Chapter 11

Geothermal, the Texas Grid, and Economic Considerations

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Geothermal energy offers environmental and performance benefits to the power sector in Texas, and will gain market share if technology transfer and cross over learnings from the oil and gas industry can be leveraged, along with new innovations, to drive down installation and operating costs.

I. Introduction

This Chapter focuses on the Texas grid and the future role geothermal might play in Texas, with consideration of the potential economic impacts, cost reductions, and knowledge transfer from oil and gas, and how those reductions could accelerate geothermal market share in a decarbonizing Texas grid. The Chapter will begin with a discussion of the structure of the Texas grid, a configuration unique to Texas, and explore the political realities of energy in Texas. Next, we will dig into the impact of gas on the global economy, and the geopolitical considerations of geothermal development in the Lone Star State. Later in the Chapter, we consider the impact of technology and knowledge transfer from the oil and gas industry into the geothermal industry, including a discussion about the learning spillover effect analyzed in Chapter 5, The Oil and Gas Industry Role. We will conclude with a discussion about the impact the growth of geothermal in Texas could have on the Texas workforce.

II. The Structure of ERCOT

Three electricity jurisdictions called Interconnections service the continental United States. These Interconnections monitor and balance the flow of electricity from generation sites (i.e., power plants) to load centers (i.e., where electricity is consumed such as cities, towns, industrial plants, data centers, farms/ranches, manufacturing facilities, etc.).

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The Three U.S. Interconnections Include:

- The Eastern Interconnection, which operates primarily in states east of the Rocky Mountains;
- The Western Interconnection, which operates mostly in states west of the Rocky Mountains;
- The Texas Interconnected system, which is wholly contained within Texas' borders.

Texas is the only jurisdiction in the contiguous United States that manages and operates its own bulk grid, presenting a unique case study for the deployment of geothermal.

There are "ties" between Interconnection systems, which allow electricity to flow within and between these three Interconnection systems. These ties are high-voltage direct current power transmission lines that allow limited amounts of electricity to flow between Interconnections. These pathways, or redundancy, are built into the system to balance and minimize loss of service due to localized failures from weather events, maintenance, or other external factors.

There are four weak ties to the Texas Interconnection; two to the Eastern Interconnection (near Oklaunion and Monticlello), and two to Mexico. The ties into the Texas Interconnection carry between 200 and 600 megawatts when at full capacity (Hartmann, et al., 2020). There are no ties between the Texas and Western Interconnections. There are six ties between the Eastern and Western Interconnections.

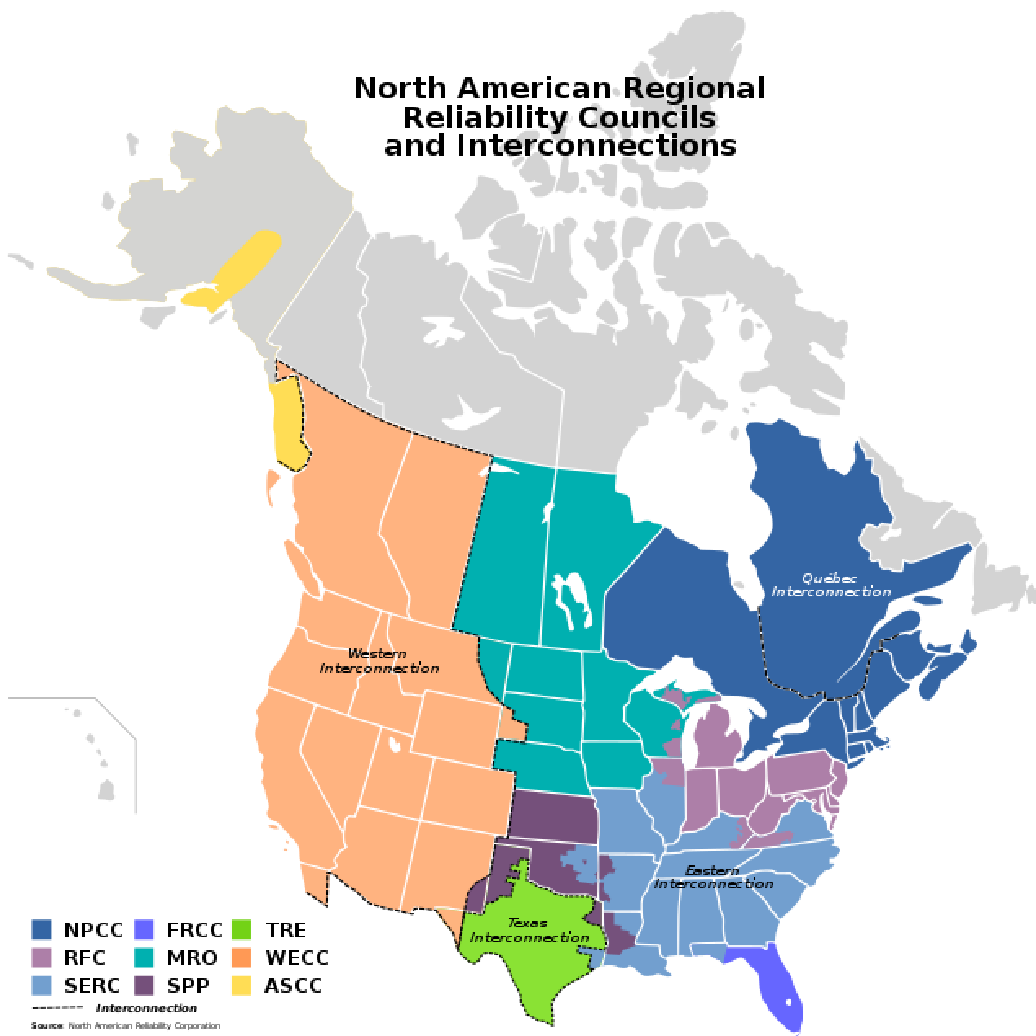


Figure 11.1. Depicts the four Interconnections and nine regions of the electrical grid in North America. *Source: Bouchecl, 2009.*

