A RENEWABLE ENERGY OPTION

DEEP GEOTHERMAL ENERGY

THE ENERGY **FROM THE EARTH**

WHAT IS DEEP GEOTHERMAL ENERGY?

IT IS ENERGY IN THE HEAT RECOVERED FROM WATER THAT OCCURS NATURALLY IN, OR HAS BEEN INJECTED INTO, A GEOTHERMAL RESERVOIR THOUSANDS OF METRES BELOW THE EARTH'S SURFACE.

Deep geothermal energy should not be confused with surface geothermal energy:

- Deep geothermal energy involves recovering heat from great depths, down to around 5,000 m, for direct heating purposes, for electric power generation using a turbine, or for both through cogeneration. The heat is extracted from the rock layers deep in the Earth's crust using a geothermal system.
- Surface geothermal energy involves harnessing heat from the shallow layers of the Earth's surface, down to about 400 m, for heating and cooling buildings. A heat pump is needed to convey the heat and render it compatible with the building's heating circuit.

Cover page: Olkaria II geothermal power plant, Kenya.

Facing page: Aerial view of a geothermal power plant in New Zealand.

GEOTHERMAL SYSTEMS

Currently, it is possible to utilize the heat stored in subsurface rock formations by drilling down 1,000 to 3,000 m or even 5,000 m and using one of the following geothermal systems:

- A hydrothermal geothermal system, or traditional hydrothermal system, makes use of the heat of the hot water or steam found naturally in permeable rock formations, meaning those with pores (e.g., limestone) or fissures (e.g., granite) through which water can pass. It is the preferred system when a geothermal reservoir presents all the desired characteristics (high temperature, fluid and permeability).
- An enhanced geothermal system (EGS), or fractured rock system, involves creating a geothermal reservoir by hydraulic fracturing. This process is used to cause fissures to form in the rock by injecting water at high pressure. Once the geothermal reservoir has been created, water is sent down an injection well, allowed to circulate through the fissures to heat up and then recovered through a production well. It can then be used as a heat source, to drive a turbine, for example. This is the solution that has been found for rock formations that have low to no permeability.

Note: This excludes shallow (near-surface) geothermal energy used for building heating and air conditioning.

The choice of system depends on the characteristics of the operating site. EGS development has accelerated in recent years, however, as we now know that most of the rock formations in the Earth's subsurface have enormous potential but low to no permeability. Rock permeability can be enhanced, and water can be injected where fluid is lacking. Deeper drilling has even made it possible to reach the temperatures required for the development of resources outside the most favourable thermal zones (geologically active regions at the edge of tectonic plates), meaning almost anywhere. EGS projects remain marginal, however, because while the system may at first glance appear simple, it is in fact quite complex to develop, and very expensive. Furthermore, EGS produce very little electrical power compared to hydrothermal systems. For instance, the Reykjanes plant in Iceland, which uses a hydrothermal geothermal system, has a generating capacity of 100 MW, while the Soultz-sous-Forêt EGS plant in France has a capacity of only 1.4 MW.

In recent years, the drilling techniques used to access geothermal fluids have been perfected, as have the techniques for creating and managing geothermal reservoirs lying several kilometres underground. While there is no doubt that the deep geothermal energy sector has made great strides, it still faces a number of technical challenges.

CURRENT STATE OF KNOWLEDGE

While often less well known than other renewable energy options such as wind and solar, deep geothermal energy is being developed worldwide. In 2020, the installed capacity for this type of energy worldwide was 30 GW for heat production (Lund and Toth, 2020) and 16 GW for electric power production (Huttrer, 2020).

The leading producer of electricity from deep geothermal energy is the United States. Its installed capacity for this type of energy was 3.7 GW in 2020 and could reach 4.3 GW by 2025. In 2020, hydrothermal geothermal systems in the United States generated 18.4 TWh of power. Some 50 other countries use deep geothermal energy to produce electricity, including Indonesia, the Philippines, New Zealand, Iceland, Mexico and Turkey. Worldwide, 95.1 TWh of power was generated by geothermal systems in 2020, the vast majority being hydrothermal systems.

