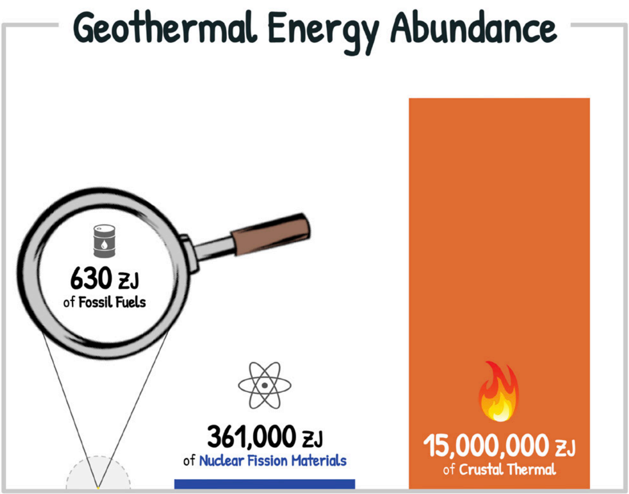
The Future of Geothermal in Texas

THE COMING CENTURY OF GROWTH & PROSPERITY IN THE LONE STAR STATE

Texas, the Geothermal Sleeping Giant, and the Coming Drilling Boom.

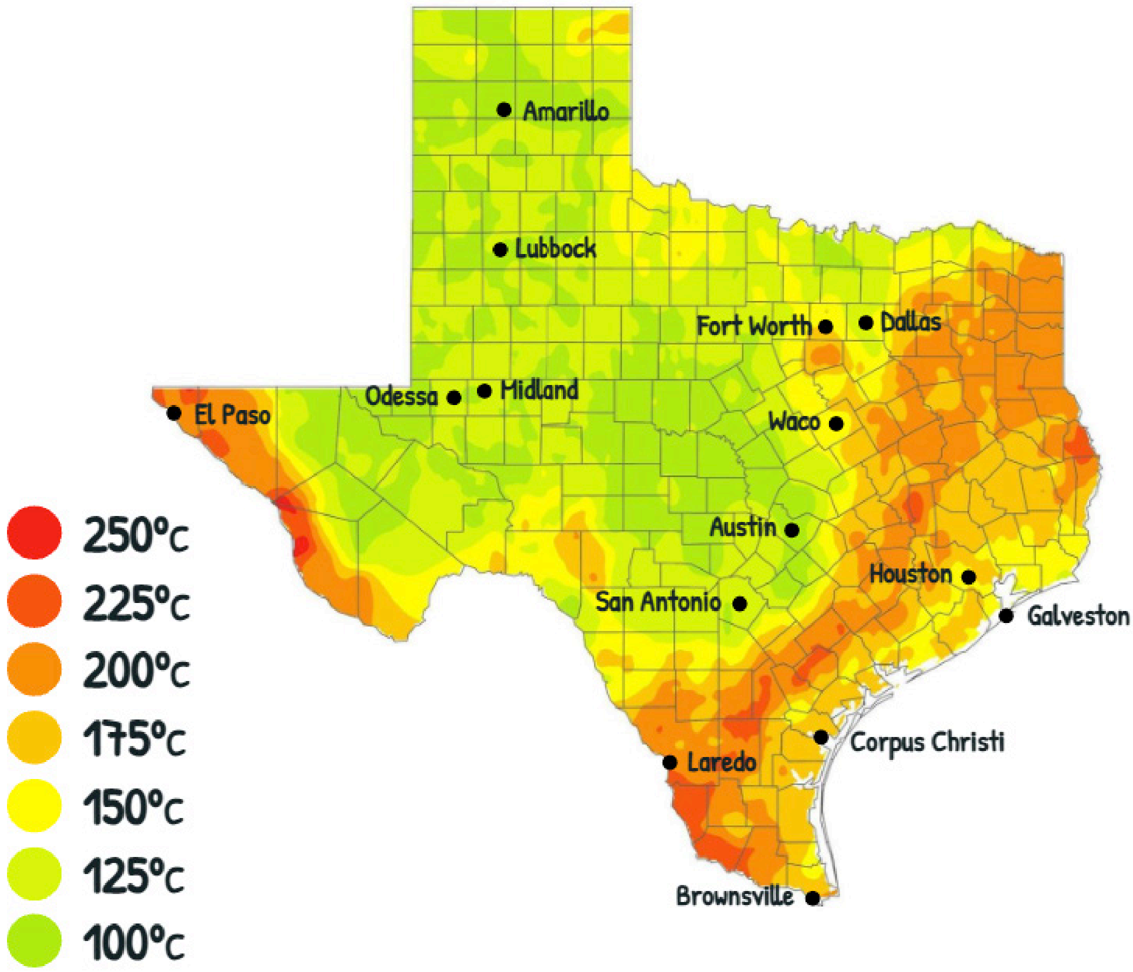
Texas is hot, and it's not just the climate. Texas geologies, including geothermal resources in the State's sedimentary basins, along with the State's status as the epicenter of the oil and gas industry, present a large and promising opportunity to develop geothermal resources in the Lone Star State. The amount of heat energy beneath our feet is estimated to be many thousands of times larger than what we would need to power not only Texas, but the world. Put another way, the oil and gas industry has powered the world through the industrial revolution and into modern times on the much smaller of our two subsurface resources – hydrocarbons and heat.



