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GEOSTRA

A proposal to unlock reliable, affordable, and sustainable power through a Geothermal Science and Technology Research Authority

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Context & opportunity

Who is the Cascade Institute?

The Cascade Institute is based in Victoria, BC, and is a non-profit, non-partisan think tank committed to addressing humanity's greatest challenges. The Institute does not have a financial interest in geothermal and is focused on providing a public good. By convening industry, government, Indigenous people, and other key stakeholders, the Cascade Institute is building coalitions for impact.

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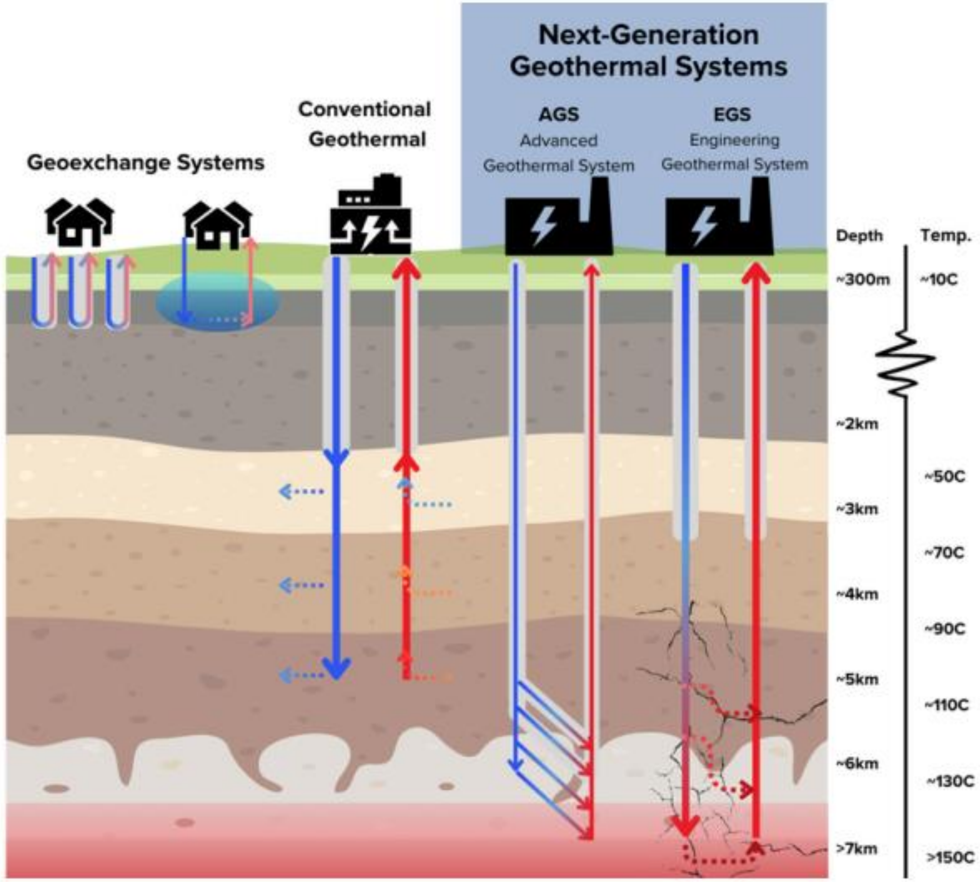
What is geothermal?

- **Geoexchange (<1 km):** uses low temperature heat close to the Earth's surface. Heat is used directly in residential, commercial, industrial applications.
  - **Status:** Mature
- **Existing - Conventional Geothermal (1 > km):** uses natural aquifers to capture thermal energy that can be used for heat, power, or both.
  - **Status:** Mature, innovation ongoing
- **'Next-Gen' Geothermal:** creates artificial reservoirs to enable 'geothermal anywhere', including advanced geothermal systems (AGS) and enhanced geothermal systems (EGS).
  - **Status:** Demonstrated, but innovation required.
- **Superhot Rock:** at temperatures of >375C, geothermal wells produce 5-10X more energy than conventional temps.
  - **Status:** Emerging, innovation required.



Conventional geothermal was limited by the need for natural aquifers. Next-gen tech opens new possibilities.

