A RENEWABLE ENERGY OPTION

DEEP GEOTHERMAL
ENERGY

ENERGY **FROM THE EARTH**

DEEP GEOTHERMAL ENERGY:
THERMAL ENERGY RECOVERED FROM STEAM, LIQUID WATER OR HOT ROCKS DEEP IN THE EARTH'S CRUST. IT IS MAINLY CONVERTED INTO ELECTRICITY BY MEANS OF A TURBINE.

CURRENT STATE OF KNOWLEDGE

Deep geothermal energy in the form of steam is currently used to produce electricity in more than 50 countries (United States, Iceland, Mexico, etc.). In 2015, installed capacity totaled 12.6 GW worldwide, producing 73.5 TWh of energy.

The deep geothermal option is being developed in every corner of the planet. Worldwide installed capacity should reach 21.4 GW in 2020 through public and private investment. Various types of technology exist but a number of technical challenges remain.

In Canada, the Western Canada Sedimentary Basin is of particular interest for its geothermal energy potential. In British Columbia (Meager Creek), the Northwest Territories (Fort Liard) and Saskatchewan (DEEP project near Estevan), hydrothermal geothermal projects (using heat from naturally present hot subsurface water) are at the technical economic study stage. A study has been conducted in Alberta on the potential of deep geothermal energy. In 2016, not a single geothermal power plant had yet been built in Canada.

In Eastern Canada, recent technological progress in drilling to reach geothermal fluids, and in creating and managing geothermal reservoirs kilometres beneath the earth's surface presage the harnessing of thermal energy at very great depths over the medium to long term.

In Québec, the potential of deep hot rock geothermal energy has been assessed. However, no exploration, demonstration or industrial operation projects have been planned for the medium or long term.

Cover page: Olkaria II geothermal power plant, Kenya.

Facing: Geothermal power plant and Blue Lagoon spa, Iceland.

POTENTIAL OF DEEP GEOTHERMAL ENERGY

The U.S. ranks first for electricity generation from geothermal steam. In 2015, U.S. installed capacity totaled 3.45 GW and energy production, 16.6 TWh. Installed capacity there could rise to 5.6 GW in 2020. In the Eastern U.S., deep hot rock electricity generation has an estimated potential of 500 GW, equal to the country's total installed capacity today.

Québec's geological environment consists of rock formations potentially thousands of metres deep. In southeastern Québec, geothermal power plants could be powered by reservoirs more than 6 or 7 km beneath the earth's surface and covering 10% to 15% of the region's area. The fluid at about 150°C from such reservoirs could power plants with installed capacities of 2 to 5 MW per production site.

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

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OUTPUT AND COSTS

Capital costs for an enhanced geothermal system (EGS), including the power plant, drilling and hydraulic stimulation, amount to at least $10,000/kW. The electricity generated would cost between 22¢ and 32¢/kWh, or even more.

Capital costs would drop to at least $6,000/kW once the technology matures. The cost of the electricity generated would then range from 10¢ to 15¢/kWh, or even more.

The efficiency of heat-to-electricity conversion is roughly 10% to 15%, depending on the temperature of the geothermal fluid and the thermodynamic cycle (power cycle) used. Over the medium to long term, however, efficiency could reach or even exceed 25% by using new geothermal fluids and higher-performance power cycles.

