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Ultradeep Geothermal Research and Action Roadmap

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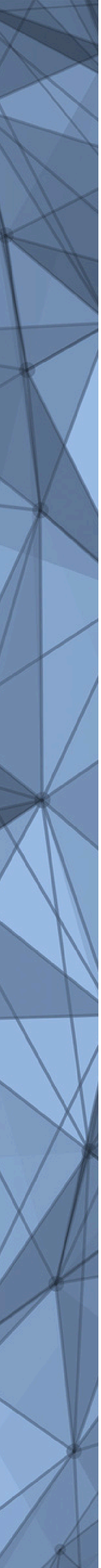

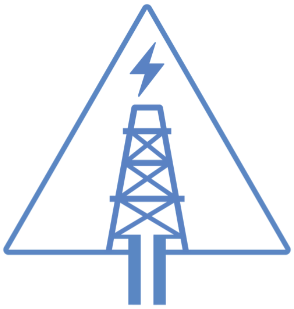

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Summary

This Roadmap outlines a plan to advance ultradeep geothermal power—that is, geothermal systems with depths greater than 5 km—to commercial operation in Canada. Intended for policymakers, geothermal developers, technology companies, and investors, it identifies the most promising opportunities and priorities for technology, policy, and regulation; highlights key gaps; and provides guidance for how public and private investment can support efforts to rapidly close these gaps.

Canada's world-class expertise and human capital in subsurface resource development (specifically in the design, drilling, and completion of oil and gas wells) is a relatively untapped competitive advantage that could be harnessed to launch Canada into the global race to develop and commercialize **ultradeep geothermal systems—**while unlocking geothermal resources at shallower depths along the way. This Roadmap provides recommendations for how to accelerate R&D and testing, coordinate stakeholders, fill policy and regulatory gaps, and de-risk the industry.

Advantages of ultradeep geothermal power

Ultradeep geothermal power has several advantages over other low- and zero-carbon energy systems. For example, geothermal power could:

- provide the massive amount of zero-emission baseload and dispatchable power that we need to meet our emission reduction targets and help integrate intermittent renewables into grids;
- reduce land requirements due to the small footprint of surface facilities;
- be deployed in urban centres, rural communities, retrofitted power stations, and where electricity load demands are high, reducing the need for extensive transmission lines;
- take advantage of existing subsurface resource development processes and technologies, creating jobs that match the existing skills and expertise in the oil and gas sector; and
- provide other climate solutions, including zero-carbon heat production, carbon dioxide sequestration, and energy storage.

Ultradeep geothermal potential in Canada

Tapping just one percent of the geothermal heat resource between 4 and 7.5 km depth in Canada could conservatively generate 77 GW of power (equivalent to half of Canada's 2021 installed generating capacity).

Highest-priority technology gaps

Ultradeep geothermal's four main technological challenges are:

1. **Reduce drilling time:** To drill faster—and therefore cheaper—in hard rock (crystalline igneous and metamorphic rock), we need to improve drilling methods and drill bit longevity.
2. **Develop high-temperature downhole tools and advanced temperature management technologies:** The deeper the well, the hotter it gets. To contend with the extreme temperatures and pressures of ultradeep geothermal drilling, we require downhole tools with higher temperature ratings and better temperature management technologies to create a cooler environment within the well during drilling.
3. **Improve well-completion technologies:** Well-completion components such as cement and well casings need to handle high temperatures and last for >40 years.
4. **Improve heat extraction methods:** Heat extraction methods for both open-loop and closed-loop systems must be optimized for heat recovery at increasing depths, pressures and temperatures.

Highest-priority policy and regulatory gaps

The top three policy and regulatory challenges for geothermal systems (of all types and depths) are:

1. **Address lack of regulatory frameworks and rules for permitting and rights/tenure:** Currently, only three Canadian provinces have regulatory frameworks that specifically address geothermal (Alberta, British Columbia, and Nova Scotia). These frameworks must be expanded and improved—and new regulations, permitting procedures, and tenure rules must be developed in other Canadian jurisdictions.
2. **Harmonize and streamline policy across jurisdictions:** Existing geothermal policy in Canada is inconsistent and fragmented across jurisdictions, creating unnecessary complexity leading to investment and development risk.
3. **Create cohesive messaging on geothermal policy:** The lack of a unified voice creates confusion for potential funders and policymakers.

A Canadian geothermal innovation ecosystem would vault Canada to a world-leading position in what is poised to be an essential future energy technology.

Four connected experimental sites

at established geothermal locations in Western Canada would share data and lessons to accelerate innovation and decrease risk.

Federal and university labs

would rapidly conduct *applied* research and analysis, catalyzing advances in the field.

$125M
for each of
4 test sites

+

$50M
for labs

→

$550M
Total

CASCADE INSTITUTE

1. Introduction

If Canada is to achieve net zero carbon emissions by 2050 and compete globally in a net-zero world, it must rapidly improve the zero-carbon energy systems already in its energy portfolio and develop new energy technologies to fill critical gaps and diversify its energy supply. Ultradeep geothermal is an emerging renewable energy system that can supply both heat and dispatchable baseload power. It involves drilling >5 km into igneous and metamorphic rock (i.e., into the “basement” or Canadian Shield) and then heating a circulating fluid that is brought up to the surface. This rock is hundreds of times harder than the sedimentary rock into which oil and gas wells are currently drilled, so substantially new drilling technologies will be needed (Finger & Blankenship, 2012).

Geothermal is currently limited to unique geological locations that have high **subsurface** temperature gradients coupled with existing water reservoirs accessible within a few kilometres of the surface. Canada does have such conventional “hydrothermal” resources in the western provinces and territories, although they remain largely unexploited due to logistical, regulatory, and financial challenges. But the true opportunity for geothermal power for Canada and the world is at greater depths, which must be accessed with **next-generation geothermal technologies** (Graham et al. 2022).

When drilling ultradeep geothermal wells becomes economical, it will be possible to produce geothermal power virtually anywhere in the world, unlocking an energy resource thousands of times larger than humanity will ever need. This opportunity is being recognized worldwide. Major government-funded research initiatives are underway in the United States, China, Japan, and the European Union. They focus primarily on how to drill into hard (igneous and metamorphic) rock formations cost-effectively. A secondary aim is to create reservoirs that can sustain the 40-plus-year lifespans of geothermal plants.

“Ultradeep” and “next-generation” geothermal systems

Ultradeep geothermal systems are geothermal systems at depths >5 km that involve drilling into hot igneous and metamorphic rock (i.e., into the “basement”). At these depths, a geothermal system may encounter a wide range of rock types, temperatures, and pressures. Unlocking the ability to produce power and heat economically at depths of 5-8 km and, ultimately, at even greater depths would transform geothermal power from a regionally specific zero-carbon energy solution into a truly disruptive technology that could play a major role in the global energy mix.

Unlike shallower **hydrothermal geothermal systems** (**conventional geothermal**), which tap into existing reservoirs of hot water or steam, ultradeep geothermal systems require the use of “next-generation” heat extraction technologies, of which there are two main types. Advanced geothermal systems (AGS) circulate the **working fluid** through closed-loop networks of connected pipe, while enhanced geothermal systems (EGS)—sometimes referred to as “open-loop systems”—circulate the fluid through artificially created fractures in the rock.

Collectively, these geothermal technologies are referred to as next-generation systems. Not all next-generation systems are ultradeep, but all ultradeep geothermal systems must use next-generation systems (Figure 1). Throughout this Roadmap, we refer to “next-generation ultradeep geothermal systems” simply as ultradeep geothermal systems. Appendix C provides a list of key terms and their definitions. I

BOX 1. ADVANTAGES OF GEOTHERMAL POWER

Provides **baseload and dispatchable** electricity

Deployable in **both rural and urban** environments

Near zero operational greenhouse gas emissions.

Uses **mature** power generation and transmission technologies

Transfers knowledge and expertise from volatile energy sectors

Achieves a capacity factor (the ratio of actual to potential energy generation) of **>90 per cent** (wind and solar are <30 per cent).

