Chapter 3

Other Geothermal Concepts with Unique Applications in Texas

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> ***Concepts that couple geothermal energy production with other technologies, such as hydrogen production, energy storage, or carbon capture and storage, although in early stages, have the potential to improve project economics, and enhance both developing and existing industries in Texas.***

I. Introduction

Geothermal for electricity production or Direct Use can stand alone as an economically viable clean energy solution. However, as we will see in greater detail in Chapter 6, The Oil and Gas Industry Engagement in Geothermal, the oil and gas industry has expressed significant enthusiasm for concepts that combine geothermal with one or more additional outputs or revenue streams due to improved project economics, alignment with existing or future business models, or use of existing assets, including oil and gas wells. Many of these coupled projects, referred to as Hybrid Geothermal Systems, or Multi-System Hybrids, are uniquely applicable to Texas due to existing oil and gas infrastructure, existing investments in future additions to the Texas economy, like CCUS and hydrogen, and favorable subsurface conditions for deployment and operation of the concepts. In this Chapter, we will consider several coupled geothermal concepts with particular applicability in Texas.

II. Hydrocarbon Well Reuse and Geothermal

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 (depth, size, age), and other factors. There are two possibilities for producing geothermal energy from existing oil and gas wells. First, an existing hydrocarbon well could be repurposed to produce geothermal energy only, known as conversion. Second, an existing well could

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produce hydrocarbons and heat simultaneously, known as co-production (Lund & Toth, 2021; Pilko, et al., 2021; Oldenburg, et al., 2019). Together, we will refer to the concepts of geothermal well conversion, and geothermal co-production as Oil and Gas Well Reuse, or more simply Well Reuse. Both of these concepts are being pursued by several geothermal energy start-ups, who are developing closed-loop technologies using pipe-in-pipe or other configurations (Carpenter, 2022; Casey, 2022; CEP, 2022; Sage, 2022; Ball, 2021; Chao, 2021; Richter, 2021d; Amaya, et al., 2020; Oldenburg, et al., 2019; Augustine & Falkenstern, 2014; Clark, et al., 2011; Abdullah & Gunadnya, 2010). We will consider technologies being developed to enable Well Reuse further below.

It is estimated that approximately 25 billion barrels of warm and hot water is produced annually from oil and gas wells within the U.S. (Transitional, 2022; Oldenburg, et al., 2019). This "co-produced" water has to be managed and disposed of, adding significant operational costs to oil and gas operations. The ratio of produced water to hydrocarbons, either oil or gas, increases over time, meaning that existing hydrocarbon wells may be good candidates for co-production or conversion. In both cases, producing geothermal energy from existing hydrocarbon wells, as electricity and/or low-temperature waste heat, can yield significant advantages over traditional geothermal wells, especially in terms of reduced capital expenditure. They also provide the advantage of energy savings, lower emissions, and extended economic life of oil and gas fields, and profitable utilization oil and gas field infrastructure (Kuru, et al., 2022; Livescu & Dindoruk, 2022a; Oldenburg, et al., 2019; Kitz, et al., 2018).

Figure 3.1. Transitional Energy successfully produced geothermal energy from produced fluids, utilizing a modular ORC unit at an oil and gas well in Colorado in 2022. *Source: Transitional, 2022.*

Co-production or conversion may use surface technologies, such as binary cycle or Organic Rankine Cycle ("ORC") units, and subsurface technologies such as pipe-in-pipe heat exchangers, to produce electricity. The electricity produced can be used for field operations, or sold onto the grid (CEP, 2022; Doran, et al., 2021; Gosnold, et al., 2020; Gosnold, et al., 2017; Gosnold, et al., 2015).

A. Size and Feasibility of the Well Reuse Opportunity

Thousands of abandoned hydrocarbon wells around the world, including in Texas, could be converted to geothermal wells (Carpenter, 2022; Kuru, et al., 2022; Livescu & Dindoruk, 2022b; Ball, 2021; Robins, et al., 2021; Richter, 2017; Augustine & Falkenstern, 2014). For instance, pipe-in-pipe heat exchangers could be inserted in abandoned hydrocarbon wells to generate power for oilfield operations as an alternative to the current diesel generators. This could be especially beneficial for offshore oil and gas operations, such as in the Gulf of Mexico. Additionally, the geothermal heat could be used to help pump hydrocarbons out of wells. The thermosiphon effect of pipe-in-pipe heat exchangers could be used to power a downhole pump, avoiding the cost of electricity that would otherwise be used for electrical submersible pumps ("ESP") (Lund & Toth, 2021; Oldenburg, et al., 2019).