ADVANTAGES AND DISADVANTAGES

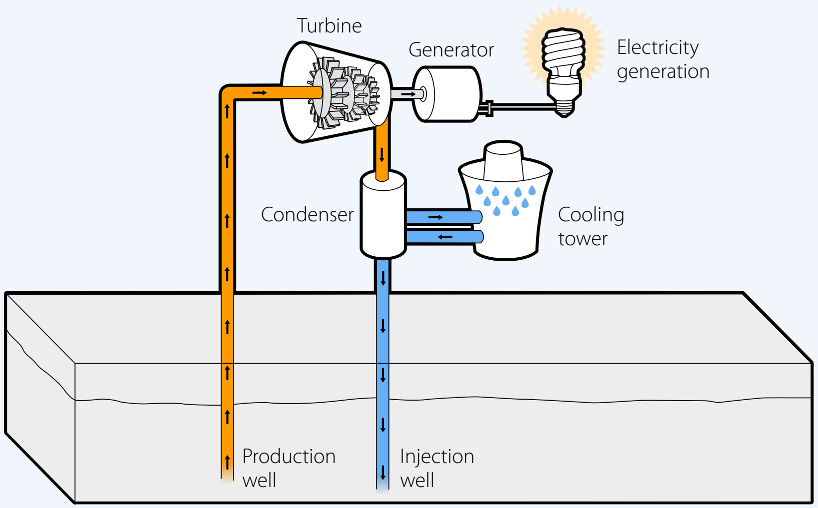
- EGS geothermal power plants can be installed anywhere, provided drilling is deep enough to reach the desired temperature
- Generation is predictable and continuous with a load factor exceeding 95%, better than with photovoltaic solar and wind generation, for example, and comparable to some nuclear power plants. An energy storage system is not needed
- The energy source requires no particular treatment analogous to oil refining or uranium enrichment
- Power plants being sited directly above the heat source, there is no need to convert and transport fuel, avoiding such hazards as oil spills
- EGS power plants will not be cost-effective in many regions over the medium term
- Geothermal energy is a renewable resource, the heat removed from a geothermal reservoir being naturally replenished

SUSTAINABLE DEVELOPMENT

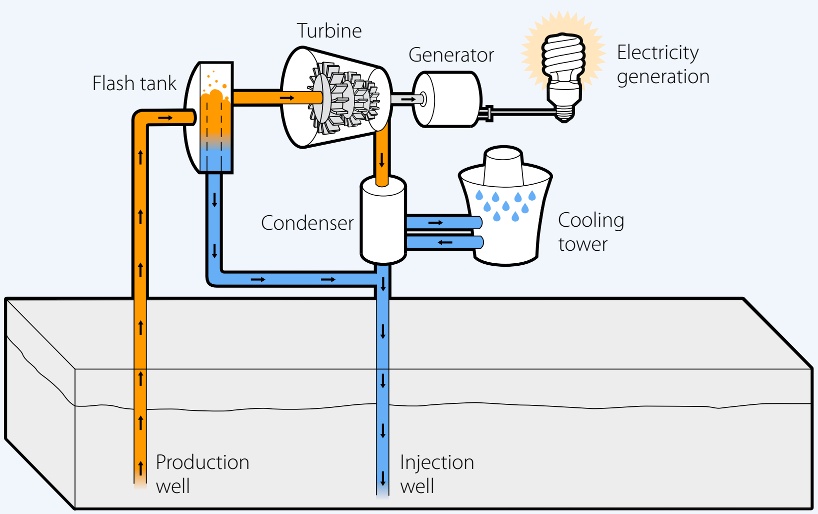
- Systems have a small footprint
- The vast majority of geothermal power plants emit few greenhouse gases and air pollutants
- Geothermal systems, and particularly EGSs, have a small environmental footprint throughout their lifecycles
- Groundwater and surface water contamination can be avoided by proper wastewater management during drilling and hydraulic stimulation operations
- Water use issues arise in regions with scant water resources
- Microseismic activity raises concerns

A **SUSTAINABLE** RESSOURCE

DRY STEAM POWER PLANTS



FLASH STEAM POWER PLANTS



Types of technology

Several types of geothermal power plants exist.

