Deep Geothermal Superpower

Canada’s potential for a breakthrough in enhanced geothermal systems

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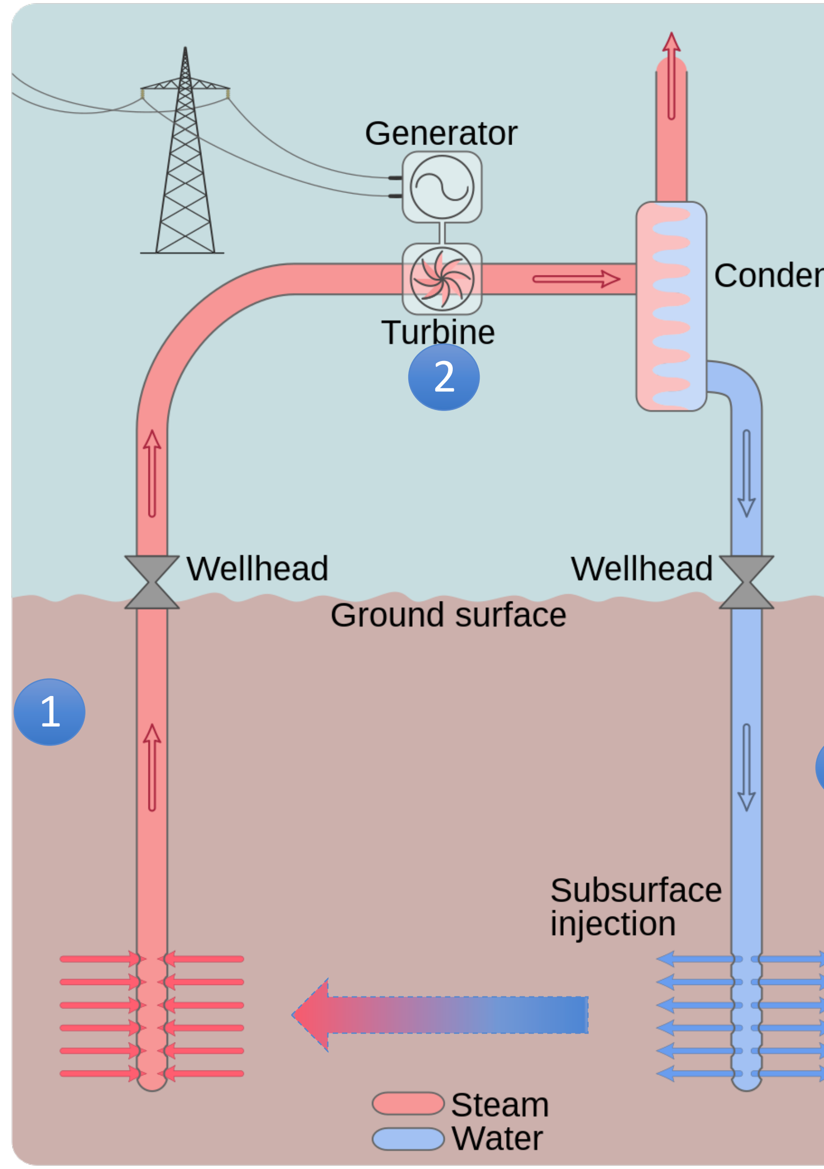
eothermal Energy Recap

- Extract heat from underground (usually water as working fluid)
- Use a heat engine (turbine) and generator to convert heat into electricity
- Return cooled fluid to underground reservoir for re-heating
- Continuous closed-loop cycle; essentially zero greenhouse gas emissions
- Proven success: 80 geothermal power stations in world today, producing over 14GW
- There is sufficient "deep" (~12km down) geothermal thermal energy to satisfy the ***entire world's*** current and forecasted electrical and thermal energy needs, many times over*



* *The Future of Geothermal Energy*. MIT: Cambridge MA, 2006.

Fig. Source: https://en.wikipedia.org/wiki/Geothermal_po

Geothermal Energy Recap (cont.)

Drill to reach the heat (ideally > 150°C) and get it out (i.e., hot fluid flow).