Additionally, there are several regions and subregions within the three major Interconnections. The Electric Reliability Council of Texas ("ERCOT") can be viewed as its own interconnected system, region, and subregion within the North American electrical grid, making it a configuration that is unique to Texas (Figure 11.1).

ERCOT manages 90 percent of the electricity load in Texas, and supplies power to 26 million Texans (ERCOT, 2022b). ERCOT is a 501(c)(4) nonprofit corporation with a board of directors that provides operational structure. The Public Utilities Commission ("PUC") of Texas, along with the Texas legislature, have oversight responsibilities of ERCOT. ERCOT is composed of members that include investor owned electric utilities, independent generators, municipally owned electric utilities, electric cooperatives, independent power marketers, retail electric providers, transmission and distribution providers, and consumers (ERCOT, 2022a).

The ERCOT grid has been evolving in response to changing customer preferences, and fuel and technology costs. Figure 11.2 shows the evolution of ERCOT fuel mixes from 2006 to 2020. Currently, 36 percent of the ERCOT grid's electricity is derived from zero-carbon sources (wind, solar, nuclear), with the majority of the remainder generated by gas and coal. The U.S. Energy Information Administration projects that nearly 50 percent of ERCOT's generation will come from zero-carbon sources by the end of 2023. While the portion of generation from gas has stayed relatively constant over time, electricity production using coal has decreased by approximately 52 percent from 2006 to 2020. Even as total Statewide electricity generation has increased, the evolving generation mix has facilitated an overall drop in emissions from the electric power sector (Campbell & Hattar, 1991).

As a result of variability in power plant availability and dynamic load, there is a need for flexible demand, greater grid connectivity between regions, energy storage, and/or firm (e.g., "dispatchable") sources of low-carbon generation for grids to remain stable. Firm energy is defined as the ability to turn on and off at will, or controllable (Sepulveda, et al., 2018). Geothermal is particularly appealing, as it is a firm and flexible source of electricity with no direct emissions that can balance the growth of solar and wind generation in the Texas electricity sector. But while each of the energy sources in Figure 11.2, as well as geothermal, which is not represented in the Figure, could play a part in the Texas grid of the future, how the grid ultimately evolves will depend significantly (though not exclusively) on costs.

There are currently no geothermal power plants located in Texas. A small scale (about one megawatt) Hybrid Geothermal System on the Texas Gulf coast provided power to a local utility for one year in the early 1990s, as part of a demonstration project that ended and shut down the plant (EIA, 2022).

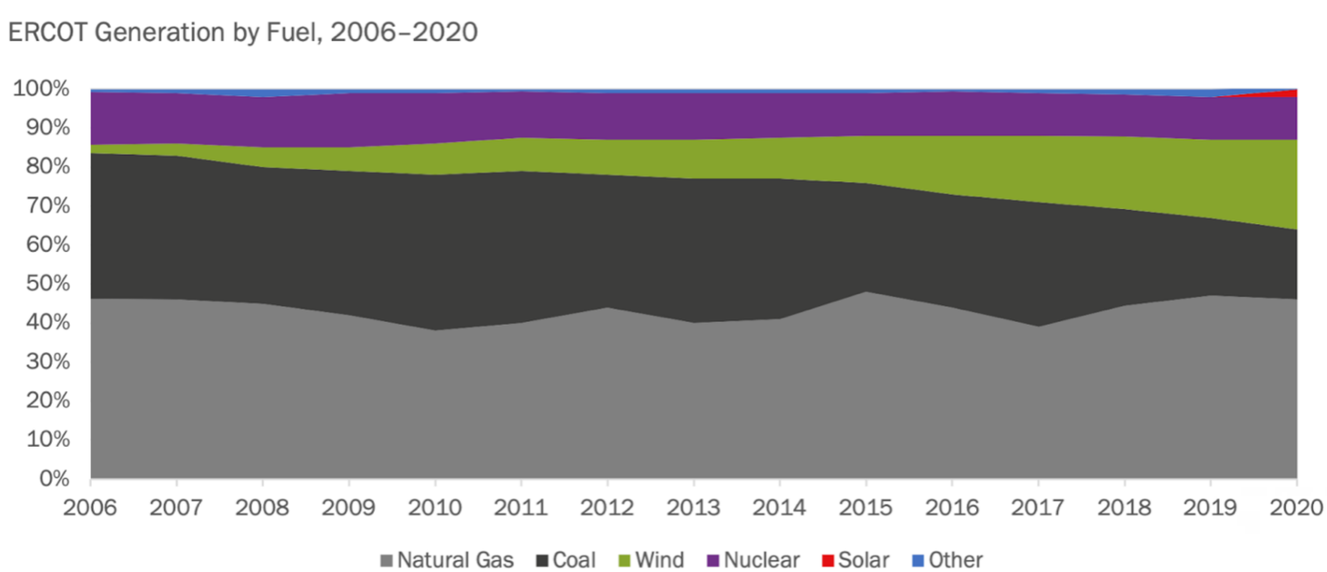


Figure 11.2. Percentage of electricity generation by fuel type in ERCOT from 2006 to 2020. *Source: Rhodes, 2021.*

