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De-Risking Geothermal for Direct-Use Heating in North America: Lessons Learned from Europe

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ABSTRACT

Geothermal for direct-use heating is a proven technology that has been utilized for decades all over the world (e.g. Germany, France, and the Netherlands). In cold, cool, or temperate regions across large portions of the North American continent, space and water heating represents a significant energy demand, but North American geothermal heating is an emerging form of energy relative to other markets. This is primarily due to the challenge of competing with relatively abundant, low-cost forms of North American energy, such as natural gas. As the global transition to a net-zero energy system unfolds, direct-use geothermal has the potential to become an important part of the energy mix. Canada and the United States can redeploy the wealth of data, equipment, and expertise honed from decades of hydrocarbon development into advancing geothermal and providing reliable, zero-emissions, baseload energy that enhances energy security while reducing emissions.

As with how Canada's oil sands were commercialized, or how the shale boom unlocked significant hydrocarbon resources using directional drilling and fracturing, there is an opportunity to develop a locally untapped resource by taking advantage of innovative practices. One such innovation is utilizing learnings from other markets with similar geologic conditions. These experiences can be leveraged to reduce risk and mitigate uncertainty to accelerate the advancement of North American geothermal energy. For example, direct-use heating projects in the Netherlands producing geofluids with temperatures up to 248°F (120°C) from aquifers in sedimentary basins at a depth range of 5000- 8200 feet (1500-2500 meters) reflect similar conditions found in many portions of western Canada and the United States. Strategic advice and practical experience from delivering these types of projects in other regions can create value in the North American market by providing key quality assurance services as well as commercial and technical insights that guide critical cost-saving decisions.

1. INTRODUCTION

Similar to Moore's Law, which describes the rate at which computational capacity doubles, Wright's Law (also known as the "experience curve") posits that for every doubling of units produced, costs will fall by a constant percentage (Nagy et al., 2013). A specialized case of Wright's Law: Swanson's Law, observes that the price of solar photovoltaic modules drops by 20% for every doubling of the total shipped volume of solar panels (Partain et al., 2017). A major barrier to adopting new forms of energy is competing with the economics of mature technologies (which have already iterated along the experience curve to establish a low-cost equilibrium), while the new technology has not yet benefited from the lower costs associated with scale.

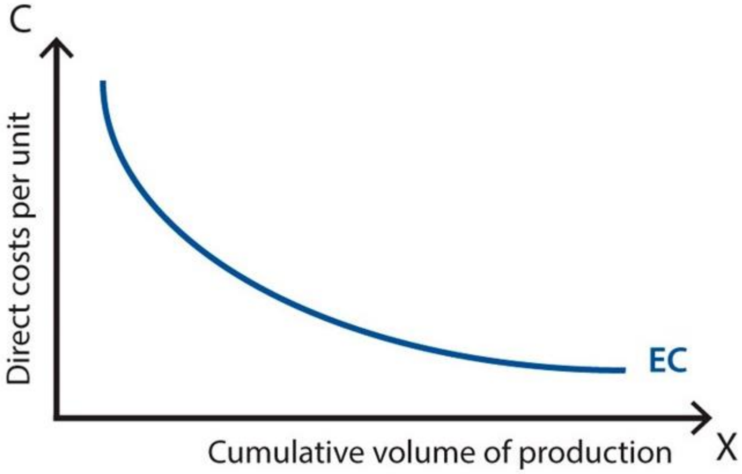


Figure 1: The experience curve. As the number of units produced increases, costs decrease ("Experience Curve Effect," 2023).

