Geothermal Energy – A Sustainable Alternative to Well Abandonment

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Introduction

Geothermal energy has the potential to supply more energy than the global total of oil and natural gas combined (Feder, 2020). It is renewable, stable, and has a minimal carbon footprint. Geothermal power plants can produce electricity consistently, constantly, and without regard to weather conditions (US DOE, 2017). The power output of a geothermal power plant can be accurately predicted, and the actual power output is very close to total installed capacity. Yet, current global geothermal energy use comprises only 1% of energy production (Feder, 2020). In North America, solar and wind rapidly surpassed geothermal energy as developed renewable energy sources (EIA, 2019). This has occurred despite the conclusion of the U.S. Geological Survey that at least 70% of global geothermal resources have yet to be discovered (Feder, 2020; Williams et al., 2008 *a* and *b*). These resources exist throughout the world, including Canada, and geothermal production is just starting in Canada.

Geothermal energy production in North America originates primarily from deep, hot, commonly volcanic rocks, using steam or hot water produced mainly from fracture systems. Conventional development of geothermal resources requires drilling deep high-temperature wells that can be both expensive and risky.

We identify the conversion of oil and gas wells to production or co-production of geothermal energy as a game-changing opportunity for increasing the value and reducing the environmental footprint of oil and gas operations. This article reviews a proprietary technology developed through all the authors' efforts including a workflow and screening platform, integrating several effective criteria to select appropriate late-stage oil and gas wells to convert to clean and lower-cost geothermal energy sources. This effort also solves the problem of large numbers of abandoned oil and gas wells, which many of them are left unplugged and create liability for companies and the states.

Geothermal Energy

Geothermal energy has been used to generate electricity since the early years of the twentieth century, and in North America since the early 1960s. Although no geothermal power plants are operating in Canada at present, here is how the Canadian Geothermal Energy Association characterizes the potential of geothermal power in Canada:

> "The potential for geothermal energy in Canada is immense - it is estimated at over 5,000 MW in traditional shallow geothermal resources with currently available technology. Altogether, this level of geothermal energy production could create approximately 8,500 operations and maintenance jobs as well as 20,000 part time construction jobs. 5,000 MW of baseload geothermal power is also able to displace an equivalent amount of coal-fired power, which would yield more than 25 megatones (Mt) of offset CO_2 emissions per year. In addition, upwards of 10,000 MW or more may be available in deep geothermal resources, which require enhanced geothermal systems (EGS) whose technology is still under development. This abundant source of clean, reliable energy can fortify Canada's domestic energy supply and support energy exports to markets demanding clean, renewable energy, such as the United States. As well, geothermal power is well suited to address the needs of northern and remote communities as it can provide electricity while also providing heat energy for space heating in residential or commercial applications such as greenhouses that grow local produce. Geothermal energy can free these communities from their reliance upon fuel imports for power and heating needs" (CanGEA, 2020).

Geothermal power plants characteristically run at very high-capacity factors, averaging greater than 70% in the U.S. from January 2017 to August 2019 (EIA, 2019; see Figure 1). Geothermal power releases greenhouse gases at rates far lower than gas- or coal-fired power plants and specifically binary (closed-loop systems) power plants are considered greenhouse gas free. Estimates of global warming emissions for open-loop geothermal systems are approximately 0.1 pounds of carbon dioxide equivalent per kilowatt-hour [CO_2(e)/kWh]. This compares favorably to estimates of life-cycle global warming emissions for natural-gas-generated electricity of 0.6 - 2.0 pounds of CO_2(e)/kWh and for coal-generated electricity of 1.4 - 3.6 pounds of carbon dioxide equivalent per kilowatt-hour (IPCC, 2011).

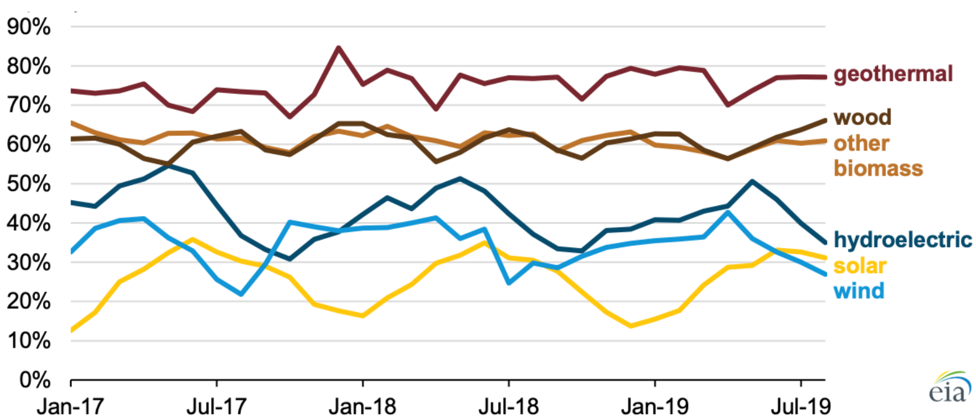

Figure 1. Capacity factors for selected utility-scale electric generators, Jan 2017 - Aug 2019 (Source: EIA, 2020).