III. Energy Independence and the Lone Star State

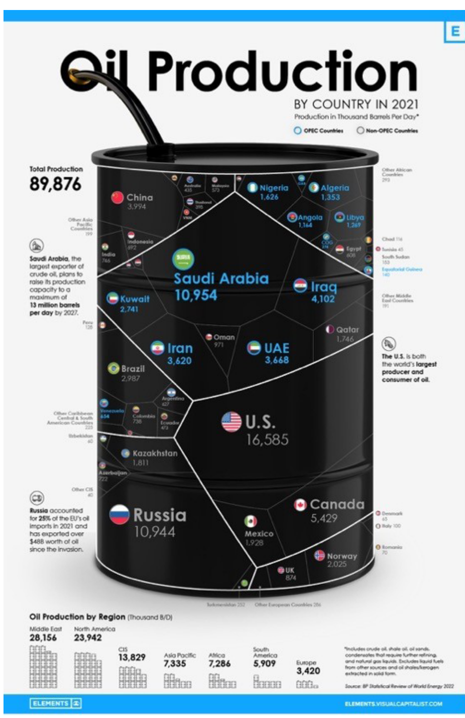
Texas has a deep and rich culture as an energy producer. The State literally and figuratively fuels the economies of not only the United States, but also the world. In 2021, according to the EIA, Texas produced 43 percent of the oil and gas in the United States (EIA, 2022). Texas is the fourth largest oil producing entity in the world, behind Saudi Arabia, Russia, and the rest of the United States, and the third largest producer of gas, behind Russia and the rest of the United States (Figure 11.3). In Texas alone, the Texas Oil and Gas Association estimates that the oil and gas industry, during fiscal year 2021, supported more than 422,000 direct jobs, and paid $15.8 billion in State and local taxes and State royalties, funding Texas' schools, roads, and first responders (TXOGA, 2022). Additionally, energy produced in Texas helps support energy independence and national security for the United States, and more recently, for allies who are attempting to reduce their dependence on Russian gas imports (Collins, et al., 2022).

Social license to operate in the State is an important enabler for Texas' robust energy industry. The oil and gas industry enjoys broad acceptance amongst the Texas population, with many residents working directly or indirectly for the industry. This social license to operate and a supportive culture for industries engaged in drilling or other subsurface activities sets Texas apart, and provides an advantage when considering the growth and development of geothermal in the State.

A. The Politics of Power in Texas

In ERCOT, and many other electric grids, the addition of new power generation capacity is currently dominated by three mature technologies: onshore wind turbines, utility scale solar photovoltaic panels, and gas power plants (ERCOT, 2022c). These deployments, especially wind and solar, are largely driven by low installation costs, short permitting times, and customer demand for clean energy sources.

After the deadly Winter Storm Uri hit Texas in February 2021, political and consumer preference emphasized reliability with greater attention. Uri dramatically surpassed the parameters of ERCOT's seasonal planning, bringing prolonged freezing temperatures, ice, and snow, which caused upstream and downstream energy assets in Texas to go offline (Potomac Economics, 2022). All major types of power generation were forced at least partially offline during the five day storm, including gas,



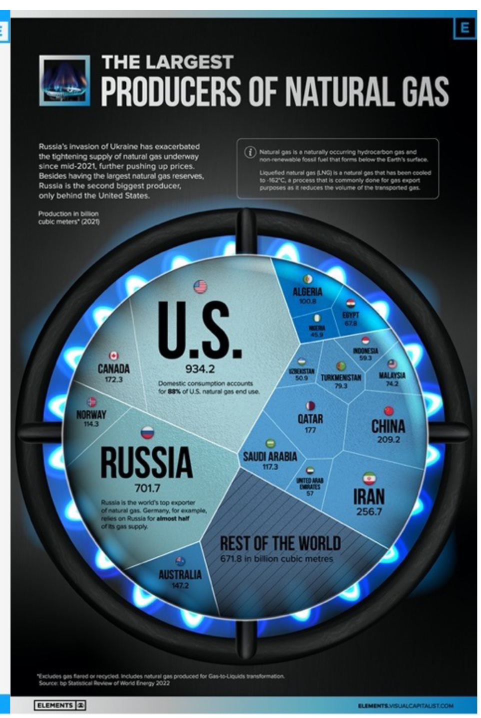


Figure 11.3. Global oil and gas production in 2021 according to BP Statistical Review of World Energy 2022. *Sources: Amoros, et al., 2022; Venditti & Lam, 2022.*

coal, nuclear, wind, and solar. Uri was one of only four comparably deep freezes to hit Texas since 1950 (Doss-Gollin, et al., 2021).

Despite the fact that Uri took all types of power generation in the State offline, the storm changed the political narrative about wind and solar in the State. After Uri, key Texas legislators and other officeholders signaled their desire for more gas power plants to be built in Texas, and more reliability to be built into the Texas grid.

