Geothermal Energy

Lecture 1

Source: https://archive.epa.gov/climatechange/kids/solutions/technologies/geothermal.html

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Geothermal Energy

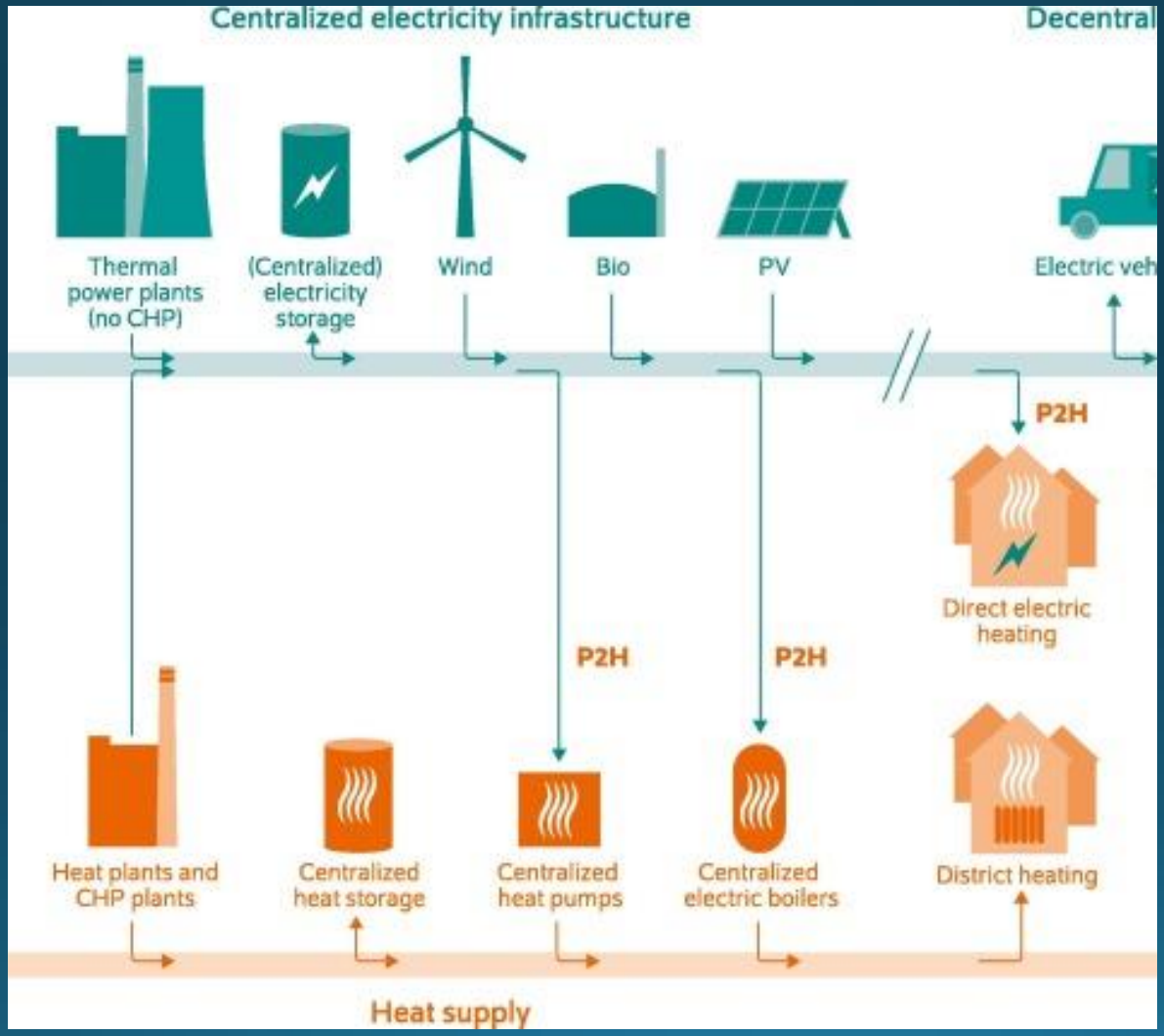
Geothermal energy is **heat within the earth**. The word geothermal comes from the Greek words geo (earth) and thermal (heat).

Geothermal energy is a renewable energy source because heat is continuously produced inside the earth. It is being used for DHW, to heat buildings, and to generate electricity.

Source: https://www.open.edu/openlearn/nature-environment/environmental-studies/understanding-deep-geothermal-energy/content-section-0?active-tab=description-tab

Geothermal Energy

Output:
Electricity
&
heat energy



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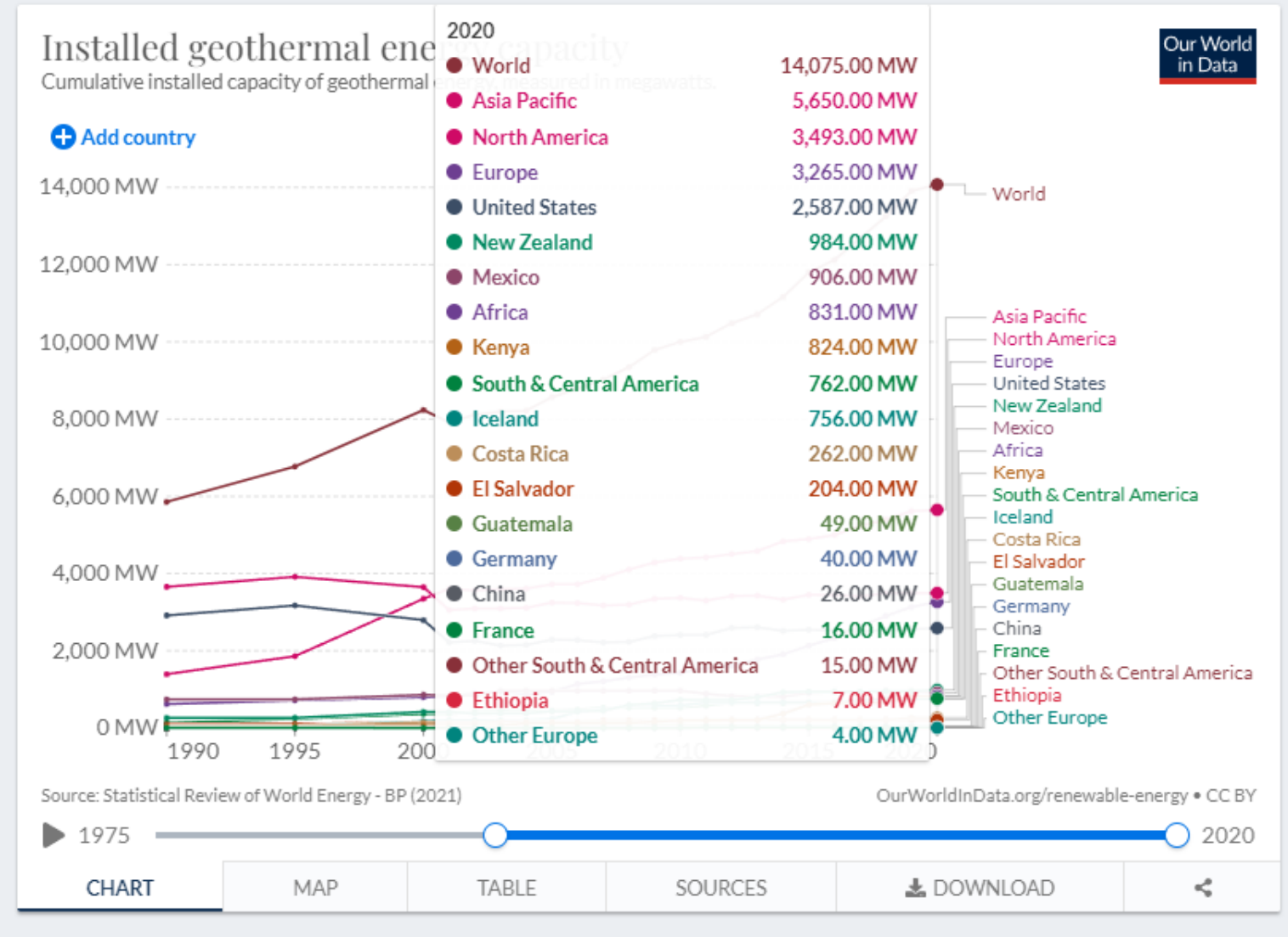
Geothermal Energy

