National Research Council of Italy

Institute of Geosciences and Earth Resources

Geothermal Energy

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Geothermal Energy

1. What is
2. How is used
3. Pros
4. Cons
5. Research frontiers

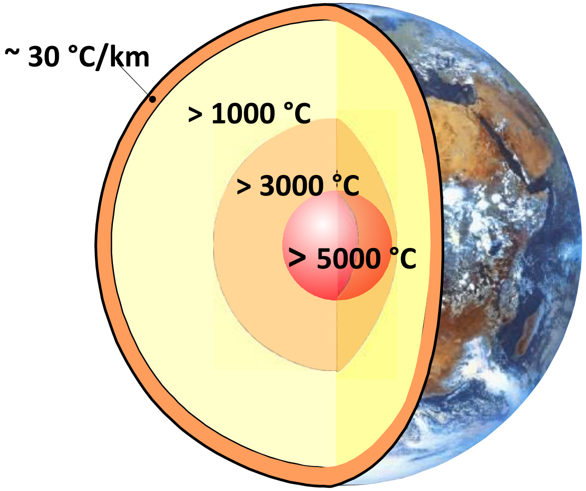
Status and perspectives

1

What is the source of geothermal energy? What part is used?

What is Geothermal Energy

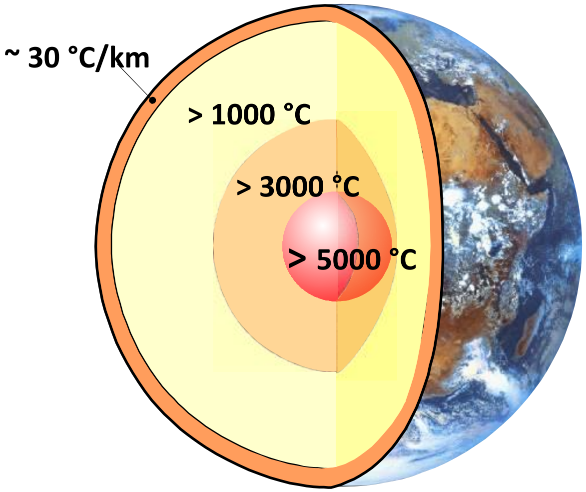
WHAT is Geothermal energy

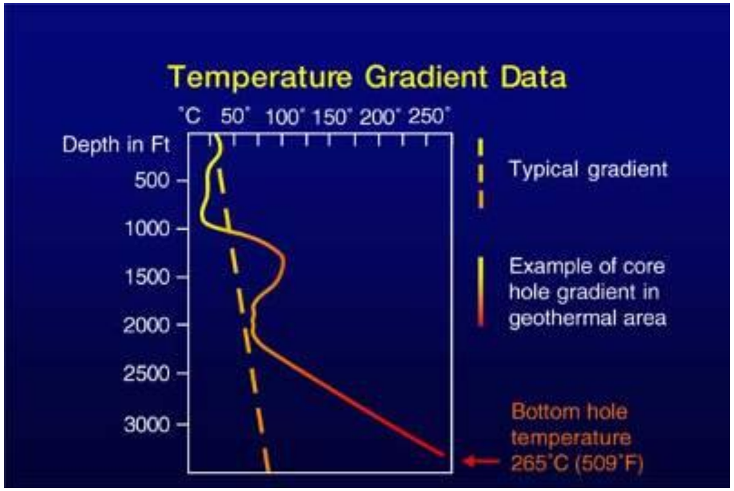


The basis of geothermal energy is the immense heat content of the earth's interior: the Earth is slowly cooling down. Since billions of years the heat in the Earth Crust is constantly supplied by the decay of natural radioactive isotopes or the cooling of hot, shallow magmatic bodies.

The resource is vast and ubiquitous and has a corresponding **large potential for utilization**.

WHAT is Geothermal energy





The resource is vast and ubiquitous and has a corresponding **large potential for utilization**.

However, only a fraction can be used with actual technology, where a carrier (water in the liquid phase or steam) may "transfer" the heat from deep hot zones to or near the surface, thus giving rise to geothermal resources.
Direct heat exchange is limited.

WHAT is Geothermal energy

The temperature increase with depth, as well as volcanoes, geysers, hot springs etc., are in a sense the visible or tangible expression of the heat in the interior of the Earth, but this heat also engenders other phenomena that are less discernable by man, but of such magnitude that the Earth has been compared to an immense "thermal engine”.

WHAT is Geothermal energy

When hot water and steam reach the surface, they can form fumaroles, hot springs, mud pots and other interesting phenomena.