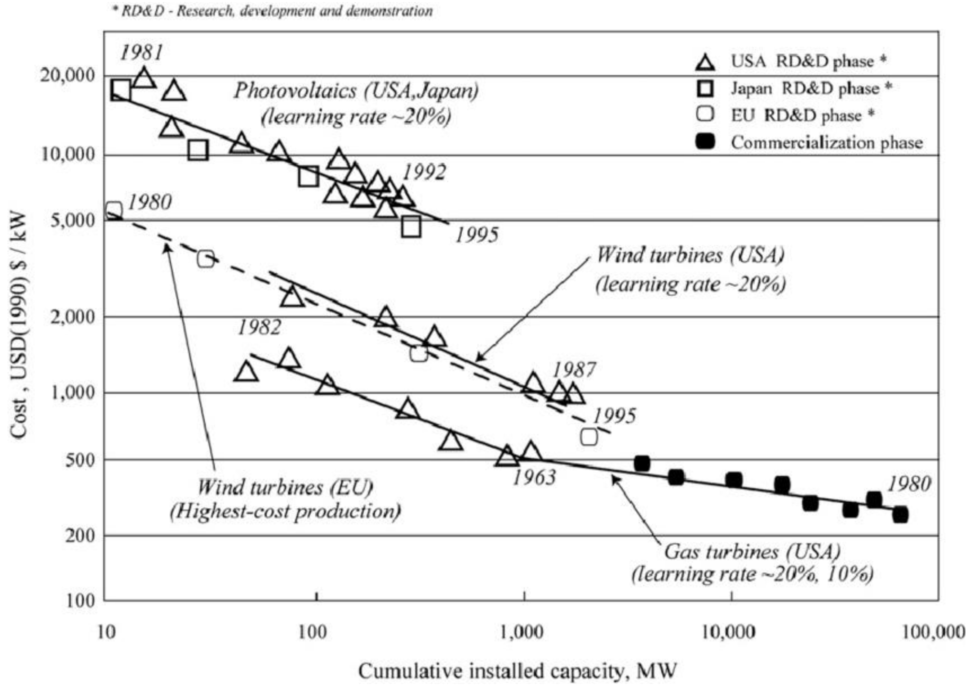
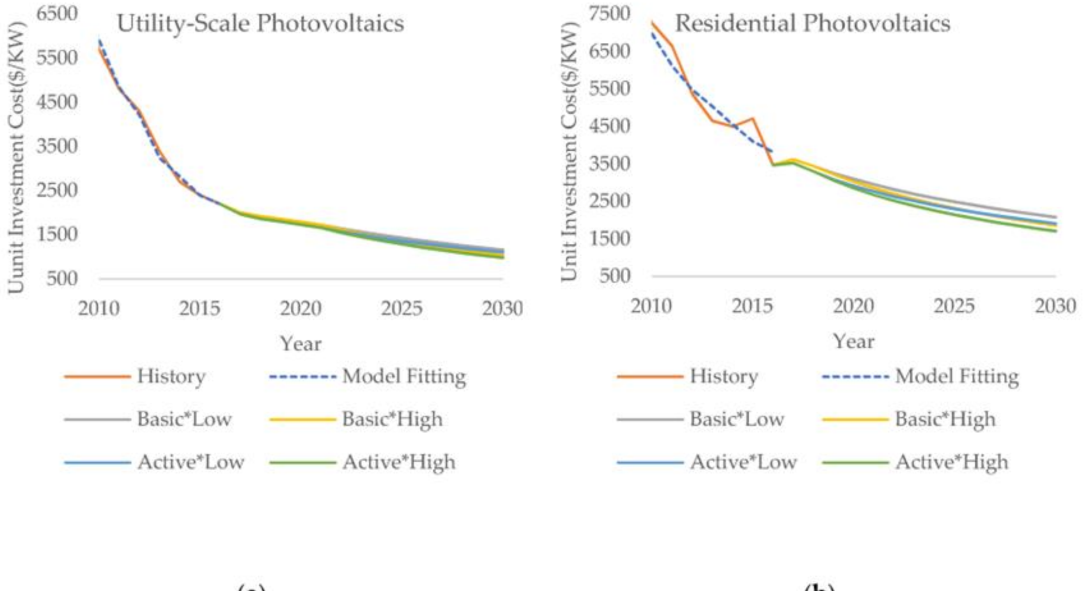


Figure 2: Learning curves for energy technologies showing cost improvement per unit of installed capacity (Nakata et al., 2011).



(a) (b)

Figure 3: Experience curve/learning rate for solar photovoltaics for utility scale (a), and residential (b) installations (Zhou & Gu, 2019).

One method of disrupting the status quo is importing skills, technologies, or innovative practices that have been incubated, tested, and grown in a foreign market. Introducing skills that have been developed in a similar but more mature market unlocks opportunities as the locally novel technology benefits from learnings, cost savings, and general momentum developed elsewhere. These factors help the newcomer compete with incumbent systems. This is especially true with respect to mitigating uncertainty and risk associated with technologies pioneering into new regional markets.