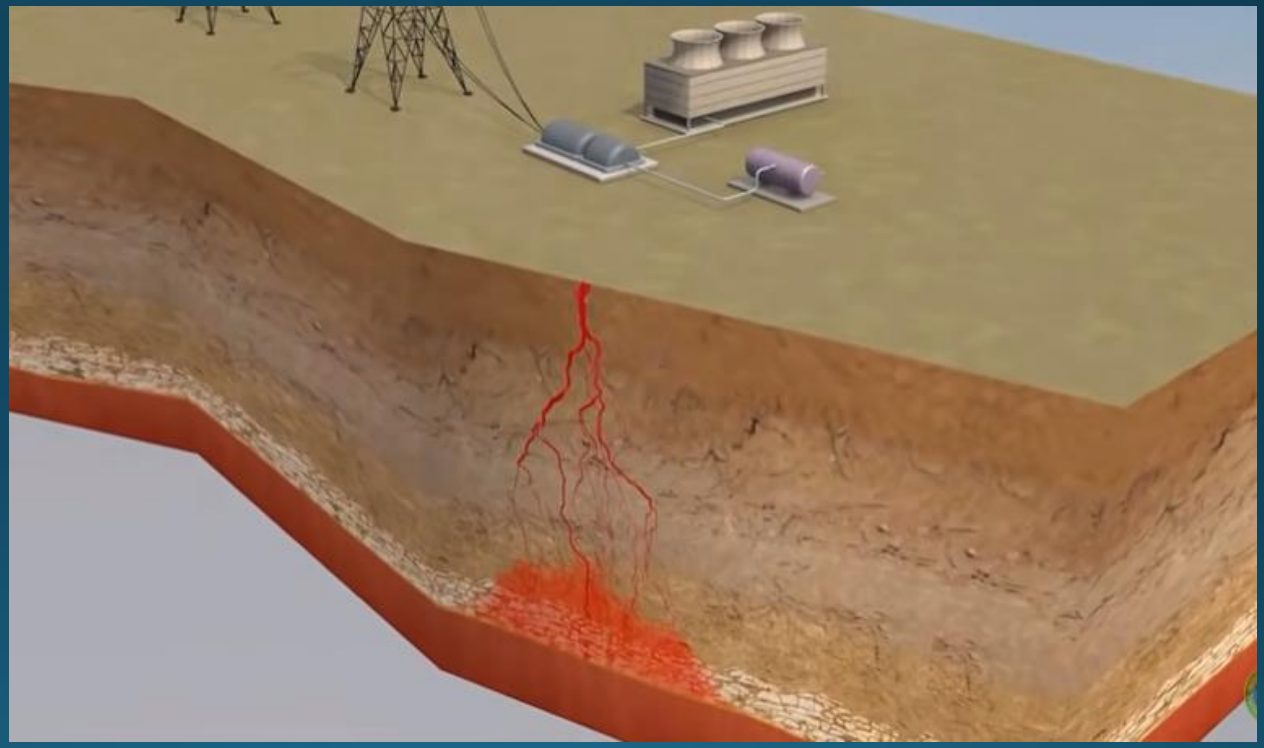


Source: https://ourworldindata.org/renewable-energy

Geothermal Energy

Heat from the Earth's Crust warms water that has seeped into underground reservoirs.

When water becomes hot enough it can break through the Earth's surface as steam or hot water.

