permian Gains Will Sustain US Oil Production Through 2030

Wood Mackenzie

98%
of global unconventional plays

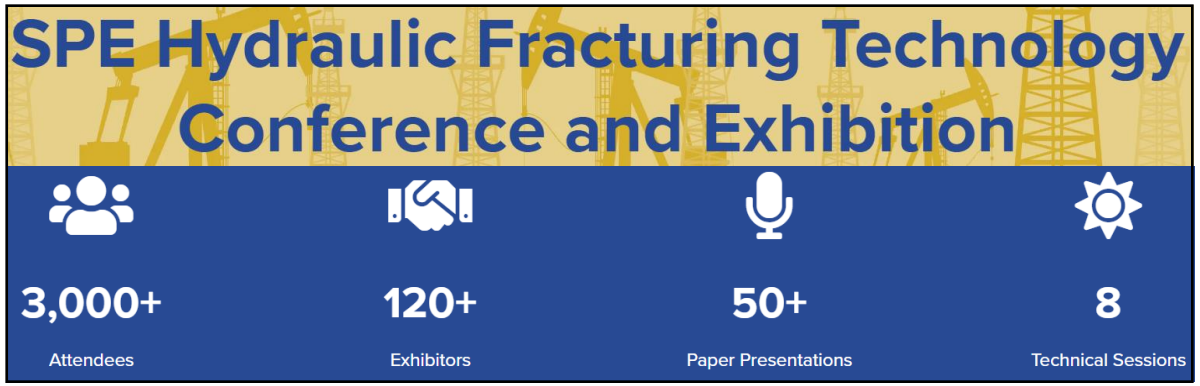
40+
countries

200+
tight oil, shale gas, tight gas and CBM plays

380
operators

- Services available range from aggregation of publicly available data, to data analysis, to in depth research reports
- What data governments require operators to disclose ultimately determines the breadth and depth of services that can be provided
- There needs to be "critical mass" within a resource type for data aggregation companies to initiate coverage (geothermal is for the most part not there yet)
- Extremely efficient way for operators and investors to access knowledge

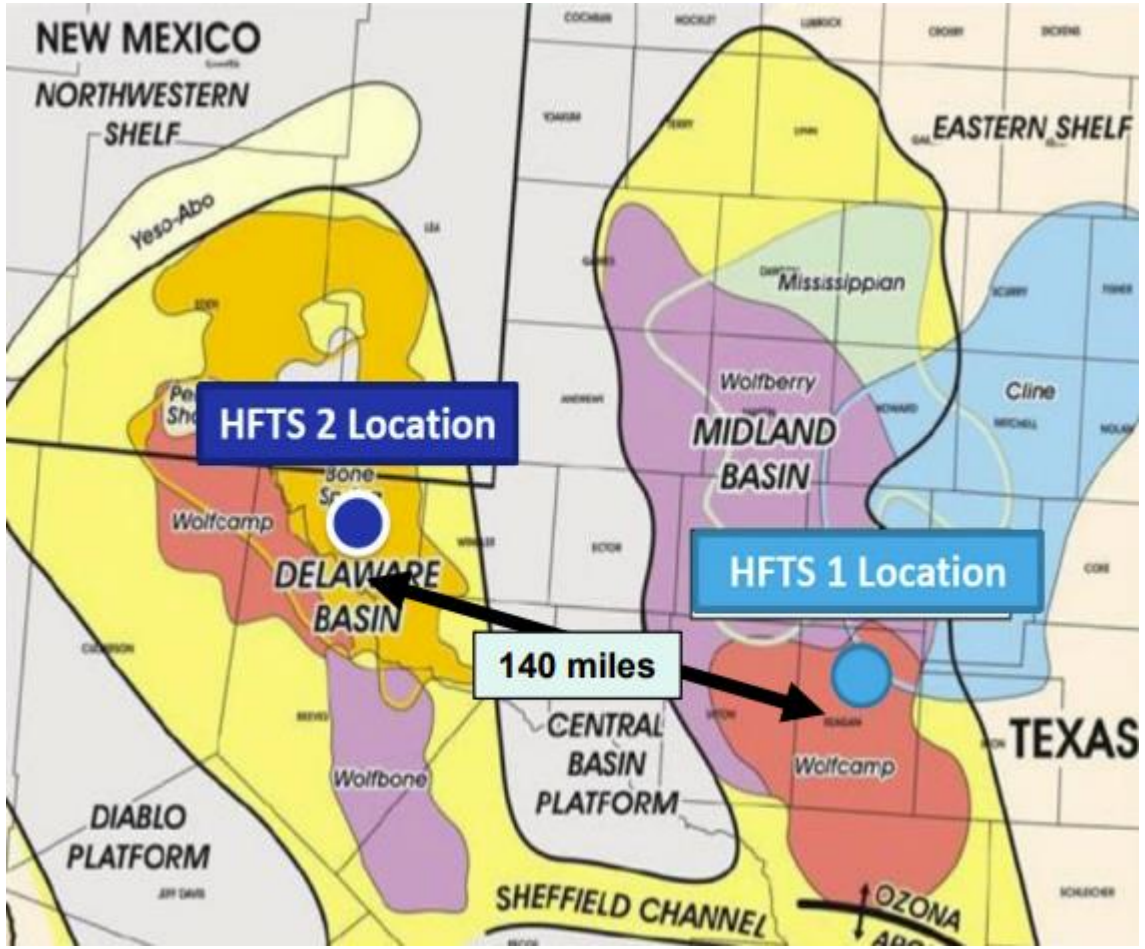
Operating companies being willing to release results and share knowledge via publications and participation in conferences