In Canada, the geothermal energy potential of the Western Canada Sedimentary Basin is of particular interest. In British Columbia (Meager Creek) and the Northwest Territories (Fort Liard), hydrothermal projects are at the technical and economic assessment stage. In Alberta, a study has been done on the potential of deep geothermal energy. In Saskatchewan, the DEEP—Deep Earth Energy Production—project has entered a new stage, with the drilling of wells in 2020, and Canada's first binary cycle power plant operating a hydrothermal system is therefore expected to come online in 2021.

There are no geothermal power plants in Eastern Canada, and more specifically, in Québec, and while work has been done to assess the geothermal energy potential, no exploration or industrial demonstration or production projects are currently being planned.

DEEP GEOTHERMAL ENERGY POTENTIAL

According to the World Energy Council (2013), the global potential for electric power from hydrothermal systems could be as great as 140 GW. For enhanced systems, the theoretical potential is huge although the exploitable potential is much less. In the United States, for instance, the electric power potential of as-yet undiscovered hydrothermal reservoirs is estimated at 30 GW. For enhanced systems, the theoretical electric power potential of rocks hotter than 150°C at a depth of 3 to 7 km is immense, estimated at more than 5,000 GW, more than the country's current total installed capacity. Most of this potential is in the Western United States, where geothermal resources are closer to surface. Due to economic, technical and socio-environmental constraints, however, only a small portion of this potential would be exploitable in practice.

Québec's potential for deep geothermal energy was assessed in 2016 (Richard et al., 2017). The province's subsurface layers do not contain hydrothermal reservoirs hot enough for the production of heat or electricity. In the St. Lawrence Lowlands, geothermal power plants could be powered by enhanced geothermal reservoirs. In order to reach 150°C rocks, however, it would be necessary to dig down more than 5 km, and even 8 km in some places. Moreover, according to the latest estimates based on 120°C rock formations lying 3 km to 10 km below surface, the theoretical potential of the St. Lawrence Lowlands would be only 45 GW (Bedard et al., 2020). Under such conditions and at such temperatures, the installed capacity of a power plant fed by geothermal reservoirs 6 km below surface would be 2 MW at best (Richard, 2016).

ENERGY EFFICIENCY AND COST

As for any system that converts heat to electricity, energy efficiency for a geothermal system depends primarily on the temperature of the heat source, in this case the geothermal fluid. When the geothermal fluid is between 150°C and 200°C at surface, energy efficiency is currently 10% to 15%. In the medium and long term, however, it may be possible to increase energy efficiency to 25% or better through the use of new geothermal fluids and higher-performance power cycles.

Geothermal power plant and Blue Lagoon spa, Iceland.

In 2019, the average capital cost of a geothermal power plant generating electricity using a hydrothermal system was about US $4,000/kW, and the cost of electricity was around US $0.07/kWh (IRENA, 2020). The lower the temperature of the geothermal fluid, the higher the cost of electricity.

According to the National Renewable Energy Laboratory in the United States, the costs of a power plant that produces electricity from an EGS are as follows:

- For high-temperature (200°C) shallow rock formations (1—3 km) located near hydrothermal vents, the cost of the plant is approximately US $15,000/kW and the cost of electricity is US $0.25/kW to US $0.30/kWh.
- For rock formations that are deeper (3—6 km) but less hot (150°C—200°C), the plant would cost approximately US $60,000/kW to build and the cost of electricity would exceed US $0.60/kWh.

In a geological environment like Québec's, the capital cost of an EGS geothermal power plant would be over US $65,000 and the cost of electricity would be at least US $0.75/kWh. Most of the costs are related to the drilling of the deep wells. It should be noted, however, that there is a great deal of uncertainty surrounding EGS operation, particularly in terms of reservoir temperature and the quality of the fracture network created by hydraulic stimulation. These factors have important implications for the system's production capacity and therefore for the costs per unit of energy (Richard, 2016). The cost of deep geothermal energy could drop sharply, however, as the technology reaches maturity.