The concept of producing geothermal energy from existing hydrocarbon wells is not new (Carpenter, 2022; Casey, 2022; CEP, 2022; Sage, 2022; Chao, 2021; Lund & Toth, 2021; Richter, 2021d; Abudureyimu, 2020; Amaya, et al., 2020; Gosnold, et al., 2020; Oldenburg, et al., 2019; Alimonti, et al., 2018; Kitz, et al., 2018; Augustine & Falkenstern, 2014; Clark, et al., 2011). It was technically field demonstrated through a project at the Rocky Mountain Oilfield Testing Center in Wyoming, where co-produced geothermal water from oil wells was used to power a 250 kilowatt electrical ORC plant (Gosnold, et al., 2020; Gosnold, et al., 2017; Gosnold, et al., 2015). The total produced power was reported as 1,918 megawatt hours from 10.9 billion barrels of co-produced water, with an ORC unit manufactured by Ormat (Gosnold, et al., 2020).

A simulation study performed in 2013 found a significant number of existing hydrocarbon wells in the U.S. with downhole temperatures and flow rates sufficient for geothermal energy production, but estimated only a modest near-term market potential of about 300 megawatts electrical of electrical output, with marginal economics (Augustine & Falkenstern, 2014). Thus, from a techno-economic point of view, conversion of existing hydrocarbon wells may be more feasible than co-production (Muir, 2020). That study also recommended installing ORCs on the many water flood projects in hydrocarbon basins in the U.S.

A more recent simulation study performed in 2020 for the Bakken basin, located mostly in the U.S. state of North Dakota and in Canada's province of Saskatchewan, indicated that previous analyses of co-production potential were based on total field multi-well pad production volumes, and did not address fluid flow per individual well (Gosnold et al., 2020). In shale plays, such as the Bakken, with temperatures between 100 °C (212 °F) in the eastern, shallower part, and 140 °C (284 °F) in the center, deeper part, the total fluid produced from a multi-well pad can be enough for co-production of tens of hundreds of kilowatts to replace the current propane or diesel generators used onsite. Note that Bakken heat flow ranges are between approximately 50 milliwatts per square meter, in the eastern part, and approximately 70 milliwatts per square meter, in the center. According to Robins et al. (2021), the study by Gosnold et al. (2020) did not find Bakken co-production of brine and hydrocarbons to be commercially feasible for power generation, but did suggest that several megawatts of power can be produced from hotter carbonate rocks underneath the Bakken.

These types of concepts have been discussed recently at numerous oil and gas industry events, and include converting existing hydrocarbon wells for geothermal brine production, rather than co-production (Pilko et al. 2021). Among those conversion scenarios are: 1) recompleting marginally economic existing oil wells and converting them to geothermal brine production; 2) installing ORCs on the many water flood projects in sedimentary basins; and 3) drilling new, deeper geothermal wells, specifically for power production. The geothermal fluids could be used in two stages, first for power production using ORCs, and second for low-cost Direct Use space heating. Producing enough electricity on site to power the oil and gas operations is another potential business case. For instance, an average ESP requires 16 kilowatts, and a 160 kilowatt ORC could supply electricity to pump ten wells.

An earlier study for the Williston basin demonstrated the technical and economic feasibility of generating electricity from non-conventional, low temperature (i.e., 90 to 150 °C (194 to 302 °F)) geothermal resources from a deep (1.6 miles or 2.6 kilometers) carbonate aquifer using binary technology (CEP, 2022; Doran, et al., 2021). The potential power output from this small-scale project was 250 kilowatts at a cost of $3,400 per kilowatt. In the beginning, an ORC produced 50 to 250 kilowatts with efficiencies of eight percent to ten percent. A new ORC unit was designed to generate 125 kilowatts with 14 percent efficiency, and could be installed in a multi-unit series to produce a few megawatts of power. The analysis of the entire Williston Basin using data on porosity, formation thicknesses, and fluid temperatures revealed that 1.36 x 109 megawatt hours of power could be produced using ORC binary power plants.