Conventional development of geothermal resources requires drilling deep, high-temperature wells that can be both expensive and risky. Drilling costs can be 50% or more of the cost of development of a conventional geothermal field, and exploration drilling and testing can take considerable time, delaying return on investment. While wind and solar grew rapidly to exceed them as renewable power sources (EIA, 2020), growth remains flat for U.S. geothermal power consumption and development (Figure 2). The high upfront cost is commonly cited as an important factor in this slowdown, as drilling techniques have continued to improve with oil and gas field expansion.

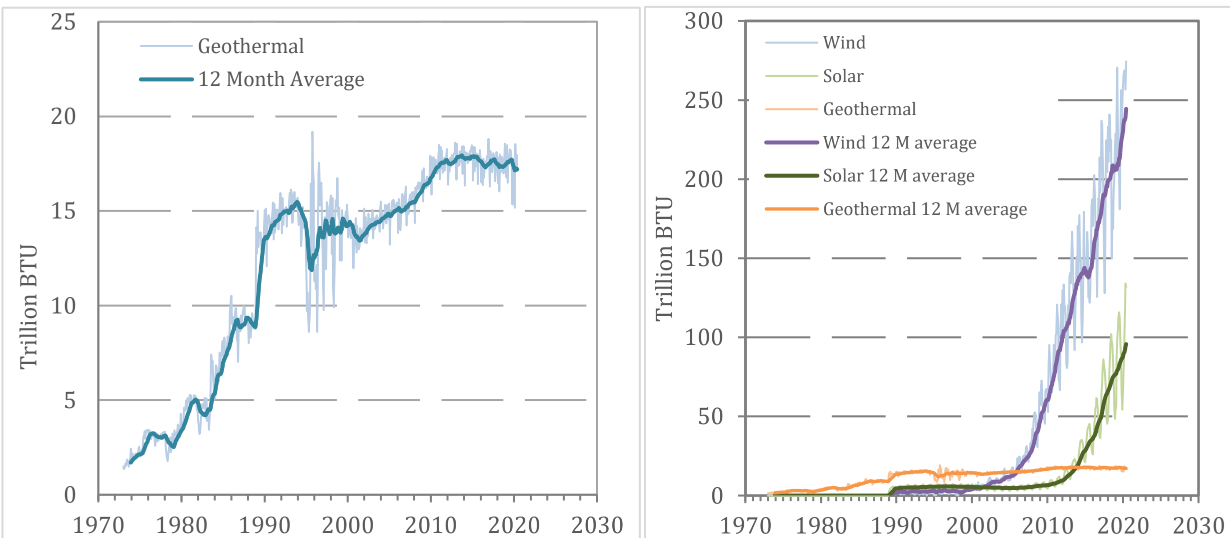

Figure 2. Monthly US consumption of geothermal energy (left), and geothermal, wind, and solar energy (right). Source: EIA, 2020.

Conversion of Oil and Gas Wells to Geothermal Production

The authors' effort is focused on repurposing existing oil and gas wells to increase geothermal energy production and usage, first in North America and then globally. Repurposing existing wells avoids expensive drilling costs for new geothermal wells. It can also defer the need for costly plugging and abandonment, while continuing to provide useful energy in an environmentally friendly way. With improved economics from ease of exploration tools and higher success rates, we expect many wells across the globe to be converted to geothermal energy production in the future.

In Canada, there are estimated to be more than 91,000 inactive wells and 2,992 orphan wells in Alberta alone, with another 10,000 additional inactive or abandoned wells in British Columbia and 24,000 in Saskatchewan (Kemball, 2020). Estimates to reclaim wells in Alberta rose to $100 billion in 2018 from earlier estimates of $58 billion (De Souza et al., 2020). In British

Columbia and Saskatchewan, the estimated costs have grown significantly since 2007 to $3 billion and $4 billion, respectively (De Souza et al., 2020). It is likely that a number of inactive wells can be converted to productive use for geothermal energy before they are orphaned or abandoned by economically stressed companies.