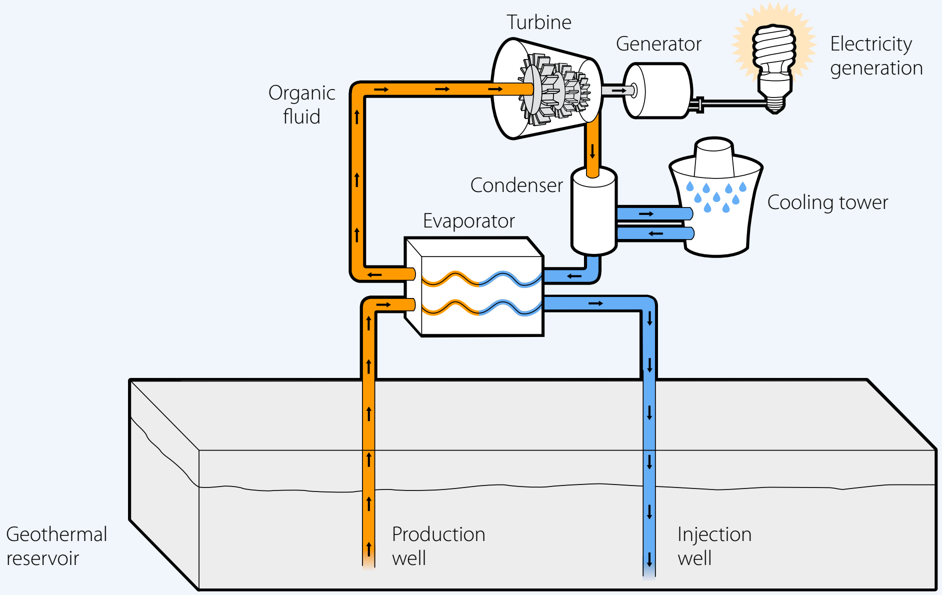
Dry steam power plants

The geothermal fluid is high-pressure superheated dry steam at between 180°C and more than 350°C that drives the turbine of a Rankine cycle power plant. The resulting cooled water is injected back into the geothermal reservoir.

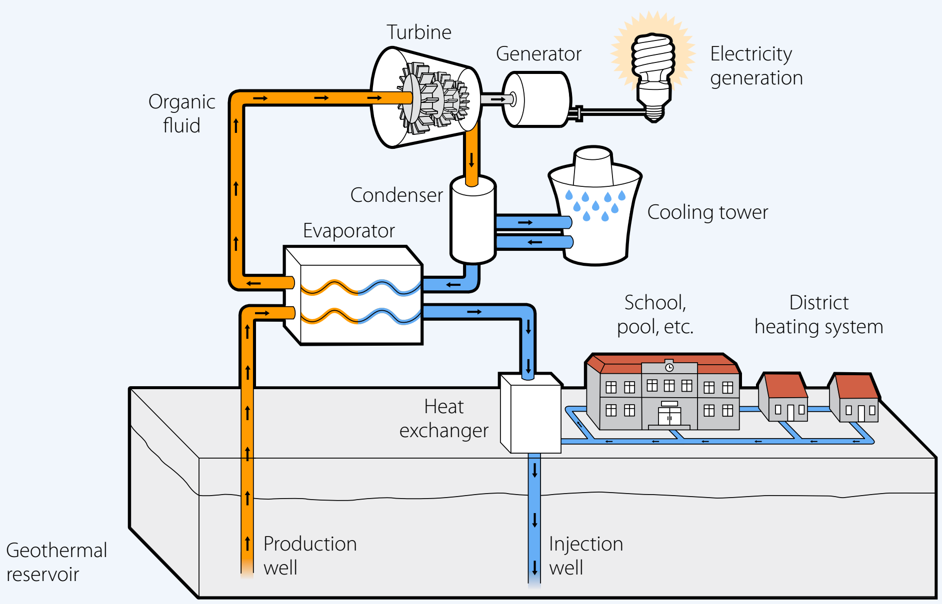
Flash steam power plants

The geothermal fluid is high-pressure wet steam (a mix of water and steam) at a temperature above 180°C. The dry saturated steam, separated from the wet steam in one or two flash tanks, drives the turbine of a Rankine cycle power plant.

HYDROTHERMAL POWER PLANTS



EGS POWER PLANTS



Hydrothermal power plants

The geothermal fluid is high-pressure water at 125°C to 180°C. To efficiently convert in electricity the heat recovered from water at such temperatures, a binary cycle power plant is required.

EGS power plants[1]

The geothermal fluid is a liquid heated by contact with hot rocks at temperatures exceeding 150°C. Extracting thermal energy from the hot rocks requires hydraulic fracturing, i.e., creating cracks in the rock by injecting high-pressure water, allowing the fluid to circulate through the geothermal reservoir. Part of the geothermal fluid can be tapped off as a direct heat source for urban or industrial geothermal heating systems.