Many of the oil fields in the Williston Basin producing from conventional reservoirs, such as the Red River or Madison Formations, have associated water flood projects. The wells that supply these projects offer a long term, reliable source of water at relatively high flow rates (tens of liters per second) which offer a potentially attractive geothermal source where fluid temperatures are more than 100 °C (212 °F). Preliminary estimates indicate that a single well providing water to an ORC at that temperature could generate over 400 kilowatts of electricity. This is adequate to supply power for all water supply pumping operations, plus a significant amount of excess energy to help reduce lifting costs and supply other local power demand. This potential resource could be optimized in future water flood projects if one of the specific design criteria for the water supply wells is to consider targeting deeper, hotter formations where the revenue from the increased geothermal power production would offset any incremental increase in drilling costs.

B. Challenges Associated With Well Reuse

Despite the great co-production and conversion potential identified by these studies (Gosnold, et al., 2020; Gosnold, et al., 2017; Gosnold, et al., 2015), several reasons, partly economic and partly infrastructure related, were identified for the lack of geothermal energy development in the Bakken formation and Williston basin. The economic reasons include long-term investment with little return, compared to the oil and gas revenue, and industry skepticism regarding revenue. Infrastructure reasons include the ability to generate only a few kilowatts of power with large volumes of produced water, high engineering and construction costs, required agreements with local electrical power providers, legal issues and access to the power grid, and water management. The downhole temperatures and sizes of existing hydrocarbon wells may limit their enthalpy output for power production.

Repurposing oil and gas wells for geothermal development in the province of Alberta, Canada was investigated by the Canadian Geothermal Energy Association (CanGEA). As of October 31, 2016, Alberta had more than 60,000 wells with bottom hole temperatures greater than 60 °C, which were labeled as well-suited for low temperature Direct Use heat applications, more than 7,700 wells with bottom hole temperatures greater than 90 °C, which were labeled as well-suited for industrial Direct Use heat applications, and 500 wells with bottom hole temperatures greater than 120 °C, which were labeled as well-suited for power generation (Richter, 2018).

Four key challenges have been identified by Santos, et al. (2022) related to repurposing oil and gas wells for geothermal development: 1) well selection, 2) subsurface data availability, 3) well integrity, and 4) legal and regulatory factors.

For instance, well selection is dependent on the physical properties of a well (i.e., bottom hole temperature, geothermal gradient, etc.), but also on its proximity to end users. Subsurface data availability depends on a well owner's appetite to invest in pre-project reservoir characterization, geomechanical modeling, and productivity analysis. Well integrity is critical for predicting cement and casing life, and safety, but also for estimating groundwater contamination issues. Well integrity failures are quite common among oil and gas wells, with around 35% of wells showing some leakage (Santos, et al., 2022). And legal and regulatory factors are complex, as the concept of repurposing oil and gas wells to geothermal is new, and entities have not fully considered potential ownership, liability, and other legal issues associated with these projects.

Further, and independent of repurposing of oil and gas wells, geothermal resource exploration and production does not have a unified authority, and may fall under existing legislation and regulatory frameworks for natural resources, hydrocarbons, geology, groundwater, and planning. On the other hand, oil and gas wells are regulated under several subcategories, such as exploration, storage, production, injection, suspended or temporarily abandoned, and plug and abandonment ("P&A") wells, and each of them has distinct requirements. These issues will be addressed by industry as projects proceed, but currently, they present uncertainty.

More research, field piloting, and legal and regulatory framework development are needed to assess the potential of using existing hydrocarbon wells for co-production and conversion to geothermal energy, but the economic benefits for the oil and gas industry in Texas could be significant, given the large number of existing oil and gas wells, if the technological and regulatory challenges are overcome.

C. The Well Reuse Business Model for Oil and Gas Entities

Recent studies have explored business opportunities for geothermal energy development by oil and gas companies (Carpenter, 2022; Casey, 2022; Livescu & Dindoruk, 2022b; Ball, 2021; Chao, 2021; Lund & Toth, 2021; Pilko, et al., 2021; Amaya, et al., 2020; Gosnold, et al., 2020; Muir, 2020; Birney, et al., 2019; Gosnold, et al., 2017). For instance, some technical challenges and climate transition risks related to societal, regulatory, and capital allocation trends related to re-purposing hydrocarbon wells to geothermal energy production have been recently explored (Ormat, 2022; Pilko, et al., 2021).