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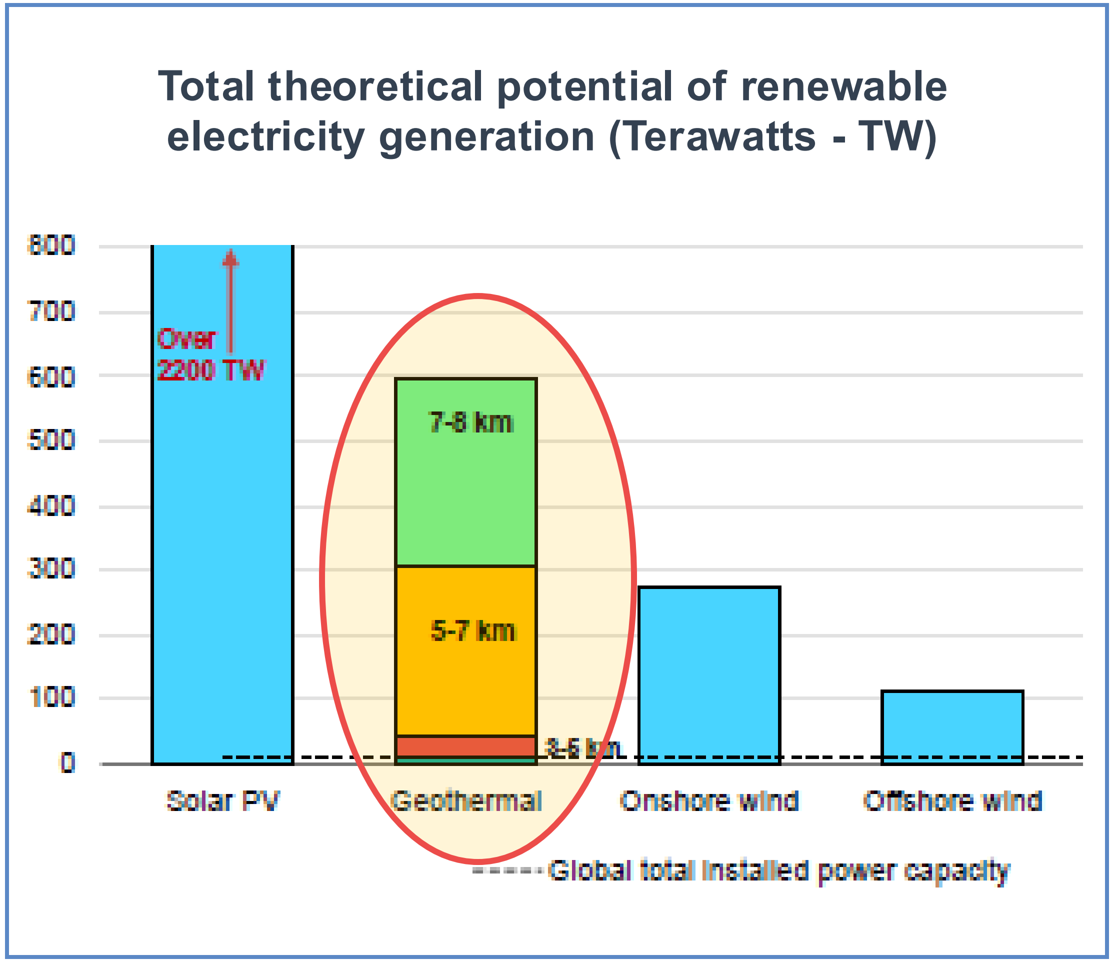
Deep geothermal: Unlocking the potential

- The International Energy Agency (IEA) estimates **600 TW** of geothermal are available with enhanced geothermal systems (EGS).
- However, rapid global proliferation of EGS requires deeper projects. Currently, only a few countries with favourable conditions can generate power.
- For example, Fervo's EGS wells at its first-of-a-kind project are just 2.5 km deep. They have a strong thermal gradient (80°C/km) and advantageous geologic conditions.
- The vast majority of geothermal potential is beyond depths accessible today. Oil and gas wells are less than 5 km deep. Geothermal must go up to 8 km.
- Accelerating innovation can unlock the immense geothermal potential that exists at greater depths.



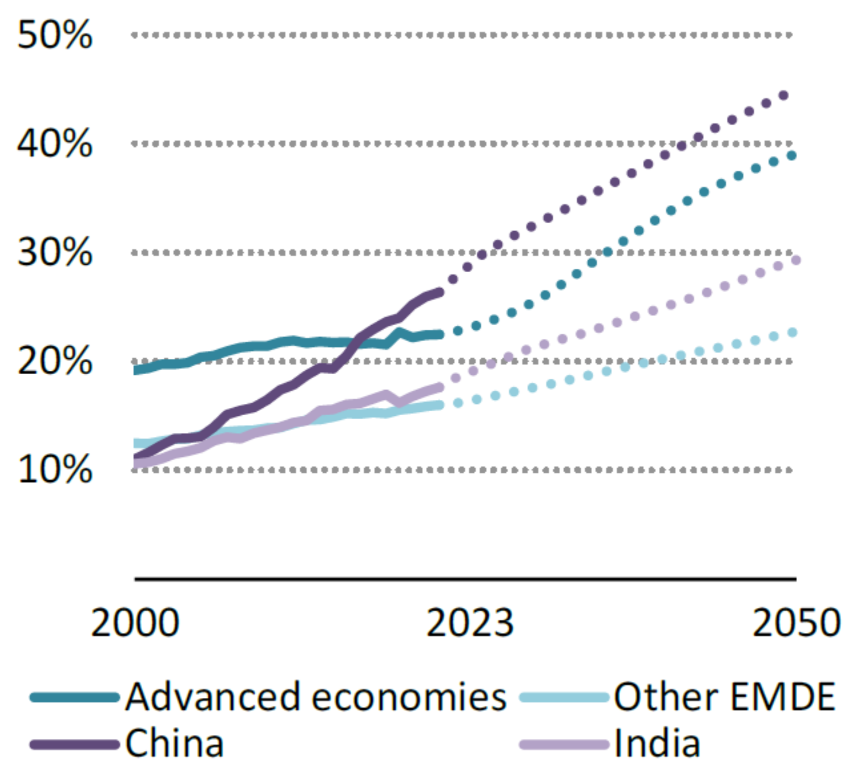
From the International Energy Agency's (IEA) Future of Geothermal Energy

Why geothermal?

Global energy systems are changing. Geothermal power is a niche source of energy today, but macro trends are poised to make it a keystone of 21st century global energy systems.