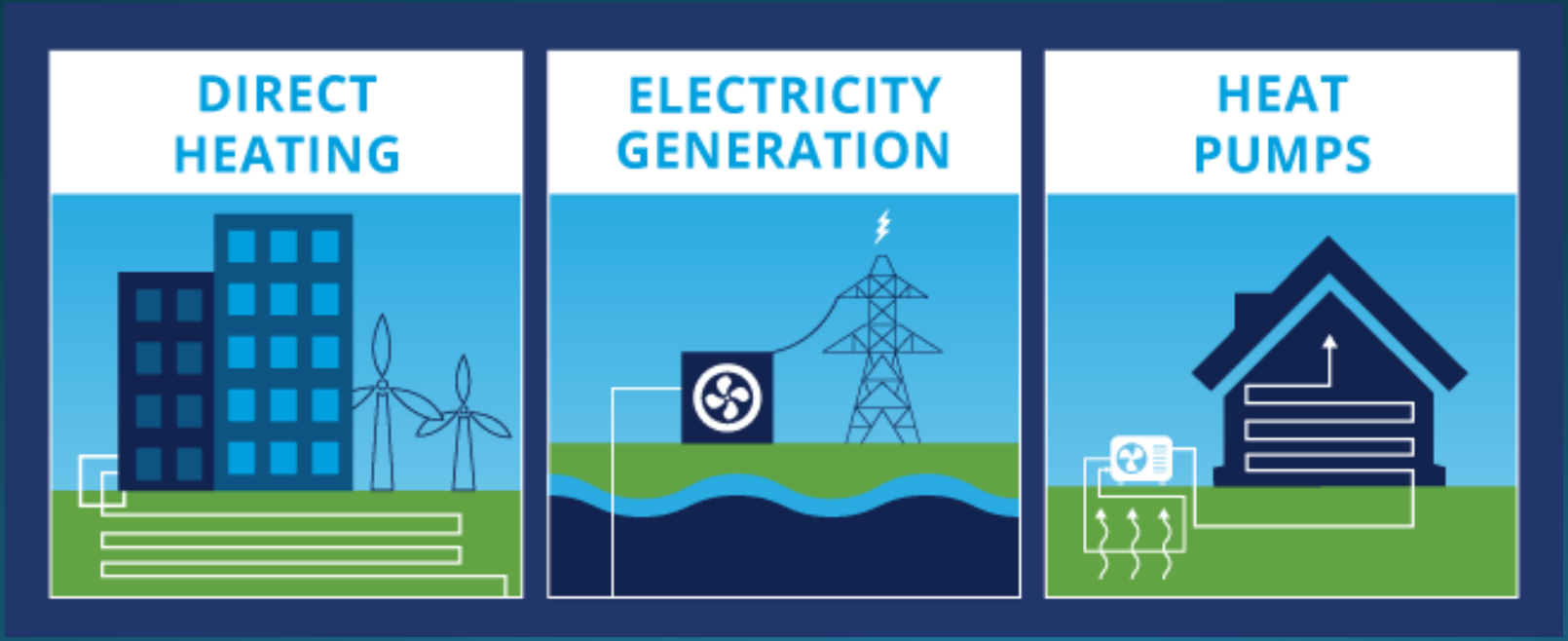


Source: https://www.energy.gov/eere/videos/energy-101-geothermal-energy

Geothermal Energy

Direct use of Geothermal Heat

This is an easy alternative to access hot water, but it applies to the areas where hot springs and underground reservoirs are nearest. A production facility, a downhole, and circulation pumps or wells are used to bring up the water.

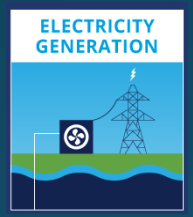


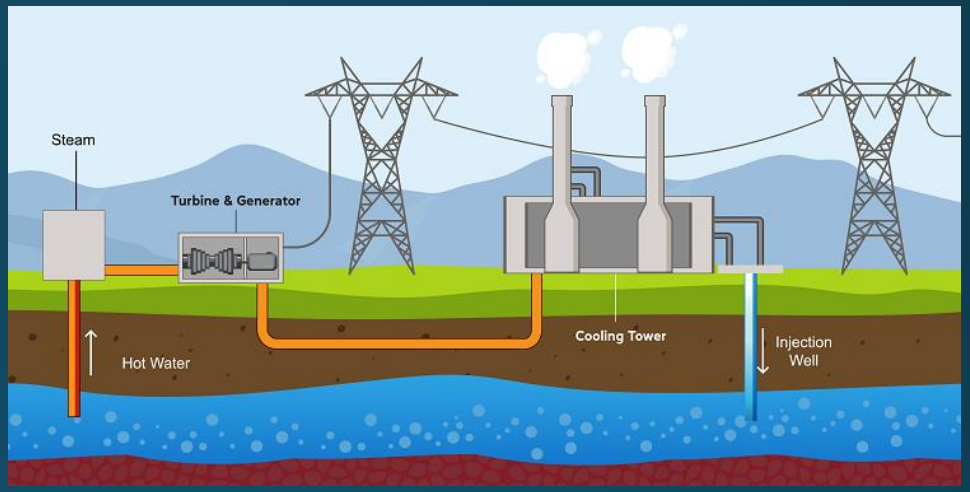
Source: EnergySage

Geothermal Energy

- **Geothermal power plants**

(which use heat from deep inside the Earth to generate steam to make electricity.)

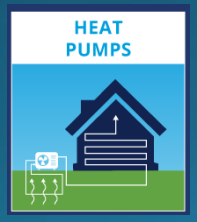


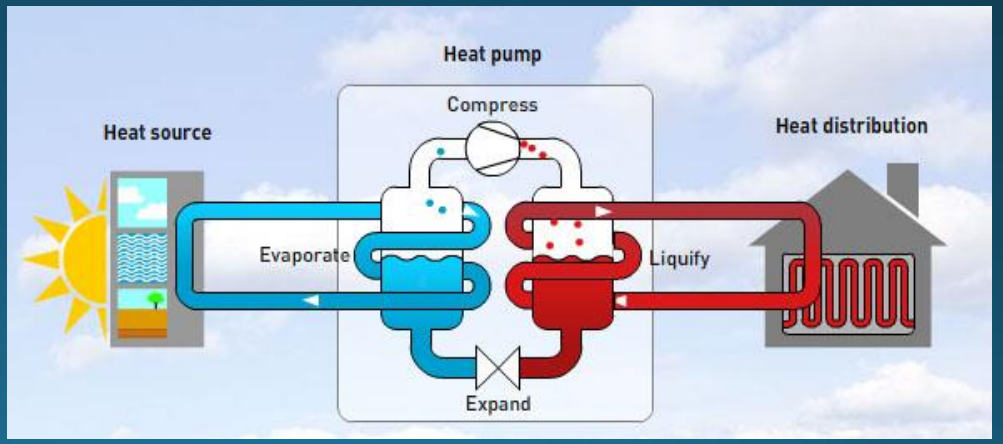


Source: https://greenesa.com/blog/geothermal-energy-types-uses-advantages

- **Geothermal heat pumps**

(which tap into heat close to the Earth's surface to heat water or provide heat for buildings.)