Comparison of total heat energy in Earth's crust, compared to fissionable materials, and fossil fuels. Note that total fossil fuels, when compared with crustal thermal energy, is the equivalent of less than one pixel at the bottom of the graphic, shown magnified to illustrate scale. Measurements in zettajoules ("zj"). *Source: Adapted from Dourado, 2021.*

What is Geothermal?

The core of the earth is 6,000°C (10,832°F), the same temperature as the surface of the sun. We don't burn our feet when we walk around barefoot outside thanks to the insulative properties of Earth's crust, but anywhere in the world if you drill deep enough, you reach boiling, even supercritical temperatures. At 10 kilometers of depth or shallower, just about every point on earth has sufficient heat for power generation. This massive heat resource is viable for electricity production in much of the State of Texas, including near its major population centers, at approximately 6.5 kilometers, a drilling depth typical in parts of the world within the oil and gas industry. In fact, analysis in this Report and a prior related study concluded that it is likely hotter in the Texas subsurface than previously estimated, by as much as 15 percent. This difference is significant enough to improve both project economics, and technical feasibility of geothermal development in the State.



Temperature of Texas geothermal resources at 6.5 kilometers depth. As mapped, much of the State is at or near conventional minimum viable temperatures for geothermal power generation. *Source: Adapted from SMU Geothermal Laboratory.*

Geothermal energy is clean, always on, ubiquitous, and has a small CO_2 and surface footprint compared with other energy sources.

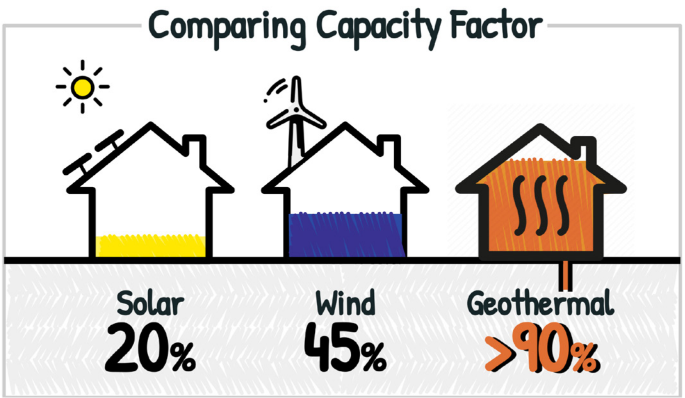
It's Hot in Texas – Above and Below Ground.

The total amount of heat in the upper 10 kilometers (6.2 miles) of the Texas subsurface is approximately one million exajoules. That is 9.4×10^{20} BTU, 163,000 billion barrels of oil equivalent or 2.8×10^{11} gigawatt hours - roughly a million times Texas' annual electricity generation.

Geothermal is Available 24/7.

Contrasted with intermittent renewables like solar and wind, geothermal is firm, or 'baseload', meaning it is always on, and does not require energy storage to operate. In this way, geothermal plays the same role on the grid as coal, nuclear, and natural gas.

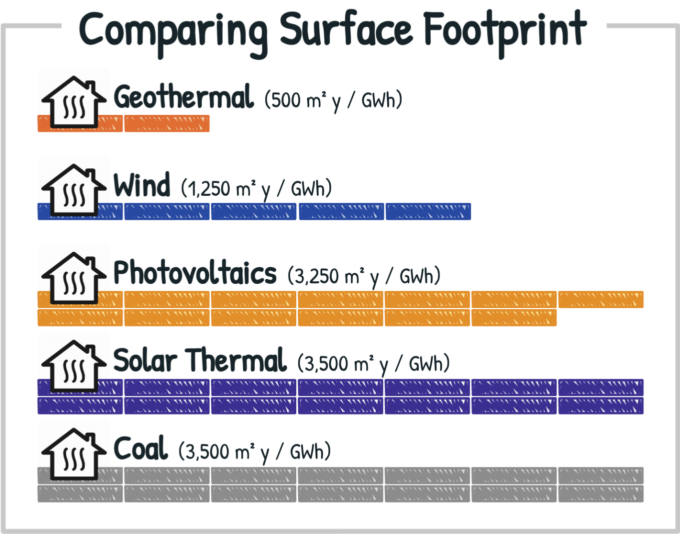
Importantly, geothermal is also quickly scalable leveraging an efficient and lean existing global giant that finds its home in Texas: the oil and gas industry. With purposeful innovation, interdisciplinary collaboration, and bold leadership by the State of Texas, geothermal energy could be quickly scaled into terawatts of output globally, at a cost competitive with solar and wind.



Capacity factor comparison for renewable energy technologies. Capacity factor is the percentage of time that a plant is generating electricity. *Source: Adapted from EIA, 2014.*

Geothermal's Environmental Footprint Shines Compared to Other Energy Sources, Topping Renewables like Solar and Wind.

Geothermal has one of the lowest lifecycle carbon emissions, smallest land footprint, and low water contamination concerns of all renewable energy technologies. Geothermal operations are also weather and attack resilient, since much of the footprint of geothermal operations are located underground (see Chapter 10).