Need right geological formation to heat and trap the fluid in a reservoir*

Current drilling tech is only cost-effective for (relatively shallow) sedimentary rock.

→ limited geographical range: roughly **1%** of earth's surface, near tectonic plate boundaries

Core Challenge: high cost of deep, hard rock drilling

If you could drill deep anywhere, **cheaply** you could:

- Hugely expand the geographical range for geothermal
- Revolutionize the geothermal energy business model

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* When a reservoir is created or "engineered" by stimulating the rock (usually by pumping in high pressure water to create fractures that allow water to flow), we use the term Enhanced Geothermal System (EGS) to describe the manufactured *geothermal system*.

Current Geothermal Power Stations: A Map of Plate Boundaries

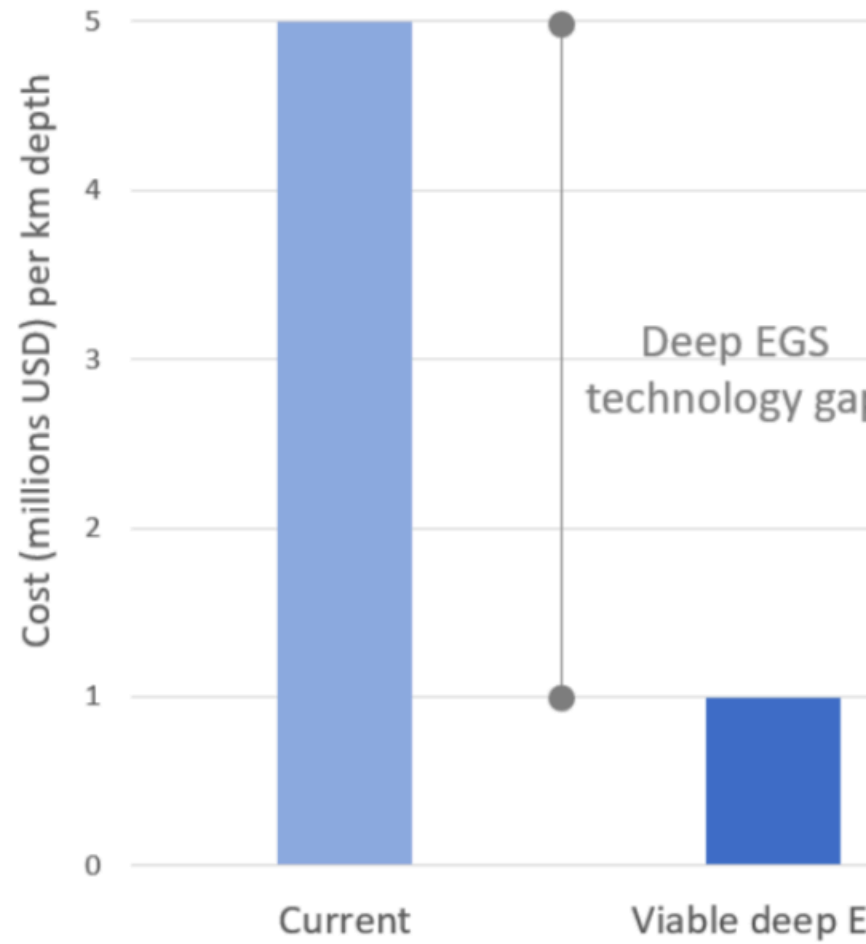
Cheap" hard rock drilling: what do we mean?

Rystad Energy data let us estimate 2020 geothermal well completion costs at **$5.3 million** (USD) / well.

Allowing for likely zero-carbon incentives (e.g., feed-in tariffs, depreciation incentives…) we estimate a conservative cost range of $5 - $10 million USD.

- ➜ Target cost: **$5 - $10 million USD**.
- Estimated cost today: **$50-100 million USD**

Need to reduce deep hard rock drilling costs by a factor of ~**10.**



this doable?

We believe yes: this is largely a drilling technology problem, with candidate technologies already under development

Main problem: hard rock drill bits.