ADVANTAGES AND DISADVANTAGES

- Power plants can be installed anywhere, as long as you drill far enough down to reach the temperature range needed for heat and power generation
- Power generation is continuous and predictable
- No energy storage system is needed
- The energy source does not require special processing along the lines of oil refining or uranium enrichment
- When the power plant sits directly above the heat source, there is no need to convert or transport fuel, thus eliminating hazards such as oil spills
- EGS power plants would not be cost-effective in many regions
- This renewable energy option is based on the development of a deep geothermal system, which comes with a high capital cost and a high risk of non-performance

LEARN MORE

- Types of technology
- Geothermal potential in Québec
- Technical challenges
- Climate change and air quality
- Life cycle assessment
- Ecosystems and biodiversity
- Health and quality of life
- Land use
- Regional economy
- Social acceptability

SUSTAINABILITY

- The surface installations have a small footprint
- The vast majority of geothermal power plants have low greenhouse gas and air pollutant emissions
- Geothermal plants have a small environmental footprint throughout their life cycle
- Groundwater and surface water contamination can be avoided by proper wastewater management during drilling and hydraulic fracturing
- The associated use of large volumes of water can be an issue, particularly in regions where water is scarce
- The impact of microseismic events raises concerns
- EGS operation carries a risk of increased seismicity
- There may be health and environmental impacts, depending on the drilling technique used for hydraulic fracturing
- If radioactive minerals occur naturally in the EGS reservoir, mitigation measures are needed to prevent them from ending up in the geothermal fluid and settling in surface plant equipment
- There is an impact on the landscape, as pipelines, cooling towers, storage basins, buildings and transmission lines are imposing infrastructure visible from a distance
- Vegetation and wildlife are lost due to the deforestation required for power plant construction

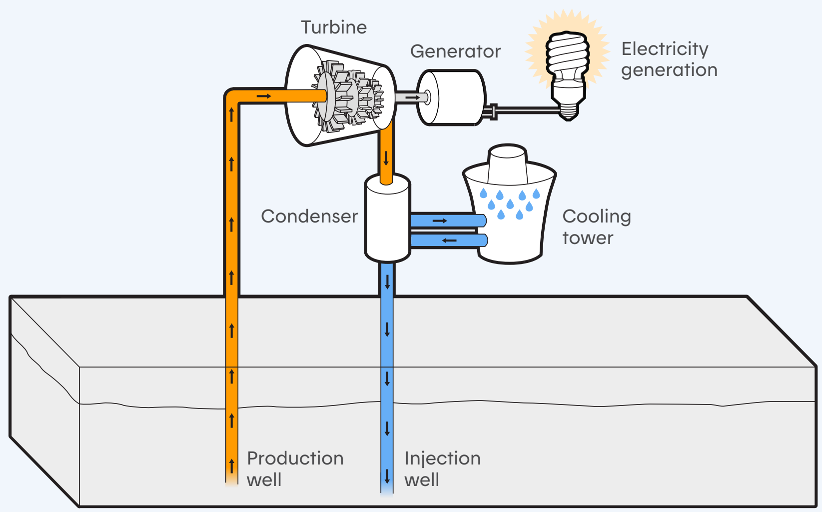
A SUSTAINABLE **RESSOURCE**

Types of technology

There are various technologies available for transforming heat from deep geothermal energy into electricity. The choice of technology depends essentially on the form of the geothermal fluid (steam, liquid or a combination of the two) and its temperature (approximately 125°C to 350°C). There are three main types of power plants:

- Dry steam power plants
- Flash steam power plants
- Binary cycle power plants

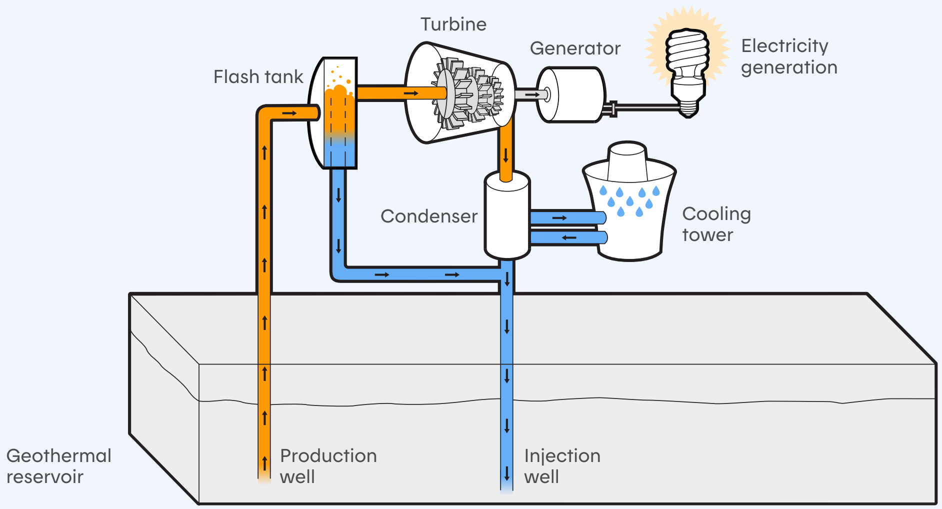
DRY STEAM POWER PLANTS



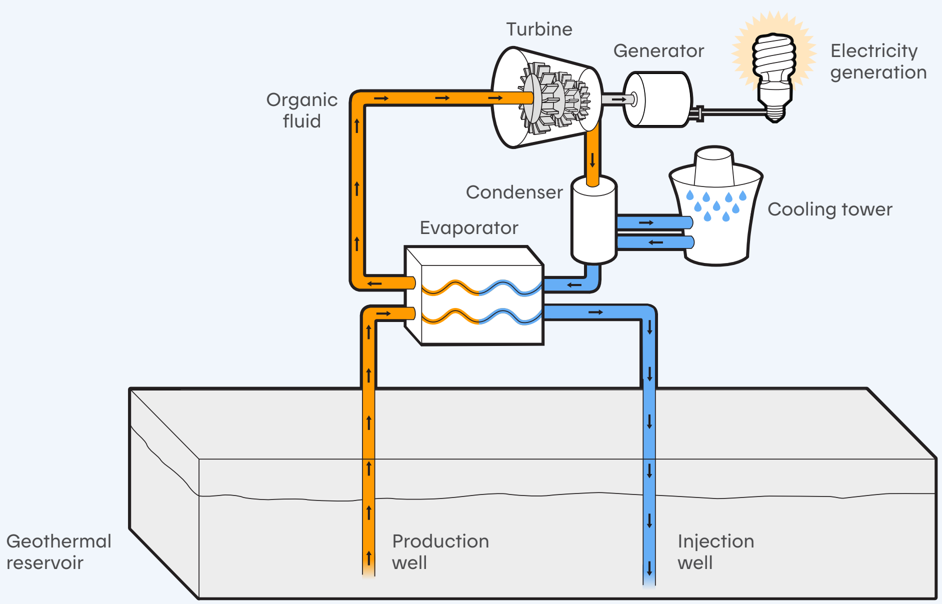
Dry steam power plant

This type of power plant is used when the geothermal fluid arrives at the production well head in the form of high-pressure superheated dry steam at a temperature of 180°C to 350°C or higher. The steam is used directly to rotate the power plant turbine. It is then condensed and the resulting water is cooled and returned to the geothermal reservoir via an injection well. The technology used is the so-called "classic" Rankine cycle.