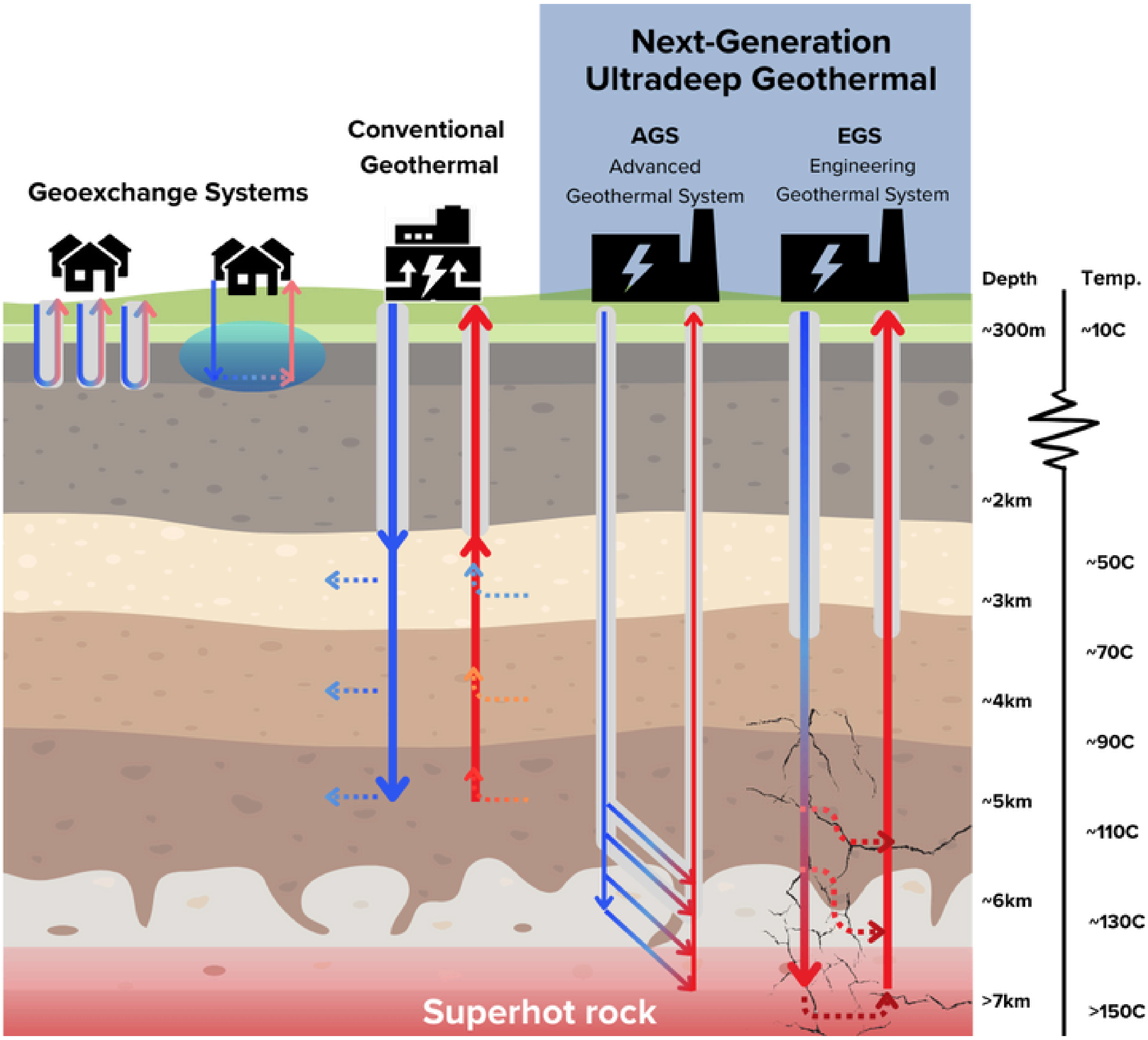

Figure 1. The spectrum of geothermal energy technologies, from shallow geoexchange systems, to conventional (hydrothermal) geothermal developments, to next-generation geothermal technologies (modified from Hickson & Smejkal, 2024).

Canadian geothermal R&D landscape

Deployment of geothermal energy in Canada is currently limited, and most existing projects provide heat. "Geoexchange" systems, shown on the left of Figure 1, store and extract heat within a few hundred meters of Earth's surface for single residences and, in a few cases, larger districts of commercial and residential buildings. Such projects are commercially viable south of the permafrost line and have been deployed countrywide.

A few "conventional" geothermal projects, which tap hot water in rock one to five kilometers deep, are also in early stages of development in Western Canada. These projects aim to provide heat for residential districts, community developments, tourism, and industrial processes such as greenhouses (Huang et al., 2024). They help the public recognize geothermal energy's benefits and potential.

Some conventional geothermal projects under development in western Canada are slated to produce electricity. The Canadian federal government has provided about CAD $97 million over the last five years through the Emerging Renewable Power Program and the Smart Renewables and Electrification Pathways Program. Also, the arms-length Canada Growth Fund has invested CAD $90 million in the Canadian geothermal company Eavor, a pioneer of closed-loop geothermal technology.

These and other projects in Western Canada are leveraging the hydrocarbon industry's existing expertise and workforce; some Canadian hydrocarbon companies are also directly evaluating the potential of geothermal power within their own portfolios.

Box 2 and Table 4 (Appendix B) list Canadian geothermal power projects currently in various stages of development. Projects in British Columbia and Alberta have encouraged those provinces' governments to develop geothermal policy (Appendix B). But all Canadian projects have faced many delays, some related to regulation and permitting, but most due to lack of investment to begin drilling. Uncertainty around policy and regulation, high CAPEX costs, and geothermal power's perceived risk have deterred Canadian investment and stalled research and development (R&D).

BOX 2. CURRENT CANADIAN GEOTHERMAL POWER PROJECTS

Alberta

- Grande Prairie: Terrapin Geothermics' **Alberta No. 1** (Conventional)
- Swan Hills: **FutEra Power Corp** (Conventional)
- Rocky Mountain House: Eavor Technologies' **Derek Riddell Eavor-Lite™ Demonstration Facility** (Next-Gen)
- Rainbow Lake: E2E Energy Solutions' **Rainbow Lake** (Next-Gen)

British Columbia

- Fort Nelson: Indigenous-owned **Tu Deh Kah Geothermal** (Conventional)
- Meager Creek: **Meager Creek Geothermal Project** (Conventional-Volcanic)

Saskatchewan

- Estevan: Deep Earth Energy Production Corporation's **DEEP** (Conventional)

Global geothermal R&D landscape

Several countries are actively investing in bold R&D programs to advance ultradeep and next-generation geothermal technology. Notable international research programs funded by governments (Box 3) include the Iceland Deep Drilling Project (IDDP), the United States' Utah Frontier Observatory for Research in Geothermal Energy (Utah FORGE), the Japan Beyond-Brittle Project (JBBP), and the European Union's ORCHYD Project. These programs focus primarily on two dimensions of ultradeep and next-generation geothermal R&D:

1. The improvement of drilling technologies necessary to create wells in hard rock formations and reduce current drilling costs by a factor of ten.
2. The creation of artificial reservoirs in various rock types and at significant depths.

Governments can stimulate investment in geothermal R&D not only through direct investment but also through policies like guaranteed loans and tax credits. For example, the 2022 Inflation Reduction Act (IRA) in the United States has supported an estimated 280 renewable energy projects, with an expected total of CAD $282 billion in new investment (Valentijn van Nieuwenhuijzen et al., 2023). The IRA enables geothermal projects to claim renewable energy investment and production tax credits. Such incentives facilitate private investment in the geothermal industry and offer an additional source of indirect public funding.

BOX 3. NEXT-GENERATION GEOTHERMAL R&D PROGRAMS

Utah’s Frontier for Research in Geothermal Energy (FORGE)

Utah FORGE is an open-source, U.S. Department of Energy-funded research facility dedicated to improving conventional drilling technologies and reservoir engineering for next-generation geothermal systems. Utah FORGE has produced dramatic improvements in rate of penetration into hard rock and successful stimulation tests in temperatures >240°C, proving the viability of EGS systems in hard rock. This facility has received over USD $250 million in funding (Pearce & Pink, 2024).

Iceland Deep-Drilling Project (IDDP)

IDDP was launched by a consortium of funders and research institutes, including EU Horizon 2020, Reykjavik Energy, and Statoil. Its primary goal is to drill into super-hot temperatures for geothermal power production. Two wells have been drilled into temperatures >450°C, proving the feasibility of using conventional drilling systems to access superhot temperatures for geothermal energy production (Pearce & Pink, 2024).

Japan Beyond-Brittle Project (JBBP)

JBBP is a research project aiming to drill beyond the brittle-ductile transition (where rock changes from brittle to plastic deformation) and conduct well-creation experiments at >300°C. The specific aims are to study rock mechanics in these conditions, improve drilling and downhole monitoring techniques, and to demonstrate the feasibility of EGS reservoir creation in these conditions (Muraoka et al., 2014; Petty, 2020).