- **Existing technologies** like EVs and heat pumps are increasingly competitive, driving higher electricity regardless of climate policy.
- **Emerging industries** such as AI and carbon management may also drive demand growth.
- **Reliability** becomes increasingly valuable as low-cost wind & solar become the main source of new electricity. Batteries alone are not enough.
- **Baseload power** will be needed to ensure reliable and affordable electricity. There are only a handful of technologies that can provide this.
- **Geothermal energy** is uniquely positioned within this limited portfolio of baseload power options.

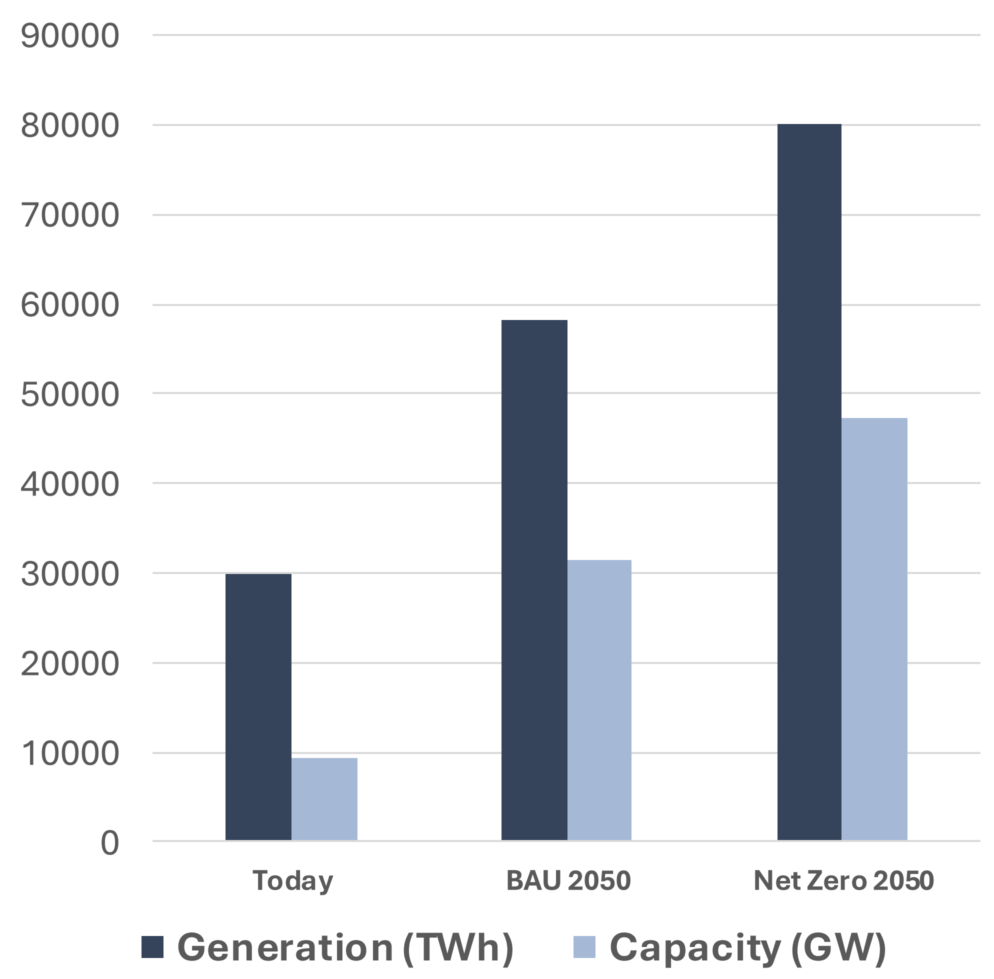
Share of electricity in meeting energy demand under BAU



From the International Energy Agency's (IEA) World Energy Outlook, 2024

The prize: Massive market, rapid growth

- Regardless of future climate policy, the electricity sector will grow rapidly in the 21st century.
- The IEA estimates that under business as usual (BAU), global electricity generation will nearly double by 2050. Under a net zero scenario, it will nearly triple.
- Generation capacity will grow even faster. Under BAU, capacity will increase over 3X by 2050 and nearly 5X under net zero.
- This rapid growth creates a major global market opportunity for geothermal power.
- The total investment opportunity for geothermal power could be ~US$750 billion by 2035 and US$2.5 trillion by 2050. Annual investment in geothermal peaks at US$200B / year in 2035.



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Data from the International Energy Agency's (IEA) World Energy Outlook, 2024 and Net Zero Roadmap

When? Now!

The world's largest companies are already procuring conventional and next-generation geothermal to power their operations – including data centres and AI.

In November 2023, Google announced it would buy 3.5 MW of power from Fervo's EGS pilot project. Google now intends to buy an additional 115 MW of power from Fervo. Google identifies EGS as **"one of the most promising opportunities"** to provide clean baseload power for its operations.

In May 2024, Microsoft announced it will use geothermal power from **Kenya's world-class geothermal resources** to power its East Africa data campus.

In August 2024, Meta announced a partnership with Sage Geosystems to expand the use of geothermal power in the US. **Sage intends to deliver power in 2027 and scale up to 150 MW**.