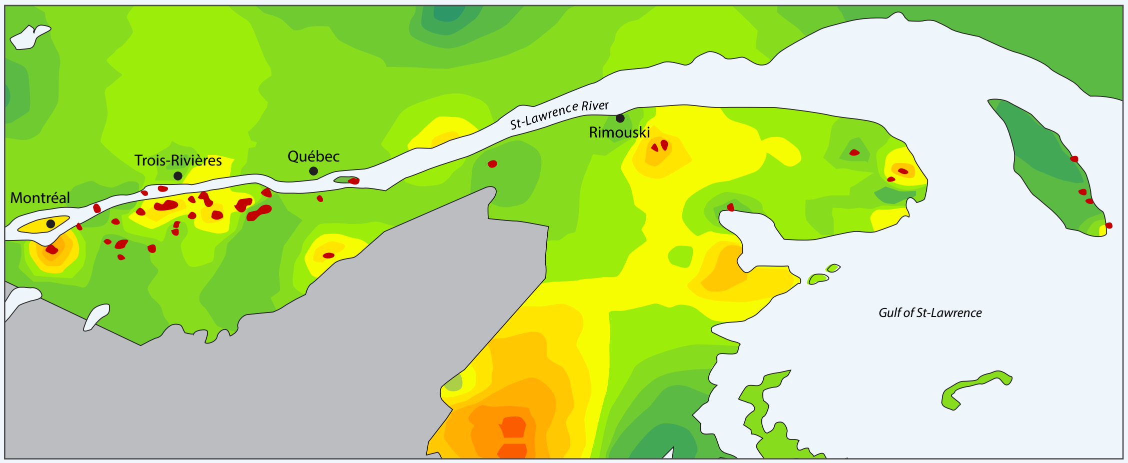
Technical challenges

The numerous long-term technical challenges ahead include developing efficient advanced prospecting methods, controlling from the surface the formation and operation of deep geothermal reservoirs, and improving heat-to-electricity conversion through new thermodynamic cycles and new heat transfer fluids, e.g., CO_2 or N_2. Adequate investment must be made in R&D and diversified financing models must be devised to minimize risk.

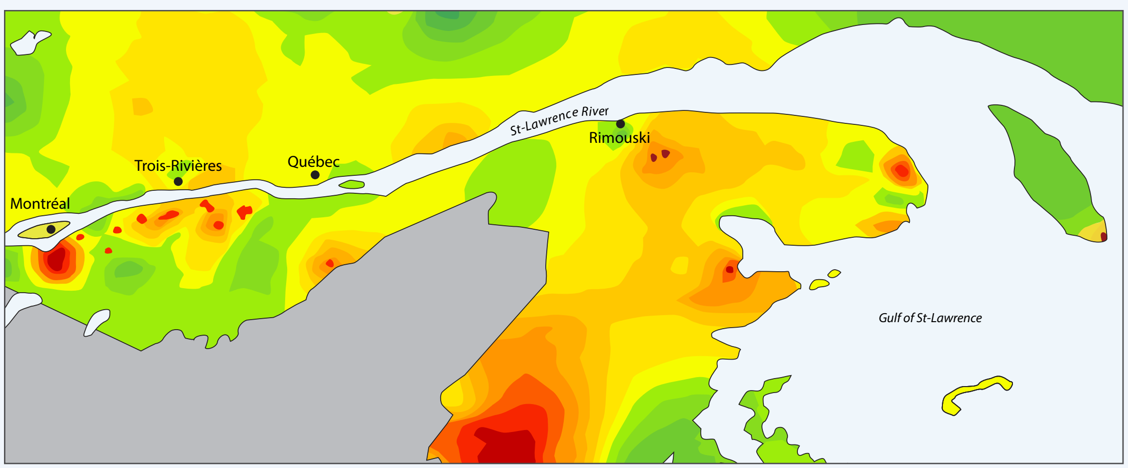
1. EGS stands for "enhanced geothermal system", sometimes called "engineered geothermal system" (in French "système géothermique stimulé" or "SGS").

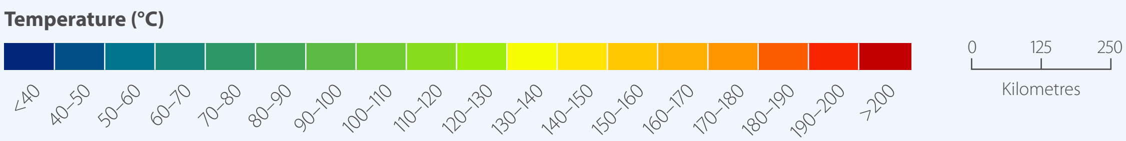
Geothermal potential in Québec

RESERVOIR TEMPERATURE AT DEPTH OF 6 KM



RESERVOIR TEMPERATURE AT DEPTH OF 7 KM





Power cycles

Rankine cycle

The Rankine cycle uses as a working fluid dry steam at over 180°C from a geothermal reservoir or separated from wet steam using a single- or double-flash system.