European Union ORCHYD Project

The EU Horizon 2020-funded ORCHYD Project aims to improve drilling efficiency in hard rock to access ultradeep geothermal resources with a unique hybrid water-jet and percussive drilling system. This research initiative has a test facility in France, and partners located in the UK, China, Greece, and Norway (Pearce & Pink, 2024).

Canada’s ultradeep geothermal energy potential

Grasby et al. (2012) presented a heat map showing temperatures at 3.5, 6.5, and 10 km depths; they used heat-flow estimates based on borehole data and geological core samples from across Canada (Figure 2 shows temperatures at 10 km depth). The study estimated that there is enough thermal energy within 6.5 km (Figure 3) to supply all of Canada’s final energy demand (8.59 EJ in 2022 according to the Canada Energy Regulator [Government of Canada, 2024]), even if only two percent of this thermal energy is ultimately recoverable. A forthcoming study by Ball et al. (2024a) supports these estimates; it shows that tapping just one percent of the 450°C geothermal heat resource between 4 and 7.5 km depth in Canada could generate 77 GW of power (equivalent to half of Canada’s 2021 installed generating capacity [Government of Canada, 2024]).

These studies show high geothermal potential in the western provinces and territories that can be developed with existing technologies. Due to its lower geothermal temperature gradient, the Canadian Shield—which covers most of central Canada—will require advances in ultradeep geothermal technologies, especially improved drilling techniques for deep hard rock drilling. But with such progress, the opportunity to generate ultradeep geothermal power will expand Canada-wide.

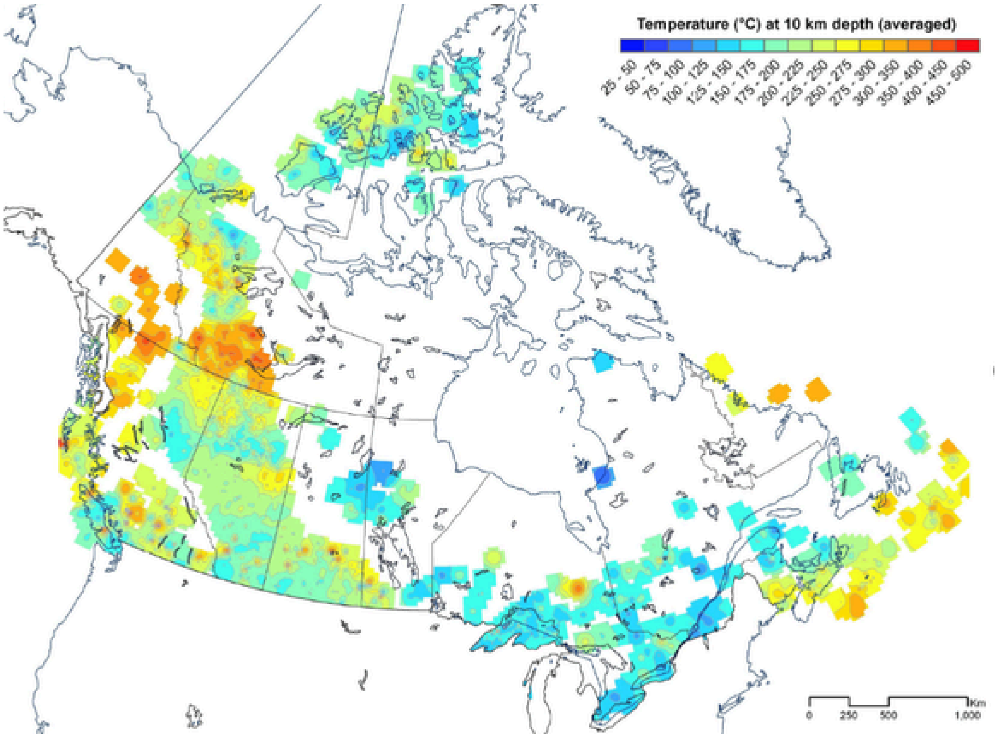

Figure 2. Heat map of Canada based on borehole data and geological samples. Mapped temperatures at 10 km depth (Grasby et al., 2012).[1]

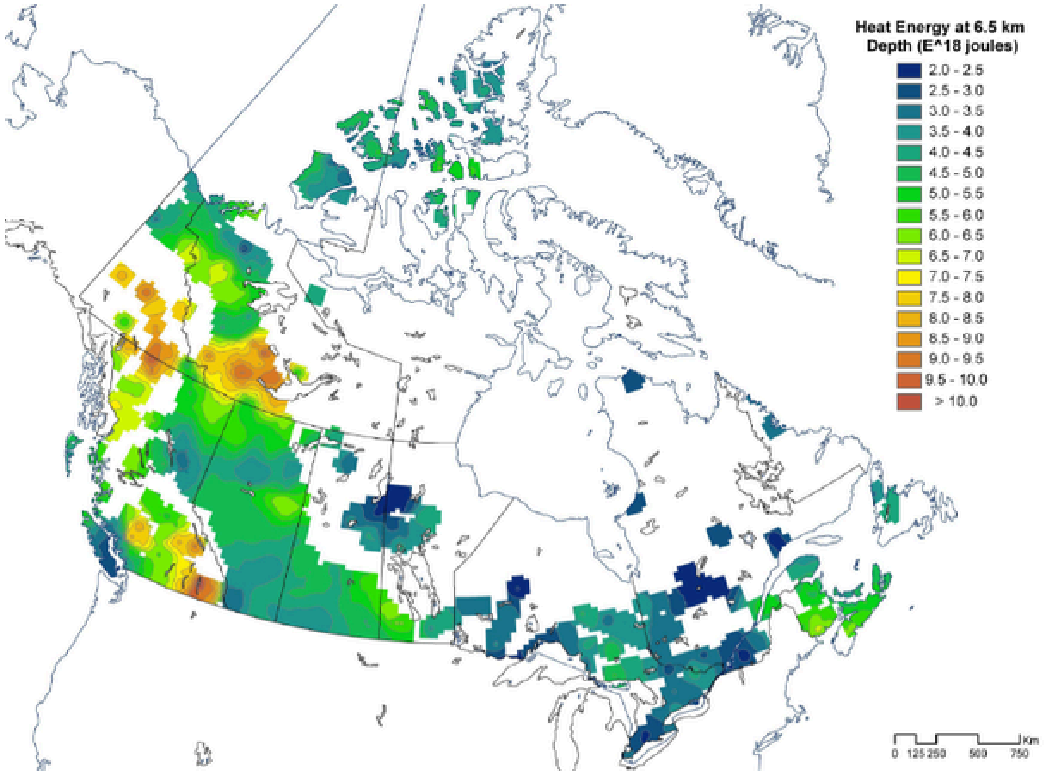

Figure 3. Thermal energy map of Canada based on borehole data and geological samples. Mapped heat energy at 6.5 km depth (Grasby et al., 2012). [1]

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[1] Note that regions in white (Figures 2 and 3) indicate areas with no heat flow data, highlighting the need for further study of Canada's geothermal resources. Most geothermal heat flow data is derived from exploration wells, supported by some limited regional geothermal-specific exploration funded by the National Geothermal Energy Program that ran from 1976-1986. Initiatives to collect new heat flow data through geophysical and geological exploration will improve heat geothermal estimates and significantly de-risk geothermal projects.

2. Technology gaps for ultradeep geothermal

The main technical stages for developing an ultradeep geothermal system include:

1. **Site selection** and geothermal resource characterization through geotechnical feasibility studies, such as geophysics, geological mapping, and drilling test wells;
2. **Deep, hard rock drilling** of injection and production wells to access the heat resource;
3. **Well completion** through cementing and casing;
4. **Heat extraction** using methods such as hydro-shearing (for open-loop), or well interception (for closed-loop); and
5. **Power plant surface facility construction**, including a heat exchanger, an electrical turbine generator, and transmission infrastructure.

Highest-priority technology gaps, challenges, and solutions

The Clean Air Task Force commissioned in-depth technology gap analyses for each of these five stages. The Cascade Institute co-led two of these analyses: drilling (Pearce & Pink, 2024) and site selection (Chunn, Saltiel, Pearce et al., 2024, *forthcoming*). Findings from all five reports are summarized in Table 1, with further detail on each technology gap presented in Appendix A.

Table 1. Key technical gaps/challenges and solutions for ultradeep geothermal.