The shift in tone post Uri marked a departure from traditional bipartisan support for wind and solar in Texas. For example, during the Administration of Republican Governor Rick Perry in 2005, the Texas Legislature ordered the PUC to work with ERCOT to identify and build out competitive renewable energy zones ("CREZ") to deliver renewable energy, generated primarily from wind, but also solar. The goal of CREZ was to enhance rural economic development, and increase the amount of electricity delivered to customers by using renewable generation resources in Texas. CREZ also aimed to alleviate a disconnect between development timelines for wind projects in West Texas, and transmission capacity (Dorsey-Palmateer, 2020; Gould, 2018). By 2013, CREZ had nearly tripled the capacity of the Texas grid to accommodate wind power in the CREZ regions (Dorsey-Palmateer, 2020).

CREZ is generally regarded as a success from a policy, economic, and technical perspective. However, from a political perspective, the marked shift in political climate in the Texas Legislature in the aftermath of Uri may hinder the progress of additional large scale transmission projects, at least in the near term. If congested transmission lines constrain opportunities to add wind and solar farms in West Texas, the buildout of new generation sources close to demand centers in the eastern half of the State could be relatively favored, and this presents an opportunity for geothermal and the Texas grid. As is considered in detail in Chapter 4, The Texas Geothermal Resource: Regions and Geologies Ripe for Development of this Report, regions ripe for geothermal development in Texas are located near, or directly under, a majority of the State's major population centers.

Opportunities for hydropower in Texas are scarce due to the arid climate and minimal surface water. No coal plants, and only two nuclear reactors are under construction nationwide, and neither is likely to be deployed in Texas in the next decade due to high costs, and environmental concerns. Most battery storage facilities are being built with one to four hour dispatch times, which can help smooth short term imbalances, but will not address multi-day events like Uri. This leaves gas and geothermal as the two most likely candidates for adding dispatchable resources in Texas in the coming decades.

IV. Gas and Geothermal in Texas

As of the publication date of this Report, Russia has entered the twelfth month of its invasion of Ukraine. With no end to the conflict in sight, and energy markets across Europe in turmoil, Europe is struggling to quickly find a path to wean itself from Russian fossil fuels. In March, 2022, U.S. President Joe Biden met with the President of the European Commission, Ursula von der Leyen, to announce a plan for the U.S. to support an end to Europe's reliance on Russian gas. The two described a plan to increase liquid natural gas ("LNG") exports from the United States to European markets by the end of 2022, with volumes increasing further beginning in 2023. "We will sharpen our sanctions and we will break free from Russian fossil fuels," noted von der Leyen at a recent summit focused on Russia's war in Ukraine (EUCO, 2022).

The potential for U.S. LNG to reduce European imports of Russian gas is not trivial (Collins, et al., 2022; Ravikumar, et al., 2022), but the European desire for American LNG marks a shift from the previous decade, when Texan LNG received a chilly reception in Europe. Some European governments had rejected the import of Texas gas due to the use of hydraulic fracturing in its production, and a perception that Texas lagged behind in regulating releases of greenhouse gasses associated with gas production (Field, et al., 2014). But as prices soared after Russia's invasion of Ukraine, and concerns about energy security and price stability grew, European ports and entities became eager to accept Texas LNG (IEA, 2022; Smith, 2022). As recently reported in Texas Monthly, "Europe was plunging into the worst energy crisis in a generation, and Texas gas was sailing to the rescue" (Gold, 2022).

In April 2022, the U.S. Department of Energy authorized additional exports of LNG from ports in Texas and Louisiana, but it will take several years to build additional capacity to meet growing export demand. Two of the five LNG terminals that make up 90 percent of U.S. LNG exports are located in Texas – one in Freeport, and the other in Corpus Christi. One additional terminal is under construction in Sabine Pass. There are also new LNG regasification terminals under construction throughout Europe (Global Data, 2022; Agarwal, et al., 2020) developing in parallel with the new LNG export terminals under construction here in Texas (S&P Global, 2022).

The United States temporarily became the world's largest exporter of LNG in 2022, a trend accelerated by the war in Ukraine and the resulting European energy crisis. Once the energy crisis subsides and the urgency, price spikes, and scarcity recede, so too may European demand for Texan LNG. Once this crisis fades and alternatives become available, Europe could return to being choosier about the fuel it imports. Europe could turn toward nuclear, or choose between Texan LNG and other producers, for example Algeria, or re-engaging with Russian gas for long term supply. These dynamics present an opportunity for Texas, however, to lead and forge new and lasting export partnerships.

So why the discussion of Texas' future as an LNG exporter in a Report about the future of geothermal energy in the State? Many concerns associated with a growing percentage of domestic energy supply being slated for export are related to the impact of exports on U.S. energy prices and markets. As an illustration of the angst the topic of increasing exports has created amongst U.S. lawmakers, in February, a group of ten Democratic U.S. Senators wrote to the Secretary of Energy urging consideration of the impact of increasing LNG exports on domestic energy prices (U.S. Senate, 2022).

Substantially increasing the availability of a firm clean energy source like geothermal in Texas could free up gas for export, which would have been utilized for domestic energy production. Increased geothermal development would increase the size of total available energy resources in the State, reducing the criticality of Texan gas for in-State consumption, thereby enabling more gas exports to other parts of the world who need it to stabilize their markets. Texas' status as a grid island, which limits its ability to export substantial amounts of electricity to other parts of the U.S., further supports this premise. If Texas developed its domestic geothermal resources for use in the State, it may allow for the resulting excess gas resources, which are readily exportable into lucrative markets, to meet export demand.