One opportunity identified is to use co-production for onsite geothermal power production to replace natural gas electrical energy (Muir, 2020). This could be very advantageous for near-shore and offshore Gulf of Mexico wells and facilities, as many of those wells are deep, have large well and casing sizes, and are high-pressure, high-temperature ("HPHT"). The northern Gulf of Mexico is one of the most active offshore areas in the world, with over 44,000 oil and gas wells drilled since the mid-1900s. A deep-water offshore platform generally requires 100 megawatts of power to operate its pumps, compressors, machinery, and lighting. Smaller shallow water and onshore facilities require 50 megawatts or less. Replacing power generated by natural gas with power generated by baseload geothermal energy, onsite or offsite, can provide significant environmental, social and governance ("ESG") incentives, in addition to operating efficiency incentives. for oil and gas operating companies. It is estimated that more than one megawatt electric output is needed from an offshore well to justify the deployment cost of geothermal for co-production or conversion, yet if there is co-production of hydrocarbons from the same well, increased efficiencies and synergies can provide cost reductions or increased power generation (Lund & Toth, 2021; Kitz, et al., 2018).

Many Gulf of Mexico wells and facilities will soon reach the end of their planned lives, incurring substantial decommissioning costs. The opportunity to repurpose those wells and facilities to geothermal energy production may offer a significant cost savings for their operating companies.

The potential benefits identified by (Lund & Toth, 2021; Kitz, et al., 2018) could also be applied to onshore wells in Texas. For instance, three Texas resources for the counties of Crockett (West Texas), Jackson (central Gulf Coast) and Webb (South Texas) were analyzed and mapped (Batir and Richards, 2020). Updated temperatures from 1,500 feet (3.5 kilometers) to 32,800 feet (10 kilometers) were calculated. Thus, for Webb County and Jackson County, temperatures of 150 °C (302 °F) are possible for depths greater than 8,530 feet (2.6 kilometers), while for Crockett County, they are possible for depths greater than 8,858 feet (2.7 kilometers). Updates for all Texas counties may yield results like these, which are more favorable for geothermal development than prior studies.

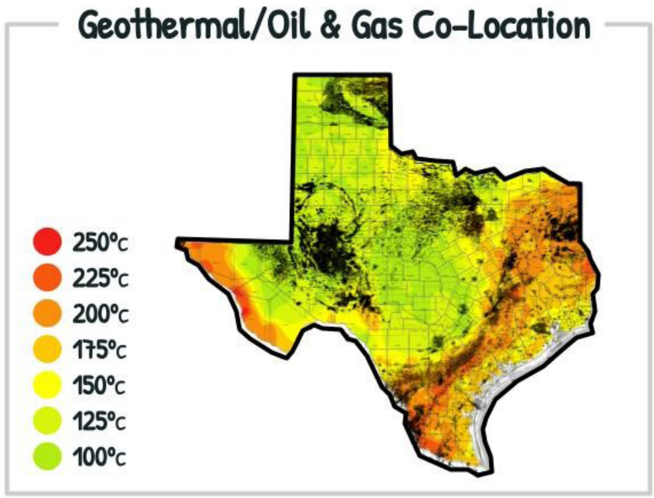

Figure 3.2. Existing oil and gas wells in Texas (black dots) overlaid onto geothermal resources. *Source: Future of Geothermal Energy in Texas, 2023*

D. Technology Development Enabling Well Reuse

There are many other theoretical studies evaluating the potential of co-production and conversion of existing oil and gas wells to geothermal energy (Greenfire, 2022; Ormat, 2022; Lund & Toth, 2021; Greenfire & Scherer, 2020; Oldenburg, et al., 2019). Several numerical and analytical solutions have been proposed for closed-loop geothermal systems ("CLGS") using pipe-in-pipe downhole heat exchangers. Recent sensitivity studies have shown the effects on several well parameters, such as the fluid flow rate, well length, inner tubing and annulus diameters, geothermal temperature, type of the Working Fluid (i.e., water-steam and supercritical carbon dioxide, or "sCO2"), and overall heat transfer coefficients, on the temperature of the fluid flowing to surface (Livescu, et al., 2021; Livescu & Dindoruk, 2020a; Livescu & Dindoruk, 2020b). While all those parameters have more or less significant effects on power production, the overall heat transfer coefficients are critical for system performance. Quantitatively, modifying the overall heat transfer coefficient between the formation and well, while keeping all other parameters unchanged, may yield a two-fold outlet temperature difference, significantly affecting the economics of a given geothermal project. However, there is very limited information in the public domain of any study for directly and accurately measuring these coefficients, either in the laboratory or in the field. Thus, using theoretical values for the overall heat transfer coefficients may result in highly inaccurate outcomes for heat and electric power generation.