Although there is an ongoing debate about how the learning rate may apply to geothermal technologies given that hydrothermal resource development tends to require site-specific designs that may not scale efficiently, innovative practices and iterative learnings undoubtedly can improve efficiency, avoid costly delays, and improve the cost competitiveness of geothermal energy (Greene, 2022; Roberts, n.d.).

2. INNOVATION

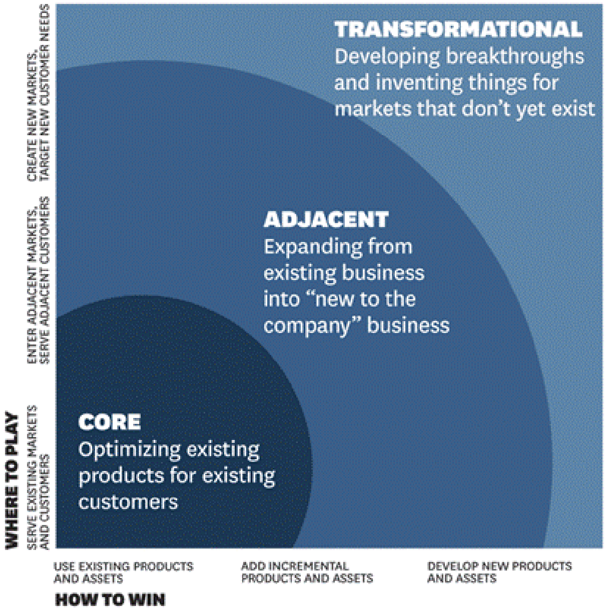


Figure 4: Types of innovation (Satell, 2021)

2.1 Core Innovation

Core innovation can spur the development of direct-use geothermal projects in North America across core innovation's two core dimensions:

- Serving existing markets and customers; and
- Using existing products and assets (Satell, 2021).

In cold, cool, or temperate regions across North America, space and water heating represents a significant energy demand. To put it pointedly: there is a market in North America for heat energy. For example, in Canada, buildings account for 57% of urban greenhouse gas emissions (*Subterra Renewables*, 2023). Sustainable, zero-carbon heat energy is required for national net-zero goals.

Similarly, by using existing products and assets like geoscientific data sets, skills, and expertise, geothermal resources suitable for direct-use applications may be de-risked. For example, Western Canada has well-characterized geology from decades of hydrocarbon development. Many of these data sets have been aggregated, are in the public domain or can be accessed via affordable geoscience tools and may be useful in characterizing low-temperature geothermal resources. This reduces exploration risk and capital expenditures associated with drilling shallower, cooler resources when compared to higher temperature resources with higher associate uncertainties.

2.2 Adjacent Innovation

Adjacent innovation may also be a practical means of moving geothermal technologies down the cost curve. Adjacent innovation in this context applies by seeking regions with well-developed geothermal sectors and similar geologic conditions (enter adjacent markets) and adopting learnings from adjacent/similar markets with established geothermal industries (add incremental products/assets).

This is a means of using existing capabilities like technology or knowledge associated with developing similar reservoirs to appeal to a new audience or enter a new market.

3. LESSONS LEARNED

The technical and commercial knowledge honed through years of experience building direct-use heating geothermal projects in regions with relatively cool geothermal gradients is especially relevant to many parts of the North American market, which tend to lack the high temperature, high enthalpy geologic conditions found in countries with well-developed geothermal industries such as Iceland or New Zealand. Geothermal gradients in regions where direct-use geothermal heating is commonplace: sedimentary basins in Germany, France, and the Netherlands, are in a similar range as those found in the Western Canadian Sedimentary Basin, Williston Basin, Denver Basin, Permian Basin, and Illinois Basin (Bauer, 2018; Bonté, 2013; Deighton, 2015; Mijnlieff, 2020; Proffitt et al., 2013; Stolldorf, 2020; Weides & Majorowicz, 2014). Lessons learned about the nuances in building and operating direct-use geothermal projects in low-temperature environments may be more valuable for direct-use geothermal than expertise developing high enthalpy projects in regions with far higher subsurface temperatures than are typically found in many regions in North America.