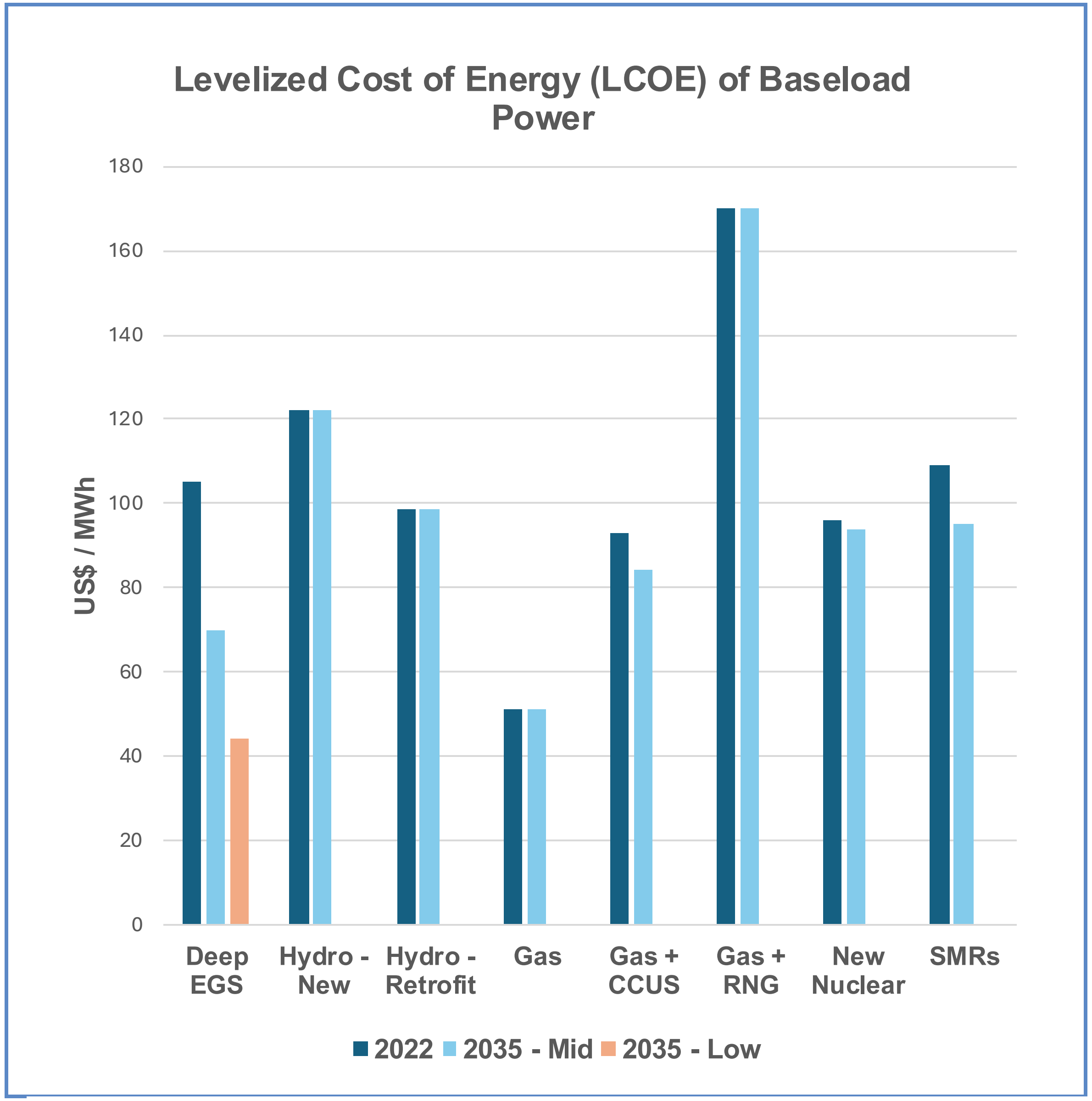
Calpine, the operator of the world's largest geothermal project, was purchased by Constellation Energy for **US $16.4 billion**. Calpine is a privately held business and is backed by the Canada Pension Plan Investment Board.

Challenges

Costs: The key challenge

Next-generation geothermal costs are currently uncompetitive. However, innovation can improve costs to be competitive with emerging – but largely unproven – low-carbon baseload options.

- **Gas** capacity costs are low but may rise with market demand. Gas becomes uneconomic if paired with net-zero aligned technologies (clean fuels, CCUS, and/or DAC).
- **New nuclear** has experienced cost overruns and is forecast to be more expensive than gas-fired power. Small modular reactors (SMRs) have limited potential for learning by doing given considerable unit sizes.
- **New hydro** has limited deployment potential with high possibility of cost overruns.



Data from National Renewable Energy Laboratory (NREL) Annual Technology Baseline

Costs in focus: Drilling

Today, drilling makes up 30-60% of geothermal project costs, and up to 90% for closed-loop projects. This makes drilling a key target for innovation.

Beyond reducing drilling costs, drilling innovation improves the viability of geothermal power by:

- Enabling deeper wells to access much of the Earth's geothermal power potential.
- Generating more power from higher temperatures.
- Reducing the number of wells required to achieve the same level of power output.
- Unlocking more efficient turbines at the surface, to further reduce energy costs.