Another potential source of inaccuracy for estimating the co-production or conversion potential of existing oil and gas wells are the pressure, volume, and temperature ("PVT") properties and phase behavior of the Working Fluids, such as water-steam and sCO2 (Ratnakar, et al., 2022). Because of convenience and simplicity, some studies assume that the fluids are single-phase, or that the density, viscosity, and thermodynamic properties such as specific heat capacity of the Working Fluid are constant over the entire range of downhole pressures and temperatures. Thus, more research is critical to fully understanding the thermodynamics and heat transfer phenomena related to any co-production or conversion project.

Before co-production and conversion can be field tested, several other topics should be addressed, for which oil and gas professionals have appropriate technical expertise and experience, such as well intervention for preventing flow assurance issues (i.e., scales, corrosion, etc.), well production and facilities, including artificial lift, drilling and completions if the wells need to be re-completed, deepened, stimulated or re-stimulated, and reservoir engineering for estimating the heat and fluid inflow along the well. These topics are addressed regularly within the oil and gas industry for their field development and exploitation in the oil and gas context.

Other potential applications of co-production or conversion include 1) using the produced water to heat or cool buildings nearby, if this would be deemed economical, and 2) managing the produced water at surface instead of re-injecting it into the subsurface, and selling the heat and water to nearby agricultural operations, etc. Both of these topics require much more collaborative research involving the oil and gas industry, government, academia, and professional societies focusing to accelerate the multi-disciplinary innovation needed to make co-production and conversion of existing oil and gas wells to geothermal energy an economically viable reality.

III. Geothermal and Lithium, Hydrogen, Other Co-Production Scenarios

Hybrid Geothermal Systems are defined as either those combining a geothermal system with any other energy sources (including other geothermal concepts), or those producing two or more products, such as power and minerals (DOE, 2017). Hybrid concepts are explored in more detail in Chapter 1, Geothermal and Electricity Production of this Report. Hybrid Geothermal Systems combining different energy sources take advantage of pairing baseload geothermal with other energy sources, such as thermo-electric power generation technologies, including solar thermo-electric, coal thermo-electric, and natural gas thermo-electric hybrid power generation systems (DOE, 2017). This is beneficial during peak hours, for instance, to offset the productivity decline of variable energy sources. In addition, Hybrid Geothermal Systems could decrease geothermal power generation costs, and increase the viability of low temperature geothermal resources. In the Texas context, hybrid geothermal systems combining geothermal and other renewable energy sources could also be critical to minimize, or even avoid, weather-related power outages such as the one that occurred during Winter Storm Uri in 2021 (Reinhardt, et al., 2011).

Other applications of Hybrid Geothermal Systems can also include carbon dioxide capture from fossil thermo-electric plants, thermal desalination, and compressed air energy storage (Howarth & Jacobson, 2021), but more research and innovation are needed. Research has been performed on coupling geothermal energy with Concentrated Solar Power ("CSP"), as the two systems can share their thermodynamic cycle, lowering the total capital cost (Richter, 2021d; Robins, et al., 2021; Muir, 2020; Wendt, et al., 2019; Wendt, et al., 2018). CSP can be used to increase the output temperature of the geothermal fluid, and improve geothermal power generation efficiency, while the geothermal fluid can serve as storage for the CSP power. Hybrid systems with solar PV panels, coupled with geothermal power have the potential to extend the power output of the coupled system past the daytime (Wendt, et al., 2019; Wendt, et al., 2018). Geographically, Texas is among the many locations in the U.S. with abundant solar and geothermal resources. However, Hybrid Geothermal Systems are a relatively new concept, and detailed techno-economic analyses need to be developed (Robins, et al., 2021). There are only a few demonstration scale Hybrid Geothermal Systems that incorporate solar power. Among those are Enel Green Power's Stillwater hybrid geothermal plant (Richter, 2021c), Cyrq Energy's 14.5 megawatt electric solar PV array, added to its Patua geothermal plant (Richter, 2017), and Ormat Technologies' seven megawatt electric solar PV system, added to their Tungsten Mountain geothermal plant (Richter, 2019).