V. The Oil and Gas Technology and Workforce Transfer, and Impact on Cost

As discussed in detail in Chapter 1, Geothermal and Electricity Production and Chapter 5, The Oil and Gas Industry Role of this Report, geothermal technology deployment would utilize a vast array of technologies and workforce capabilities developed in the oil and gas sector. But technology transfer from the hydrocarbon industry into the geothermal industry is still in its infancy. In response to increasing traction for geothermal within the oil and gas industry over the past few years, the U.S. Department of Energy ("DOE") issued a $165 million dollar Funding Opportunity Announcement ("FOA") in July 2022 to facilitate technology and workforce transfer from oil and gas into geothermal. The FOA, titled the Geothermal Energy from Oil (and gas) Demonstrated Engineering ("GEODE"), seeks to facilitate "collaborative research, development, and demonstration focused on realizing technology improvements and transfer from oil and gas, deploying geothermal energy nationwide, evaluating and recommending ways to address regulatory and permitting barriers, and developing opportunities in the geothermal sector for the skilled oil and gas workforce."

GEODE is part of another recently announced DOE initiative related to geothermal, called the "Enhanced Geothermal Shot," ("Earthshot") announced in September 2022. The goal of Earthshot is to reduce the cost of Enhanced Geothermal Systems, also referred to as Engineered Geothermal Systems ("EGS"), by 90 percent, to $45 per megawatt hour by 2035 (DOE, 2022). In an ongoing study funded by Project InnerSpace, and led by Chapter author Daniel Cohan at Rice University, a team is modeling potential geothermal deployment scenarios in the electric grid from current to 2050 using a capacity expansion model called the Regional Energy Deployment System model ("ReEDS"). ReEDS, developed by the National Renewable Energy Laboratory ("NREL"), is widely used to project the evolution and operation of the electric grid in the contiguous United States (Ho, et al., 2021). The Rice University team will model a series of geothermal cost projections, with a close look at EGS cost reduction scenarios consistent with DOE's Earthshot targets. The study is expected to be published in late 2023 or early 2024.

Deployment of scalable concepts like AGS and EGS is one pathway toward "Geothermal Anywhere" that would enable oil and gas companies to utilize technologies and techniques from industry to develop geothermal energy in Texas. The potential for breakthrough impact the application of oil and gas technologies and know-how may have on geothermal development has been demonstrated in the DOE's Frontier Observatory for Research in Geothermal Energy ("FORGE") project, an EGS demonstration project located in Milford, Utah. Below is a case study that highlights the significant impact of oil and gas engagement on FORGE outcomes, and the potential for innovations such as these to push the cost of geothermal development down over the coming decade.

Case Study: Increasing Performance and Driving Down Cost

Oil and Gas Technology Transfer and Learning Spillover Into Geothermal

Polycrystalline Diamond Compact ("PDC") drill bits are used in over 90 percent of oil and gas wells that are drilled today. (Xie, et al., 2020). Though PDCs are regarded as industry standard in oil and gas due to their reliable performance and durability, particularly in hard sedimentary rocks, they have not been widely adopted in the geothermal drilling context, especially in crystalline rocks like granite.

In 2021, an oilfield consortium consisting of Texas A&M petroleum engineering faculty members Sam Noynaert and Fred Dupriest, who also served as former chief drilling engineer at ExxonMobil, oilfield service company NOV, and technology provider Sanvean International was selected by the U.S Department of Energy ("DOE") to demonstrate that application of oilfield workflows and modern technologies from oil and gas, including PDC bits, could produce breakthrough outcomes in the harder and hotter subsurface environments encountered in geothermal drilling.

When the Texas team deployed their technology and techniques in the field trial, performed at the DOE's Frontier Observatory for Research in Geothermal Energy (FORGE) site, their performance significantly exceeded expectations, resulting in the geothermal wells being drilled in half the allotted time. As a result of this oil and gas technology and knowledge transfer into the geothermal industry, previous hard rock drilling records were exceeded by approximately 10X (Pink, et al., 2023; Sugiura, et al., 2021). Because drilling is the largest expenditure associated with the development of geothermal projects, large reductions in drilling time will translate into significant cost savings for projects.

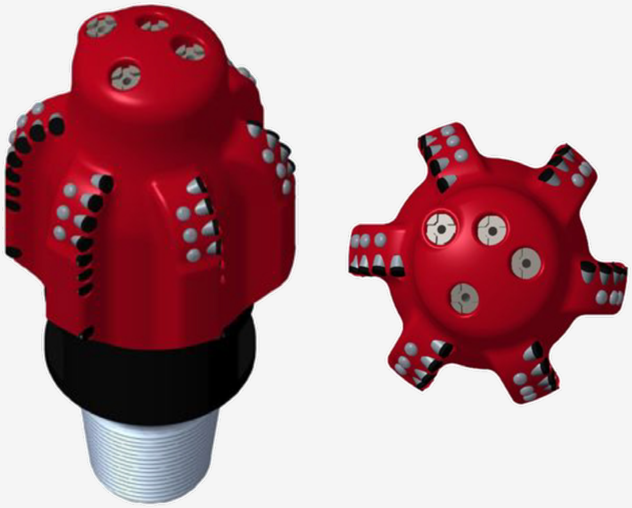


Figure 11.4. The Particle/PDC drill bit, combining leading edge PDC technology with an innovative steel shot drilling method. *Source: Image from NOV.*

Building on this outcome, in 2021, NOV and Houston based startup Particle Drilling, teamed up to design and build a hybrid Particle/PDC bit that would combine the reliable performance of PDCs, with an innovative new technology that continuously shoots millions of steel pellets into the rock while drilling. After the rock is impacted by the pellets in the drilling process, the PDC portion of the bit then drills the rock that remains, cutting drilling time. This design was aimed at drilling very hard and hot rocks, which are typically associated with the most economically interesting global geothermal opportunities. The newly designed bit was prototyped within months of the conclusion of the DOE test, and ready for a field trial.