Opportunities exist to produce cost-effectively from moderate- to high-temperature sedimentary rock formations, repurposing already drilled oil and gas wells and either converting them to geothermal wells or coproducing heat and hydrocarbons. The first use case is to identify and convert late-stage oil or gas wells entirely to geothermal production, or use dry holes that lacked economic hydrocarbons, but produced substantial amounts of water. Secondly, one can potentially coproduce hydrocarbons and heat from wells at earlier stages in their hydrocarbon lifecycle if enough water is already being produced.

The first option is especially interesting for later-stage oil and gas wells with limited current profitability, which produce large amounts of water, and which would soon need to go through a costly permanent abandonment process. Instead, conversion provides an incentive for oil and gas companies to support and potentially profit from going into geothermal energy production. Some of the geothermal energy could be distributed to the utility industry and households as heat or electricity; in addition, some of this energy could be used to power oil and gas operations in a greener fashion. This reduces the need for additional power generation by the utility. For conversion to geothermal energy generation, several requirements must be met including:

- *Nearby heat demand*: Unlike oil and gas, heat is not easily transportable for long distances as it requires costly insulated flowlines. A distance of 10 km or less from well to boiler is necessary for current economics if used as part of a direct use heating opportunity.
- *Heat resource matching demand*, in temperature and flow rate. The flow rate depends on geologic characteristics but can be enhanced by connecting multiple zones or multiple wells in a field. Ideally wells should provide pressure drive, but downhole pumps can be used to lift the fluids, at some expense in system efficiency.
- *Adequate well integrity:* Wells at the end of their productive lifetime may be compromised, as casing and cement can deteriorate over time and may require expensive well interventions, and not qualify for a conversion.

Typically, oil or gas production declines while water increases through the lifetime of a well. Produced formation water from deep reservoirs may have temperatures at 90°C or higher at the surface. This hot water is usually reinjected in the reservoir to enhance production and maintain pressure, wasting the heat energy of the water. An alternative is to extract the heat prior to re-injection, for direct use (district heating or industrial uses) or for electricity production. Even for producing oil and gas wells, sustainable utilization of geothermal energy means that hydrocarbons are produced and used in a way that is more compatible with the well-being of future generations and the environment. This technology encourages the oil and gas industry to power their operations in a more environmentally friendly way by using geothermal energy, and in addition, delivers heat and electricity to utility companies and households.

Recent Trend in Development of Geothermal Energy in Sedimentary Basins

According to the U.S. Department of Energy (2010), Low-Temperature & Coproduced Resources represent a small but growing sector of hydrothermal development in geothermal resources below 150°C (300°F). Considered non-conventional hydrothermal resources, these technologies are bringing valuable returns on investment in the near-term, using unique power production methods. DOE is working with industry, academia, and national laboratories to develop and deploy new low-temperature and coproduction technologies that will help the geothermal community achieve widespread adoption of under-utilized low-temperature resources, including a recent announcement of funding for research and development to help grow U.S. low-to-moderate-temperature geothermal resources.

A well recently drilled in Saskatchewan, supported in part by federal funding, has demonstrated high potential for generating electricity from a Hot Sedimentary Aquifer (HSA) in the Williston Basin (https://deepcorp.ca). This well, and a project in adjacent North Dakota utilizing a water well for oil and gas waterflood operations (Gosnold et al., 2017), demonstrate the potential for harnessing the heat of sedimentary basins for production of geothermal energy.

The global geothermal power market was valued at $4.6 billion in 2018, and is projected to reach $6.8 billion by 2026, growing at a compound annual growth rate (CAGR) of 5.0% from 2019 to 2026 (Allied Market Research, 2019). Zion Market Research projects expected generation around $9 billion by 2025, at a CAGR of around 11% between 2019 and 2025 (Zion Market Research, 2019). Rystad Energy (2020) forecasts an increase in global capacity from 16,000 MW in 2020 to 24,000 MW in 2025.

The Missing Link and the Well Conversion Technology

We strongly believe that the conversion of oil and gas wells to production or co-production of geothermal energy as a game-changing opportunity for increasing the value and reducing the environmental footprint of oil and gas operations. Our preliminary economics from sample conceptual conversion projects indicate repurposing some of the late-stage oil and gas wells to geothermal heat and power is profitable with internal rate of returns (IRR) in the range of interest (7 to 27%) by investment banks. It not only indicates the oil company's commitment to green energy solutions in a short turnover, it also saves abandonment costs and avoids decreasing profits by having to write down or take losses on assets. However, all these benefits are achieved when appropriate wells are selected at the right time for conversion, otherwise the spent capital will be lost.