A. Geothermal and Lithium

Lithium is another resource that has received significant attention recently, especially in regions with high lithium content in geothermal brines. Currently, lithium is mostly produced from hard rock mines in Australia, or from subsurface brine deposits in Chile and Argentina (Richter, 2021a). The environmental impact and carbon footprint of current lithium production methods is quite severe, with estimates of around 15 tons of CO2 for each ton of lithium produced. The method used for lithium production from geothermal brines is likely to have a smaller environmental footprint compared to other methods (Chao, 2020; 2021). Further study is needed as projects are developed.

Geothermal brine may contain minerals, such as iron, magnesium, calcium, sodium, and lithium. However, the extraction of lithium from geothermal brine is still in a nascent phase. Most efforts, especially in the U.S., Germany and New Zealand, focus on a technique called Direct Lithium Extraction ("DLE"), with about 60 different variants of that technology. All of them use some kind of chemical separation method, such as nano-filtration or ion exchange resins, to target the separation of lithium chloride, purifying it to produce lithium hydroxide, which is then used for batteries. Many oil and gas companies, geothermal companies, and mining companies are evaluating lithium production from their assets, either as a by-product or as a main product, as the price of around $12,000 per ton of lithium can be a significant source of revenue (EERE, 2021; Richter, 2021a).

Figure 3.3. Controlled Thermal Resources' Hell's Kitchen Lithium and Power project, being developed in the Salton Sea Geothermal Field in Imperial Valley, California. This is an example of a Hybrid Geothermal System. *Source: Controlled Thermal Resources, 2022.*

B. Geothermal and Green Hydrogen

Texas uses roughly one-third of the hydrogen consumed in the United States, about 9 million kilograms per day (DOE, 2017). Multiple recent announcements in Iceland (Richter, 2021b), Canada (Bennett, 2021), and Japan (Richter, 2021d) have explored the concept of pairing geothermal energy production with green hydrogen production. By conventional terminology, green hydrogen is produced from water via electrolysis powered by renewable electricity, which does not emit carbon dioxide at the point of hydrogen generation, unlike the traditional, natural gas-fed steam methane reforming ("SMR") process. Deploying geothermal power plants coupled with hydrogen production could be one way of developing a domestic or international green hydrogen market. As far back as the 1920s (DOE, 2017), a few electrolyzer facilities were built next to hydroelectric power plants. Co-locating facilities may also reduce transmission costs.

Electrolyzer costs are currently high, so they are often operated constantly to reduce per-unit hydrogen production costs. This requirement compliments the constant energy production of geothermal power plants, and the waste heat of the plant can also increase the efficiency of the electrolysis process by preheating the water.

C. Geothermal and Direct Air Capture

Direct air capture ("DAC") is the process of capturing carbon dioxide from the atmosphere to be utilized in other industries or stored underground. The two main methods for direct air capture are liquid systems ("L-DAC") that pass air through chemical solutions, and solid systems ("S-DAC") that pass air through solid sorbent filters that chemically bind with carbon dioxide. Solid systems require 80 to 120 °C (176-248 °F) to release captured carbon dioxide, compared to liquid systems requiring more than 800 °C (1,472 °F). Thus, solid systems may be able to use waste heat from geothermal energy production alongside the energy that is already being produced (Kurk, et al., 2022).

To maximize DAC systems, it is important to balance the placement of DAC facilities between the energy source and the carbon storage or utilization site. Doing so could also reduce the cost of power transmission, and the cost of carbon dioxide transportation. Many of the best locations for geothermal power production in Texas (e.g., East Texas) also contain promising potential storage sites in the subsurface.

