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Co-producing Geothermal Power from Oil and Gas Operations: A Case Study from Alberta, Canada

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1. ABSTRACT

This paper discusses the challenges and opportunities of the pioneering co-produced geothermal power plant project in Swan Hills, Alberta, Canada. The project leverages the existing infrastructure of high thermal gradient reservoirs, where the bottom hole temperatures range from 110 to 120 degrees Celsius, to generate electricity through an integrated generation system employing both a binary Organic Rankine Cycle (ORC) power plant and a natural gas-fired turbine (NGT). The ORC power plant converts geothermal heat and NGT waste heat into power. The project has a nameplate capacity of 21 MW, of which 4 to 6 MW are derived from renewable geothermal and waste heat sources. This reduces greenhouse gas emissions by up to 398,000 tonnes of CO2 over a minimum twenty-year plant operation life. The project demonstrates the economic feasibility of repurposing existing hydrocarbon infrastructure for sustainable energy initiatives.

The paper also addresses the reservoir characteristics, the reservoir temperature measurement methods and estimates, and the project performance indicators. It shows how the project utilizes a geothermal hot spot within the Western Canadian Sedimentary Basin to produce electricity from a high thermal gradient reservoir with high permeability and porosity. We also examine the technical and regulatory challenges faced by such projects in North America. We discuss how the project integrated the ORC system with the NGT, how it coped with supply chain disruptions, transportation delays, budget inflation, and COVID-19-related constraints. We also address the concerns about the sustainability of geothermal energy from oil and gas facilities, which often face funding and regulatory challenges due to the perceived contradiction between fossil fuels and renewable energy sources. The paper explains how these challenges were overcome by comprehensive testing, collaboration with expert engineers and suppliers, and contingency planning and risk mitigation. The paper provides an assessment of the project, and the lessons learned that can guide future geothermal endeavours. The paper aims to contribute to the advancement of geothermal energy development from deep reservoirs and existing hydrocarbon infrastructure, both in Canada and globally.

2. INTRODUCTION

The global energy landscape is undergoing a significant diversification of energy supply by adding renewable energy sources to the current system that relies heavily on fossil fuels. This shift is driven by the urgent need to reduce greenhouse gas (GHG) emissions and its climate change impact. Renewable energy sources, such as wind, solar, and geothermal energy, play a crucial role in achieving low carbon emissions energy supply. Among them, geothermal energy uniquely offers an advantage as a stable, baseload energy source that operates independently of weather conditions to provide continuous and reliable heat for direct use or power generation. Despite the potential of geothermal, the development of the industry faces many challenges – economic, technical, and political – which currently impact the wide-spread adoption of geothermal energy.

Case in point, according to the Internal Renewable Energy Agency (IRENA), geothermal energy for power generation has grown around 3.5% annually, reaching a total installed capacity of approximately 15.96 gigawatts electric (GWe) in 2021 (IRENA, 2023). However, that still only represents a 0.5% share of renewables-based installed electricity generation capacity globally (ibid). Figure 1 illustrates the growth of installed geothermal electricity capacity globally and in North America.

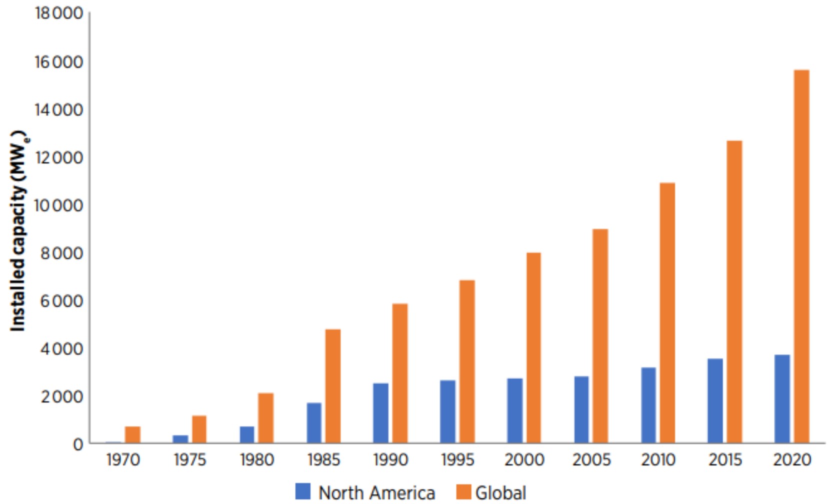

Figure 1. Growth of installed geothermal electricity capacity (ibid)

Before project commencement in 2019, there were only 32 geothermal fields in North America with 93 geothermal electric plants in operation; and all within the United States. FutEra Power Corp. (FutEra) commissioned the first commercial geothermal power plant in Canada in 2022 – the Swan Hills Geothermal Project (SHGP).