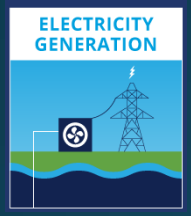


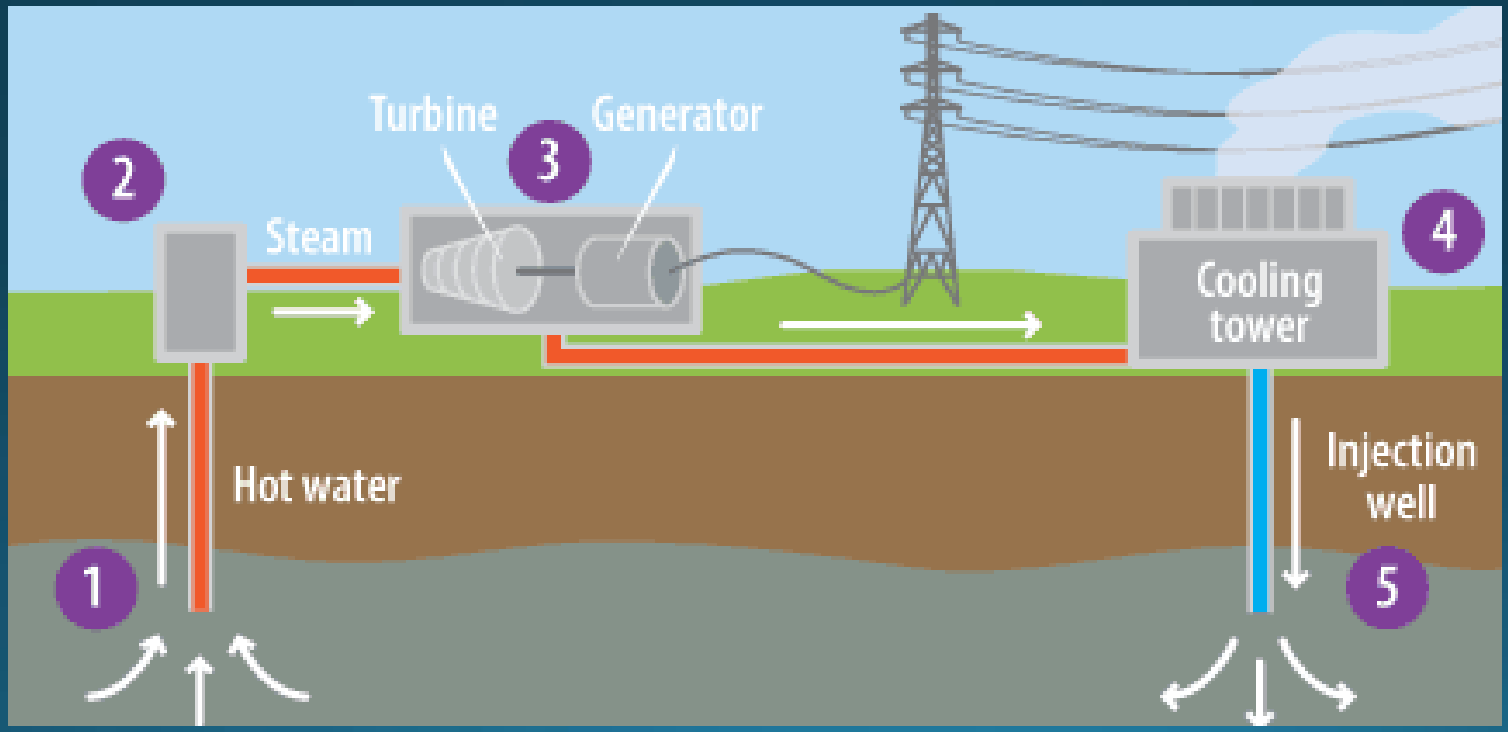


Source: http://eu-gugle.eu/heat-pumps-a-versatile-solution-for-low-carbon-cities/

Geothermal power plants

1. Hot water is pumped from deep underground through a well under high pressure.
2. When the water reaches the surface, the pressure is dropped, which causes the water to turn into steam.
3. The steam spins a turbine, which is connected to a generator that produces electricity.
4. The steam cools off in a cooling tower and condenses back to water.
5. The cooled water is pumped back into the Earth to begin the process again.

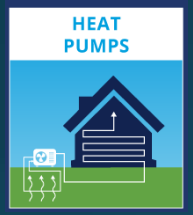


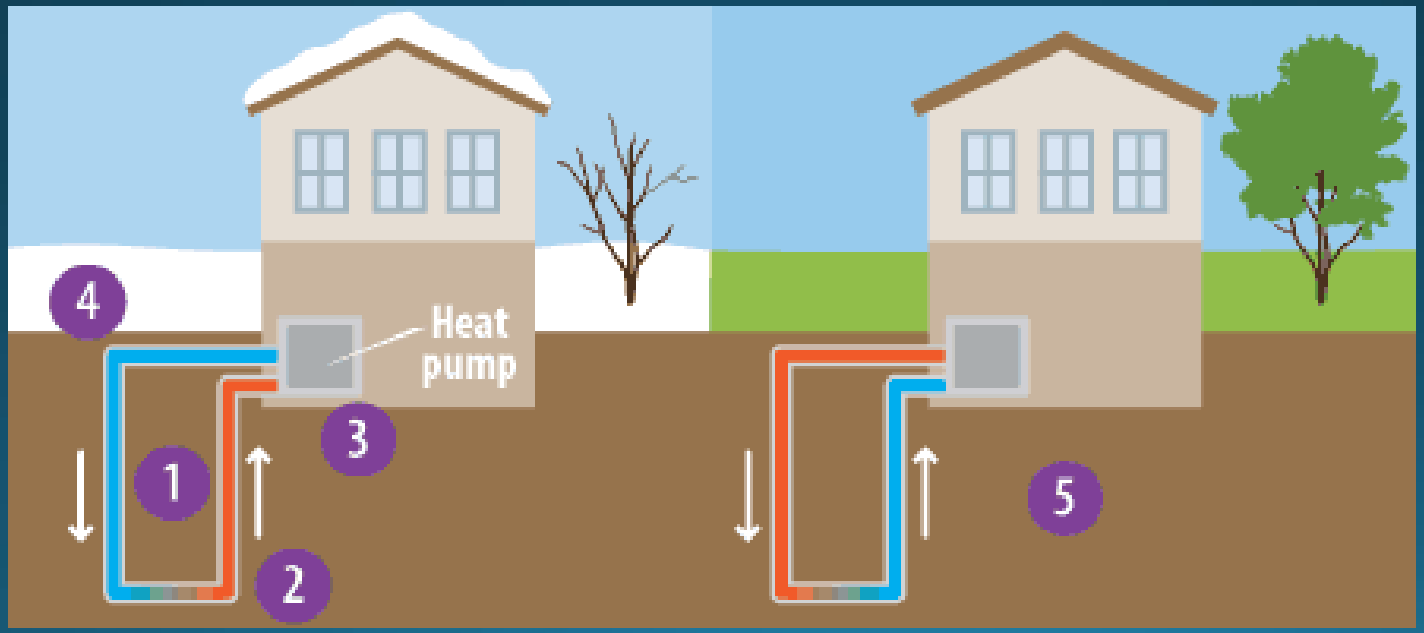


Source: https://archive.epa.gov/climatechange/kids/solutions/technologies/geothermal.html

Geothermal heat pumps

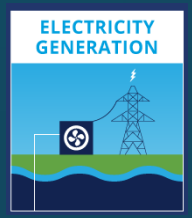
1. Water or a refrigerant moves through a loop of pipes.
2. When the weather is cold, the water or refrigerant heats up as it travels through the part of the loop that's buried underground.
3. Once it gets back above ground, the warmed water or refrigerant transfers heat into the building.
4. The water or refrigerant cools down after its heat is transferred. It is pumped back underground where it heats up once more, starting the process again.
5. On a hot day, the system can run in reverse. The water or refrigerant cools the building and then is pumped underground where extra heat is transferred to the ground around the pipes.