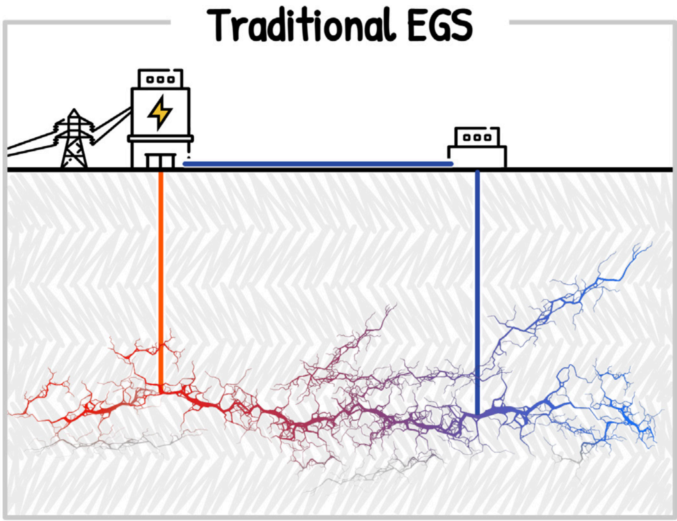


The project surface footprint, acre for acre for one gigawatt of generated power, is smallest with geothermal compared to other renewables and coal. *Source: Adapted from Lovering et al., 2022 and NREL, 2020.*

The Texas Geothermal Innovation Ecosystem is Fast Advancing.

There are three major areas of technology development in scalable geothermal concepts, otherwise known as 'Hot Dry Rock' geothermal, and many of these advancements are happening here in Texas. By scalable, we mean geothermal systems that could feasibly be constructed anywhere in the world, and that are not dependent on the presence of specific subsurface conditions, like rock type, porosity, and the presence of water (see Chapter 9).

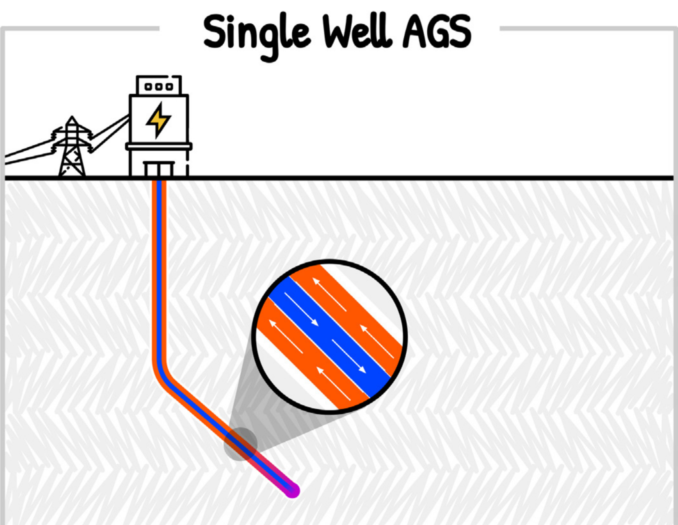
Engineered (or Enhanced) Geothermal Systems ("EGS") are man-made reservoirs, created by the use of hydraulic fracturing techniques to provide pathways through the rock through which fluids can be pumped. Those pumped fluids become heated while they circulate in the subsurface, and are produced to the surface, where they power turbines to generate electricity.



Schematic of a Traditional EGS approach, featuring two vertically drilled wells, with a fracture network connecting them in the subsurface. *Source: The Future of Geothermal in Texas, 2023.*

Closed-Loop Geothermal Systems ("CLGS"), also referred to as Advanced Geothermal Systems ("AGS"), are also man-made geothermal reservoirs like EGS, but they differ in that they operate in a closed loop with no fluid exchange in the subsurface, and they do not utilize hydraulic fracturing.

There are, however, several technology challenges associated with CLGS, including high drilling cost associated with well development, and the need for more advanced and higher temperature drilling technologies to develop the systems in deeper, hotter reservoirs.

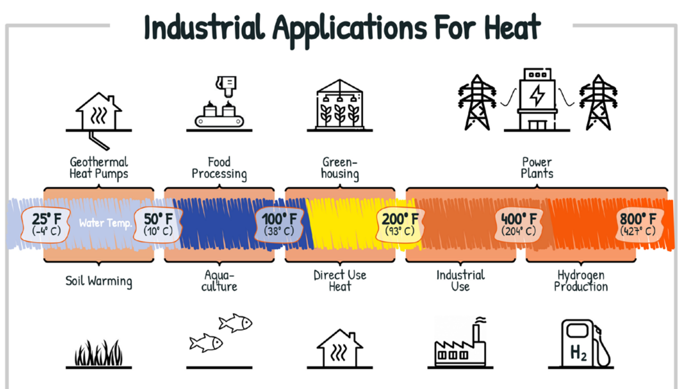


Schematic of a single well, concentric "pipe-in-pipe" AGS concept, demonstrating fluid flow through the system. *Adapted from: Greenfire, 2022.*

The use of CLGS allows for utilization of non-water Working Fluids, such as supercritical CO2, which increase heat harvesting at lower temperatures, a benefit of CLGS.

Finally, there are **Multi-System Hybrids**, like CLGS/EGS combinations, for instance, that couple multiple geothermal system types and features into one system. Entities are working to test and deploy scalable geothermal concepts such as these in the State currently (see Chapter 1).

Aside from electricity production, several of these geothermal concepts can be used for "Direct Use" applications, meaning utilization of produced geothermal heat to directly heat and cool buildings, or for applications that utilize low enthalpy heat, such as agriculture, manufacturing, food processing, and industrial processes. These low enthalpy applications offer a significant opportunity for geothermal to contribute to heat decarbonization of the built environment.