Key geothermal capabilities developed in regions that parallel the geologic conditions found in the North American market provide essential services to screen project opportunities, facilitate site selection, model financial performance, complete technical and economic due diligence, and assess the risks of potential geo-hazards. These skills provide strategic advantages in reducing risks associated with geothermal project development. Many of the skills that help de-risk a geothermal reservoir in a sedimentary basin are familiar to professionals working in oil & gas industry: geophysical, petrophysical, reservoir modelling, and geo-hazard analysis. Delivering these insights for geothermal projects reduces uncertainty, identifies critical aspects of a project, and generally helps developers avoid surprises when bringing a project online. For example, geothermal reservoir modelling, analyzing fracture containment, assessing caprock integrity, modelling a reservoir's temperature profile, and identifying seismic or subsidence risks can provide consequential value to change the risk profile of a potential project. Once a geothermal project comes online, expertise in optimizing an asset's production, mitigating corrosion, treating scaling, and monitoring potential subsidence or seismic activity can also have a tremendous upside for the efficiency of a geothermal project's operation.

Strategic advisory services also extend beyond technical, engineering, or geoscience expertise into the realms of stakeholder management, supporting procurement decisions, providing quality assurance services on system design, offering regulatory guidance, assessing funding proposals, and completing financial analysis. This is especially true for potential developers who already hold a diverse portfolio of conventional and renewable energy assets. Energy advisory services can unlock value for clients who are interested both in better understanding how geothermal energy fits into broader carbon management plans while exploring other novel technologies that are emerging as sources of value in the energy transition. Expertise in completing systemic analysis of the energy value chain uncovers new opportunities and provides strategic benefits to organizations operating in the rapidly changing energy landscape.

3.1 The Netherlands

The Netherlands sits on a sedimentary basin with similarities to the Western Canadian Sedimentary Basin and other sedimentary basins in North America home to prolific hydrocarbon deposits. The Netherlands has geothermal gradients in the range of 30-35ºC/km, but despite these relatively underwhelming subsurface temperatures, there are 36 geothermal doublets in operation at 26 locations around the country that generated 6.8 PJ (6.8 million GJ or nearly 19 million MWh) of heat energy in 2022, (saving 193,000,000 m^3 of natural gas) ("Geothermal Energy, an Essential Source of Energy," 2023).

The geothermal industry in the Netherlands is growing rapidly: targeting nearly 10x growth in the next decade with a goal of achieving 40-50 PJ of annual energy production by 2030. Minister Jetten (Minister of Climate and Energy) expects that at least 18 new projects will be developed through an operating grant totaling almost €2 billion. The goal is to supply 25% of the entire country's heat demand by geothermal heat by 2030 ("Geothermal Energy, an Essential Source of Energy," 2023).

Hans Bolscher, chairman of Geothermie Nederland was quoted:

> "In recent years, too much attention has been paid to electricity in the Netherlands. You cannot heat the whole of the Netherlands sustainably with electricity. Fortunately, we are now seeing a clear change when it comes to attention for large-scale sustainable heat production."
>
> "more heat networks and storage solutions are quickly needed […] This requires a coordinated approach between governments, geothermal companies and other stakeholders." ("Geothermal Energy, an Essential Source of Energy", 2023).

The growth of the Dutch geothermal industry was driven in large part by two factors:

- a robust greenhouse industry that was historically heated via natural gas; and
- scaling down production of the Groningen onshore natural gas field in the early 2010s.

In the Netherlands, in the early 2010s the greenhouse industry used nearly 3 billion m^3 of natural gas pear year (8% of total national gas use). Production in the Groningen field was scaled down in the 2010s due to public concerns associated with induced seismicity attributable to onshore hydrocarbon development; this started a push from greenhouse operators to search for cost certain, low-carbon, sustainable heating alternatives. The demand has only gotten stronger since Russia's invasion of Ukraine and the consequent energy shortage in Europe. Low-mid enthalpy geothermal development has helped the industry reduce gas usage by at least 23% (Ministry of Economic Affairs and Climate Policy, 2023).