Replicability: A key challenge for EGS

- Fervo has successfully demonstrated enhanced geothermal systems and produced increasingly impressive results.
- However, EGS projects may be dependent on local geologic conditions, including temperature, depth, permeability, and stress regimes.
- Replicating EGS projects in a variety of geologic conditions is essential to accelerate uptake.
- This would be facilitated by a series of test centres, in various geologies, to serve as demonstration projects and accelerate innovation.

Innovation: The obstacle is the way

There are four critical technology pathways to unlock the full potential of geothermal power. While this innovation requires upfront investment, it also creates an opportunity for Canada to seize a competitive position and create a durable moat for industry.

Drilling time

Drilling makes up 40-60% of project costs and must fall significantly.
Key opportunities: drill bit longevity, rate of penetration, high-temperature drilling, novel drilling technologies (e.g. plasma).

High temperature management

Downhole tools must withstand extreme pressure and temperatures.
Key opportunities: insulated drill pipe, mud chemistry/additives, high-temperature rated tools, low-temperature coatings.

Well completion

Wells must withstand extreme temperature and harsh conditions.
Key opportunities: advanced materials (steel, cement, titanium), anti-corrosion, self-healing/ductile cement.

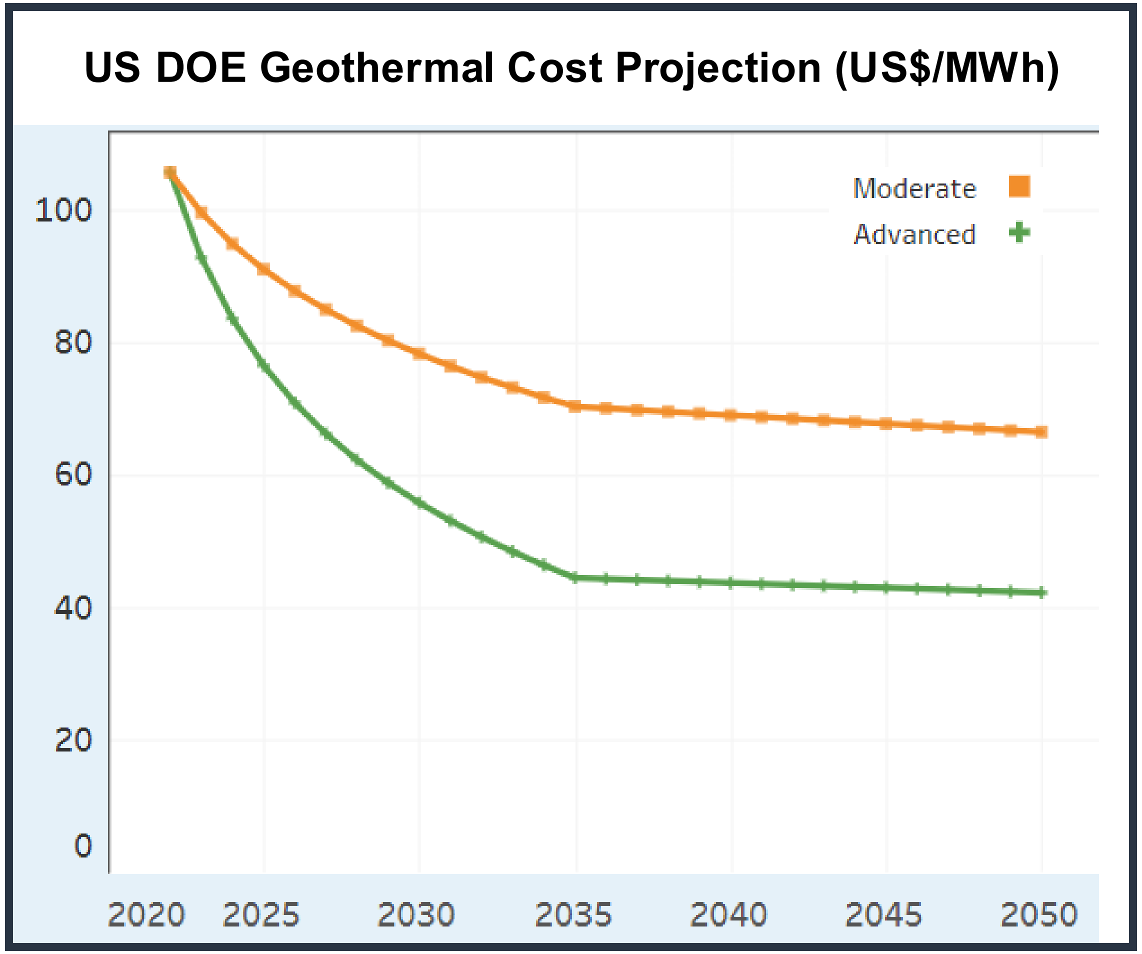
Heat extraction

Optimizing reservoir engineering techniques to maximize power.
Key opportunities: demonstrating reservoir creation in diverse geologies, both closed-loop and hydro-shearing, reservoir modelling.

Future cost potential

In addition to the diverse innovation opportunities that exist, there are several credible reasons to expect geothermal costs to decline rapidly in the near future.

- **Rapid progress:** US DOE estimates fell ~50% in recent years. Fervo is reporting learning rates over 15%.
- **Limited deployment:** There is just 15 GW of geothermal power globally and negligible levels of next-gen systems. This suggests significant room for improvement via learning by doing.
- **Modularity:** Individual wells produce ~ 5MW each. This supports the role of learning by doing, which has been critical to improvements in wind, solar, and batteries.
- **Compounding innovation:** Improvements in drilling cost and performance can lead to significant cost declines in other project elements, such as pumping and turbines.