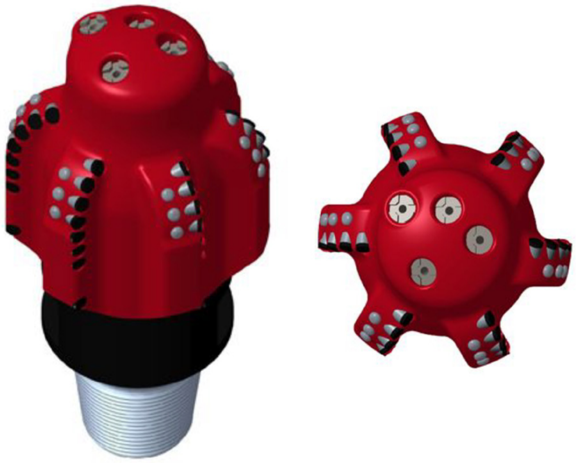


Direct Use applications of geothermal energy. *Adapted from DOE, 2019.*

Direct Use geothermal for heating and cooling historically includes using shallow and low-temperature reservoirs to exchange cold and heat with the subsurface, depending on seasonality and needs. Direct Use systems include both Geothermal Heat Pumps ("GHP") for buildings, and more recently, networks of wells for clusters of buildings, agriculture, aquaculture, food processing, and other light industry. Industrial heat pumps are also gaining popularity, providing heat for industrial processes like cooking, sterilizing, drying, preheating of boiler feed water, and many more. Direct Use systems are a mature, well-established technology, but will benefit from spillover of oil and gas technologies and know-how (see Chapter 2).

Oil and Gas Technology and Methods Transfer in Action:

Texas based oil and gas technology company NOV became the latest example of the impact of oil and gas technology and know-how transfer into geothermal when they deployed a team to a U.S. Department of Energy geothermal test well, and drilled the well in half of the allotted time utilizing a bit design ubiquitous in the oil and gas industry.



The Particle/PDC drill bit, combining leading edge PDC technology with an innovative steel shot drilling method. *Source: Image from NOV.*

Why Geothermal in Texas Now?

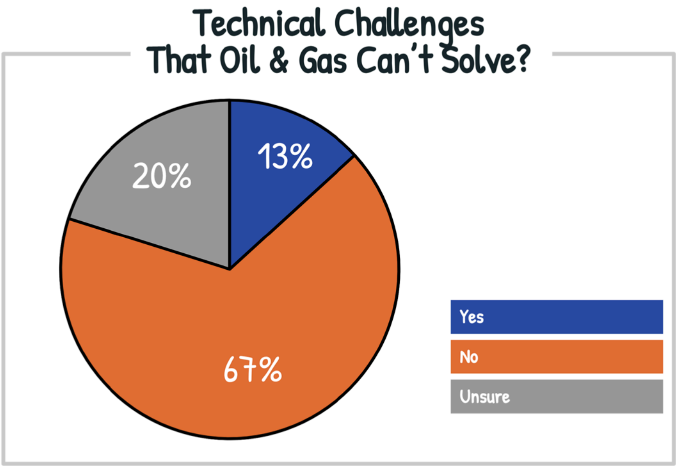
Over the past two decades within the oil and gas industry, there have been significant and enabling technology improvements as a result of deepwater oil and gas exploration, and the invention of directional drilling technologies and hydraulic fracturing techniques, the enabling features of the "shale boom".

New technologies and methodologies emerging from and perfected over the past 20 years in the oil and gas industry, such as horizontal drilling, multi-stage fracturing, and managed pressure drilling, have proven so disruptive that over the past decade they have rearranged global geopolitics and propelled the United States into energy independence. But these disruptive technologies and methodologies have just barely begun to be applied in the geothermal context, and when they are applied through oil and gas industry engagement in geothermal, we should expect, and even plan for, breakthrough impact, and fast, exponential leaps in capabilities and performance in the years to come.

Curiously, most if not all geothermal focused vision statements and analyses over the past years have failed to consider the swift impact oil and gas industry engagement would have in geothermal development, deployment, and scale over the coming decades. As a result of either underestimation, or failure to acknowledge the impact of technology transfer, fast innovation, and engagement at scale by the oil and gas industry, projected geothermal growth lingers consistently in the single or low double digits over the coming decades in energy transition reports and models. These numbers have failed to inspire entrepreneurs, funders, governments, the media, civil society, and even the oil and gas industry to recognize the sleeping clean energy giant beneath our feet as a potentially significant player in the energy transition. This dynamic presents Texas a unique opportunity to lead.

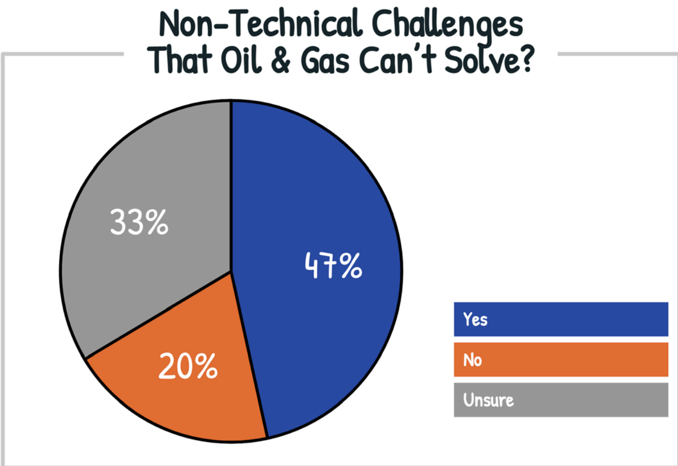
Much like the rise of unconventionals in oil and gas, whose meteoric ascent largely took the world by surprise, geothermal is poised for similar, exponential growth, should technology development and transfer follow the footsteps of the shale boom. Given increasing oil and gas industry engagement in geothermal, this is a possibility that should no longer be overlooked as the world searches for energy transition strategies.