Source: https://archive.epa.gov/climatechange/kids/solutions/technologies/geothermal.html

Types of Geothermal power plants



- **Dry Steam Geothermal (DSG).**

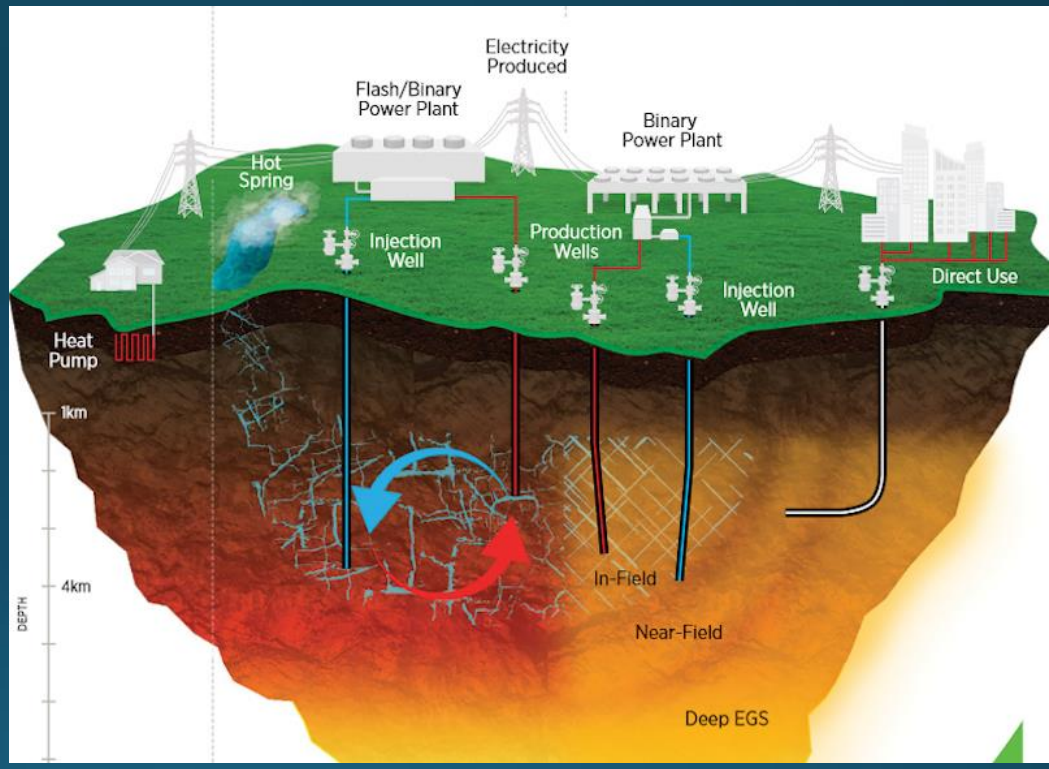
(Dry stream flows directly to a turbine to drive a generator that produces electricity.)

- **Flash Steam Geothermal (FSG).**

(A pump pushes hot fluid into a tank at the surface where it cools. The fluid then quickly turns into vapor which drives a turbine.)

- **Binary Cycle Geothermal (BCG).**

(It uses two types of fluid. Hot fluid from underground, heats a second fluid called a heat transfer fluid in a big heat exchanger. The second fluid – with a much lower boiling point turns into vapor at a lower temperature and spin a turbine.)



Source: https://www.thinkgeoenergy.com/power-energy-electricity-heat-and-geothermal-the-importance-of-the-right-terminology/

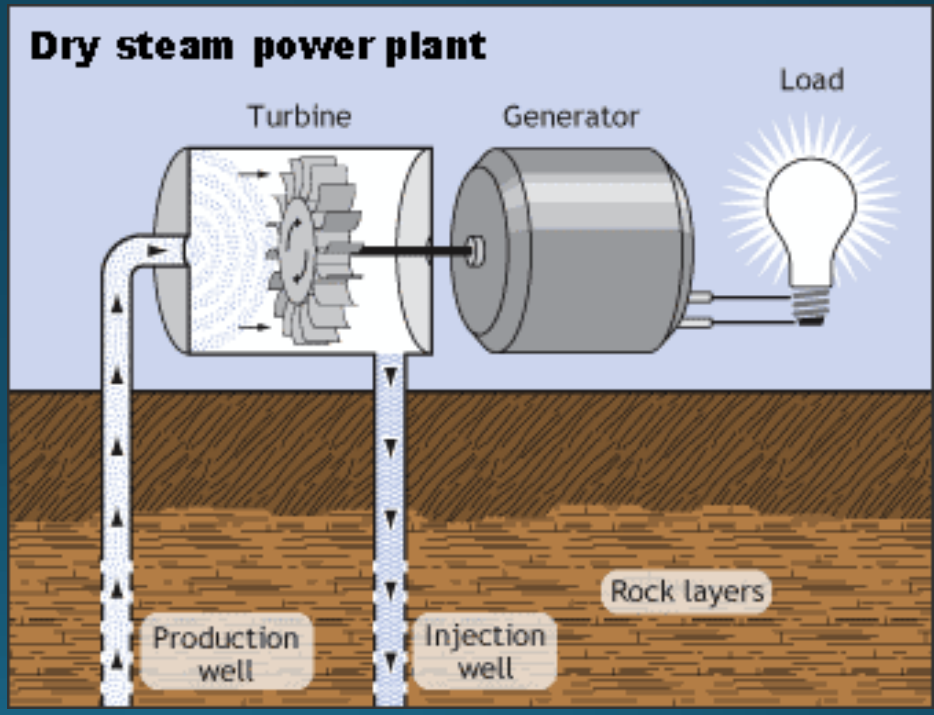
Types of Geothermal power plants

- **Dry Steam Geothermal (DSG).**

These plants use dry steam that is naturally produced in the ground. This steam travels from the production well to the surface and through a turbine, and after transferring its energy to the turbine it condenses and is injected back into the Earth.

These types are the oldest types of geothermal power plants, the first one was built back in 1904 in Italy.

Because this type of power plant requires the highest temperatures they can only be used where the temperature underground is quite high, but this type requires the least fluid flow.



Source: US Department of Energy, Energy Efficiency, and Renewable Energy

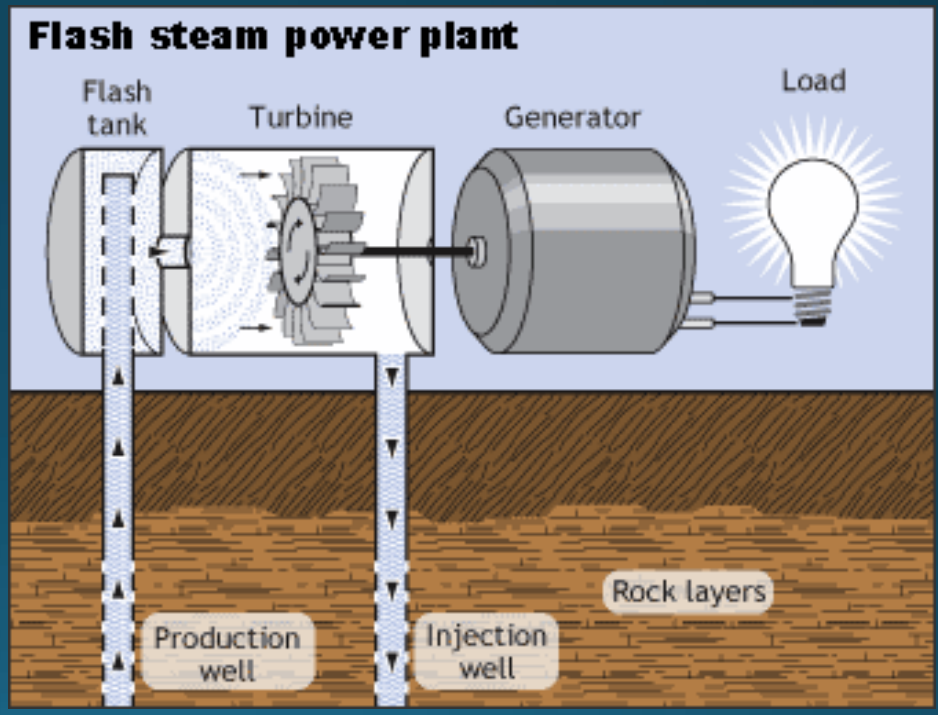
Types of Geothermal power plants

- **Flash Steam Geothermal (FSG).**

These types are the most common due to the lack of naturally occurring high-quality steam. In this method, water must be over 180°C, and under its own pressure it flows upwards through the well.