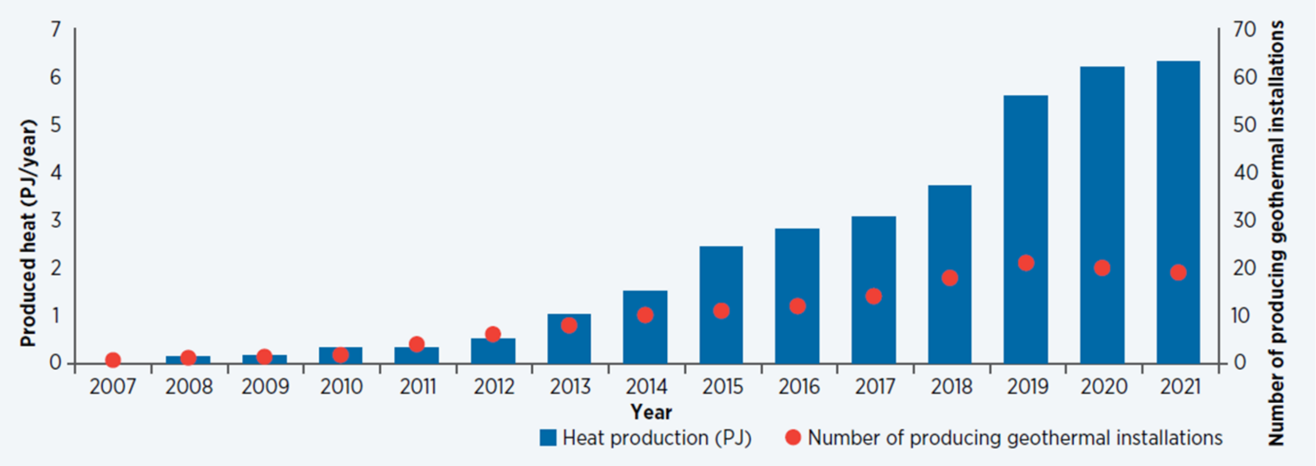


Figure 5: Number of producing geothermal installations (red dots, right axis), and annual geothermal heat production in Petajoules: PJ (blue bars, left axis) in the Netherlands by year (Ministry of Economic Affairs and Climate Policy, 2023).

3.2 Geothermal Resources

Many of the direct-use geothermal heating in the Netherlands is being supplied by the Delft Sandstone Member. This is an early Cretaceous, matrix permeable, sandstone aquifer, with a depth range of 4900-8200 ft (1500-2500 m), with geofluid temperatures typically below 212ºF (100ºC).

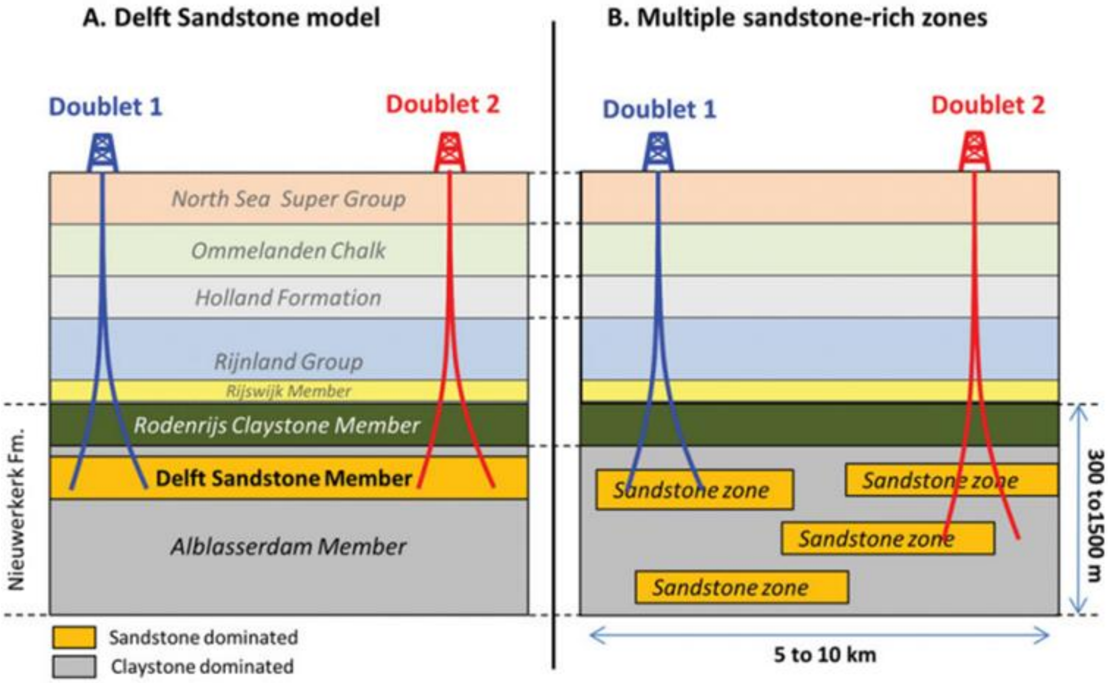


Figure 6: Schematic of a typical geothermal doublet in the Netherlands producing from the Delft Sandstone Member or sandstone zones (Willems et al., 2017).