Almost 80 percent of oil and gas entities interviewed for this Report stated that they now have a geothermal strategy in place or in development, and almost 70 percent noted that there is no geothermal related technical challenge that the oil and gas industry cannot solve.



Nearly 70 percent of oil and gas entities interviewed for this Report believe there is no technical geothermal related challenge that the oil and gas industry will not be able to solve. *Source: Future of Geothermal Energy in Texas, 2023.*

When oil and gas entities were asked if there were non-technical challenges associated with geothermal that the oil and gas industry will not be able to solve, many more entities expressed that there were indeed non-technical challenges that may be unsolvable by industry. These concerns, listed in order of those most frequently raised, were 1) regulatory and permitting issues, 2) legal uncertainty, 3) social license issues, and 4) lack of funding for pilots and essential research. These are areas that should be the focus of policy-makers looking for ways to support the growth and development of geothermal energy (see Chapter 6).



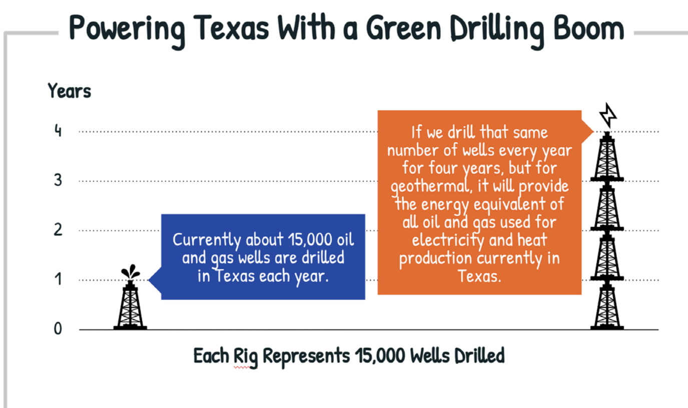
Oil and gas entity responses when asked if there were "non-technical" geothermal challenges that the oil and gas industry could not solve. *Source: Future of Geothermal Energy in Texas, 2023.*

Oil and Gas Industry Engagement in Geothermal is Expected to Have Breakthrough Impact on Cost, Efficiency, and Scale.

Geothermal and upstream oil and gas developments have many overlapping features. Both require a detailed understanding of the subsurface, the drilling and completion of wells, the ability to understand and predict fluid flows in the subsurface, the handling of fluids for flow assurance, and management of large-scale project developments. Technologies that share similar ancestry, such as geothermal and upstream oil and gas, may have the potential to achieve a radical, "step change" style innovation by building on each other's strengths and resources.

Historically, Texas industry and academia have helped to expand the frontiers of oil and gas production, and boost the efficiency of extraction. For example, the unconventional oil and gas revolution began in the 1990s with Mitchell Energy's focus on the Barnett Shale in Texas, and as unconventional drilling techniques were applied in the Permian Basin, production increased substantially. Today, Texas is the fourth largest oil producing entity in the world. As the world increasingly looks to transition to clean energy, geothermal energy, with its synergies with the oil and gas sector, has become a natural focus area for the oil and gas industry. **Researchers in this study concluded after analysis that through know-how and existing technology transfer alone, the oil and gas industry could reduce the cost of geothermal development between 20 to 43 percent, depending on the type of geothermal technology, in the coming years** (see Chapter 5).

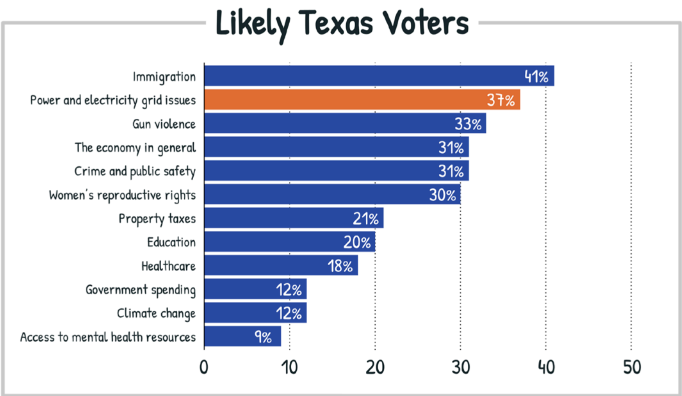
As an example of the fast scale in Texas that the oil and gas industry could help geothermal achieve: industry currently drills approximately 15,000 oil and gas wells in the State each year. **Should the industry drill 15,000 geothermal wells each year for four years, it would provide the energy equivalent of all oil and gas used for electricity and heat production in the State today, including industrial heat. An aggressive geothermal drilling program at 'home' such as this may serve to free up Texan natural gas for export, instead of being required for domestic electricity production** (see Chapter 7).



A graphic illustration of the potential for a geothermal drilling boom in Texas. It would take approximately four years of drilling at the rate Texas currently drills for oil and gas to produce the equivalent energy of all oil and gas used for electricity and heat production currently in the State from Texas' geothermal resources. *Source: Future of Geothermal Energy in Texas, 2023.*

What Does the Texas Public Think?