In August 2021, NOV and Particle Drilling deployed a drilling rig to a granite quarry in Coldspring, Texas, where the team tested two new particle drilling bits, shown on the right. The newly designed bits drilled the rock twice as fast as the best PDC used in the FORGE demonstration, which was used as a control sample. This new bit, when deployed in a geothermal project, is expected to deliver another step change forward in drilling performance in hard rock, within an ultra-fast design cycle, concept to field deployment, of about a year.

Innovative new technologies, and the fast innovation cycles of the oil and gas industry, like the Particle/PDC drill bit example, are key to driving down the cost of geothermal projects, and to unlocking broader access to deeper and hotter geothermal resources.

The spillover learning showcased in the Case Study with PDC and industry workflow deployment at FORGE, as well as subsequent advances resulting from quick-turn, iterative innovation that led to the NOV/Particle Drilling field trial, is just one example of the types of outcomes, time savings, cost reductions, efficiency increases, and capability gains that oil and gas engagement in geothermal would enable.

The authors of Chapter 5, The Oil and Gas Industry Role modeled the extent of potential cost reductions in geothermal from immediate learnings and technology transfer across all geothermal technology types from the oil and gas industry, and found cost reduction potential to be between 20 to 43 percent, without the need for new inventions or technology leaps. To explore details, see Chapter 5, The Oil and Gas Industry Role.

The cost reductions that can be realized through learning and technology spillover from oil and gas, as illustrated in the above Case Study, are likely to improve the case for more deployment of geothermal assets on the Texas grid. But as is explored in detail in Chapter 7, The Geothermal Business Model & the Oil and Gas Industry: Challenges and Opportunities of this Report, even its current price per kilowatt hour, geothermal is well positioned as a competitive contender in ERCOT's future energy mix.

VI. Co-location of Geothermal Resources with Existing Infrastructure

Every energy source has siting limitations. Access to fueling infrastructure, local emissions constraints, security requirements, and cooling water availability can limit the placement of thermal power plants, such as gas, coal, and nuclear. Wind and solar are often limited to areas that have available land, favorable wind speeds, and sufficient solar insolation.

Because the temperature of the Earth's subsurface is not homogeneous, there are locations that are better suited for geothermal development than others. Figure 11.5 shows the various classes of available underground heat across the State. In the case of EGS as an example, which the Figure focuses on, about 11 percent of the State (about 28,225 square miles, 73,100 square kilometers) consists of Class 2 EGS development regions, the second highest class in quality of resources (Turchi, et al., 2020). Chapter 4, The Texas Geothermal Resource: Regions and Geologies Ripe for Development provides in-depth consideration of the different classes and qualities of geothermal resources in Texas.

The majority of the Class 2 EGS regions in Texas are located in northeast Texas, with other regions along the Eagle Ford Shale formation in southern Central Texas down to the Mexican border in South Texas. There are also some smaller pockets of Class 2 EGS regions in far West Texas. These areas either contain or are located nearby a majority of the Texas population, with the greater metro