Interestingly, production at many direct-use doublets in the Netherlands is limited by permeability of the aquifer, which influences flow rate and injectivity. For direct-use assets, it has been observed that this factor can have a larger impact on production than fluid or reservoir temperature. Hotter temperature resources tend to capture the bulk of attention in the geothermal industry, with geofluid temperatures of 248°F (or 120°C) generally considered as the minimum viable temperature for electricity production with higher output and efficiencies occurring at higher temperatures and with higher enthalpy resources. However, there is useful energy that can be extracted from a resource that is “only” 175°F (80°C) when that heat energy is used directly. Exploration risk tends to be relatively low with these resources, and capital expenditures (CAPEX) associated with drilling shallower, cooler resources is lower. However, there are challenges to operating these resources that are similar to higher-temperature geothermal assets: corrosion and scaling need to be managed successfully through effective use of chemical inhibitors and effective well design. CAPEX and operational expenditures

(OPEX) may be reduced by designing a well with appropriate materials such as Glass Reinforced Epoxy (GRE) lined tubing and selecting a corrosion management program that is tailored to the specific geochemical properties of the asset.

3.3 North American Analogues

Many of the geothermal resources developed in the Netherlands utilizing the early Cretaceous Delft Sandstone member parallel sandstone aquifers found in North America. For example, the Bow Island, Viking, Pelican, and Peace River formations are laterally extensive, early Cretaceous, interbedded sandstones found across the Canadian province of Alberta.

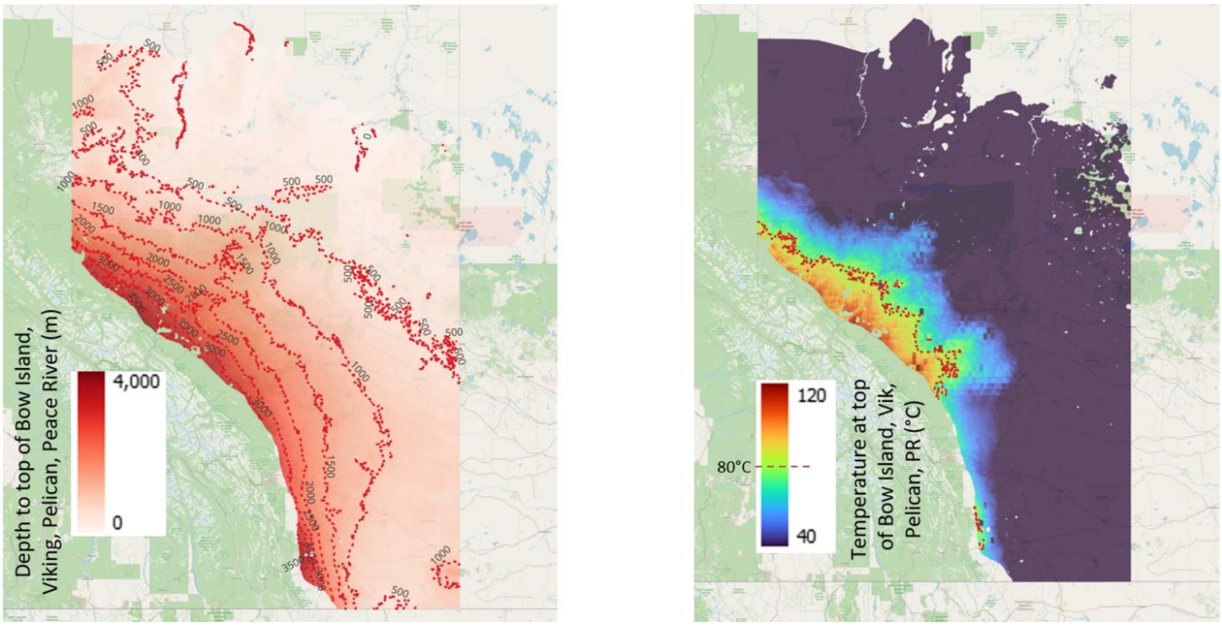


Figure 7: Map of the approximate depth to the top of the early Cretaceous Bow Island, Viking, Pelican, and Peace River sandstone formations in Alberta, Canada (left), and the estimated temperature at the top of the formations (right). Maps developed by the authors using geologic atlas information from Brinsky et al., (2022), and Weides & Majorowicz, (2014).