- Significant support from operators in the form of sponsorship, encouragement for employees to submit papers, and 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

Joint industry-government-academia demonstration projects

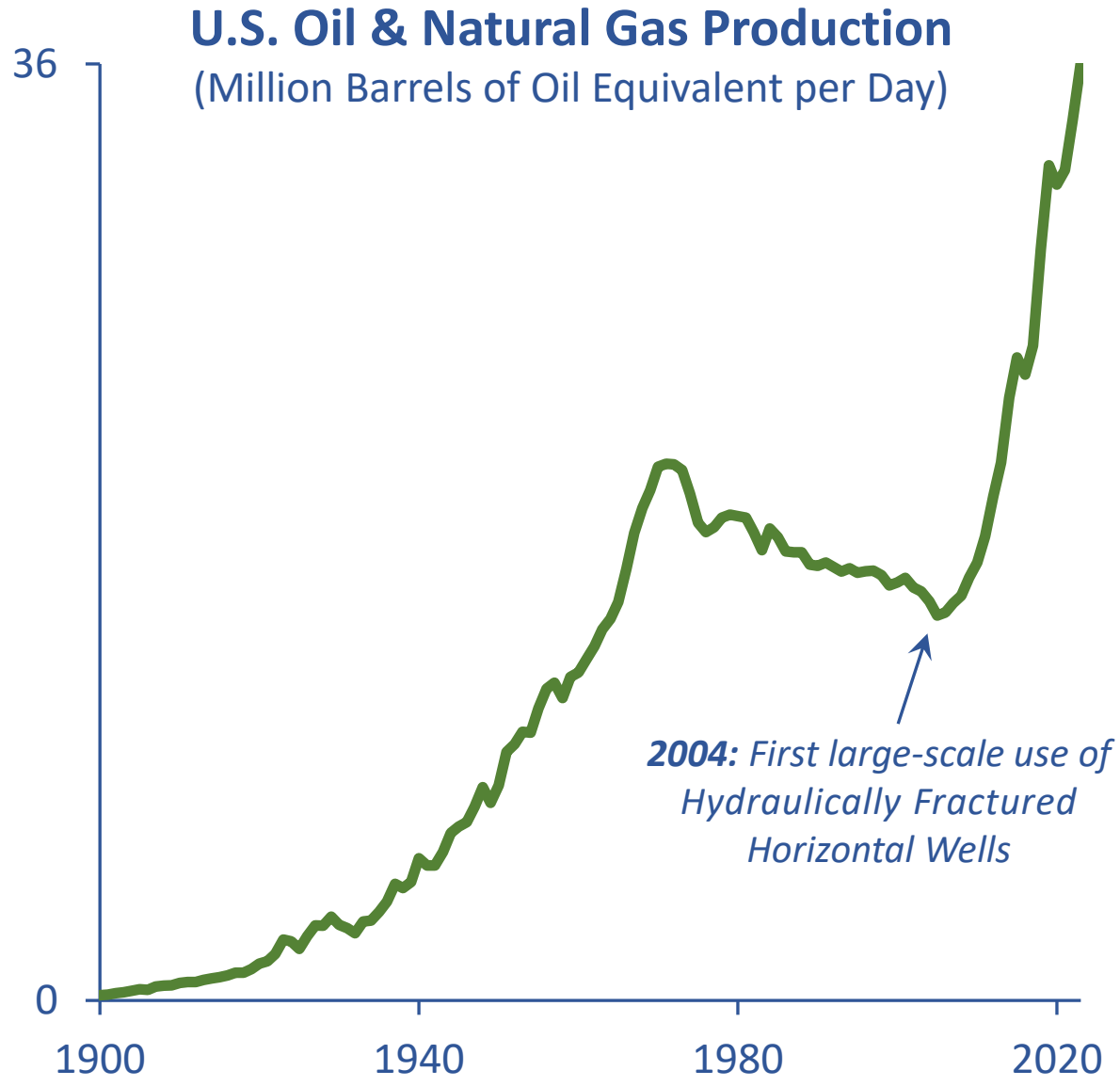


Project	Duration	DOE $	Industry $	Total $
HFTS 1	2014-23	21.5	22.7	44.2
HFTS 2	2018-22	7.8	12.6	20.4