Thus, we are developing a workflow and screening platform to identify appropriate late-stage oil and gas wells to convert them to clean and low maintenance geothermal energy sources in a systematic and efficient way. It integrates several important parameters including geology, reservoir characteristics, well integrity, engineering, infrastructure, and economics to identify the appropriate wells and also provides practical guidance for the conversion. This platform prevents spending millions of dollars on wells that are not suitable for conversion to geothermal wells. The plan is to test the technology on some pilot wells in collaboration with an oil and gas operator and surface facility partners. It is crucial to identify a set of test cases using the screening tools, to interest industry and governments in funding the conversion of oil and gas wells to geothermal energy generation.

A play fairway analysis was completed for the Mississippi-Alabama-Georgia region for a major regional utility company (Petrolern & WellPerform, 2020). The current focus of interest in this area lies in the deep sedimentary basins of southern Alabama and Mississippi, where conversion of oil and gas wells to geothermal energy generation would be the optimal path. We are focused on geothermal resource evaluation and development in sedimentary basins and on the conversion of existing oil and gas wells. Figure 3 is a conceptual diagram of the activities and competencies for development of a Play Based Geothermal Exploration program to arrive at well-characterized prospects.

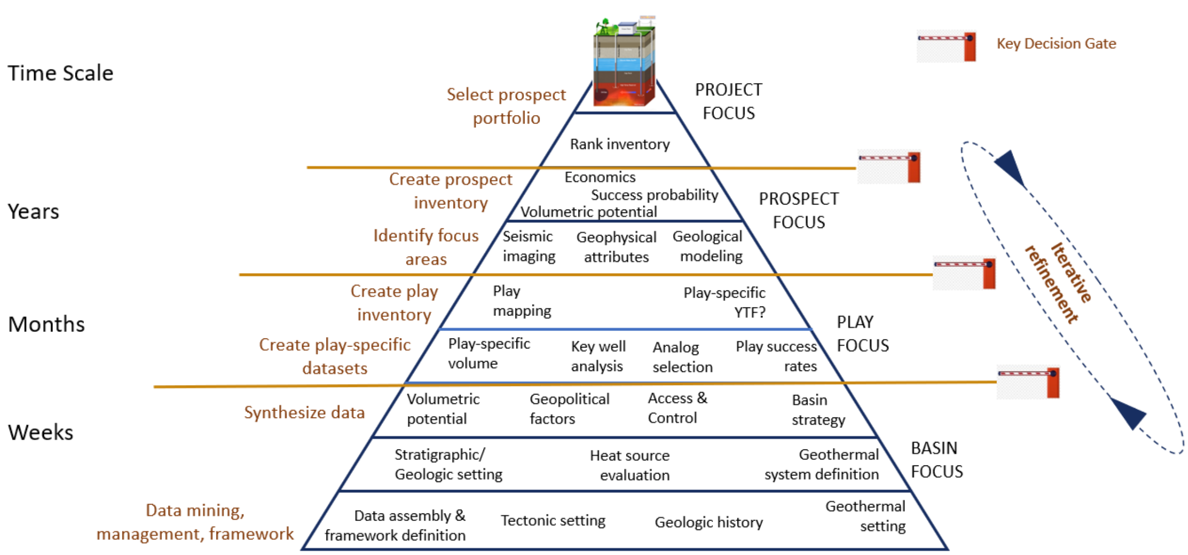

Figure 3. Play-Based Exploration pyramid for development of geothermal resources (©Petrolern).

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***Maria Richards**, SMU Geothermal Laboratory Director in the Roy M. Huffington Department of Earth Sciences, researches geothermal resources and oversees Federal and State government grants and company contracts for SMU Geothermal Lab's faculty, staff, and students. Maria was President of the Board of the Geothermal Resources Council (GRC) in 2017-18, and a Named Director of the 2015-16 Board for the Texas Renewable Energy Industries Alliance (TREIA). Her research is focused on expansion of geothermal energy utilization into sedimentary basins. This work includes improving heat flow and temperature-depth maps, on-site geothermal exploration and data collection, and assessment of low temperature heat sources for utilization potential such as the conversion of oil and gas fields into production of geothermal energy. Her field work experience includes temperature measurements and sample collection in the Northern Mariana Islands, South Korea, Peru, and Montana. Along with Cathy Chickering Pace, Richards coordinated the SMU Node of the National Geothermal Data System funded by the Department of Energy, and, with David Blackwell completed the 2004 Geothermal Map of North America, Dixie Valley Synthesis, and the resource assessment for the MIT Report on the Future of Geothermal Energy. Maria coordinated nine "Power Plays" conferences focused on geothermal energy in oil and gas fields. Through the SMU Geothermal Lab outreach efforts, Maria assists numerous companies and students world-wide to disseminate information on geothermal energy and resources. Maria holds a Master of Science degree in Physical Geography from the University of Tennessee, Knoxville and a B.S. in Environmental Geography from Michigan State University.*