Table 1: Summary of Temperatures and Depth to the Top of the Bow Island, Viking, Pelican, and Peace River Formations near Communities in Alberta

Community	Temperature at top of Bow Island, Viking, Pelican, Peace River Formations	Approximate Depth to top of Bow Island, Viking, Pelican, Peace River Formations
Fox Creek	149-158°F (65-70°C)	5400 ft (1650m)
Hinton	203-212°F (95-100°C)	11300 ft (3450m)
Rocky Mountain House	158-167°F (70-75°C)	7700 ft (2350m)
Porcupine Hills	167-176°F (75-80°C)	11480 ft (3500m)

A similar assessment can be completed for other early Cretaceous sandstone units: the Sprit River and Mannville Formations.

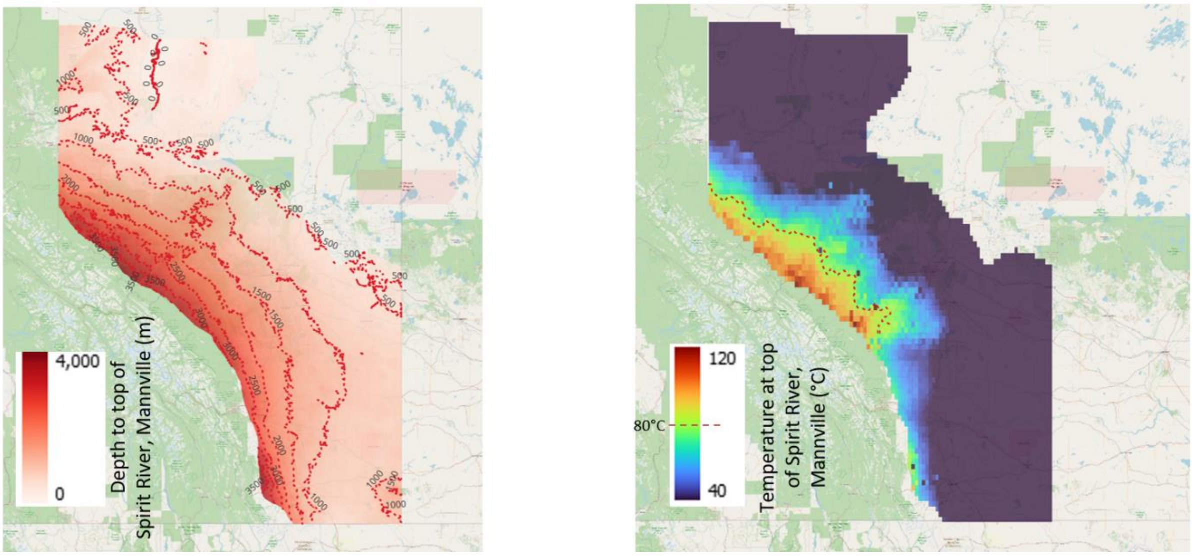


Figure 8: Map of the approximate depth to the top of the early Spirit River and Mannville sandstone formations in Alberta, Canada (left), and the estimated temperature at the top of the formations (right). Maps developed by the authors using geologic atlas information from Brinsky et al., (2022), and Weides & Majorowicz, (2014).

Table 2: Summary of Temperatures and Depth to the Top of the Spirit River and Mannville Formations near Communities in Alberta

Community	Temperature at top of Bow Island, Viking, Pelican, Peace River Formations	Approximate Depth to top of Bow Island, Viking, Pelican, Peace River Formations
Fox Creek	149-167°F (65-75°C)	5580 ft (1700m)
Hinton	212-230°F (100-110°C)	11480 ft (3500m)
Rocky Mountain House	167-176°F (75-80°C)	7880 ft (2400m)
O'Chiese First Nation	185-203°F (85-95°C)	8370 ft (2550m)

Proximity to customers to offtake heat energy is crucial for direct-use geothermal projects so evaluating the spatial distribution of these geothermal resources in relation to nearby communities is of note. However, there are also rural portions of the province where direct-use geothermal may be feasible for industrial, forestry (timber drying), or agricultural applications.