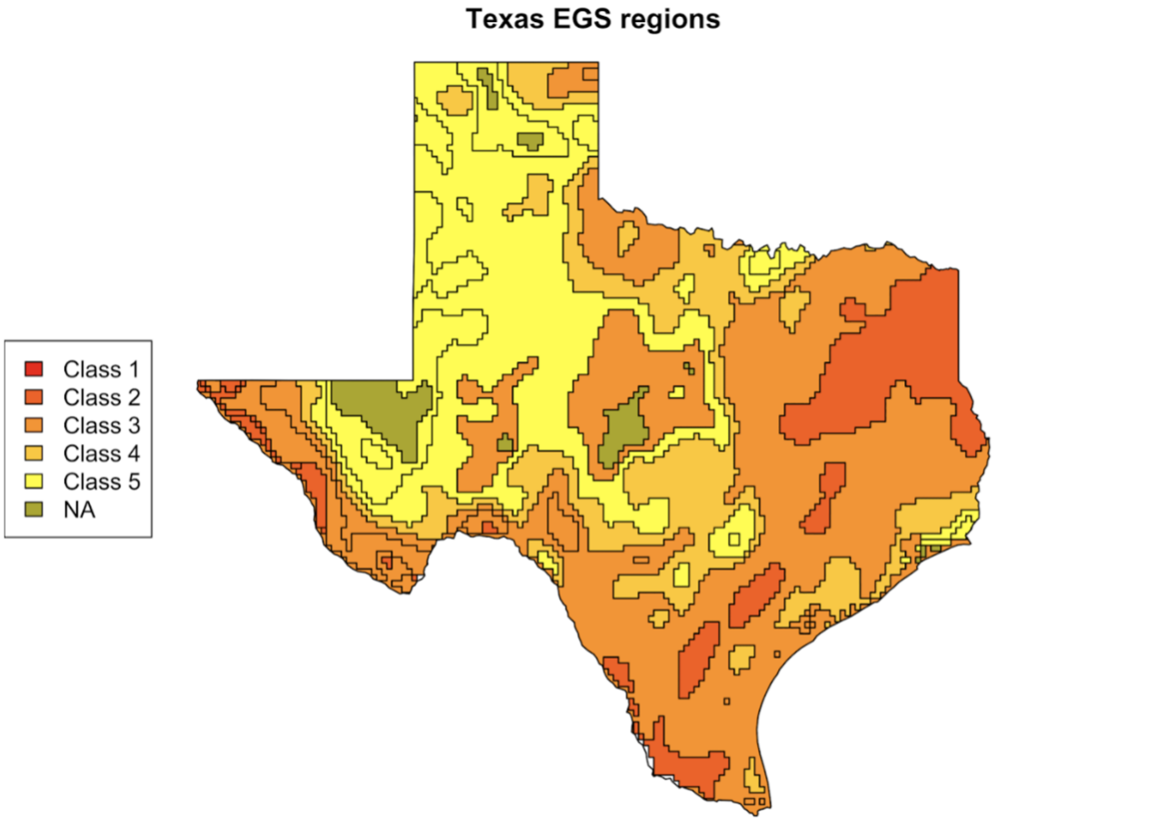


Figure 11.5. Classes of engineered or enhanced geothermal system ("EGS") resources across Texas. *Source: NREL, 2022a.*

areas of Houston, San Antonio, Dallas Fort Worth, and Corpus Christi, among others, within or nearby these EGS regions.

It is reasonable to assume that the development of geothermal resources in Texas would start in regions that would result in the lowest overall costs. These regions would include those with the best available underground temperatures, as well as those that already have existing infrastructure that could be utilized to reduce the capital costs of the geothermal power plant.

For example, if a coal power plant retired in a location that had viable geothermal resources, the site's existing cooling water and electric substation/switchyard could be repurposed for geothermal power production. In the case of SuperHot Rock coal plant conversions, some existing coal plant turbomachinery may be able to be repurposed for geothermal power production. This is a quickly developing area of inquiry and innovation in Texas that will require further study. We consider the opportunity in further detail below.

A. Coal Power Plant Conversions in Texas

There is growing interest in the U.S., including in Texas, to investigate the feasibility of utilizing both old coal mines (Kowalski, 2021; Andrews, et al., 2020; Madera-Martorell, 2020) and coal plants slated for decommissioning (Petty, 2016) for geothermal generation.

A case study of retrofitting coal-fired power plants in Poland to geothermal found that EGS systems could theoretically operate at up to 90 percent of a smaller coal plant's annual output using the same land footprint, and that retrofitting can decrease costs compared to building new plants; though this does not necessarily guarantee their competitiveness in the market (Qvist, et al., 2020). There are constraints to retrofitting, however. The same study of Poland found that some of the existing coal plants in the region analyzed were co-located with geothermal resources with subsurface temperatures below 300 °C, which was too cold to use in existing steam cycles that operate between 510-600 °C without modifications to the equipment.

Figure 11.6. An operating coal power plant. Texas based CPS Energy has publicly expressed interest in exploring geothermal as part of a conversion project for its J.K. Spruce Power Plant, located southeast of San Antonio, Texas. *Source: Stock photography.*

There are about 38 existing power plants that overlay the Class 2 EGS regions of Texas. Table 12.2 shows the number, capacity, and average capacity factor of power plants, by fuel type, located within Texas' Class 2 EGS regions. These power plants produced about 20 percent of the total electricity consumed in Texas in 2019 (EIA, 2022).

The Class 2 EGS regions also intersect with over 530 major electric substations and about 6,500 miles of high-voltage (greater than or equal to 69 kilovolt-ampere) electric transmission lines. Thus, there appears to be a significant amount of infrastructure already in place in the regions of Texas with the best geothermal potential. There are over 750 coal power plants in the United States, of which only 200 remain in operation (Richter, 2022). The rest are shuttered due to economics, as coal is not an economically viable baseload electricity generation source, often being outcompeted by gas (Morris, et al., 2019).

A potential conversion candidate from a coal power plant to a geothermal power plant is the J.K. Spruce Power Plant, operated by CPS Energy and located southeast of San Antonio, Texas (Mendoza-Moyers, 2022). CPS Energy indicated in 2022 that the company is considering converting unit 1 into a source of zero carbon emissions, which may include an AGS geothermal component, and unit 2 into a gas power plant (a source of less carbon emissions compared to coal).

Currently, the J.K. Spruce Power Plant is the largest generator of carbon emissions in Bexar County, Texas, producing about 60 percent of greenhouse gas emissions in the county, or 5,800,000 metric tons of carbon emissions into the atmosphere (Mendoza-Moyers, 2022; Sabawi, 2022). Additionally, the coal power plant is no longer economically viable using coal as a fuel source primarily because of competition from gas (Morris, et al., 2019). The San Antonio and Bexar County region sources a quarter of its electricity from the J.K. Spruce Power Plant, resulting in a significant amount of demand to convert from coal to other reliable sources. The subject of coal plant to geothermal conversion was explored by a panel of experts at the PIVOT2022 conference, where entities, including CPS, expressed their views of the future of this application (PIVOT, 2022a; 2022b).