Binary cycless

- **Organic Rankine cycle**
  The organic Rankine cycle, a variant of the Rankine cycle, uses as a working fluid an organic fluid, e.g. hydrofluoro-carbon, with a low boiling point. The latter is vaporized by the heat coming from water of the geothermal reservoir at a temperature below 180°C.

- **Kalina cycle**
  Similar to the organic Rankine cycle, the Kalina cycle uses as a working fluid a mixture of two fluids, e.g., ammonia and water. As a result, the evaporation and condensation processes occur at variable temperatures, increasing the heat-to-electricity conversion efficiency compared to the conventional and organic Rankine cycles.

Climate change and air quality

For the deep geothermal option, greenhouse gas (GHG) emissions and air pollutants, associated with compounds contained in geothermal fluids, depend on natural conditions at the production site. CO_2 and H_2S are the prevalent gases emitted. If H_2S is present, a scrubber is normally used to minimize the amount released. Usually GHG emissions are very low. In rare cases, they are as high as those of thermal power plants fired by fossil fuels. Deep geothermal power plants do not generate emissions once in operation.

Life cycle assessment

The main environmental impacts of the deep geothermal option (binary cycle EGS power plants) are similar to those of other renewable energy options when viewed from a life cycle standpoint. Materials used, equipment manufacturing and transportation are the top-ranking factors in the life cycle analysis, as well as the type of machinery used for drilling, and the number and depth of production and injection wells drilled.

The operating conditions of deep geothermal power plants, on the other hand, vary considerably from plant to plant making it difficult to generalize. In rare cases, their climate change indicator results may be similar to those of thermal power plants fired by fossil fuels.

Ecosystems and biodiversity

Endemic species live in certain exploration sites. The impact on such species must be assessed prior to implementing a deep geothermal project.

Chemicals are added to the water injected into wells, which circulates in a closed loop, limiting potential contamination of ecosystems. 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 environmental impacts, the power plant design should incorporate site characteristics and consider the animal species living there.

Health and quality of life

Noise from an operating deep geothermal power plant is similar to that from other types of power plants. The most noise is generated at the production and injection well drilling stage. Mitigation measures can be implemented, if needed.

Easily spotted by its plume of steam, a geothermal power plant indisputably has a visual impact on the landscape. The color of its surface plant must match that of the environment in order for it to blend into its surroundings.

Well drilling and hydraulic fracturing require quantities of water that vary from site to site. The impact becomes substantial in regions with scant water resources.

Land use

With most of its equipment underground, a deep geothermal power plant has a small surface footprint compared to other types of power plants. The ponds built to collect wastewater may occupy more area. Surface facilities do not preclude nearby farming. The cooling towers do not consume water but do occupy a considerable area.

At some sites, land subsidence has occurred when water was been removed at a rate exceeding that at which it is naturally replenished. Today, new production sites are better evaluated and injecting geothermal water back into the system has become a routine practice to prevent subsidence.

Hydraulic fracturing can induce greater seismicity, imperceptible microseisms measuring less than 3 on the Richter scale. This phenomenon is sometimes observed during hydraulic fracturing to facilitate oil or natural gas extraction. For geothermal power plants located in seismic zones, it may be difficult to distinguish between induced and natural seismic events.

Regional economy

In the past, operating geothermal power plants has led in some locations to the destruction of such natural phenomena as geysers, hot springs and mud pools, probably to the detriment of local tourism. Today, comprehensive studies for new projects propose solutions to negate this environmental impact.

Multipurpose use of production sites could improve the regional economy. In certain projects, instead of injecting geothermal water back into the reservoir, it could 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 could prompt the development of other industries, such as greenhouse farming.

Social acceptability

For any electricity generation project, the public must be consulted. Multipurpose use (tourism, farming, etc.) of geothermal production sites could help make projects socially acceptable.

Based on a 2013 Léger Marketing survey, most Quebecers have a favorable view of deep geothermal energy as a renewable energy option.

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