Project stage	Gaps and challenges	Solutions
Site selection	• Fragmented databases and a lack of data sharing between industry and research groups. • Data scarcity and costly geoscientific surveys.	• Establish standard procedures for data collection (large scale/low-density and small scale/high-density) that can be customized at each site to regulate/de-risk data. • Obtain greater funding for resource characterization data collection and analysis.
Deep, hard-rock drilling	• Rate of penetration (ROP) must be increased to reduce drilling time and improve the economics of geothermal projects. • Downhole tools cannot withstand temperatures >200°C. Well-temperature management technologies must compensate for downhole tool limitations.	• Drill >200°C test wells with novel, high temperature rated, hard rock drill bits. • Increase temperature limits of downhole electronics through iterative innovation. • Improve well temperature management technologies in laboratory conditions followed by in-field testing.
Well completion	• Casing and cement fatigue at high temperatures. • Casing and cement longevity over the lifespan of the well .	• Conduct experiments on high-temperature casing and cement in controlled laboratory conditions. • Conduct well longevity modelling with novel technologies, followed by in-field testing.
Heat Extraction	• Reservoir stability at extreme depths and temperatures (open-loop) . • Heat depletion and well stability (closed-loop) .	• Conduct lab and in-field experiments on high-pressure, high-temperature rock mechanics. • Extend experiments to include tracer and proppant engineering (for open-loop) and heat depletion in various reservoir conditions and configurations (for closed-loop).
Surface facility	• Wellhead failure and blow-outs.	• Establish pilot sites with high temperatures at relatively shallow depths to test and improve wellhead management technologies.

Geothermal R&D must address **four primary technology gaps** for **ultradeep geothermal systems** to reach widespread, global commercialization:

1. Reduce drilling time: Although a great deal of commercially exploitable heat is available with conventional technologies now, drilling time must ultimately be reduced by about a factor of 10 if depths are to be reached that would allow geothermal power to be deployed virtually anywhere in the world. Geothermal drilling generally accounts for 40 to 60 percent of geothermal project costs. In the last two years, Utah FORGE and other hard rock geothermal drilling operators have achieved impressive **rate of penetration** (ROP) improvements. Further ROP advances must be unlocked by increasing bit longevity and sustaining high ROP performance at increasing depths and temperatures (Pearce & Pink, 2024).

2. Develop high-temperature downhole tools and advanced temperature management technologies: To contend with the extreme temperatures and pressures, deep geothermal drilling requires downhole tools with higher temperature ratings. These tools are best coupled with temperature management technologies that cool the well to the temperature threshold of the tools (through use of, for instance, insulated drill pipe, mud coolers, and additives that reduce mud temperatures).

3. Improve well-completion technologies: Well-completion components such as cement must remain stable for the lifespan of a geothermal plant, projected to be 40 to 70 years. Key areas of R&D include the thermodynamic properties of high-temperature rated casing material, downhole corrosion and scaling mitigation, the development of cement that can withstand long-term, high-temperature cyclic loading and fatigue, and casing connectors that withstand high temperatures and fatigue.

4. Improve heat extraction methods: Open-loop and closed-loop concepts require substantive in-field testing to identify optimal reservoir engineering techniques that sustain the productivity of the geothermal plant for its lifetime. Fracture propagation and longevity in plastically deforming rock must be further understood for open-loop systems, and optimal configurations for closed-loop systems in hotter regimes must be modelled and tested through in-field experimentation.

3. Canadian policy and regulatory gaps for ultradeep geothermal

Canadian geothermal policy and regulatory landscape

Shallow geothermal systems (i.e., geoexchange systems above and within the groundwater table) are typically governed by existing groundwater and building regulations. The regulatory frameworks for deeper geothermal systems (whether they are hydrothermal or next-generation systems) are more complicated.

All stages of geothermal development involve government regulation, permitting, **leases**, and **licensing**. Relevant regulations include:

1. Surface land use (environmental and social impact),
2. Subsurface geothermal resource rights,
3. Water rights (subsurface water use, water circulation and disposal), and
4. Surface facility construction (power and heat regulations, industrial building codes).

As outlined in the Constitution Act of 1982, each of Canada's provinces and the Northwest Territories owns and governs sub-surface resources within its boundaries. Exceptions are resources in Indigenous lands, federal lands, and the Yukon and Nunavut territories, which are governed federally (Constitution Act 1982 Document, 1982). Partly as a result, geothermal policy and regulations relevant to ultradeep geothermal have evolved at different rates across the country and vary greatly between jurisdictions.

The lack of deep geothermal policy and regulations in 10 of Canada's 13 jurisdictions is a major barrier to future geothermal development. Currently, only British Columbia, Alberta, and Nova Scotia have standalone geothermal legislation and accompanying regulations, while the Yukon and Saskatchewan are in the early stages of developing their geothermal regulatory regimes, and Nunavut's subsurface and water rights are owned and regulated by the Federal government and can be interpreted to include deep geothermal (Figure 4).

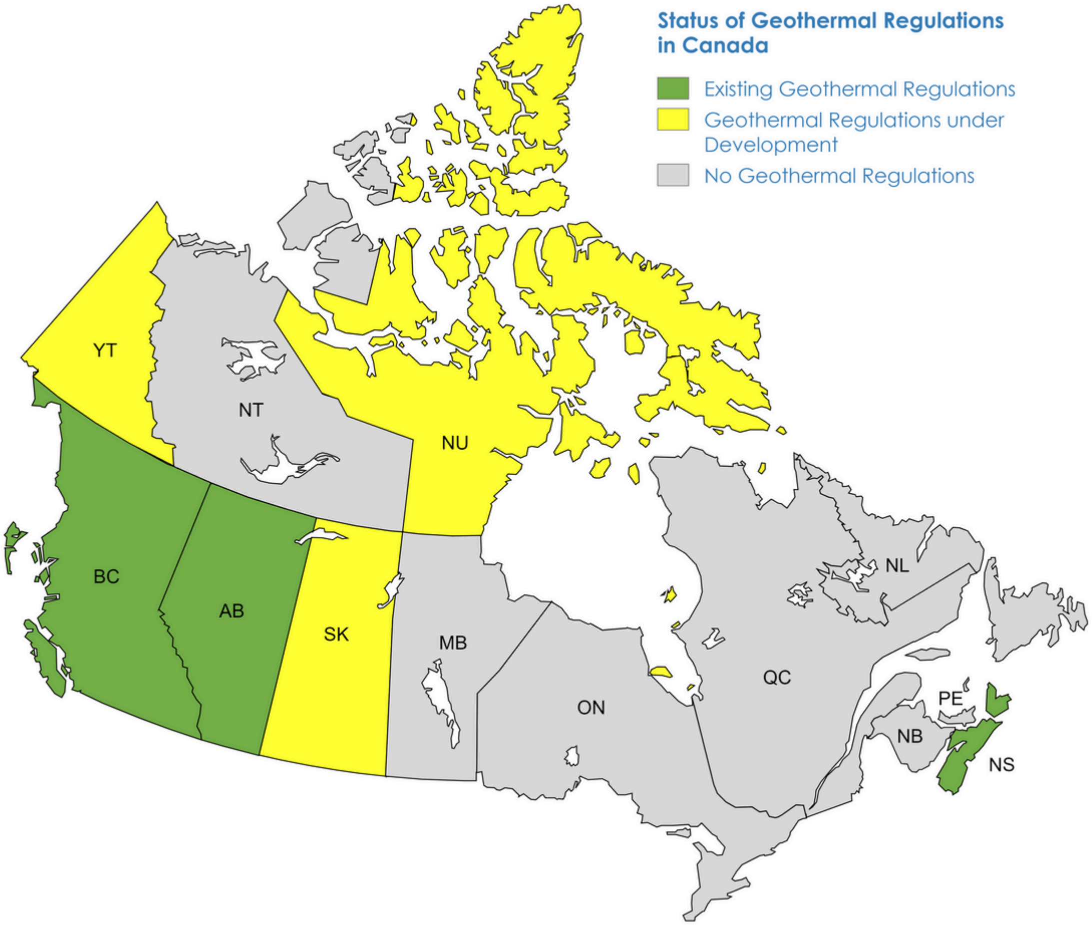

Figure 4. Status of existing geothermal regulations in Canada's provinces and territories (Mapchart.net).

Four geothermal projects—Alberta No. 1, DEEP Earth Energy, Novus Earth, and Tu Deh-Kah Geothermal—were awarded a combined CAD $97 million in funding through Canada's Emerging Renewable Power Program and Smart Renewables and Electrification Pathways Program. All four projects are in various stages of development and are not yet producing heat or power. Many have faced major delays in development due to uncertain, complicated, or non-existent geothermal legislation and regulatory processes.

Canadian geothermal developers have highlighted numerous issues with current geothermal policies but have largely pursued reform in isolation from one another and within their own jurisdictions. Over the past five years, they have had limited success in advancing geothermal policy and unlocking more public funding to support advancing the industry. Appendix B provides a province-by-province snapshot of current Canadian geothermal policy and regulation.