Geothermal can be expensive, with the cost of drilling and well preparation being the dominant cost of each geothermal project. In some cases, the repurposing of existing oil and gas infrastructure for geothermal energy production is available (Santos, Dahi Taleghani, & Elsworth, 2022). This strategy capitalizes on the synergies between the two industries, leveraging existing wells, pipelines, and facilities to reduce costs and environmental impacts allowing for a commercial outcome. This is one of the primary drivers for locating the project in Swan Hills region in the province of Alberta.

The objective of this paper is to present a comprehensive case study of SHGP, a first-of-its-kind initiative in Alberta and Canada. The paper aims to: (1) highlight the project's innovation, (2) discuss the complexities of such projects, and (3) describe the technical and operational aspects of co-producing geothermal power with oil and gas infrastructure, focusing on the integration of the organic Rankine cycle (ORC) and natural gas turbine (NGT) systems to optimize energy production and efficiency.

3. OVERVIEW OF THE SWAN HILLS GEOTHERMAL PROJECT

FutEra is a pioneer in the industry and owner and operator of Canada's first co-produced geothermal power plant. The project is located within the oil and gas assets once operated by Razor Energy Corp. (Razor) in the Swan Hills region of Alberta, Canada (Figure 2). Specifically, the project operates in a process facility where substantial oil and water production and processing occurs. The satellite facility processes an oil production rate of approximately 3,000 barrels per day (bbl/d) alongside significant water production, with a flow rate of 80,000-100,000 barrels per day (bbl/d).

Figure 2. Project location

The Swan Hills region lies within the Western Canadian Sedimentary Basin (WCSB). Figure 3 shows the breadth of the WCSB, which extends the length and width of Alberta, and is largely responsible for Canada's position as the fifth largest natural gas and fourth largest oil producing country in the world. The WCSB has promising potential for geothermal development due to its abundant high thermal gradient reservoirs and established hydrocarbon infrastructure. Swan Hills is located to the northwest from the city of Edmonton; as indicated by the mark on the map in the middle of Alberta, Swan Hills is approximately 2.5 hours away from Edmonton.

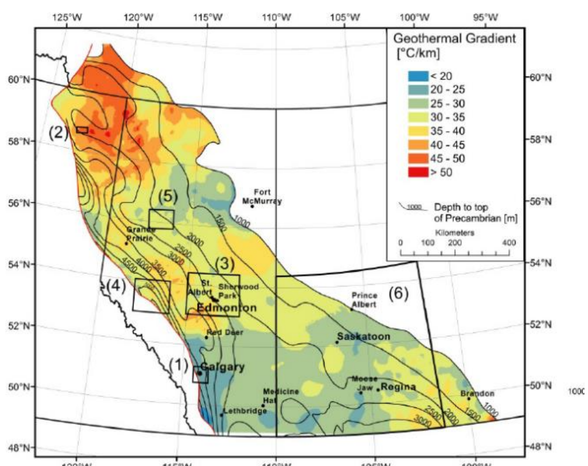

Figure 3. Geothermal gradient of the WCSB based on 68,377 gradient values from 26,492 wells (Weides & Majorowicz, 2014)

Extensive oil and gas operations have existed in the Swan Hills area since the 1950's with water injection techniques adopted in the 1960's and heavily used since. Water injection or water flooding involves the injection of water into an oil reservoir to increase the oil-production rate, and ultimately, oil recovery. When oil is brought to the surface, it is carried by waste or "produced" water which has now been geothermally heated. As in this case, reservoir production techniques like water flooding have great potential for geothermal energy exploitation. By leveraging this oil recovery technique, geothermal heat brought to surface is used or converted to enhance energy efficiency and lower carbon footprints.

The geothermal potential in Swan Hills is attributed to the combination of elevated bottom-hole temperatures, which range between 110°C and 120°C, and favorable subsurface characteristics, such as high permeability and porosity. These factors make the area an ideal candidate for geothermal energy extraction.