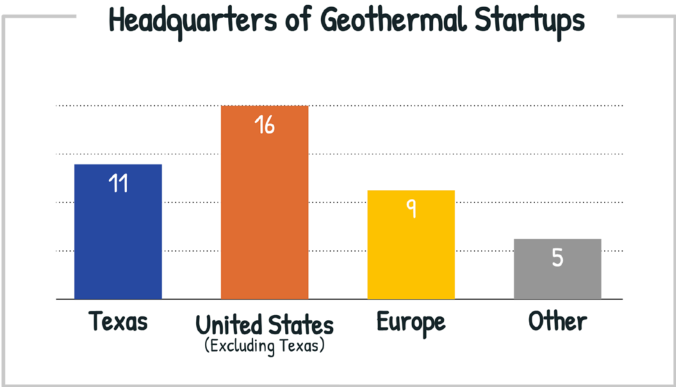
It's not just industry who is eyeing geothermal as an option for Texas' energy future. Recent polling data shows that Republican, Democrat, and Independent voters all support a greater emphasis on developing policies that seek to empower and deploy geothermal technologies. In a September 2022 survey of Texas voters, the second highest policy concern, behind immigration, was power and electricity grid issues, and 73 percent of Texas voters support investments into new energy technologies that will alleviate periods of high stress on the electric grid and high energy demand in Texas. Additionally, geothermal energy has the lowest unfavorable ratings compared to all energy sources among Texas voters, making geothermal a uniquely bipartisan energy solution.



Top policy concerns for Texas voters during the 2022 midterm elections. Concerns about the electrical grid in Texas are second only to immigration as top of mind for Texas voters. *Source: Adapted from DFP, 2022.*

The Quickly Growing Texas Geothermal Startup Ecosystem.

Geothermal entrepreneurship has entered a period of renaissance, with more geothermal startups launching over the past 2 years than in the past 10 years combined, many buoyed by oil and gas investments, and a majority being led by life-long oil and gas industry veterans. Several of these companies are planning or currently deploying pilot projects and demonstrations in Texas.



Location of geothermal startups between 2016 and 2022. *Source: Future of Geothermal Energy in Texas, 2023.*

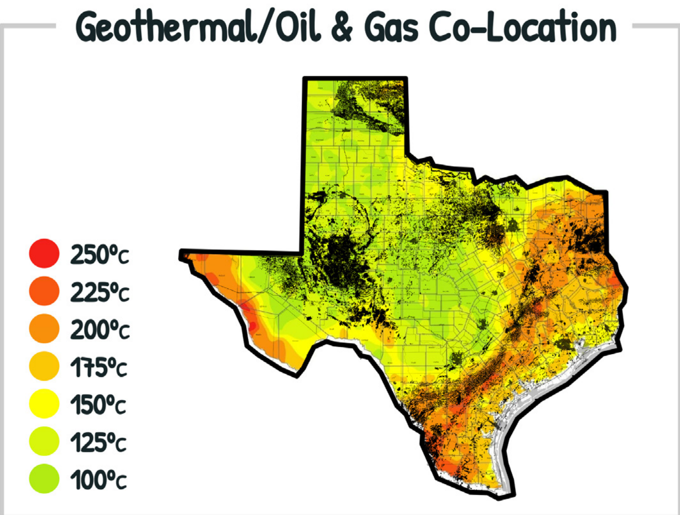
There are at least 11 geothermal startups headquartered in Texas currently, with many more maintaining a business presence, employees, or planning projects in the State. All of these entities have oil and gas industry veterans in their ranks, with a majority founded and led by life-long veterans hailing from entities like ExxonMobil, Shell, Weatherford, Anadarko, Schlumberger, and bp. Almost 90 percent of these startups were founded and launched in the last 24 months (see Chapter 9).

Sage Geosystems, a startup launched in 2020 with an all oil and gas industry executive team began a field demonstration in 2021 of their geothermal concept on an existing oil and gas well near McAllen, Texas. The demonstration is currently ongoing.

A Sage Geosystems demonstration project in 2022, located near McAllen in South Texas. *Source: Sage, 2022.*

A Unique Geothermal Application for the Lone Star State: Oil and Gas Well Reuse.

It is estimated that an average of 25 billion barrels of warm and hot water is produced annually from oil and gas wells within the United States. This "co-produced" water must be managed and disposed of, adding significant operational costs. Geothermal energy can be produced from existing oil and gas wells, as either electricity or Direct Use heat, depending on the location, subsurface properties, well parameters, and other factors (see Chapter 3) .



Existing oil and gas wells in Texas (black dots) overlaid onto geothermal resources. *Source: Future of Geothermal Energy in Texas, 2023.*

Synergies Between Three Areas of Texas Excellence: Geothermal, Defense, & Space.

The aerospace industry and its developments in extreme temperature materials holds the potential to increase the depth and temperature of geothermal projects, positioning it as a viable firm energy source for widespread deployment on the Texas grid. Technologies developed at the National Space and Aeronautics Administration ("NASA") and the Department of Defense ("DOD") may benefit the industry greatly as we look to realize the impact of this large and ubiquitous energy resource beneath our feet.

Geothermal and National Security.

The construction of geothermal power plants "inside the wire" of DOD military installations through the deployment of proven and emerging geothermal technologies provides an impactful solution to DOD's current dependence on civilian power grids, with a cost-effective, resilient clean energy that is less vulnerable to attack and natural disaster. These plants possess significant advantages over commercial power from off-site or other on-site solutions:

- **Physical Security:** Location inside the perimeter of military installations is more secure and includes the ability to easily ramp-up security as needed under threat warning;
- **Baseload Energy Supply:** Geothermal power is "always on" and can be load following;
- **Self-Contained:** Unlike conventional standby generators, no outside fuel resources for resupply are needed, with decades-long operational lifetimes, and relatively low operations and maintenance costs;
- **Scalable:** If more power is needed, in many cases, more wells can be drilled;
- **Safe:** No combustion or radioactivity is involved in operation;
- **Green, Clean, and Renewable:** AGS and some Hybrid Geothermal Systems are expected to emit little or no pollution/greenhouse gasses, and have the potential to be carbon-negative through sequestration of additional carbon in the heat-exchange path; and
- **Electro-Magnetic Pulse ("EMP") Resiliency:** Extremely short electricity transmission distance to load (co-location) greatly reduces vulnerability to EMP induced power surges.