This is a lower temperature than dry steam plants have. As its pressure decreases, some of the water "flashes" to steam, which is passed through the turbine section.

The remaining water that did not become steam is cycled back down into the well, and can also be used for heating purposes. The cost of these systems is increased due to more complex parts, however they can still compete with conventional power sources.



Source: US Department of Energy, Energy Efficiency, and Renewable Energy

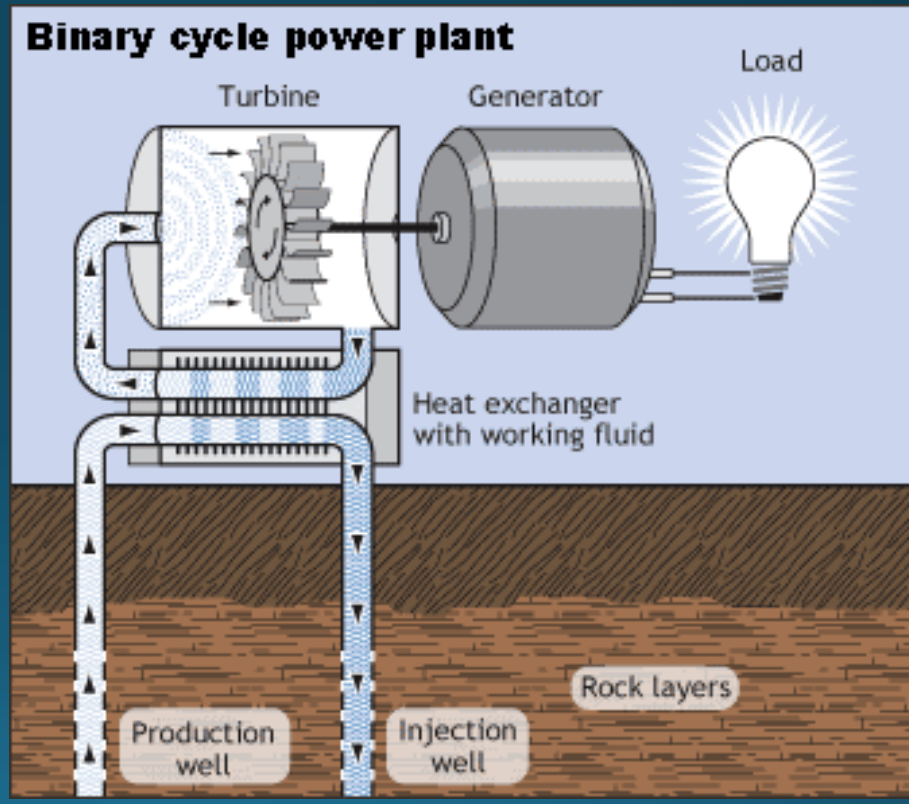
Types of Geothermal power plants

- **Binary Cycle Geothermal (BCG).**

Binary power plants are expected to be the most commonly used type of geothermal power plant in the future, as locations outside of the known hot spots begin to use geothermal energy.

This is because binary cycle plants can make use of lower temperature water (100 - 180°C) than the other two types of plants. They use a secondary loop (hence the name "binary") which contains a fluid with a low boiling point, such as pentane (36°C) or butane (-0.5°C).

The water from the well flows through a heat exchanger which transfers its heat to this fluid, which vaporizes due to its low boiling point. It is then passed through a turbine, accomplishing the same task as steam.

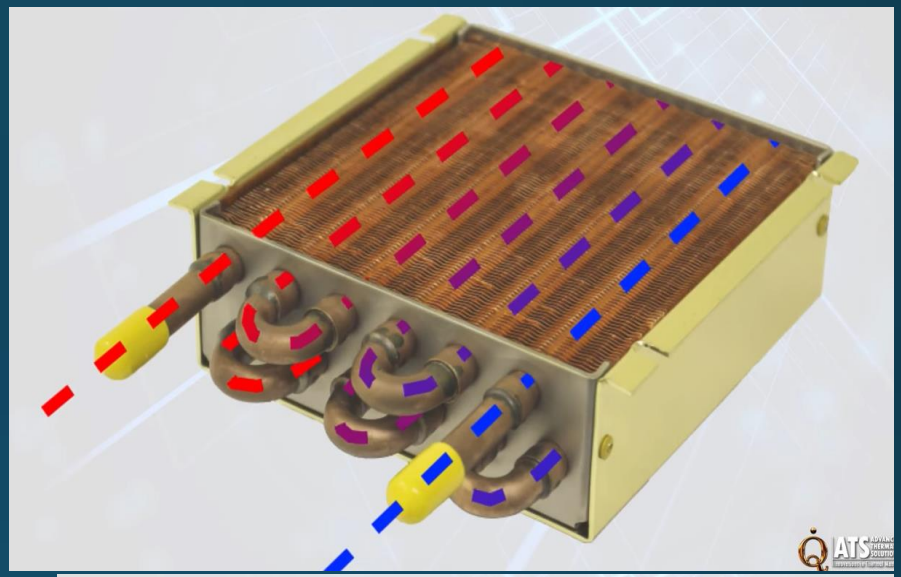


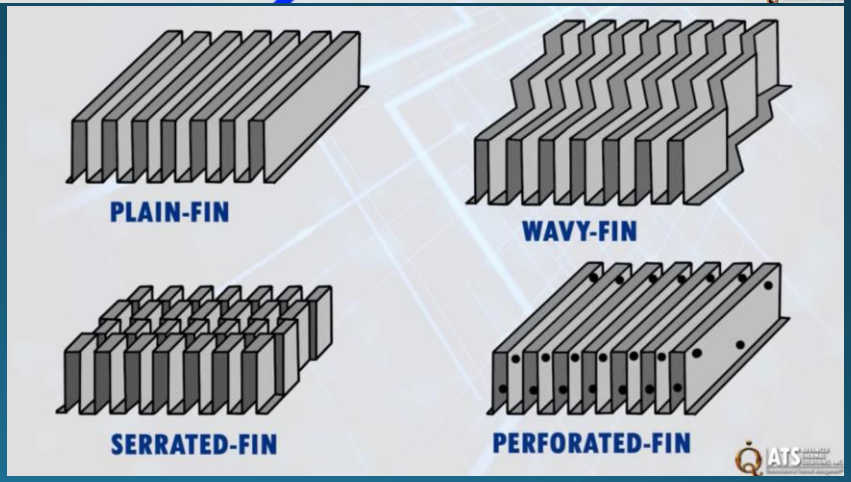
Source: US Department of Energy, Energy Efficiency, and Renewable Energy

Heat exchanger

A heat exchanger is a system used to transfer heat between two or more fluids (liquid or gas). Heat exchangers are used in both cooling and heating processes.