The primary goal of the project was to address two critical challenges faced by Razor:

- Clean Power Supply: as the site was dependent on self-supplied natural gas reciprocating engines for consistent operations, which are high GHG emitters; and
- High Energy Costs: the Alberta electricity market operates on an open-market basis, where fluctuating power prices, coupled with additional transmission and distribution costs, resulted in unpredictable and often high operational expenses. Canada has a carbon tax that has increased in cost every year since inception in 2019 and may continue to rise to 2030.
- To overcome these challenges, FutEra contemplated using the hot reservoir in the Swan Hills asset to produce power through geothermal energy. The objectives were twofold:
- Energy Independence: Generate sufficient power on-site to meet the operational energy needs; and
- Environmental Benefits: Reduce GHG emissions by leveraging geothermal heat and the waste heat from natural gas turbines, thereby enhancing and sustaining the oil and gas operations.

Figure 4 shows the simplified diagram of the SHGP which includes a binary ORC and NGT system.

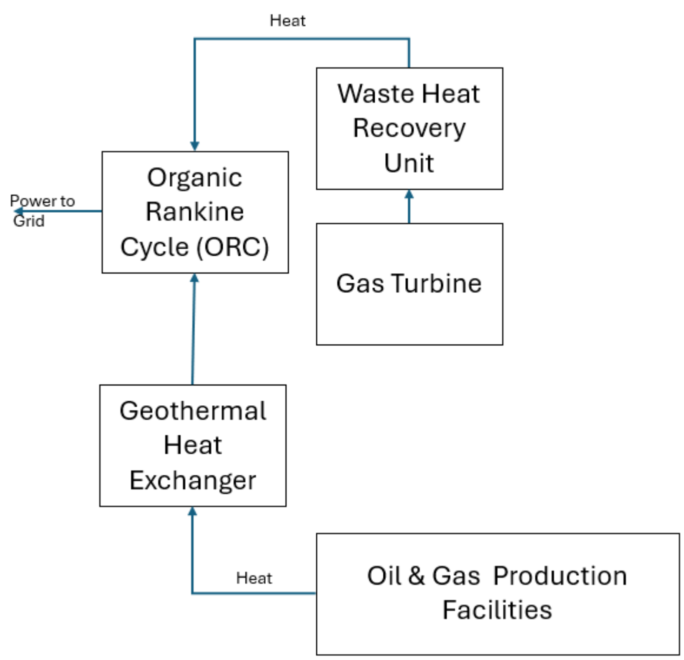

Figure 4. Simplified diagram of the SHGP

The project features an ORC integrated with an existing NGT to maximize energy production from geothermal energy produced from an oil and gas reservoir. A working fluid with a low boiling point is used in the ORC to convert heat from the geothermal reservoir into mechanical energy, which in turn is transformed into electricity. This design allows efficient energy capture from the reservoir's moderate temperatures. In the case of SHGP, produced water from the existing water flood enhanced oil recovery operation is used to heat the working fluid. The produced water can reach temperatures of 108°C at the well head and enter the processing battery at temperatures up to 90°C.

ORC turbines typically require minimum fluid temperatures of 120°C to operate economically and thus a secondary thermal source is required to boost the working fluid temperature. This project uses one Solar Titan-130 Natural Gas Turbine Generator with the turbine exhaust gas providing the additional heat to the ORC waste heat recovery unit (WHRU). The WHRU is equipped with a bypass exhaust duct to allow operation of the NGT while the ORC is unavailable.

From the energy production point of view, the power generation capacity is 15MW for the NGT and 7.5MW for the ORC, which is derated due to elevation and ambient conditions, to a nameplate capacity of 21MW depending on the time of the year.

FutEra engaged two engineering firms to cover the entirety of the project scopes. One engineering firm, with support of the ORC vendor, completed the ORC and produced water tie-in, while the other engineering firm oversaw the completion of the NGT system, fuel gas tie-in, and, ultimately, the integration of both scopes of the project. The battery limit of the two scopes was at the inlet flange to the WHRU.

The project's design exemplifies a scalable and sustainable approach to integrating renewable energy with hydrocarbon infrastructure, offering a blueprint for similar initiatives across the WCSB. This energy mix not only supported the operational energy demands, as a financial hedge, of Razor but also reduces GHG emissions by an estimated 398,000 tonnes of CO2 over a minimum 20-year plant operation life.

Of note, Razor was a junior oil and gas outfit, which sought bankruptcy and insolvency protection last year. This highlights the life cycle challenges of existing oil and gas assets, and the opportunity for geothermal companies to leverage the sunk costs of oil and gas assets and provide a public service by curtailing the abandonment of those oil and gas assets, which has been at significant cost to the public purses of both Canada and the United States.