- Slow penetration rates (today's bits cut through hard rock very, very, very slowly…)
- Wear out quickly (so you must extract the drill string, replace the bit, lower it down…)

Need drills that (a) have fast penetration rates and (b) last a long time before needing replacement.

There are four known technologies that show good promise

All (and likely others) are under development in academic R&D and in small drilling startups.

rrent Candidate Technologies

rcussive | **Strada Global**

- Drill bit percussively hammers against the rock face, fracturing it.
- Has achieved penetration rates of 23 m/hour through hard granite
- Strada Global is developing this technology with a focus on geothermal projects

Water-jet

- Augments conventional and percussive bits with high pressure water (similar to water jets used to cut steel)
- A potential augmentation to other approaches, in particular, percussive drill bits

asma | **GA Drilling**

- Use rapid pulses of high-T (>2000°C) plasma to vaporize / fracture rock face.
- Expected long bit lifetime since 'bit' never touches rock face.

Millimeter Microwave | **Quaise Energy**

- Uses gigahertz microwave to weaken, fracture the rock surface. Based on work originally at MIT.
- Quaise Energy recently raised circa $40 million in venture funding to advance this technology

rrent Candidate Drilling Technologies (cont.)

t is unlikely any one technology will solve the deep EGS drilling challenge.

- Different types of rock may require different technologies or combinations of technologies

nvestments should be made in all these potential solutions (and likely others).

More broadly, we also need to look at other aspects of the “drilling stack” (casings, liners, high emperature electronics) for cost reduction opportunities.

- Focus on reducing well-completion time
- But we first need a drilling technology breakthrough. It all hinges on better drilling tech.

ep Geothermal: Technical and Environmental Risks

GS in deep metamorphic/igneous rock?

- EGS has been demonstrated in shallow hard rock. But we still need to show viability in deep ha rock scenarios (10k or deeper).

nduced Seismicity?

- Shallow EGS can induce local seismicity: the fluid pumped in to create the reservoir adds stress the rock and lubricates existing fractures in the stimulated region. This can lead to deep, local seismicity which may be felt at the surface as earthquakes.
- Notably, though, most shallow EGS projects are near tectonic plate boundaries, where there is elevated risk of existing stress in the rock.
- It is believed that seismicity may be a smaller problem with deep EGS:
  - the stimulated seismic activity will be deeper underground (10 vs. 2-3km) which should reduce the impact at the surface
  - It is believed that, far away from plate boundaries, there is less existing stress in deep rock formations.

othermal: Canadian Position

Ve believe Canada should make a large industrial and R&D bet on EGS, to help chieve Canada's net-zero electricity targets and provide worldwide engineering pportunities for Canadian businesses.

Ve frame this in term of several ***audacious technical and business goals***.

hese may change over time but the serve to provide:

- Clear vision and direction
- Clear benchmarks for measuring success
- A tool for focusing the efforts of people, governments, agencies and business .

chnical Goals: “The $10 Million Well”

- Drill commercial quality geothermal wells to a depth of 10 km through hard rock, achieving a bottom hole temperature of at least 250°C, for <$10 million/well.
- Create functional, economically viable EGS reservoirs at depths of up to 10 km at commercially feasible cost.
- Build geothermal wells with a practical lifetime of over 75 years.

siness Goals: “World Leading Canadian Industry & IT”

- Create a world-leading Canadian capacity to design, build, and operate deep EGS plants in Canada and internationally.
- Ensure the IP from this industry remains a Canadian asset, through Canadian crow corporations and/or public stakes in private Canadian-owned corporations.

st Step: A Community of Intent

We want to build a broad community with a shared interest in transforming Canad into the global leader in deep EGS.

The goal is to achieve an understanding of:

- Scope and magnitude of the opportunity
- Key R&D gaps
- Most significant R&D, investment, and policy obstacles
- A portfolio of possible strategies / solutions for overcoming these obstacles
- The most effective governance and incentive structure for building a deep EGS "innovation ecosystem"

The community will also map an "R&D Pathway" between the current state of drilling and a target state where EGS can be competitive at scale.