Highest-priority policy and regulatory gaps, challenges, and solutions

Geothermal projects (deeper than geoexchange systems) require regulatory frameworks that are specifically designed for geothermal. As outlined above, only Alberta, British Columbia, and Nova Scotia have regulatory frameworks that were tailored, at least in part, for geothermal power. However, even these regulations borrow heavily from existing water and oil and gas frameworks and lack the flexibility to keep up with rapidly evolving geothermal technology.

Geothermal developers have highlighted the policy, regulatory, and financing challenges facing their geothermal projects but lack a unified voice to communicate these challenges to government. Addressing these regulatory challenges help facilitate the rapid innovation and adoption of ultradeep geothermal across Canada.

Policymakers in the federal, provincial, and territorial governments, along with geothermal developers and technology companies, must address three overarching policy and regulatory challenges for geothermal systems (of all types and depths) to reach commercialization:

1. **Address lack of regulatory frameworks and rules for permitting and rights/tenure:** Currently, only three Canadian provinces have regulatory frameworks that specifically address geothermal (Alberta, British Columbia, and Nova Scotia). These frameworks must be expanded and improved—and new regulations, permitting procedures, and tenure rules must be developed in other Canadian jurisdictions.

2. **Harmonize and streamline policy across jurisdictions:** Existing geothermal policy in Canada is inconsistent and fragmented across jurisdictions, creating unnecessary complexity and leading to investment and development risk.

3. **Create cohesive messaging on geothermal policy:** The lack of a unified voice creates confusion for potential funders and policymakers.

Table 2. Key policy and regulatory gaps/challenges and solutions for all geothermal technologies.

Gaps and challenges	Solutions
Lack of regulatory frameworks, permitting, and rights/tenure required for rapid project development, R&D, and commercialization.	• Develop a geothermal regulatory framework template that can be customized for each jurisdiction. • Establish direct communication of proposed frameworks and rules between governments, regulators, and geothermal developers.
Inconsistent and fragmented geothermal policy creates investment and development risk.	• Achieve clear, certain, timely, and transparent permitting and development processes and timelines across jurisdictions.
Canadian geothermal developers have identified and highlighted numerous issues, but only within their own jurisdictions.	• Develop communication channels among key developers and between developers and policymakers to encourage collaborative problem solving. • Deliver consistent and unified messaging from geothermal developers to all levels of government.
Overly prescriptive regulations create unnecessary hurdles to rapid development.	• Establish norm of flexibility in policy to allow for innovation and experimentation.

4. Accelerating ultradeep geothermal research and action in Canada

As discussed in the previous section, policy and regulatory obstacles can be largely addressed through better coordination between project developers, the rapid development of new policies and frameworks at the provincial level, and harmonization and learning across jurisdictions. The Cascade Institute Geothermal Energy Office in Ottawa (CI-GEO) will be supporting and facilitating this work. However, closing the four primary technology gaps highlighted in Section 2 is a significant engineering challenge. Fortunately, there are feasible solutions to all of these challenges, as well as opportunities for government and industry to make strategic, high-leverage investments in R&D and testing to pursue multiple solutions simultaneously.

Here, we propose a carefully planned and well-coordinated Canadian geothermal "innovation ecosystem" that should address many of the highest-priority technology gaps and accelerate Canada's pathway to commercializing shallow, deep, and ultradeep geothermal systems. This approach seeks to leverage both public and private sector leadership. It builds on similar models such as the Alberta Oil Sands Technology and Research Authority that accelerated R&D to create new industries for Canada (Box 4).

BOX 4. WHAT WAS AOSTRA?

The **Alberta Oil Sands Technology and Research Authority (AOSTRA)** created the modern oil sands industry by de-risking a technology known as steam-assisted gravity drainage (SAGD). Before SAGD, only oil sands at the surface could be extracted, leaving 80 percent of Alberta's oil sands out of reach.

In 1974, the Alberta government launched AOSTRA to develop SAGD and supporting technologies. AOSTRA was a public (but independent) organization that collaborated with private oil companies, matching their investments in research and pilot projects and leveraging an innovative IP model that allowed co-funders to distribute risks and share rewards. Ultimately, AOSTRA funded a large-scale SAGD demonstration that sparked a boom in projects across Alberta.

AOSTRA provides a stark contrast to how governments today usually seek to advance and accelerate innovation. Conventional wisdom favours a "technology neutral" approach that provides broad support to incremental innovation priorities defined by industry. Instead, AOSTRA defined a clear mission and took informed and calculated risks on transformative opportunities. A similar approach could help Canada unlock ultradeep geothermal.

A Canadian geothermal innovation ecosystem

We propose a CAD $550 million program to construct at least four linked in-field test sites at established geothermal locations in Canada, with the total investment shared about evenly between public and private sectors. The test sites would conduct essential research into hard-rock drilling, aiming to dramatically lower CAPEX costs. Sites would also test and improve well-creation, reservoir-creation, and surface-facility technologies and methods.

Specifically, the test sites would:

- test conventional and novel drilling methods to further improve ROP and bit longevity;
- deploy well-temperature management technologies and high-temperature downhole tools to progressively increase downhole temperature limits for drilling operations;
- test high-temperature cement and casing technologies; and
- construct open- or closed-loop reservoirs and run stimulation tests.

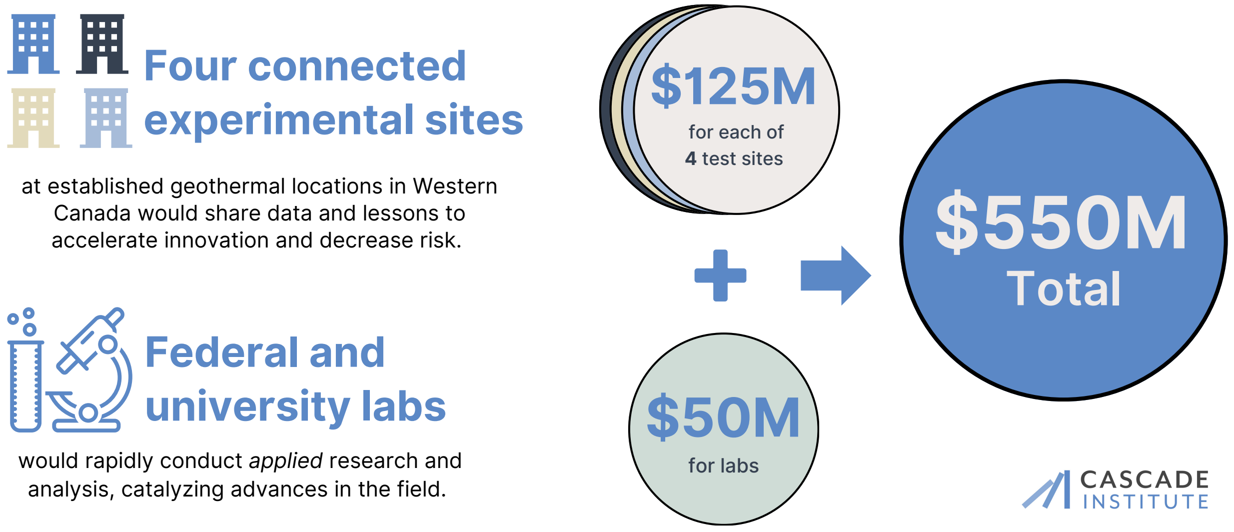

Figure 5. A Canadian geothermal innovation ecosystem would vault Canada to a world-leading position in what is poised to be an essential future energy technology.

Each test site would be allotted up to CAD $125 million to cover drilling costs, reservoir preparation, and surface facilities. Each would generate about 50 megawatts of power for local or regional consumption. To ensure accelerated R&D and decrease risk, the sites would share data and lessons with one another, and each would satisfy the following prerequisites:

1. Verified, high-potential geothermal heat gradient;
2. Support from local communities and from Indigenous nations;
3. Secured drilling permits and subsurface rights;
4. Constrained tectonic stress fields that can facilitate drilling tests;
5. Location outside of environmentally sensitive areas or vulnerable ecosystems; and,
6. Proximity to industrial, commercial, or residential electricity demand.

Today, at least six locations in Canada already meet these criteria. All are located in Alberta, Saskatchewan, British Columbia, and the Northwest Territories, where heat gradients tend to be higher (Table 3).

Table 3. Possible innovation test sites.