Table 11.1: The number, capacity, and capacity factor of thermal power plants, by fuel type, located within Texas' Class 2 EGS regions. *Source: Future of Geothermal Energy in Texas, 2023.*

Power plant type	Number of power plants	Capacity of power plants (megawatts)	Average capacity factor
Gas	16	7,136	38%
Coal (subbituminous)	5	5,744	49%
Coal (lignite)	5	7,095	74%

B. Abandoned and Orphaned Oil and Gas Wells

According to the Texas Railroad Commission ("RRC"), there are over 140,000 abandoned or orphaned oil and gas wells ("AOGW") in Texas (RCC, 2022). These AOGW could be used for geothermal electricity generation if they provide sufficient temperatures, but are more likely to be used as a heat source for nearby buildings, agriculture, manufacturing, or industry. This is a unique opportunity in Texas due to the number of and density of wells.

Recently, the Department of the Interior under the Biden Administration approved $4.7 billion to address the growing challenge of AOGW management, including efforts to plug the wells to avoid errant emissions (BLM, 2022; Menon, 2022; Kang, et al., 2021; S&P Global, 2021). However, thousands of these wells may have the potential to be repurposed for heat or electricity production. We raise this point briefly in this Chapter because this is an interesting opportunity for geothermal co-location with existing Texan infrastructure. For additional details on the technical aspects of Oil and Gas Well Reuse, refer to Chapter 3, Other Geothermal Concepts with Unique Applications in Texas.

VII. Expanding Geothermal Power Generation Creates Jobs

A report on the future of Texas climate jobs published by the Workers Institute at Cornell University notes that a policy decision to encourage the installation of 5,000 megawatts of geothermal electricity capacity in Texas will create 162,500 new jobs, far more per megawatt than solar and wind. The addition of 5,000 megawatts of geothermal capacity in Texas creates 62,500 direct jobs, 53,750 indirect jobs, and 46,250 induced jobs over ten years (Skinner, et al., 2021; Pollin, et al., 2014). This is significant because geothermal jobs offer six figure salaries, are eligible for participation in a number of labor unions, and value subsurface skills and knowledge. Furthermore, NREL's Jobs and Economic Development Impacts ("JEDI") model estimates that geothermal power has a (direct and indirect) jobs impact of about 1.36 twenty-year full-time equivalent ("FTE") jobs per megawatt of capacity (NREL, 2022b). The JEDI model also estimates that wind produces about 0.38 twenty-year FTE jobs per megawatt, while solar produces roughly 0.26 twenty-year FTE jobs per megawatt. Because geothermal power plants also have higher capacity factors, that means each megawatt of capacity from geothermal resources can be expected to create more jobs and generate more electricity over its operational lifespan (NREL, 2022b).

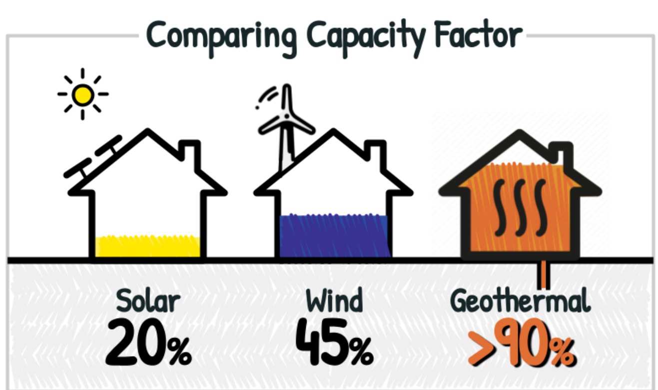


Figure 11.7. Generator capacity factor data for renewable energy technologies. Capacity factor is the percentage of time that a plant is generating electricity. *Source: EIA, 2014.*

Although the business models for the oil and gas industry and the geothermal industry differ, the technical skills and competencies of their workforces have many similarities. For instance, the technical disciplines listed by the Society of Petroleum Engineers, the largest professional organization for the professionals from the oil and gas industry in the world, are: reservoir engineering; including geomechanics and reservoir characterization; drilling; completions; production engineering and facilities; data science and engineering analytics; and health, safety, environment, and sustainability ("HSE&S"). All of these disciplines apply directly to geothermal resource exploration and development, thus, oil and gas industry workforce retraining and redeployment for geothermal may be easily achievable. However, government support may be needed initially to expand the geothermal industry, including building robust workforce retraining and transition programs for oil and gas workers entering the geothermal industry. This, and other policy based solutions to growing geothermal in Texas are considered in further detail in Chapter 12, Policy, Advocacy, and Regulatory Considerations in Texas of this Report.

VIII. Conclusion

Currently, a primary hurdle facing geothermal power for gaining market share is its high up-front costs. However, as other parts of the energy sector such as wind, solar, and batteries have shown, costs can drop significantly in the span of a decade or so with technology development, scale, and proper support and incentives. Presuming that technology and learnings transfer from the oil and gas industry enables new capabilities and cost reductions, as we saw in the Case Study in this Chapter, geothermal as a clean, firm source of energy may be well positioned to play a significant role in the future Texas grid. Further, significant geothermal deployment in Texas may position the State to increase its gas exports as heat and electricity demands of the State are increasingly met with geothermal at home, providing an opportunity for Texas to strengthen export relationships, and assist allies in stabilizing their energy markets.

Conflict of Interest Disclosure

Michael Webber serves as a Professor of Mechanical Engineering at the University of Texas at Austin, and is compensated for this work. He also serves as chief technology officer of the venture capital firm Energy Impact Partners. Outside of these roles, Michael Webber certifies that he has no affiliations, including board memberships, stock ownership and/or equity interest, in any organization or entity with a financial interest in the contents of this manuscript, and has no personal or familial relationship with anyone having such an affiliation or financial interest.

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