FutEra was created as a subsidiary of Razor Energy and has become a standalone entity backstopped by the Alberta Investment Management Corp, or AIMCo, which represents Alberta’s pension fund investments. FutEra wholly owns SHGP.

4. ANALYZE THE CHALLENGES ASSOCIATED WITH THE PROJECT

SHGP faced several important challenges that are worth discussing. This study is unique as not many studies have investigated producing geothermal power from oil and gas operations, making this project singular and complex. These challenges need to be examined closely to understand the scope of the difficulties and explore possible solutions. The challenges can be categorized according to Figure 5, where:

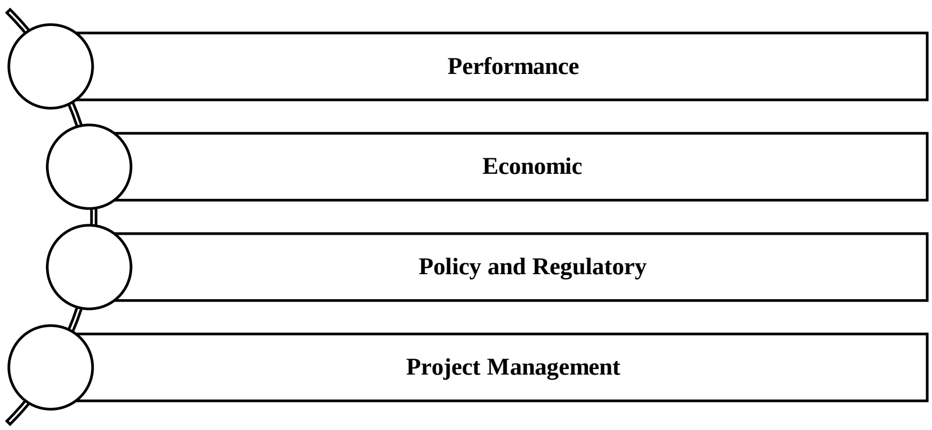

Figure 5. Challenges categories

1. Performance challenges refer to the difficulties encountered in the development, implementation, and maintenance of the project, in particular, within the context of oil and gas operations;
2. Economic challenges refer to the financial barriers and considerations associated with the project;
3. Policy and regulatory challenges refer to the legislative and regulatory obstacles that hinder the development of project; and
4. Project management challenges refer to the difficulties in planning, organizing, and managing resources to execute and complete the project.

4.1. Performance Challenges

<u>The impact of reservoir characteristics and fluctuations in heat supply and performance</u>

Geothermal heat supply is variable and depends on several factors, including reservoir properties and the operational dynamics; this is particularly true when the project is integrated with the oil and gas facility and operations. In this case study, where the oil and gas extraction rely on water flooding methods across multiple wells, we found fluctuations in reservoir performance including variations in depth, temperature, permeability, and porosity of the reservoir. These variations result in differing thermal outputs from each well. For this project, the bottom-hole temperature fluctuates by up to 10°C across the various wells, while the water flow rates also fluctuate. This translates into a fluctuation of up to 8°C in the working fluid temperature of the ORC system.

On the other hand, the various parts of the reservoir undergo different thermal charging and discharging cycles due to dynamic water injection and oil production system. In other words, the produced water temperature and flow rate are impacted by operational variables such as reservoir depletion and water injection dynamics. Evidence from geothermal projects globally highlights similar challenges (DiPippo, 2015).

Heat loss and pressure drop during operations
The cold climate of Alberta results in temperature loss in the produced water lines. As oil and gas production facilities do not exploit the heat from the produced water, measures to preserve the heat are not implemented. The geothermal heat exchanger is linked to approximately 130 metres of above ground piping from the oil processing plant. During the winter, when temperatures can drop below -10°C, this distance results in a temperature loss of approximately 1.5°C as the water travels through uninsulated pipelines which impact on the Q transfer from the produced water into the ORC working fluid. Therefore, insulating the pipes are necessary as this heat loss also contributes to a pressure drop in the system, which affects the efficiency of fluid circulation. However, heat losses are also experienced from the satellite units of the oilfield, which aggregate produced water from the area wells, and sends them to the processing battery via many kilometres-long pipeline infrastructure, albeit underground piping; where heat losses are harder, if not wholly impractical to mitigate. Underground piping does provide insulating value as at the depth of the pipelines' temperatures remain more constant.