Province / Territory	Location	Current Development Stage	Approximate Depth to Basement
Alberta	Grande Prairie	Drilling	3,600m
Alberta	Northwest	Drilling	2,100m
Alberta	West Central	Site selection	3,500m
British Columbia	Garibaldi Volcanic Belt	Drilling	Volcanic target <2,000m
Northwest Territories	South Slave	Drilling and well completion	3,000m
Saskatchewan	Estevan	Drilling and well completion	3,000m

Additional locations in Central and Eastern Canada are also potentially attractive. Each site would address research challenges that align with the operator's technical skills and specializations. For example, one could focus on closed-loop systems, another on conventional versus percussive drilling systems, while another focuses on the performance of C0 as a drilling fluid or as a circulating working fluid.

In parallel, select federal and university research institutes would be funded up to CAD $50 million to participate in a high-pressure, high-temperature laboratory network conducting applied research, supportive R&D, and bench-tests on:

1. Site selection and regional geologic mapping;
2. Novel and conventional drill bits;
3. High-temperature downhole tools;
4. Well-temperature management technologies;
5. Cement and casing technologies;
6. Pipe metallurgy and corrosion inhibitors;
7. Methods for heat extraction (open- and closed-loop); and
8. The physical, thermal, and mechanical properties of rock under the extreme pressures and temperatures.

Both the laboratory network and the interconnected in-field demonstration sites should be largely open access to promote an exchange of data, findings, technology, and process advances between industry and academia. This ecosystem would serve as the primary testing ground for ultradeep geothermal technologies designed within and outside of Canada, while providing a data-and technology-sharing framework for the global geothermal community.

Findings from laboratory experimentation could be immediately transferred to the in-field demonstration sites, and new technology gaps identified at the in-field sites could be prioritized by the laboratory network. This complementary research approach, combined with a streamlined and open-access approach to knowledge transfer, will accelerate ultradeep geothermal innovation and vault Canada to the leading edge of this technology frontier.

BOX 5. POTENTIAL CANADIAN PARTNERS INCLUDE (BUT ARE NOT LIMITED TO):

RESEARCH

- Institute for Integrated Energy Systems (University of Victoria)
- University of British Columbia
- University of Alberta
- University of Calgary
- Northern Alberta Institute of Technology
- Southern Alberta Institute of Technology
- Red Deer Polytechnic
- University of Regina
- University of Saskatchewan
- Petroleum Technology Resource Centre
- University of Waterloo
- Institut national de la recherche scientifique
- Petroleum Technology Research Centre

GOVERNMENT

- Natural Resources Canada (Federal)
- CanMET Energy Lab, Bells Corners (Federal)
- Geologic Survey of Canada (Federal)
- British Columbia Energy Regulator
- Alberta Innovates
- Alberta Energy Regulator
- Saskatchewan Energy Regulator

Appendix A: Technology Gap Assessment

Site selection and characterization

To identify the optimal location for an ultradeep geothermal facility, many factors must be considered such as population density, transmissibility, hazard risk, and geological domain. In this stage, the geotechnical analysis must “constrain” the contending sites’ depth to basement, geothermal gradient, stress field, porosity, permeability, fracture density, induced seismicity risk, fault systems, presence of volatiles or corrosive fluids, and many other properties of the prospected rock formation. These constraints are established using geoscientific data collected by satellites, airborne surveys, geological mapping, field geophysics, exploratory drilling, and borehole surveys. Data are processed and interpreted through modelling software and programs, some requiring high-power computing clusters to perform the analysis.

The resource characterization process is essential to accurately select a drilling target and de-risk ultradeep geothermal projects. However, the resource costs (financial and time) can be a significant obstacle for prospective geothermal developers. A standardized approach to the resource characterization process (one that is approved by geothermal specialists globally) will help alleviate these pressures. Repeated case studies can refine these characterization techniques to produce a streamlined model to be adopted by future projects. Other components of a standardized approach could include: national-scale, coarse-resolution data; optimization techniques for fine-resolution data; and specialized, open-access data-modelling programs.

A technology feasibility assessment of site selection (commissioned by Clean Air Task Force and co-led by the Cascade Institute and Cornell University) will be published in late-2024 (Chunn et al., 2024).

Drilling and well construction

Drilling is the most cost-intensive stage of a geothermal program, accounting for >40 - 60 percent of capital expenditure. As projects pursue hotter, deeper domains in hard rock, these expenses will increase significantly and render projects economically unfeasible with current technologies and processes.

Traditional drilling technologies are not optimized for hard, hot rock formations. Drill bit technologies must be advanced to cope with these conditions while generating high ROP with improved bit longevity to reduce the economic burden on the project. Established drilling firms, in partnership with next-generation geothermal experts, are already addressing this challenge, and drastic reductions (>70 percent) in drilling time with conventional drill bits through hard rock have been observed in the last three years alone. These improvements are the result of optimized drill bit design and manufacturing, vigilant monitoring of downhole bit dysfunction, and refined mechanical-specific energy management.

While conventional drilling methods with polycrystalline diamond carbide bits have achieved these leaps in drilling performance, alternative drilling technologies are emerging that may surpass conventional methods as projects access deeper, hotter geological regimes. These emerging technologies include percussive, water jet, particle, plasma and millimetre wave drilling, which have TRL (technology readiness level) statuses ranging from 3 to 8 (Pearce & Pink, 2024). All drilling mechanisms (including conventional) require further in-field experimentation to overcome outstanding technical challenges, and to improve the economic case for ultradeep geothermal through reductions in drilling costs.

In addition to specialized drill bits and novel rock-excavation techniques, further innovation in downhole temperature management is required to drill ultradeep geothermal wells. Even if drilling operations are equipped with bits rated to >400°C, they are limited to the temperature ratings of downhole sensors and electronics that monitor well conditions and log critical data transmitted to operators at the surface. Current downhole electronics are not capable of withstanding supercritical temperatures (Pearce & Pink, 2024). Traditional downhole sensors—such as measurement-while-drilling and magnetic ranging tools—are typically rated to <175°C, although some firms pursuing supercritical geothermal wells have designed tools rated up to 250°C.

While increasing the temperature of down-hole tools is important, the best strategy is to also cool the well to the operable temperatures of downhole tools with temperature management equipment such as insulated drill pipe, mud coolers, and drilling fluids. Advanced temperature management technologies are under development by several firms and range from TRL statuses of 4-9. Deployment of these technologies at in-field demonstration sites with supercritical conditions is a key step to advancing these methods to commercial scalability. Rig capacity must be considered in the experimental process, as rigs must be compatible with unique, high-temperature borehole assemblies, and able to support the weight of this equipment.

See Pearce & Pink (2024) for a detailed technology feasibility assessment on drilling and well construction for superhot rock applications.

Well completion

Well design and completion technologies must sustain the integrity of the injection and production wells (the core method of geothermal heat transfer from the subsurface to the energy production facility). The wells—possibly deployed in supercritical temperatures and pressures—must remain stable for the lifespan of a geothermal plant, projected to be 40 to 70 years. Oil and gas wells have a much shorter life cycle and are typically drilled in softer, shallower rock formations. Therefore, conventional well completion technologies must advance to cope with the lifespan of ultradeep geothermal projects and the depth, pressure, and temperature regimes they will encounter.

Areas of R&D focus include (1) geochemical interactions between supercritical water and rock; (2) thermodynamic properties of high-temperature rated casing material, including its response to high-temperature cyclic loading, (3) methods to prevent precipitation, corrosion, and scaling downhole to maintain working fluid circulation, (4) development of cement that can withstand long-term, high-temperature cyclic loading and fatigue, and (5) development of casing connectors that withstand high temperatures and fatigue. These technology gaps may be closed through modelling, experimentation, and in-field testing.

See Suryanarayana et al. (2024) for a detailed technology feasibility assessment on well completion for superhot rock applications.

Heat extraction

To extract geothermal heat from hot rock, water/fluid must be efficiently circulated in the subsurface. Both open-loop and closed-loop systems face unique technical challenges and require substantial in-field testing to identify optimal reservoir engineering techniques that sustain the productivity of the geothermal plant for its lifetime. Open-loop systems must artificially stimulate the reservoir through hydro-sheared fractures, requiring proppants and tracers that withstand supercritical temperatures and pressures at >5 km depth. At these conditions, rock may behave plastically and rapidly heal fractures (<100 days), “short-circuiting” the system. Hydro-shearing techniques may induce seismicity that must be vigilantly monitored, while naturally fractured media may experience substantial fluid circulation loss.

Closed-loop systems may avoid these complications because they use impermeable, interconnected wells that contain the working fluid. However, these systems require more complex well configurations, which involve higher drilling costs. Closed-loop systems may also experience rapid heat depletion due to conductive heat transfer limitations.