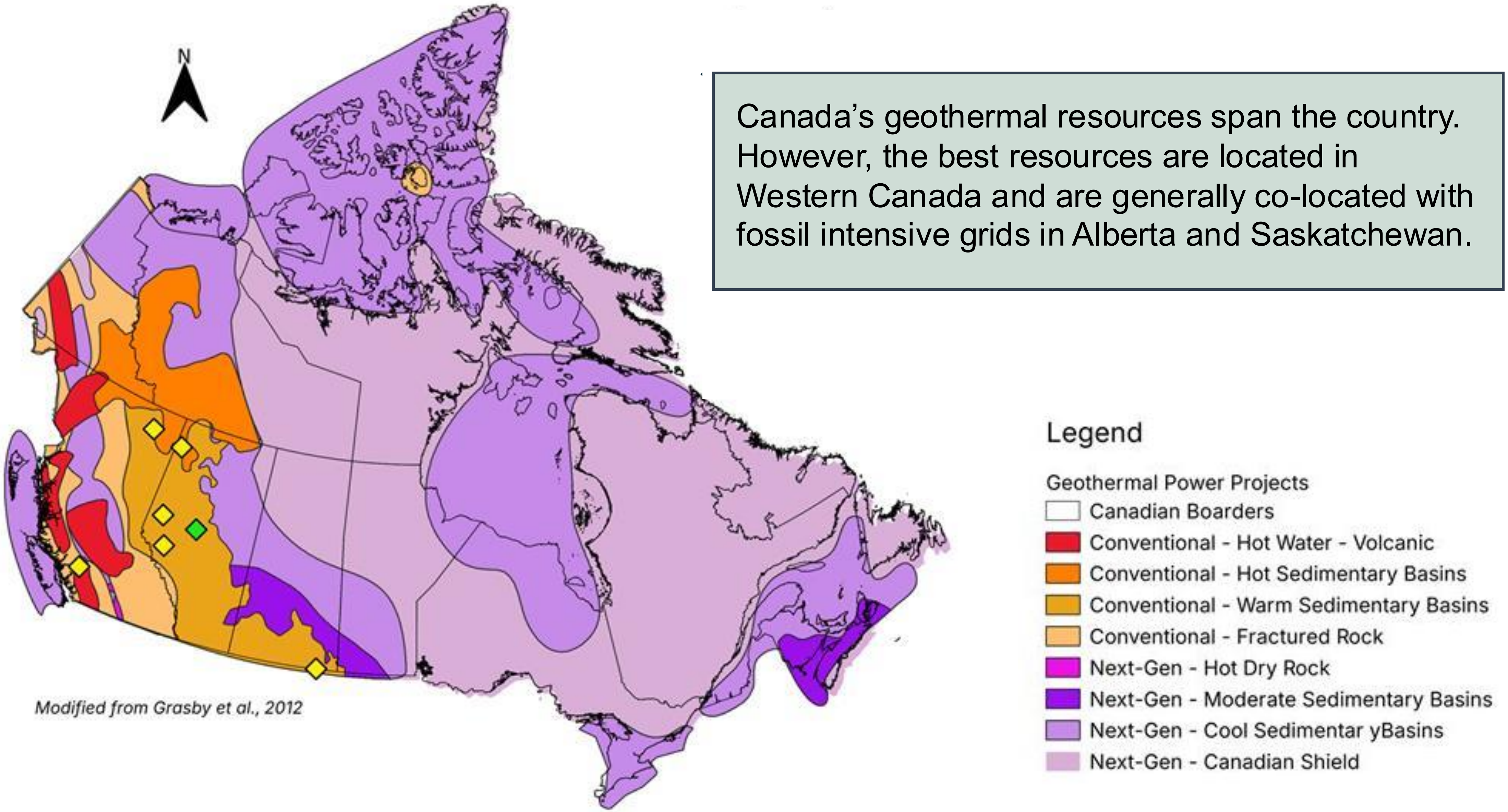


Data from National Renewable Energy Laboratory (NREL) Annual Technology Baseline

Why Canada?

Canada hosts strong geothermal resources…

Canada's geothermal resources span the country. However, the best resources are located in Western Canada and are generally co-located with fossil intensive grids in Alberta and Saskatchewan.



…a world-class & dynamic energy sector…

- The IEA estimates 80% of skills needed for geothermal projects are transferrable from oil and gas (e.g. exploration, drilling)
- Canada's world-class oil and gas sector is an industrial and regional strength
    - **Crude:** 4th largest producer, 3rd largest exporter
    - **Gas:** 5th largest producer, 6th largest exporter
    - **7.7%** of Canada's GDP in 2023
    - **447,000** jobs, of which over 181,000 are direct
    - **$64 billion** in capital expenditures
- Canadian drillers are internationally recognized and leading drilling campaigns on key projects
- Geothermal represents an opportunity to leverage Canada's existing strengths to compete in tomorrow's markets

Canada's innovation advantage

Canada is "hyper-dominant" in ~0.2% of patent areas, many of which are in oil and gas technologies relevant to geothermal:

- Positioning, fracturing, and completing wellbores
- Single-trip milling and whipstock systems
- Advanced flow control for wellbores and hydrocarbon reservoirs
- Agitation tools for enhancing well pump efficiency
- Automated systems for well monitoring, gas analysis
- Tools and methods for well servicing, borehole production
- Wireline tools and continuous circulation systems
- In situ heavy oil recovery
- Enhanced recovery techniques and steam injection

Canada can maximize the impact of investments in innovation by focusing on existing strengths.