Geothermal Power in Space.

Texas is and has been a leader in government, and now also in private, space technology development and exploration. Texas is also steering into the new geothermal paradigm. Combining these two areas yields a potential future market for geothermal deployment in space. The aerospace, oil and gas, and geothermal industries have developed remarkable technologies, which have been advancing the possibilities within their individual domains. There may be no better time than now to unlock the potential that we have in establishing Texas as the leader in geothermal power through inter-industry collaboration and technology transfer, leveraging Texas' legacy industries (see Chapter 8).

The U.S. Air Force has described geothermal as a first priority energy solution for base energy innovation (OEA, 2022), and a critical solution to address energy reliability and resiliency at military installations around the world.

Geothermal is Complementary, Not Competitive, With the Texas Oil and Gas Industry.

Substantially increasing the availability of a firm clean energy like geothermal in the State of Texas could free up natural gas that would have been utilized for domestic energy production for export, in support of allies in search of solutions to energy market instability.

Geothermal and the Resilient Texas Grid.

In ERCOT, the addition of new power generation capacity is currently dominated by three mature technologies: onshore wind turbines, utility-scale solar photovoltaic panels, and natural gas power plants. After the deadly Winter Storm Uri in February 2021, political and consumer preference emphasized reliability with greater attention, and Texas legislators and other officeholders signaled their desire for more firm sources of power, such as gas power plants, to be built in Texas.

No coal plants and only two nuclear reactors are under construction nationwide, and neither is likely to be added in Texas in the next decade due to high costs and other concerns. Most battery facilities are being built with one or two hour dispatch times, which can help smooth short-term imbalances, but not cover multi-day events like Winter Storm Uri. This leaves natural gas and geothermal as the two most likely candidates for adding firm, yet dispatchable resources in Texas, placing geothermal in a uniquely impactful role (see Chapter 11).

The Coming Century of Growth and Prosperity Following a Uniquely Texan Playbook.

For over 100 years, policy-makers in Texas have supported the development and growth of the State's energy industries. This support began when the State legislature gave the Texas Railroad Commission ("RRC") jurisdiction to regulate the production of oil and gas in 1919. In the early 2000s, hydraulic fracturing (more commonly known as frac'ing), and innovations in horizontal drilling led to a new era of oil and gas development in the United States, with Texas once again leading the way. Similarly, geothermal offers a valuable political solution for Texas policy-makers.

Geothermal is Naturally Bipartisan.

Geothermal sits in a rare political and social space in an increasingly polarized political and policy climate. It is on the precipice of gaining significant political support from policy-makers across the ideological spectrum, who see specific aspects of interest for their constituents, in which their values can be realized through the development and deployment of geothermal technologies. In Texas, terms such as resilience, energy independence, security, workforce transition, drilling, and baseload are used to describe the attributes of geothermal. Environment and climate organizations, on the other hand, are attracted to geothermal because it is a clean, ubiquitous, small footprint, and limitless source of renewable energy that could be deployed to help achieve climate and environmental goals. These narratives describe the same unique energy source, but with different political and cultural constituencies using different languages, narratives, and terminologies to describe why they support it. This presents an extraordinary and unique regulatory and political opportunity for geothermal, where even the most polarized political adversaries may find themselves both in support of the same geothermal effort. Policy-makers from both sides of the aisle can support the growth of geothermal in Texas by taking actions like:

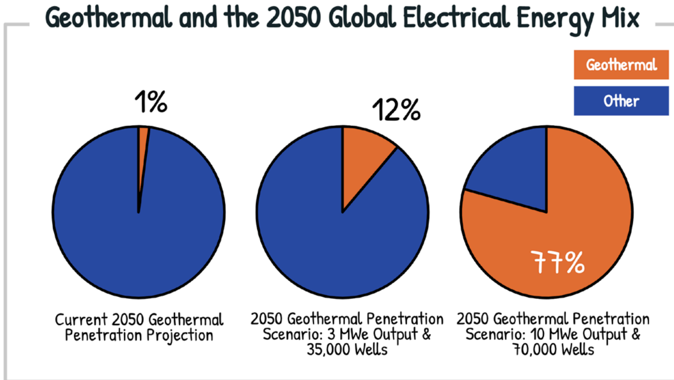
Recommendations for Policy-Makers to Support Growth of Geothermal in Texas.

- Convene geothermal-specific legislative hearings to learn about geothermal technologies and applications;
- Clarify the issue of heat ownership to provide certainty for developers;
- Establish a risk mitigation program for geothermal developers;
- Build Levelized Avoided Cost of Electricity into ERCOT and RRC valuations of energy systems;
- Build a geothermal heating and cooling (Direct Use) grant program for agriculture and manufacturing;
- Build and support workforce training and transition programs from oil and gas into geothermal (see Chapter 12).