Heat exchangers are systems that use a fluid to absorb heat from a hotter outside source without the fluid and hot source mixing together.
Therefore, the fluid that entered hot, leaves cold and the initially cold fluid leaves hot.
The two fluids do not mix or come into direct contact.





Source: https://www.qats.com

Types of Geothermal power plants (new)

- **Enhanced Geothermal System (EGS).**

A geothermal resource requires fluid, heat and permeability in order to generate electricity:

Fluid—Sufficient fluid must exist naturally or be pumped into the reservoir.
Heat—The earth's temperature naturally increases with depth and varies based on geographic location.
Permeability—In order to access heat, the fluid must come into contact with the heated rock, either via natural fractures or through stimulating the rock.

Conventional hydrothermal resources contain all three elements naturally. Increasingly, however, geothermal systems where subsurface fluid and permeability are lacking are being engineered or enhanced to access the earth's heat by adding fluid to these hot subsurface resources.

This technology is expected to be a game-changer in the geothermal sector, tapping 100+ gigawatts of geothermal energy, roughly ten percent of domestic energy demand.

Source: https://www.energy.gov/eere/geothermal/electricity-generation

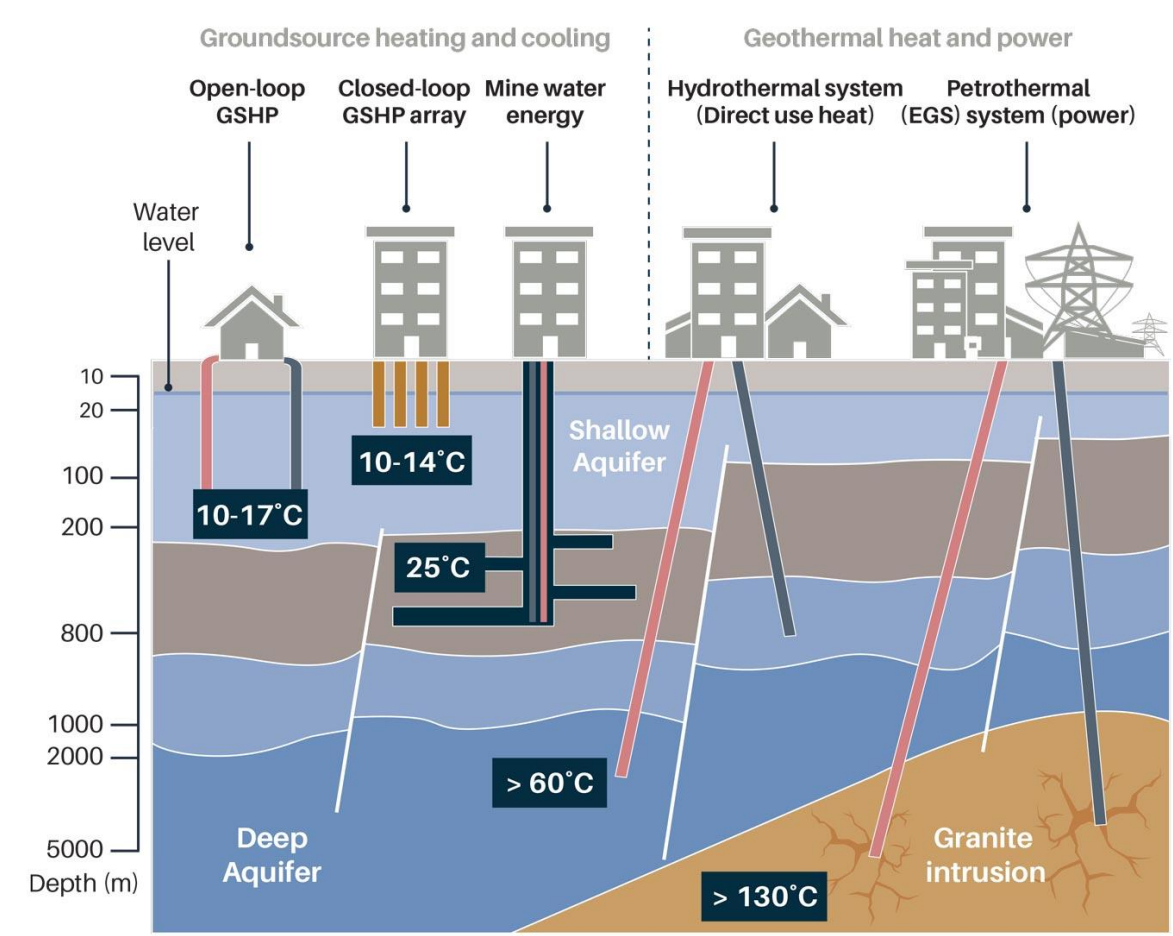
Deep and shallow geothermal energy

The terms “shallow” and “deep” refer to the depth of the heat absorber, which can harvest heat either from subsurface water with an open loop system or from the solid ground with a closed loop system.

The depth separation is regulated by the Mining Act requiring a permit for drillings (mostly between 100 and 400 meters below surface).

The Mining Act influences the drilling market and the depth range. For depth levels up to around 150 meters, a large market exists offering low drilling costs, which makes shallow geothermal energy affordable to private households as well.

In contrast, deep geothermal energy requires long term planning and high investments with regard to drilling costs.



Source: https://www.bgs.ac.uk/geology-projects/geothermal-energy/

Deep and shallow geothermal energy

Characteristic	Shallow Geothermal	Deep Geothermal
Depth range	No permission for drilling, standard drilling range up to around 150 meters	Permission for drilling required, drilling depths >150 meters to 5.000 meters
Temperature level	0 °C to <30 °C	30 °C to 200 °C
Thermal capacities	<10 kW to <5 MW	1 MW to >50 MW
Electricity production	No electricity production possible	Binary circle: 90 °C – 200 °C Direct use: >200 °C
Cooling	Free cooling	Forced cooling
Heat supply	Individual building, heating and cooling networks	Industrial heat, heating networks

Source: https://geoera.eu/blog/muse-differences-between-deep-and-shallow-geothermal-energy/

Geothermal power plants
Practicalities

The most common problems:

- Scaling (in production, wells, piping, reinjection, turbines)
- Corrosion (in production wells)
- Mineral scaling problems (Chemical inhibitors and mechanical cleaning are the most common methods to overcome the mineral scaling problems)
- Major maintenance activities (quantity of steam, geochemistry of the reservoir fluid, chemical traces)
- Silica sinter problem (controlled by pressure and temperature adjustments)
- Well production decline rate (3–4% per year)
- Reserve well and “make-up” wells to maintain steam supply
- Life time analysis of the equipment every …. years due to all the above)