Produced water characteristics
The produced water from oil and gas facilities contains various underground elements, a slightly basic pH, and microbes. These traits introduce several material challenges including dissolved salts, heavy metals, other corrosive agents such as chlorides, sulfates, and hydrogen sulfide (H_2S), and microbes. These components can accelerate corrosion and scaling in pipes and heat exchangers. To address these concerns, a suitable material was selected and other mitigations implemented, like microbiological controls and chemical inhibitor protection.

Integration of ORC and NGT systems

The successful integration of the ORC and NGT was critical to optimizing energy recovery and conversion. However, challenges arose in the design and operation of the heat exchangers and waste heat recovery systems. For example, the ORC system relies on efficient heat transfer from both geothermal water and waste heat from the NGT. Variability in heat supply can reduce the performance of the ORC system. In such a system, the working fluid in the ORC system must be carefully selected and monitored to ensure compatibility with fluctuating thermal conditions and to minimize energy losses. FutEra implemented several initiatives to resolve this issue and continue to optimize performance.

4.2. Economic Challenges

Economic challenges are faced by every project but may have proven to be more difficult in the nascent geothermal industry context. This can be demonstrated by the struggles of other geothermal developers in Canada, whose projects have all but stalled, largely due to the access to capital. Even SHGP was always undercapitalized during project execution and decisions were heavily influenced by this. Investments in a 'first of its kind' project were seen as higher risk. This project received government grants which reduced risk for external capital and debt financing was eventually obtained.

Budgetary increases during the project development
The project was executed in three years, two of which were COVID years. The COVID economic climate did little to improve the situation. Global supply chain disruptions, increased demand for raw materials, and labour constraints and shortages through the period led to rising costs. For example, construction material prices, such as steel and concrete, easily increased by over 20%-25% during the period from 2021 to 2023. Contractors were also required to implement costly COVID measures to continue work. This ultimately led to higher costs unforeseen by an already stressed innovation budget.

Uncertainty in deregulated power markets
Alberta's deregulated electricity market provides opportunities for competitive pricing but also introduces a level of volatility. Power prices are influenced by various factors, including the penetration of large-scale renewable energy sources such as wind. At the time of project planning and early execution, projections for electricity prices suggested an average of $80-$100 per MWh. In 2022, power generators experienced a banner year with prices well exceeding those early projects, which fortunately buoyed the undercapitalized project. However, once commissioned, the prices regularly dropped into the range of $50-80 per MWh, heavily influenced by surplus wind power generation and other projects coming online. These fluctuations adversely affect the ability to accurate project revenues, making it challenging to establish a stable financial model for geothermal power generation and development. This impacts the long-term financial viability of future projects and may further eliminate early geothermal innovators.

High financial risk for early-stage projects
The lack of extensive geothermal development experience in Alberta and North America resulted in limited access to financial support mechanisms, such as low-interest loans or risk-sharing models that are available in more mature markets (e.g., Iceland, New Zealand). This is further exacerbated by the fact that local capital providers have little exposure to geothermal. The hybrid

nature of the plant created more confusion, as capital markets can be divided into green funds and traditional energy funds and this project spanned both satisfying neither a fully green mandate nor the traditional energy return expectations. Though, there seems to be a correction to the polarizing ESG positions previous taken making investment capital more accessible to diversification projects. Capital seems to be more concentrated on return profile than simply ESG as it was in the early days of the project.

4.3. Policy and Regulatory Challenges

Regulatory challenges

SHGP is a pioneer project in an environment new to geothermal regulation. As the first-of-its-kind project in Alberta and Canada, FutEra was well positioned to influence regulatory development and the implementation of Bill 36, the Geothermal Resource Development Act (Alberta), the first regulatory foray into geothermal energy. Despite that enactment and the geothermal industry is still often managed under systems originally designed for oil and gas projects (Alberta, 2020).

The Alberta Energy Regulator (AER) continues to classify and regulate geothermal resources using methodologies used in oil and gas operations. This new Act has not been fully tested by geothermal development making some regulatory guidelines unclear in their application for geothermal developers. Further, high regulatory burden for nascent geothermal developers with regulations applicable to the oil and gas industry may lead to impractical results that stifle further geothermal development. However, the AER recognizes this and has established an internal innovation group to help facilitate innovative projects, to foster learnings, and to ultimately implement practical regulation.