Torrance, Andrew and Friedman, Lisa C., 'Own the Technology Podium',2024

…and a vibrant geothermal sector.

Canada hosts innovative firms and projects that are part of a robust industrial ecosystem.

- FutEra Power: uses geothermal heat and methane to generate power (Swan Hills, AB).
- Eavor: next-gen AGS system that extracts heat with a closed loop (Alberta, Germany).
- DEEP: next-gen EGS system developed in partnership with SLB (Estevan, SK).
- Tu Deh-Kah: Indigenous-led project aims to produce 15 MW of power (Ft. Nelson, BC)
- Cenovus: Canada oil & gas major exploring geothermal energy up to 6.4 km deep.
- Alberta Drilling Accelerator: open-access industry-led hub to leverage Alberta's unrivalled drilling expertise.
- World Geothermal Congress: will be hosted in Calgary in 2026.

Other key players in Canada's geothermal innovation ecosystem

- **Public labs / test sites:** federal CanmetENERGY labs, the Petroleum Technology Research Center, and federal / provincial geological surveys.
- **Universities**: UWaterloo, UCalgary, UAlberta, and others.
- **Technology developers**: Eavor, FutEra, CardinalVolta, and others.
- **International firms** with an interest in Canada, including Liberty Energy (C. Wright), SLB, Halliburton, and Ormat.

A proposal for GEOSTRA

GEOSTRA: Seizing Canada's geothermal opportunity

Proposal: Investing $550M in a **Canadian Geothermal Science and Technology Research Authority (GEOSTRA)** could accelerate the innovation needed to access greater depths at lower costs. GEOSTRA would include:

4 connected experimental test sites
across Canada to accelerate innovation and decrease risk. Each site would be allotted up to $125M.

Federal, provincial, and university labs
that convene Canada's best researchers and scientists to conduct *applied* research and analysis, catalyzing advances in the field.

An innovative intellectual property framework
to facilitate collaborative innovation, create and maintain made-in-Canada IP, and ensure both private and public investors benefit.

Stage-gate investments
Against key milestones to manage risk and ensure results.

Why test centres?

Test centres have a proven track record of convening multi-sector coalitions to accelerate energy technology innovation through smart and strategic risks. Key examples include:

- **Alberta Oil Sands Technology Research Authority (AOSTRA)**: Leveraged public-private collaboration to demonstrate the technology that unlocked in situ oil extraction, transforming Alberta's economy.
- **US Federal Wind Energy Program**: Led by NASA, accelerated progress towards modern wind turbine design and scale through collaboration with the aerospace industry and utilities.
- **US Frontier Observatory for Research in Geothermal Energy (FORGE): A**dvanced EGS through federally funded, university-led facility that facilitates private-sector R&D.

GEOSTRA would build on the test-centre model of cross-sectoral collaboration.

In focus: Test centres

Canada's diverse geology creates an opportunity to test a complementary suite of technologies in different sites.

British Columbia – the hottest rocks in Canada

- British Columbia hosts several extinct volcanoes with world-class geothermal resources. These conditions are ideal for superhot rock, high-temperature drilling and operations, and Canada's first volcanic geothermal project.

Alberta – the deepest well in Canada

- Deep drilling in Alberta would unlock crystalline rock drilling, stimulation, deep well operations, and enhanced geothermal potential for Canada. Successfully demonstrating enhanced geothermal in these conditions would prove global potential.

Saskatchewan – a rich sub-surface innovation system

- South Saskatchewan has a robust history of sub-surface energy innovation, including Weyburn-Midale and Boundary Dam. A GEOSTRA site in this location could leverage the dynamic innovation system already in place.

Notional test site costs

- Each test centre will notionally require $125M in total funding. This may vary according to site-specific R&D priorities. Funding will support two sets of activities:
  - **Infrastructure ($95M)** including site characterization, experimental drilling, stimulation, and potentially small-scale power generation.
  - **R&D Program ($30M)** to advance key technologies under each site's research agenda.
- Activities conducted at the test centre will accelerate early innovation to reduce costs and improve performance.
- As technologies move through the innovation cycle from early-stage R&D to commercialization, it will be critical to identify and attract the appropriate sources of capital.
- Both public and private funding will have important roles in financing the test centres and follow-on deployment.

GEOSTRA site investment	
Activity	**Cost**
Infrastructure	
Site characterization	$500,000
Pre-development	$5,000,000
Exploration wells	$20,000,000
Wells and stimulation	$30,000,000
Initial power generation	$20,000,000
Infrastructure total	**$95,000,000**
Ongoing RD&D (4 years)	
Regulatory science	$2,000,000
Basic R&D	$5,000,000
Applied R&D	$8,000,000
Demonstrations	$15,000,000
R&D total	$30,000,000
Total per GEOSTRA Site	**$125,000,000**

Test centres: Sparking learning by doing

- Clean energy technologies including wind, solar, and storage have experienced rapid cost declines in recent decades.
- These declines are the result of ‘learning by doing’, which occurs as an industry gains experience producing a technology.
- However, these improvements were preceded by decades of R&D that advanced the technologies to the point where they could be deployed at commercial scale.
- GEOSTRA could rapidly advance next-generation geothermal to a point where it can benefit from learning by doing via commercial deployment.
- Without this upfront push, it is unclear that geothermal power can jump directly to commercial deployment.