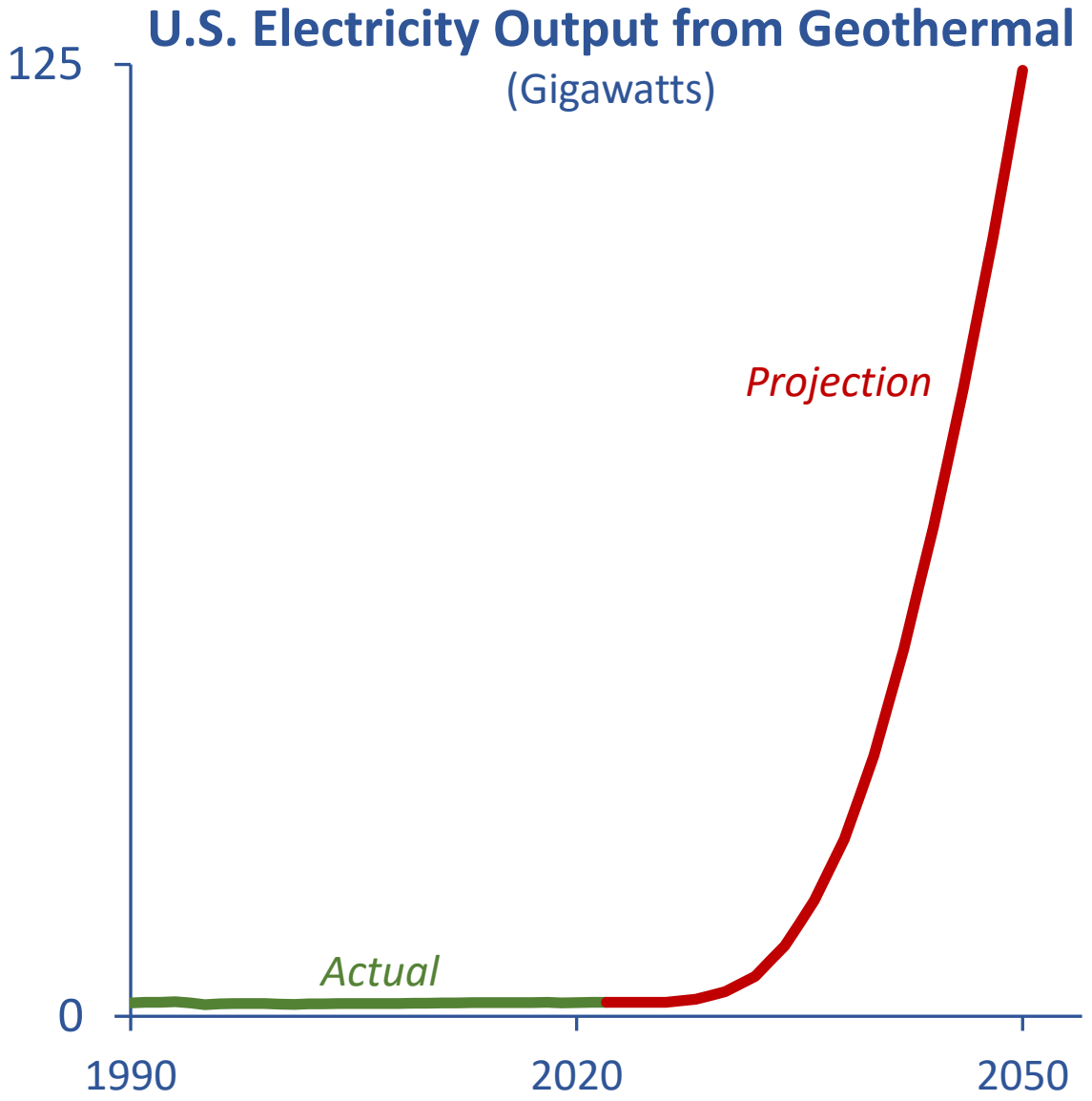
- Hydraulic Fracturing Test Sites 1 and 2 were excellent examples of field-based, high-impact, joint industry-government-academia demonstration projects
- Both projects had a lead operator on whose acreage the projects were executed
- Other operators and government entities provided funding and expertise;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

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

Achieving a similar level of experimentation and knowledge sharing in geothermal would be invaluable for driving rapid growth in power output



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

Rapid Experimentation and Sharing of Knowledge – Two Factors Critical for Delivering Breakthroughs of Enormous Scale

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