Geothermal and Our Global Energy Future:

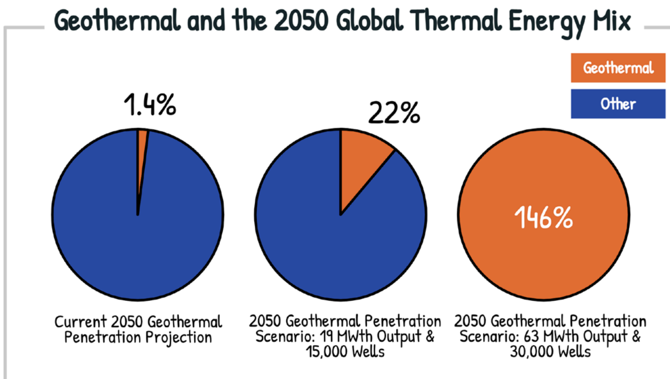
This Report frames the conversation about the future of geothermal to the upper limits of possibility, placing the technical, policy, legal, and scaling barriers of geothermal onto the backdrop of the Lone Star State, where "everything is bigger" - and asking the question - how would the millions of innovators, policy-makers, entrepreneurs, oil and gas workers, academics, other stakeholders, and industry entities in the State nurture and grow this resource, as they did the oil and gas industry.

With robust leadership by both Texas and ecosystem stakeholders, geothermal could play a globally significant, and even dominant role in the future energy mix. Researchers in this study calculated multiple growth scenarios for geothermal development placed in the context of the scale of the oil and gas industry, and found that **drilling 1.4 million wells globally between 2030 and 2050 could meet 77 percent of the world's projected electricity demand.**



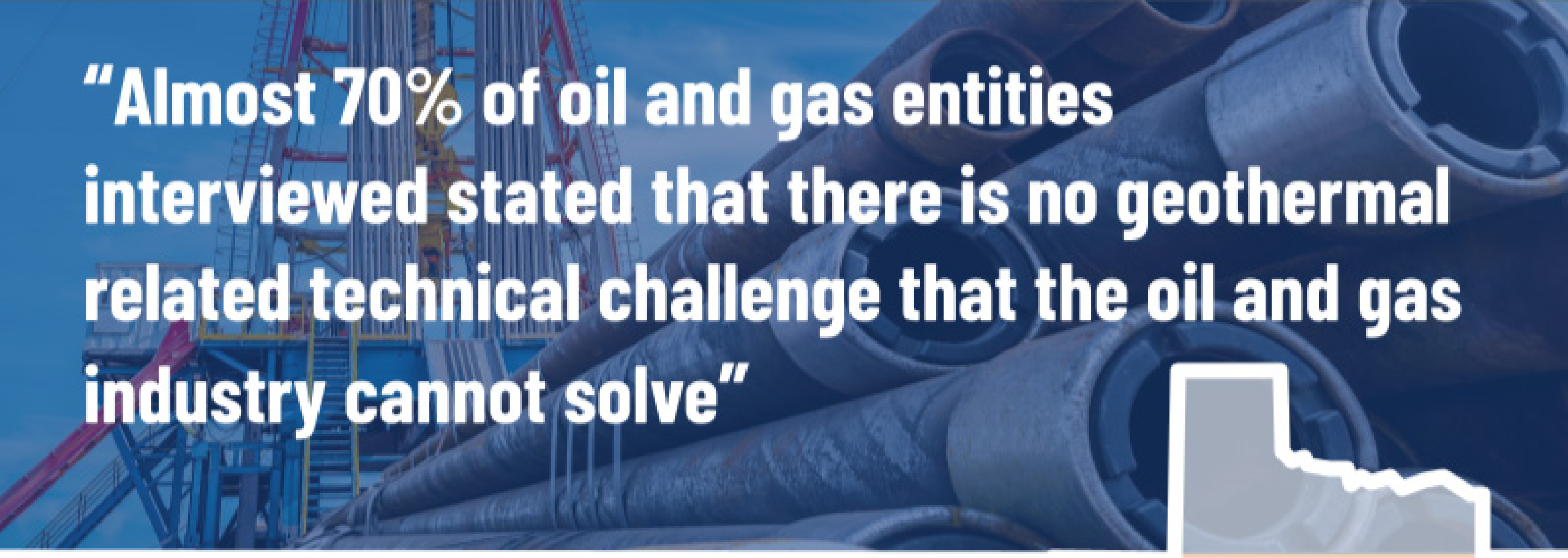
2050 geothermal electrical energy contribution to the global energy mix under three calculated scenarios: 1) current IEA projection (left), 2) scenario of 35,000 geothermal wells drilled per year from 2030-2050, having three megawatts electric per well output (middle), and 3) scenario of 70,000 geothermal wells drilled per year from 2030-2050, having ten megawatts electric per well output (right). *Source: Future of Geothermal in Texas, 2023 and IEA, 2022.*

Further, turning to the world's 2050 demand for heat, researchers found that **drilling 600,000 wells globally between 2030 and 2050 could meet more than 100 percent of the world's projected demand for thermal energy** (see Chapter 7).



2050 geothermal thermal energy contribution to the global energy mix under three calculated scenarios: 1) current IEA projection (left), 2) scenario of 15,000 geothermal wells drilled per year from 2030-2050, having 19 megawatts thermal per well output (middle), and 3) scenario of 30,000 geothermal wells drilled per year from 2030-2050, having 63 megawatts thermal per well output (right). *Source: Future of Geothermal in Texas, 2023 and IEA, 2022.*

While an "Apollo Mission" style mobilization of industry globally to achieve the levels of development reflected in the illustrations above would require an approach to speed and scale that would rival the greatest of human achievements, an "all hands on deck" approach to geothermal development, as we see in the above hypothetical scale estimates, would result in massive, globally transformative outcomes for geothermal in the world's energy mix by 2050, and contribute to rapid global decarbonization.



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