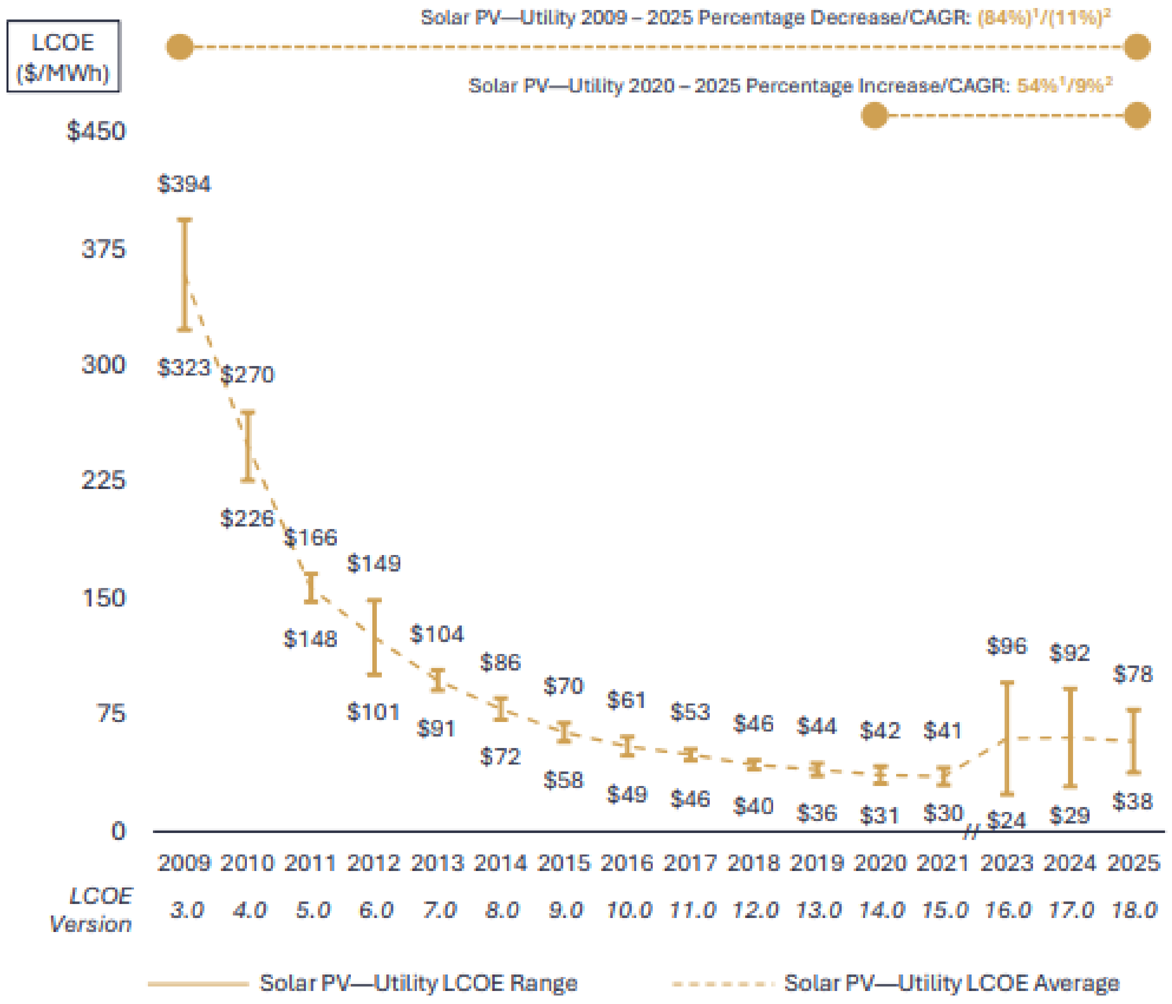


Image from [Lazard LCOE 2025]

Next steps

The Cascade Institute is advancing the GEOSTRA proposal across three paths:

Building the coalition

with a diverse array of actors. Key stakeholders include geothermal proponents, technology developers, oil and gas firms, drillers, utilities, and others.

Developing the plan

for GEOSTRA test sites. These plans include R&D agendas, costing details, potential partners, financing requirements, and possible returns.

Engaging decision makers

to build the case for public leadership at all levels. Public leadership is essential to coordinate action and de-risk early activities that catalyze industry action.

Looking ahead: A Canadian Geothermal Roadmap

Technologies do not exist in a vacuum. Seizing Canada's geothermal opportunity must involve more than R&D alone.

To spark a globally competitive Canadian geothermal industry, we must develop a coordinated suite of policies, including:

- Resource characterization,
- Regulatory frameworks,
- Financial measures, and
- Electricity market design.

A **Canadian Geothermal Roadmap** could convene stakeholders to devise a comprehensive view of the policies needed to ensure technical innovation translates into prosperity for Canadians.

If you are interested in learning more, please contact Peter Massie, Director of the Cascade Institute's Geothermal Energy Office (massie@cascadeinstitute.org).