Heat extraction requires further R&D through modelling, experimentation, and in-field testing. Existing technologies from the hydrocarbon sector can be leveraged to overcome these gaps, such as high-temperature rated magnetic ranging tools and proppants that can be adapted to the supercritical regimes targeted by ultradeep geothermal projects. Researchers must improve the current state of knowledge on fracture propagation and longevity in plastically deforming rock for open-loop systems, as well as alternative working fluids that yield higher potential from lower temperature formations, such as liquid CO^2 for closed-loop systems. Seismic monitoring systems must also be deployed for all geothermal projects.

See Cladouhos & Callahan (2023) for a detailed technology feasibility assessment on heat extraction for superhot rock applications.

Surface facility

Surface infrastructure converts the extracted geothermal heat into distributable electricity. Depending on the geothermal resource and project location, this facility may perform auxiliary processes such as CO^2 sequestration, lithium extraction, and hydrolysis for green hydrogen production. The technology that converts heat to electricity is already mature. Generally, low-enthalpy geothermal systems provide <150°C water to a binary cycle heat exchanger that heats the secondary working fluid (e.g., isobutane or isopentane) to its vaporization point to drive the turbine. High-enthalpy systems with >150°C water drive the turbine through flash or dry steam brought up well.

These same principles can be transferred to next-generation geothermal projects, with the energy conversion method tailored to the temperature of the artificial reservoir. Remaining technological gaps, such as preventing wellhead failure and blowouts, geochemical reaction management, and facility cost reduction can be unlocked by demonstration sites operating at supercritical conditions, with novel wellheads (rated to >140 bar) and water treatment technologies.

See Brown et al., (2024) for a detailed technology feasibility assessment on surface facilities for superhot rock applications.

Appendix B: Policy and Regulatory Gap Assessment

British Columbia

Geothermal resource definition

Geothermal power falls under the Geothermal Resources Act (Geothermal Resources Act, 2010) and applies to water >80°C. Geothermal resources are defined in the Act as follows: “the natural heat from the earth and all substances that derive an added value from it, including steam, water, and water vapor heated by the natural heat from the earth, and all substances dissolved in the steam, water, or water vapor obtained from a well, but does not include (a) water that has a temperature of less than 80°C at the point where it reaches the surface, or (b) hydrocarbons.”

Summary of resource tenure

- Resource is governed by fluid temperature.
- Multicommodity extraction is not permitted (e.g., hydrocarbons and/or mineral commodities, like lithium in brine).
- Rights are granted via public tender.
- Lease is one “Block” (defined by the Petroleum and Natural Gas Grid Regulation; approximately 136 KM^2).
- Rights are exclusive to a single owner.

Gaps and challenges

- The Act does not consider next-generation geothermal technologies.
- Timelines are uncertain for getting approvals, permits or licenses.
- Regulations for the coproduction of other natural resources are uncertain.

Actions underway

- BC Energy Regulator has stated there is a possibility of exceptions during geothermal exploration and development, but none have been granted to date.

Alberta

Geothermal resource definition

Geothermal power falls under the Geothermal Resources Development Act (Directive 089, 2022) and applies to "natural heat below the base of groundwater." Geothermal resources in Alberta are defined in both the Mines and Minerals Act and in Bill 36: Geothermal Resource Development Act as "the natural heat from the earth that is below the base of groundwater protection."

Summary of resource tenure

- Resource is governed by heat.
- Multicommodity extraction is permitted (but appropriate rights must be held, such as petroleum and natural gas (PNG) rights for hydrocarbon extraction).
- Rights are granted via application.
- Lease is nine sections, all of which must be laterally or diagonally adjoining.
- Rights are non-exclusive to a single owner (e.g., a geothermal lease, brine hosted mineral lease and hydrocarbon lease can all be issued at the same location over the same depths).

Gaps and challenges

- Geothermal rights are non-exclusive to other resources.
- Coproduction requires additional rights.
- Surface land leases must be privately negotiated with surface land holders.

Actions underway

- Gaps are being communicated to government by the geothermal industry.
- Alberta Drilling Accelerator (ADA) feasibility study has received funding from the Alberta government.
- Alberta Energy Regulator has demonstrated an openness to adjusting regulations within the existing legislation.

Saskatchewan

Geothermal resource definition

Geothermal resources are not yet defined in Saskatchewan legislation. However, some guidance is available through the Government's Integrated Resource Information System (Government of Saskatchewan, 2019), which defines a geothermal project as follows: "A geothermal project means a development where geothermal energy is recovered through deep well(s). There are two main types of geothermal projects: open-loop and closed-loop. An open-loop system includes: (1) withdrawing formation water for the purpose of extracting geothermal energy as part of an industrial process, and (2) disposing of the cooling fluids into the subsurface following the extraction of its heat content. In a closed-loop system, source fluids are circulated in a sealed wellbore, heat exchange loop, and there are no formation fluids to be withdrawn or fluids to be disposed. The geothermal project application is only applied to subsurface activities."

Summary of resource tenure

- Resource is governed by pore space.
- Multicommodity extraction permission is unknown.
- Rights are granted at government discretion.
- Lease's size is not defined.
- Rights are exclusive to a single owner.

Gaps and challenges

- Current projects are granted special permission via ministerial order.
- Rules, timelines, and processes are uncertain.

Actions underway

- Industry consultation is currently being conducted jointly by government and the Saskatchewan regulator (Ministry of Energy and Resources and the Ministry of Environment).

Manitoba

Summary

Manitoba has no current legislation or regulation for deep geothermal. All geothermal developments to date have been shallow geoexchange systems, which are governed by the Manitoba Geothermal Energy Alliance which certifies geoexchange installers (Manitoba Geothermal Energy Alliance, 2014).

Gaps and challenges

- All geothermal development has been shallow geoexchange systems.
- Geoexchange systems are regulated by the Manitoba Geothermal Energy Alliance.

Actions underway

- None known

Yukon

Summary

Yukon has no current legislation or regulation for geothermal. In the 2020 government document, “Our Clean Future: A Yukon Strategy for Climate Change, Energy and a Green Economy,” the Yukon government committed to was developing a Geothermal Resources Act (Action E11) that would regulate geothermal energy development in the territory (Government of the Yukon, 2020). A public engagement process was hosted by the Department of Energy, Mines and Resources through an open, direct call for submissions. Overall, the feedback received was positive, with strong support for the development of geothermal resource legislation in the territory (Government of the Yukon, 2023).

This feedback further reinforced the Government of Yukon’s interest in and commitment to the development of geothermal resource legislation and ongoing governmental commitment to government discussions involving Indigenous communities that may be affected by any potential geothermal exploration and development. The geothermal legislative framework remains under development.

Gaps and challenges

- Regulator has started internal regulatory development, but government has not yet become engaged.

Actions underway

- Policy is currently under development in the department of Geothermal and Petroleum Resources.

Northwest Territories

Summary

Northwest Territories has no current legislation or regulation for geothermal. In 2010, the Government of Northwest Territories (GNWT), Department of Environment and Natural Resources, commissioned the Pembina Institute to complete an inter-jurisdictional review of geothermal energy legislation and policy. However, this report did not result in further activity toward the development of a geothermal regulatory framework (Dagg & Holroyd, 2011). In 2018, the GNWT released its “2030 Energy Strategy,” which identified geothermal energy as one potential component of the government’s strategy for greenhouse gas emission reductions and the development of secure, affordable, and sustainable energy in the NWT (Government of the Northwest Territories, 2018).

In 2021, a new report was commissioned by the University of Calgary School of Public Policy’s Extractive Resource Governance Program. This report is not yet available publicly and has not resulted in the development of geothermal legislation to date (Archibald et al., 2022).

Gaps and challenges

- Does not appear to be a current government priority.

Actions underway

- Government has commissioned multiple reports proposing policy, but it has not yet acted on recommendations.

Nunavut

Geothermal resource definition

Nunavut's water rights are currently governed by the Federal government under the Nunavut Waters Regulations (Nunavut Waters Regulations, 2013). These regulations include the use of waters for power generation, including "use of waters for authorized hydro, geothermal or nuclear electrical generation". This regulation covers the development of deep geothermal resources but has yet to be tested by developers.

Gaps and challenges

- Regulations do not define geothermal for heat use.
- Regulations do not define water depth and are assumed to apply to all water.

Actions underway

- Shallow geothermal R&D is underway and will test the existing regulations.

Ontario

Summary

There is at present no current legislation or regulation for deep geothermal in Ontario, but there are regulations around ground source heat pumps and water wells that may apply to deeper developments. Closed-loop ground source heat pumps are defined as "a system that is designed to heat and cool a building or structure by using a heat-transfer fluid to exchange heat with the ground or ground water" (Environmental Protection Act ONTARIO REGULATION 98/12 GROUND SOURCE HEAT PUMPS, 2014). While a minimum depth of five meters is outlined, the regulations identify no maximum depth.