3.4 Political and Practical Considerations

Locating direct-use geothermal projects close to residential developments optimizes efficiency for heating as it reduces the amount of energy lost in transporting hot fluids to the site for use. Comfort living beside subsurface development offers a lesson that people who espouse a "Not In My Back Yard" (NIMBY) attitude could learn from. As discussed in Section 2.1, there are significant concerns about induced seismicity in the Netherlands that curtailed Dutch on-shore gas production, but by proactively engaging with stakeholders with a credible, and technically sound approach to addressing public concerns and managing operational risk, these direct-use geothermal projects are granted the social license to operate and geothermal projects have been able to proceed successfully near residential developments.

Regulatory agencies in the Netherlands have strong, but practical requirements for a potential geothermal project to appropriately evaluate the seismic hazard and seismic risk associated with development. A project also requires rigorous seismic response protocols. However, rather than forcing developers to complete costly and lengthy surveys to fulfill these requirements, baseline seismic activity studies can be completed using public data from the global seismic monitoring network. The same public data from global seismic monitoring stations can be used to monitor potential seismic events and determine if seismicity can be attributed to geothermal operations, and this data can be utilized to guide a project's seismic response protocols. This approach saves CAPEX and allows a geothermal developer to avoid installing costly monitoring stations while providing the public with credible, practical, technically sound means of addressing concerns with induced seismicity. A similar approach to subsidence monitoring using public satellite Interferometric Synthetic Aperture Radar (InSAR) data rather than periodic, labor-intensive, and costly high-precision GPS surveys.

The national government in the Netherlands also supports geothermal development through 3 main channels:

- investment,
- resource exploitation subsidies, and
- guarantees/insurance.

The government has invested heavily into researching and developing low carbon technologies and has facilitated development of direct-use geothermal projects through policy instruments such as the Sustainable Energy Transition Subsidy Scheme (SDE++). This subsidy program supports geothermal projects through direct investment: it is projected that 18 new geothermal projects will be developed before 2030 through an operating grant totaling almost €2 billion. The SDE++ program also subsidizes carbon-free heat by tying the cost of geothermal heat to the price of natural gas with the subsidy amount calculated by subtracting the conventional heat cost (natural gas price) from the cost of generating geothermal heat.

The government in the Netherlands further de-risks geothermal development through a well insurance program that essentially acts as a guarantee. If a geothermal doublet underperforms the pre-drill P90 geothermal production estimate due to disappointing aquifer characteristics, the project may be eligible for an insurance claim.

These practical policies and funding programs, coupled with learnings from the growth of the geothermal industry in the past 15 years offer a roadmap for how direct-use geothermal energy can be scaled in North America. Even without generous subsidy programs, strategic advice at the planning and design stage of a project can de-risk development and avoid costly delays that may jeopardize a project's economic viability or threaten a geothermal facility's social license to operate.

4. CONCLUSIONS

The success of direct-use geothermal in Europe offers a roadmap for deployment and scaling projects targeting similar resources in the North American market. As with how Canada's oil sands were commercialized, or how the U.S. shale boom unlocked significant hydrocarbon resources using directional drilling and fracturing, there is an opportunity to develop direct-use geothermal resources in North America by taking advantage of innovative practices, policies, and program incubated in markets with similar geologic conditions. Geothermal gradients in regions where direct-use geothermal heating is commonplace: sedimentary basins in Germany, France, and the Netherlands, are in a similar range as those found in the Western Canadian Sedimentary Basin, Williston Basin, Denver Basin, Permian Basin, and Illinois Basin. Targeting aquifers in sedimentary basins at a depth range of 5000- 8200 feet (1500-2500 meters) producing geofluid temperatures that tend to be lower than 212°F (100°C) reflect similar conditions found in many portions of western Canada and the United States. Many of these geothermal plays can be characterized utilizing existing seismic data and drilling techniques that may be locally available from decades of North American hydrocarbon development. By targeting matrix-permeable, sandstone reservoirs, encouraging North American governments to deploy similar subsidies as utilized in the Netherlands, and taking advantage of learnings from regions with well-developed direct-use geothermal industries, the geothermal market in North America may benefit from some of the growth experienced in Europe over the past 15 years. Deploying these practices, policies, and programs reduces risk, mitigates uncertainty, and will facilitate geothermal energy's movement down the cost/experience curve. Strategic advice and practical experience from delivering these types of projects in other regions can create value in the North American market by providing key quality assurance services as well as commercial and technical insights that guide critical cost-saving decisions.

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