A recent techno-economic analysis (Kuru, et al., 2022) of three specific regions within the United States (Texas Gulf Coast, Los Angeles Basin, Alaska's Cook Inlet) and one European region (Netherlands Groningen Gas Field) that may potentially be attractive S-DAC sites suggests a S-DAC cost range of $200 to $1,040 per tonne of carbon dioxide captured, depending on the underlying cost model and the region of the S-DAC facility. However, the savings calculated from using geothermal resources to provide the thermal energy are more consistent. The averages of the models by region indicate that the Texas Gulf Coast would be the lowest cost S-DAC region, while Alaska's Cook Inlet would be the most expensive.

Another possibility is to use the captured carbon dioxide as the geothermal Working Fluid (King, et al., 2021). Using carbon dioxide as the Working Fluid has a few benefits: as we explored further in Chapter 1, Geothermal and Electricity Production. Carbon dioxide has a higher heat extraction rate than water, it is a poor solvent for minerals, and it generates buoyancy force. Additionally, fluid loss in the subsurface with carbon dioxide would actually be a climate benefit as the lost carbon dioxide would then likely be sequestered underground. With S-DAC, it might be possible for geothermal power production to have net negative emissions.

D. Geothermal and Brackish Water Mineral Production

In some locations, the hot water used to drive geothermal energy production might contain valuable minerals other than lithium as discussed above, including calcium carbonate, among others (EERE, 2021; Richter, 2021a). If these minerals could be efficiently extracted, it is possible that the economics of geothermal could improve and simultaneously provide a useful product for other energy sectors (Veil, 2020; DOE, 2017; Clark, et al., 2011). A water quality analysis (i.e., what minerals are present at what concentrations) would be key to determining the viability of recovering minerals from individual wells. While many existing geothermal power plants re-inject water that comes to the surface back into the reservoir, it may be possible to process minerals from the water within the normal operation of the facility, without the use of holding ponds, before re-injection. This is an area of innovation that is being pursued currently by several startup companies, including California based Lilac Solutions.

E. Geothermal and Oil & Gas Produced Fluids

Geothermal plants may also reuse treated, produced water from nearby oil and gas operations as the source water or cooling water for geothermal operations that use water as the Working Fluid. For instance, EGS requires 510 gallons of water downhole per megawatt hour (DOE, 2017), and geothermal power plants require 1,700 to 4,000 gallons of cooling water per megawatt (UCS, 2013). Treating and reusing nearby oil and gas produced water would reduce the strain on local surface or groundwater resources, but it could also introduce logistical challenges, like ensuring there is adequate produced water of appropriate quality in the vicinity. However, this approach could allow both industries to operate within a potentially smaller environmental footprint. The development and use of Engineered Working Fluids would of course negate the high water needs of EGS, AGS, and other scalable geothermal concepts.

F. Geothermal and Blue Hydrogen

Blue hydrogen refers to the production of hydrogen through Steam Methane Reforming ("SMR"), with added carbon capture and storage. The goal is to produce reduced amounts of greenhouse gasses in the production of hydrogen, as compared to SMR by itself. However, emissions from blue hydrogen still exceed that of burning natural gas, and are only marginally better than SMR (Howarth & Jacobson, 2021). This is primarily due to the use of natural gas to supply the hot steam needed for SMR, and power needed for carbon capture. It is possible that geothermal energy could be utilized to make blue hydrogen less polluting. The two areas where geothermal energy could be applied are the initial steam supplying step of SMR, and the final step of carbon capture. The steam for SMR needs to be at least 700 °C (1,292 °F), so it would not be possible for geothermal heat to provide all of the energy needed to create this steam. However, geothermal energy could be used to preheat the water, and even create a low-grade steam that could then be further heated by natural gas. Geothermal could also be utilized in the carbon capture step of blue hydrogen as the heat supply to degas the carbon dioxide from the solid sorbent of S-DAC, which only requires temperatures between 80-120 °C (176-248 °F) (Kuru, et al., 2022).

IV. Geothermal and Agriculture

There are many applications of geothermal heat and geothermal water in the realm of agriculture. One of the most commonly used applications is greenhouse heating. Depending on the temperature of the geothermal source, there are many ways to design the greenhouse to best take advantage of the heat. The simplest method is to use Direct Use heat to maintain temperatures inside the greenhouse. Additionally, geothermal water can be used to help maintain the humidity within a greenhouse, or to water the crops. In a similar manner, geothermal heat can also be used to heat up soil to extend the growing season of crops. This would primarily be done by running pipes that would circulate geothermally heated fluid underground, which would prevent the ground and air from dropping too low. Extension of the growing season may be the most relevant concept for Texas, and geothermal in most regions of the State may have the potential to extend the growing season to year round.