All wells drilled deeper that 3 m are governed by the Wells Regulation (Regulation 903) and the Ontario Water Resources Act (Ontario Water Resources Act, R.S.O. 1990, CHAPTER O.40, 2024; Ontario Water Resources Act, Wells, 2020). These regulations are primarily designed to govern open-loop, ground-source heat pumps and were not designed with deep geothermal developments in mind.

Gaps and challenges

- Current geothermal policy covers geoexchange projects (no maximum depth stated) but does not differentiate geoexchange and deep geothermal projects.

Actions underway

- Planned deep geothermal developments will test the geoexchange regulations for deeper geothermal systems.

Québec

Summary

Québec has no legislation or regulation for deep geothermal. However, “Deep geothermal energy” is defined in Bill 22: “Loi visant principalement à mettre fin à la recherche et à la production d’hydrocarbures ainsi qu’au financement public de ces activités,” which was adopted in 2022 (SQ 2022, c 10 | An Act Mainly to End Petroleum Exploration and Production and the Public Financing of Those Activities, 2022). This new bill is an important step taken within Québec’s energy transition plan since it aims to end the exploration for and production of hydrocarbons (and end the public financing of these activities). This new bill authorizes the implementation of pilot projects to acquire geoscientific knowledge related to deep geothermal energy potential. Shallow resources associated with geothermal heat pump resources remain regulated through the Règlement sur le captage des eaux souterraines of the Loi sur la qualité de l’environnement.

Gaps and challenges

- All geothermal developments to date have been shallow geoexchange systems.

Actions underway

- Government is exploring development of deeper geothermal as part of their mandate to stop oil and gas exploration and production.

New Brunswick

Summary

New Brunswick has no current legislation or regulation for deep geothermal. Open-loop geothermal developments are governed based on the circulated water volume. Projects circulating 50 to 120 cubic metres of water per day are required to notify the Environmental Assessment (EA) Section of the project details. Projects circulating more than 120 cubic metres of water per day are required to register the project under the EIA Regulation within the Clean Environment Act (Government of New Brunswick, 2016). These regulations were designed for open-loop geoexchange developments but would likely also apply to deep geothermal developments. Deep geothermal developments typically circulate >100 cubic metres of water per second and operate very differently from geoexchange systems.

Gaps and challenges

- Current geoexchange regulations are based on flow volumes and could be interpreted to include geothermal, but were not designed for high water-flow projects.

Actions underway

- None known.

Prince Edward Island

Summary

Prince Edward Island has no current legislation or regulation for deep geothermal. Geothermal developments in Prince Edward Island are currently governed under the Water Act (WATER ACT, WELL CONSTRUCTION REGULATIONS, 2021). These regulations define an “open-loop system” as “an earth energy system designed to use groundwater or surface water for the purpose of extracting or rejecting heat by use of a liquid-source heat pump.” While this legislation was designed for shallow geoexchange systems, it may also apply to deep geothermal developments as the legislation does not define well depth.

Gaps and challenges

- Depth is not defined in current geoexchange legislation and could be interpreted to include geothermal but was not designed for deep projects.

Actions underway

- None known

Nova Scotia

Geothermal resource definition

Geothermal is defined under the Mineral Resources Act (Mineral Resources Regulations - Mineral Resources Act (Nova Scotia), 2018) and applies to “all fluids below the earth’s surface that can carry heat.” The purpose of the Act is to “support and facilitate responsible mineral resource management”. Both minerals and geothermal energy are included as mineral resources. The Act defines a geothermal resource as the following: “a substance, including steam, water and water vapor, that is found anywhere below the surface of the earth and that derives an added value from the natural heat of the earth present in, resulting from or created by the earth.”

Summary of resource tenure

- All minerals are reserved for the Crown.
- A “geothermal resource area” is designated by the Governor in Council.
- A royalty regime is provided for mineral resources.
- Includes both shallow and deep geothermal resources.

Gaps and challenges

- All geothermal development to date has been shallow geoexchange systems.

Actions underway

- There is strong government support for geothermal developments of all scales in the province.

Newfoundland and Labrador

Summary

Newfoundland and Labrador have no current legislation or regulation for geothermal. Under the Water Resources Act, "groundwater" means all water that exists beneath the land surface in the zone of saturation and includes springs (SNL2002 CHAPTER W-4.01 - WATER RESOURCES ACT, 2002). This Act appears to apply to groundwater at all depths and could be interpreted to include deep geothermal resources. The province has a well drilling regulation (NLR 63/03 - Well Drilling Regulations, 2003 under the Water Resources Act, 2003) that would apply to any geothermal well development in the province. While neither of these statutes mention geothermal developments, the government of Newfoundland and Labrador has issued a guidance document for geoexchange systems (Government of Newfoundland and Labrador, 2022). There is currently no guidance from the government on the development of **deep geothermal systems** in the province.

Gaps and challenges

- The province has both water and well regulations that apply to geoexchange and possibly deep geothermal.
- Currently, no guidance from the government on the development of **deep geothermal systems**.

Actions underway

- None known

Table 4. Current Canadian geothermal power projects and their stage of development.

Company	Project name	Location	Geothermal technology	Next stage	Federal funding received	Notes
Tu Deh Kah Geothermal	Tu Deh Kah Geothermal	Fort Nelson, B.C.	Conventional	Drilling production and injection wells	CAD $40.5M	Using a depleted gas reservoir, 100% Indigenous-owned
Meager Creek Development Corp.	Meager Creek Geothermal Project	Meager Creek, B.C.	Conventional-Volcanic	Drilling production and injection wells		High-temperature volcanic resource at <2km depth.
Alberta No. 1	Terrapin Geothermics	Grande Prairie, AB	Conventional	Drilling appraisal well	CAD $7M	First geothermal drilling license issued in Alberta.
FutEra Power Corp.	FutEra Power Corp.	Swan Hills, AB	Conventional / Coproduced with Natural Gas	Operating		21MWe generating with 30% attributed to geothermal.
Eavor Technologies Inc.	Derek Riddell Eavor-Lite™ Demonstration Facility	Rocky Mountain House, AB	Next-Generation – Advanced Geothermal System	Technology demonstration	CAD $90M	Completing (Q3 2024) the feasibility study for the Alberta Drilling Accelerator, a geothermal drilling test facility.
E2E Energy Solutions	Rainbow Lake	Rainbow Lake, AB	Next-generation-enhanced geothermal system	Drilling appraisal well		Aim to power the town entirely with geothermal energy.
Deep Earth Energy Production Corporation	DEEP	Estevan, SK	Conventional	Drilling production and injection wells	CAD $25.6M	Signed power purchase agreement with SaskPower

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Appendix C: Glossary

GEOTHERMAL SYSTEMS

Shallow geothermal systems: Geothermal systems (often called geoexchange systems) constructed above and within the groundwater table (i.e., in the shallow subsurface) to provide heating and cooling.

Deep geothermal systems: Geothermal systems constructed below the groundwater table (typically >1 km) that can provide heat and/or power, depending on the subsurface temperature.

Ultradeep geothermal systems: Geothermal systems at depths >5 km that involve drilling into igneous and metamorphic rock (i.e., into the "basement") that can provide both heat and power.

Conventional/Hydrothermal geothermal systems: Geothermal systems (often called hydrothermal geothermal systems) that use existing subsurface fluids and flow paths to bring Earth's heat to the surface for heat and power production.

Next-generation geothermal systems: Geothermal systems where artificially created flow paths and pumped fluids bring Earth's heat to the surface for heat and power production. The two sub types are closed-loop networks (advanced geothermal systems, AGS) that circulate the working fluid through sealed tubes and open-loop reservoirs (enhanced geothermal systems, EGS) in which the fluid flows through artificially created fractures and comes in direct contact with the rock.

TECHNOLOGY

Rate of penetration (ROP): The speed at which the drill bit can break the rock and increase the borehole depth.

Working fluid: Fluid used to transfer Earth's heat from the subsurface to the surface for heat and power production.

GEOLOGY

Subsurface: The soil (shallow subsurface) and rock (deep subsurface) that occur below the surface of Earth.

POLICY AND REGULATION

Geothermal Rights: The right to explore for, develop, recover, and manage the geothermal resources within a subsurface reservoir. The exact definition will vary by jurisdiction.

Lease: A contract by which the subsurface landowner (typically the provincial or territorial government) conveys land to a developer for a specified time in return for payment.

Licence: A permit issued by a governing authority to drill a geothermal wel

Permit: An official document issued by a governing authority that gives a geothermal developer authorization to explore an area, drill a well, or construct a geothermal facility.