Lack of incentives for innovation

The financial drivers and incentives to support geothermal projects in Alberta are still insufficient. Alberta could benefit from more comprehensive incentive programs, such as grants or tax credits, specifically targeted at geothermal, including for feasibility studies, pilot projects, and drilling cost reductions. Enhanced government support for retrofitting and repurposing legacy or mature oil and gas wells for geothermal purposes could also significantly lower project costs and risks. These challenges underscore the need for more proactive and tailored policy measures to position Alberta as a leader in geothermal energy, building on its expertise in oil and gas. A thriving geothermal industry in Alberta, particularly one that can leverage sub-economic oil and gas facilities, is a boon to the public purse and facilitates true energy transformation and diversification.

4.4. Project Management Challenges

Supply chain issue

Geothermal projects, especially those integrating existing oil and gas infrastructure, face unique project management challenges. Effective management is crucial to mitigate delays, ensure cost control, and achieve technical success. As discussed, COVID pandemic caused cost-overruns and delays on the project. The impact of COVID was expansive; it changed construction practices to meet prevailing orders and regulations and disrupted global supply chains and impacted delivery timelines and costs.

Complexity of team collaboration

Coordination among diverse stakeholders, including engineers, suppliers, and contractors, was a considerable challenge. Misaligned priorities and communication gaps occasionally hindered smooth project execution. Effective contracts and pre-defined responsibilities were critical to avoiding disputes. For example, dedicating sufficient time upfront to drafting detailed contracts ensured clearer expectations regarding delivery timelines, material quality, and scope. In a few cases, lack of detail in contracts sometimes led to performance bottlenecks with contractors, particularly those less experienced in geothermal applications.

Consistent project management

Our project faced challenges due to changes in project management throughout project execution. The project team was small and undercapitalized in the early days resulting in hiring of external project management. With two changes in leadership of project management, inefficiencies resulted from periods of familiarization and getting up to speed. Each new project manager also brought different perspectives, strategies, and management styles, which led to inconsistencies in project execution. The changes would lead to communication gaps, which led to misunderstandings and misalignments among team and project members. Factor in the loss of the valuable insights and knowledge gained by outgoing project managers, changes to project managers become an outsized impact on the project.

5. CONCLUSION

Innovation is in its nature difficult and the challenges numerous. With this project, FutEra contended with fluctuating oil and gas production outside the project control, heat loss, and material issues, to budgetary increases and market volatility, as well as policy and regulatory and project management challenges. Meeting all these challenges were crucial to the success of this project and will continue to be crucial to further clean energy developments.

FutEra had many valuable learnings from the project. It was essential to develop adaptable technologies that could handle variability in design versus actual conditions, and to integrate effectively with oil and gas operations. It is important to have robust financial planning and flexible models that can adapt to the market and respond to once in a generation event, like COVID-19. Though a thorough understanding of the regulatory landscape is important, early engagement with policymakers are necessary to tackle regulatory and legislative obstacles in a nascent industry. Finally, ensuring consistent leadership throughout the project lifecycle is critical to avoid communication breakdowns, delays, and loss of institutional knowledge.

In hindsight, an overview of the success in the project is in order. When FutEra first set upon this path to building a geothermal power plant in 2018, the economics of geothermal were uninvestable. Innovation and practical thinking, driven by the creation of a competitive return on capital, created the co-produced hybrid geothermal power plant because 'it was the project that could be built'. Added to the economic drivers, the ESG pressures on decarbonizing the energy supply mix were global and omnipresent. The FutEra mandate was to build the first geothermal power plant in Canada, in one of the best geothermal reservoirs in Alberta, to inform a nascent industry and create a corporate growth model for FutEra, which it is currently executing.

Geothermal sits adjacent to oil and gas as both are considered resource production, sharing technical and economic vernacular, human capital and support industries. This is especially true now with oil and gas technologies largely driving next-generation geothermal development. Also, drilling a well, whether for oil and gas or geothermal, looks strikingly similar. FutEra has adopted a very pragmatic approach that largely informs its development plans to continue to develop geothermal energy production by leveraging oil and gas infrastructure to improve geothermal outcomes and economic return.

Undoubtedly, geothermal energy development has unfettered potential as a cornerstone of the energy diversification and decarbonizing strategy offering a sustainable, reliable, and low-carbon alternative to fossil fuels. Its potential to provide baseload renewable power makes it uniquely suited to complement intermittent sources such as wind and solar. The repurposing of existing oil and gas infrastructure, as demonstrated in the Swan Hills project, can significantly reduce upfront drilling costs and accelerate deployment, leveraging the expertise and assets of the fossil fuel industry to support decarbonization. FutEra will continue to innovate, with intellectual property development, using a practical approach to geothermal that harnesses a wealth of knowledge, data and infrastructure available from a highly sophisticated oil and gas industry.

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