FLASH STEAM POWER PLANTS



BINARY CYCLE POWER PLANT



Flash steam power plant

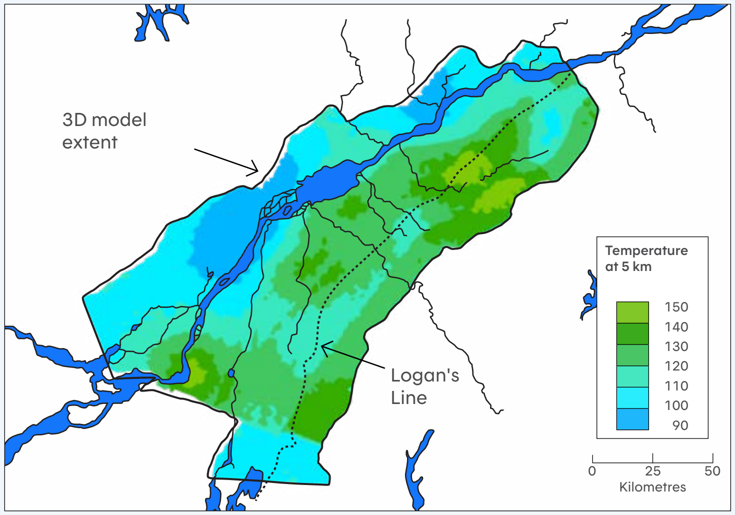
This is the type of power plant chosen when the geothermal fluid arrives at the production well head as a high-pressure mix of water and steam at temperatures above 180°C. The fluid first flows through an expansion tank to lower its pressure—or through two tanks, depending on whether the plant has a single or double flash system. Once separated from the water, the dry saturated steam is used to rotate the turbine of the power plant. It is then condensed and the resulting cooled water is returned to the geothermal reservoir through the injection well. Here again, the technology used is the classic Rankine cycle, the only difference being that the geothermal fluid drawn from the reservoir must be vaporized before it can be used to rotate the turbine.

Binary cycle power plant

Binary cycle technology is used when the geothermal fluid at the production well head is pressurized hot water at a temperature of 125°C to 180°C. At the well head, the geothermal fluid is fed into a heat exchanger (evaporator) that transfers its energy to an organic working fluid with a low boiling point. The geothermal fluid, which remains liquid during heat exchange, is then pumped back into the reservoir through the injection well. Heated by the geothermal fluid, the second fluid vaporizes and can then be used to rotate the turbine. It is then condensed and pumped, and the cycle begins again. The most commonly used technology, which is the one described here, is the "organic Rankine cycle." A binary cycle power plant can also use a process called the Kalina cycle, where the working fluid is a mixture of ammonia and water (not shown here).

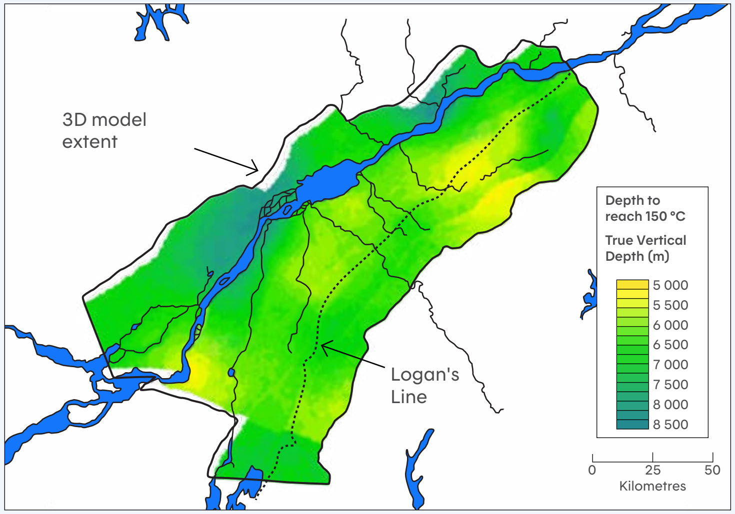
Québec's geothermal potential

UNDERGROUND TEMPERATURES IN THE SAINT-LAWRENCE LOWLANDS AT 5 KM DEPTH



Source: Bédard and coll., 2020.

ROCK DEPTH TO REACH 150°C IN THE SAINT-LAWRENCE LOWLANDS



Source: Bédard and coll., 2020.