Geothermal power plants Practicalities

Parameters of the field & calculation of number of wells required as production wells in the beginning of the project

No.	Parameter	Value	Simbol
1	Plant Capacity	55	MWe
2	Lifetime project	30	year
3	Turbin Input Pressure	6.5	bar
4	Turbin Efficiency	85%	Ƞt
5	Steam flow rate	371	ton/h
6	Specific steam consumption	6.7	ton/h/MW
7	Average well production rate	20	kg/s
8	Steam fraction in well	90%	
9	Steam flow rate from a well	18	kg/s
10	Total mass flow rate (required)	114.6	kg/s
11	Well drilling success ratio	80%	
12	Average well capacity	9.6	MW
13	Required production wells	8	unit
14	Excess Steam	10%	
15	Minimum Steam Supply	60.5	MW
16	Decline Rate	3%	Per Year
17	Average Production Capacity	9.6	MW/well

Source: https://www.researchgate.net/publication/322374944_Make-up_wells_drilling_cost_in_financial_model_for_a_geothermal_project

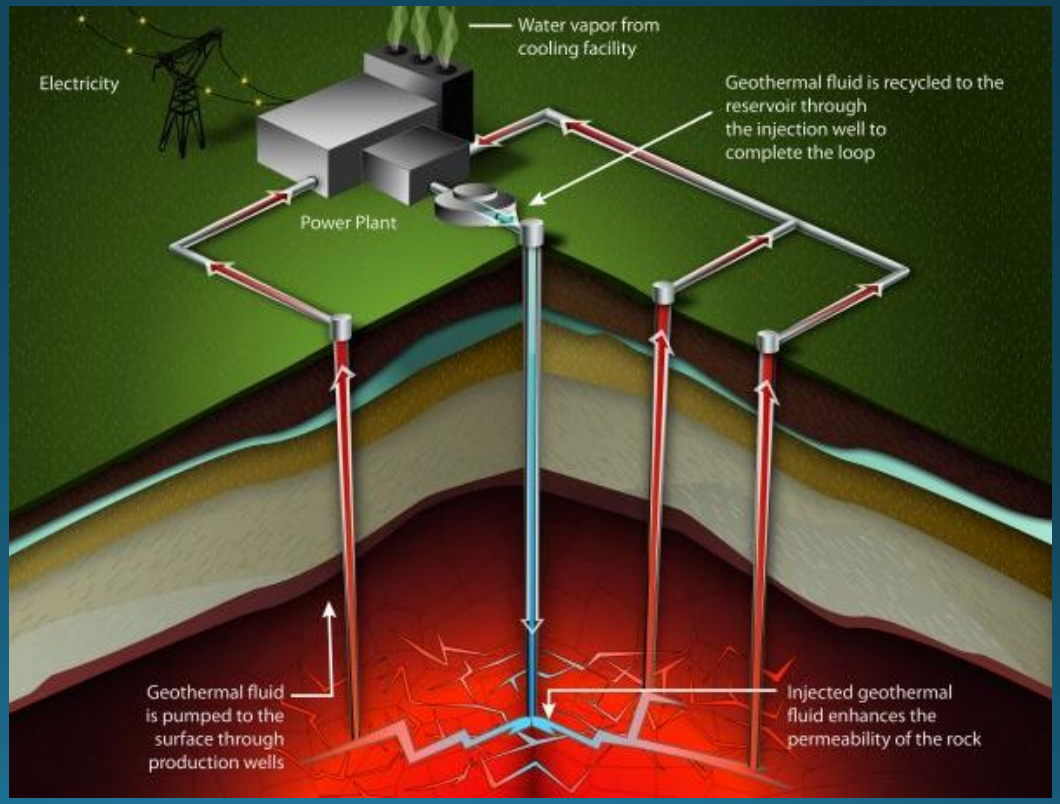
Geothermal power plants Practicalities

After commissioning of a geothermal power plant, geothermal reservoir will encounter pressure decline, which will affect wells productivity.
Therefore, further drilling is carried out to enhance steam production.
Make-up wells are production wells drilled inside an already confirmed reservoir to maintain steam production in a certain level.

Geothermal power cost consists of three components:

- Capital cost,
- O&M cost,
- Make-up drilling cost.

The make-up drilling cost component is a major part of power cost which will give big influence in a whole economical value of the project.



Source: https://www.energy.gov/eere/articles/geothermal-energy-glance-back-and-leap-forward

Geothermal power plants Practicalities

Make-up drilling cost

Table 3. Resume of financial model for all scenario

Resume	Drilling Time		Total Make-Up Wells Cost (USD Million)	NPV (USD Million)	IRR (%)	Payback Period (Year)
Strategy 1	4 Wells	2029	98.32	74	17.5	11
	4 Wells	2046				
Strategy 2	8 Wells	2029	77.98	66	16.5	11
Strategy 3	4 Wells	2029	87.68	72	17.4	11
	4 Wells	2038				
Strategy 4	3 Wells	2029	69.55	77	17.8	11

APPENDIX B. Calculation of required time, which is anticipated that additional make-up wells drilling is required and make-up well (Scenario 2)

Production Year	Well Capacity (MW)	Required (MW)	Available before make up (MW)	Additional Make-up Wells	Available After Make-up (MW)	Make Up Well Cost (USD)
2021	55	60.5	76.82	0	76.82	0
2022	55	60.5	74.51	0	74.51	0
2023	55	60.5	72.28	0	72.28	0
2024	55	60.5	70.11	0	70.11	0
2025	55	60.5	68.01	0	68.01	0
2026	55	60.5	65.97	0	65.97	0
2027	55	60.5	63.99	0	63.99	0
2028	55	60.5	62.07	0	62.07	0
2029	55	60.5	60.21	8	137.02	77,977,785
2030	55	60.5	132.91	0	132.91	0
2031	55	60.5	128.93	0	128.93	0
2032	55	60.5	125.06	0	125.06	0
2033	55	60.5	121.31	0	121.31	0
2034	55	60.5	117.67	0	117.67	0
2035	55	60.5	114.14	0	114.14	0
2036	55	60.5	110.71	0	110.71	0
2037	55	60.5	107.39	0	107.39	0
2038	55	60.5	104.17	0	104.17	0
2039	55	60.5	101.05	0	101.05	0
2040	55	60.5	98.01	0	98.01	0
2041	55	60.5	95.07	0	95.07	0
2042	55	60.5	92.22	0	92.22	0
2043	55	60.5	89.45	0	89.45	0
2044	55	60.5	86.77	0	86.77	0
2045	55	60.5	84.17	0	84.17	0
2046	55	60.5	81.64	0	81.64	0
2047	55	60.5	79.19	0	79.19	0
2048	55	60.5	76.82	0	76.82	0
2049	55	60.5	74.51	0	74.51	0
2050	55	60.5	72.28	0	72.28	0
2051	55	60.5	70.11	0	70.11	0
Total				**8**		**77,977,785**

Source: https://www.researchgate.net/publication/322374944_Make-up_wells_drilling_cost_in_financial_model_for_a_geothermal_project