As discussed in further detail in Chapter 2, Direct Use Applications, another application of geothermal heat is crop drying. Temperatures as low as 40 °C (104 °F) can be used to dry crops and lumber. Waste heat from geothermal power facilities or hot steam from reservoirs that may not be hot enough to generate power can be passed through a heat exchanger to dry crops. In a best case scenario from a heat utilization perspective, waste heat from geothermal power plants could be used to dry several different crops (which dry at different rates and temperatures) as the quality of the heat degrades. The primary limiting factor for crop drying is the needed proximity to sources of geothermal heat, therefore co-location of agricultural and geothermal facilities would be required (Abdullah & Gunadnya, 2010). Texas based startup Viridly is pursuing such a co-location concept.

V. Geothermal and Subsurface Energy Storage

Wind and solar, either PV or CSP, are intermittent energy sources. As increasing amounts of intermittent renewable energy is added to the electric grid, more dispatchable power sources, such as those provided by geothermal energy, will be required to maintain grid stability. Geothermal energy can provide this dispatchability, independent of time of the day or weather conditions (Casey, 2022; Cestari, et al., 2022; EarthBridge, 2022; Quidnet, 2022; Sage, 2022; Kitz, et al., 2018). Geothermal storage, or underground thermal storage, shows promise by offering small footprint stability and predictability to the energy system, but the concepts remain in their nascency.

Pumped hydro is a centuries-old, gravity-based energy storage technology that has been reborn due to the excess wind and solar power (Casey, 2022). It works by pumping water to an upper reservoir whenever excess wind or solar power is available. When needed, water from the reservoir flows downhill to a power station, where it runs turbines to generate electricity. Even if pumped hydro still accounts for about 93 percent of utility-scale energy storage capacity in the United States, these conventional 'water batteries' involve a massive amount of above-ground infrastructure, and they require topography that provides for the difference in elevation.

Quidnet Energy, headquartered in Texas, uses a version of the water storage concept which, relies on use of the subsurface as energy storage (Quidnet, 2022). Their facilities operate with closed-loop water systems, to prevent evaporative loss. The energy-storing rock bodies are non-hydrocarbon bearing, and found abundantly throughout the world, intersecting with major electricity transmission and distribution hubs. Conceptually, their workflow is as follows: first, when electricity is abundant, it is used to pump water from a pond down a well and into the subsurface; second, the well is closed, keeping the energy stored under pressure within the subsurface; and third, when electricity is needed, the well is opened to let the pressurized water pass through a turbine to generate electricity, and return to the pond ready for the next cycle (Quidnet, 2022).

EarthBridge Energy is pursuing a similar thermal storage concept for sedimentary basins, which are plentiful in Texas (EarthBridge, 2022). The thermal energy stored in sedimentary basins contains a tremendous amount of development potential (Johnston, et al, 2020; Augustine & Zerpa, 2017; Augustine, 2016). If geothermal gradients are high enough, thermal energy storage from sedimentary basins, combining technologies from the oil and gas industry and power generation industry, could provide clean, baseload power and Direct Use heat. The prospect of combining geothermal with subsurface energy storage was explored by a panel of experts at the PIVOT2022 conference, who considered these, as well as other subsurface energy storage concepts (PIVOT, 2022).

VI. Conclusion

This Chapter explored geothermal concepts with unique applications to Texas, such as co-production and conversion of existing oil and gas wells to geothermal energy production. While high-pressure, high-temperature near-shore and offshore wells have great potential for co-production or conversion to produce electricity, some onshore wells also have potential for both power and Direct Use heat production. Heat from produced water could also be used to heat or cool buildings nearby, or for nearby agricultural or industrial operations, instead of re-injecting it into the subsurface.

The oil and gas industry has the expertise and experience to address these co-production and conversion applications, but much more collaborative research is needed to make co-production and conversion a reality. Concepts such as co-production of lithium, hydrogen, and brackish water minerals, and using geothermal to reduce the S-DAC cost were also explored. While these concepts are emerging, a significant amount of fundamental and applied research literature already exists, and they present potentially significant opportunities for Texas as geothermal is increasingly deployed in the State.

Conflict of Interest Disclosure

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