Technical challenges

The many technical challenges to be addressed in the longer term include:

- Developing efficient advanced exploration methods
- Reducing the costs of very deep drilling
- Controlling, from surface, the creation and operation of deep geothermal reservoirs
- Improving heat-to-electricity conversion through new thermodynamic cycles
- Devising diversified low-risk financing models

Climate change and air quality

Greenhouse gases and air pollutants associated with compounds in the geothermal fluid vary depending on the natural conditions of the production site. CO_2 and H_2S are the gases most commonly emitted. If H_2S is present, a scrubber is normally used to minimize the amount released. Greenhouse gas emissions are generally very low. In rare cases, they are as high as for thermal power plants fired by fossil fuels. Deep geothermal power plants do not generate emissions once in operation.

Life cycle assessment

From a life cycle standpoint, the environmental impacts of the deep geothermal energy option are similar to those of other renewable energy options, at least for binary cycle EGS power plants. The materials used and equipment manufacturing and transportation are the most important factors in the life cycle analysis. Other factors to be considered are the type of machinery used for drilling, the number of production and injection wells drilled and the depth of such wells.

The operating conditions of geothermal power plants vary considerably from plant to plant, and generalizations are therefore difficult. Their climate change indicator results, for instance, can sometimes be similar to those of thermal power plants fired by fossil fuels.

Ecosystems and biodiversity

Some exploration sites are home to endemic species. The impact of a deep geothermal energy project on such species must be assessed before the project goes ahead.

The water injected into the wells has chemicals added to it but circulates in a closed loop, limiting the potential for ecosystem contamination. Precautions must nevertheless be taken to avoid contaminating groundwater or surface water.

Waste heat from power plants is normally dissipated in cooling towers. If not, it takes the form of thermal waste discharged into adjacent streams. To mitigate the environmental impact, power plant design should take the specific site characteristics into consideration and allow for the protection of local animal species.

Health and quality of life

The amount of noise generated by a deep geothermal power plant once in operation is similar to that of any other type of power plant. Drilling of the production and injections wells is what generates the most noise. Mitigation measures can be applied as needed.

Easily spotted by its plume of steam, a geothermal power plant clearly has a visual impact on the landscape. Matching the colour of the surface installations to those of the local environment can help the plant blend into its surroundings.

Well drilling and hydraulic fracturing require varying quantities of water depending on the site. Water use can become a problem in regions with scarce water resources.

Land use

With most of its equipment underground, a geothermal power plant has a small surface footprint compared to other types of power plants. The ponds built to store wastewater are often what take up the most space. The surface facilities are not a hindrance to nearby farming. The cooling towers do not consume water but they do occupy a fairly large area.

Subsidence has been known to occur at some sites where water was removed at a rate higher than the natural replenishment rate. Assessment of new production sites has since improved, and injecting geothermal fluids back into reservoirs has become routine.

Hydraulic fracturing can induce microseismic events. Detectable by instruments but generally not by humans, such micro-earthquakes register less than 3 on the Richter scale. This phenomenon is sometimes observed during hydraulic fracturing to facilitate oil or natural gas extraction. When geothermal power plants are located in seismic zones, it can be difficult to distinguish between natural seismic events and those induced by hydraulic fracturing.

Regional economy

In the past, geothermal power plant operation has sometimes led to the destruction of natural phenomena such as geysers, hot springs and mud pools, likely to the detriment of local tourism. Nowadays, comprehensive studies for new projects provide ways of avoiding this type of impact.

Production sites designed for multipurpose use can enhance the regional economy. For instance, instead of being injected back into the reservoir, the geothermal fluid can be used to create wildlife habitats or promote co-sited tourist attractions like the Blue Lagoon, a geothermal spa in Iceland. The waste heat from geothermal power plants can support the development of other industries, such as greenhouse farming.

Social acceptability

The public must be consulted on any electric power generation project. Multipurpose use of geothermal production sites (tourism, farming, etc.) can help make projects more socially acceptable.

A 2013 Leger Marketing survey indicated that the majority of Quebecers are in favour of deep geothermal energy as a renewable energy option.

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February 2021

2020G916A-4