WHAT is Geothermal energy

The Earth's heat flow at the surface is the amount of heat that is released into space from the interior though a unit area in a unit of time. It is measured in milliwatt per square meter (mWm^{-2})
The heat flow is the product of the geothermal gradient and the thermal conductivity of rocks. On average, heat flow is 40-90 mW/m^2

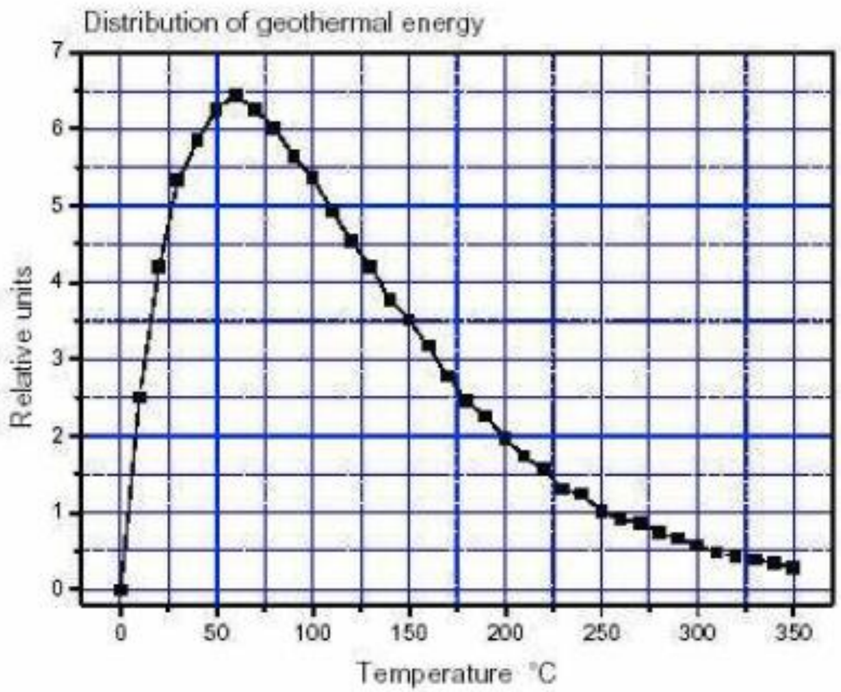
The total global output is over 4×10^{13}W, four times more than the present world energy consumption which is 10^{13}W.

The thermal energy of the Earth is therefore immense, but only a fraction can be utilized by man.

WHAT is Geothermal energy

Only a fraction can be utilized by man, because **this heat is available at a low average temperature.**

So far our utilization of this energy has been limited to areas in which geological conditions permit a carrier (water in the liquid phase or steam) to "transfer" the heat from deep hot zones to or near the surface, thus giving rise to geothermal resources.



WHAT is Geothermal energy

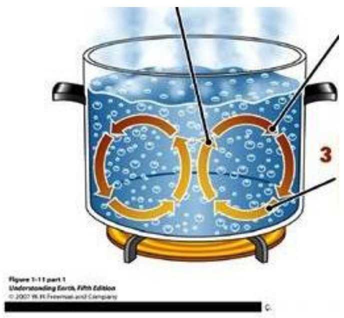
Two forms of heat transfer occur within the Earth:

Conduction

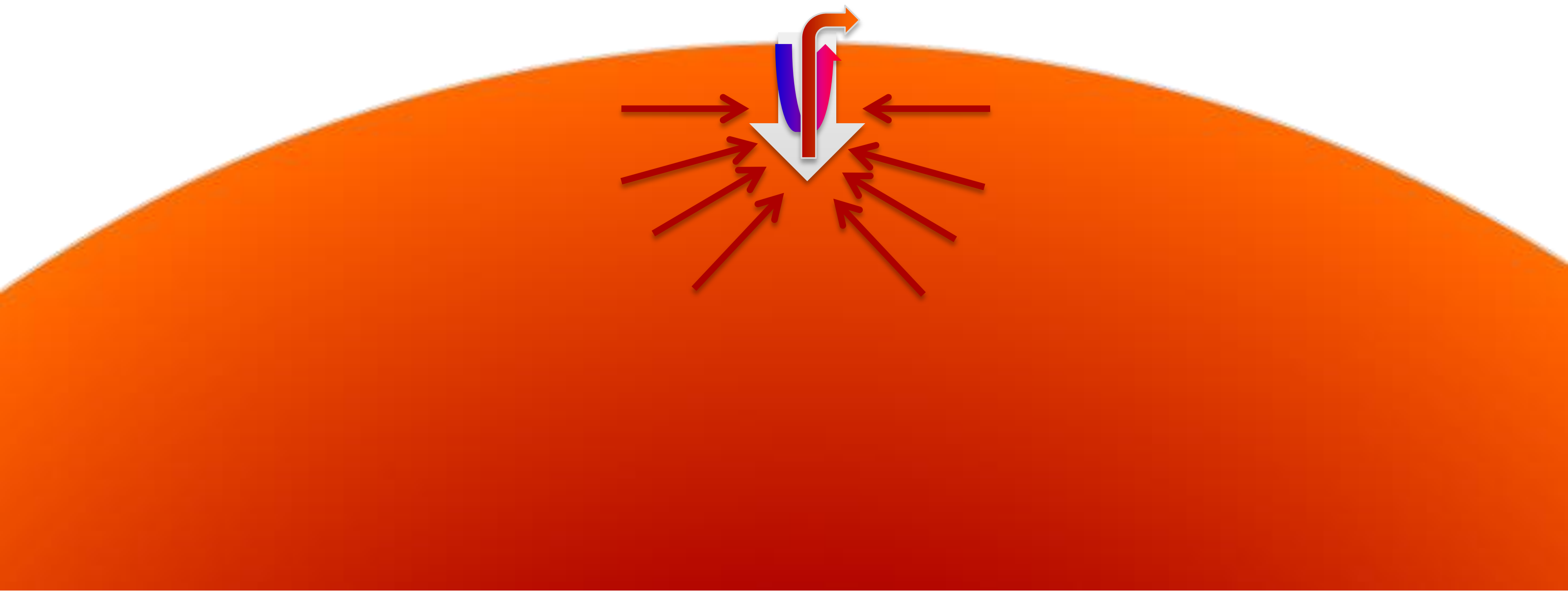
- transfer of random kinetic energy between molecules without transfer of material. Moving molecules strike neighbouring molecules, causing them to vibrate faster and thus transfer heat energy.
- Primary heat transfer mode in solids.

Convection

- Movement of hot fluid (liquid or gas) from one place to another. Because motion of material occurs, it is more efficient than conduction.
- Common heat transfer process in liquids or gases



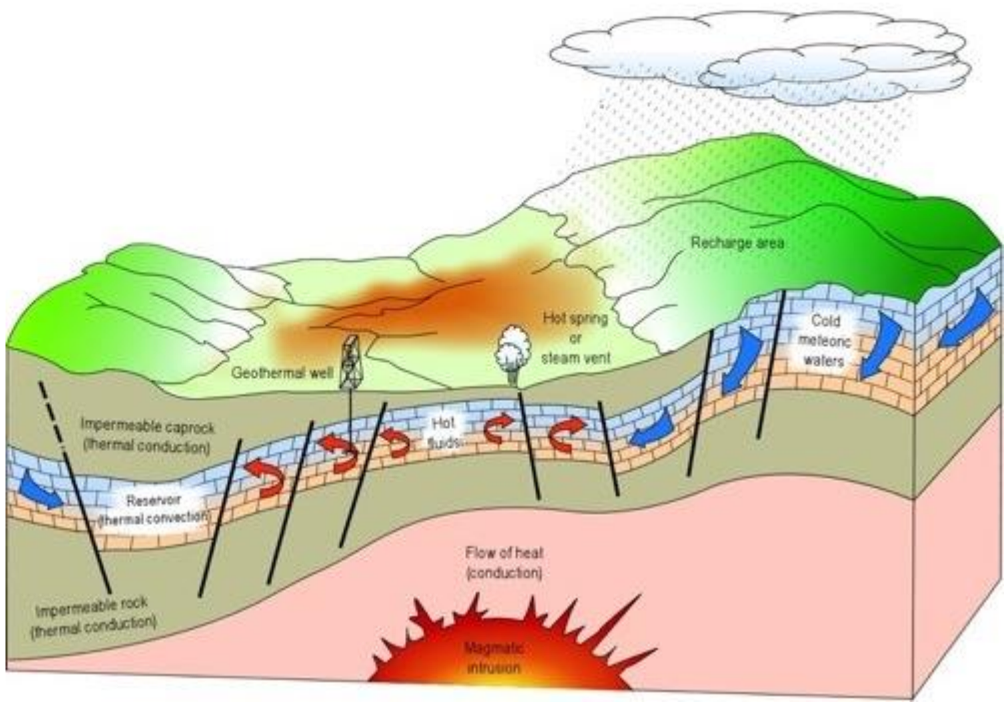
WHAT is Geothermal energy



WHAT is Geothermal energy

A heat source alone is not enough for creating a geothermal resource.

A *geothermal system* can be described schematically as "convecting water in the upper crust of the Earth, which, in a confined space, transfers heat from a heat source to a heat sink, usually the free surface".



WHAT is Geothermal energy

Elements of a hydrothermal geothermal system:

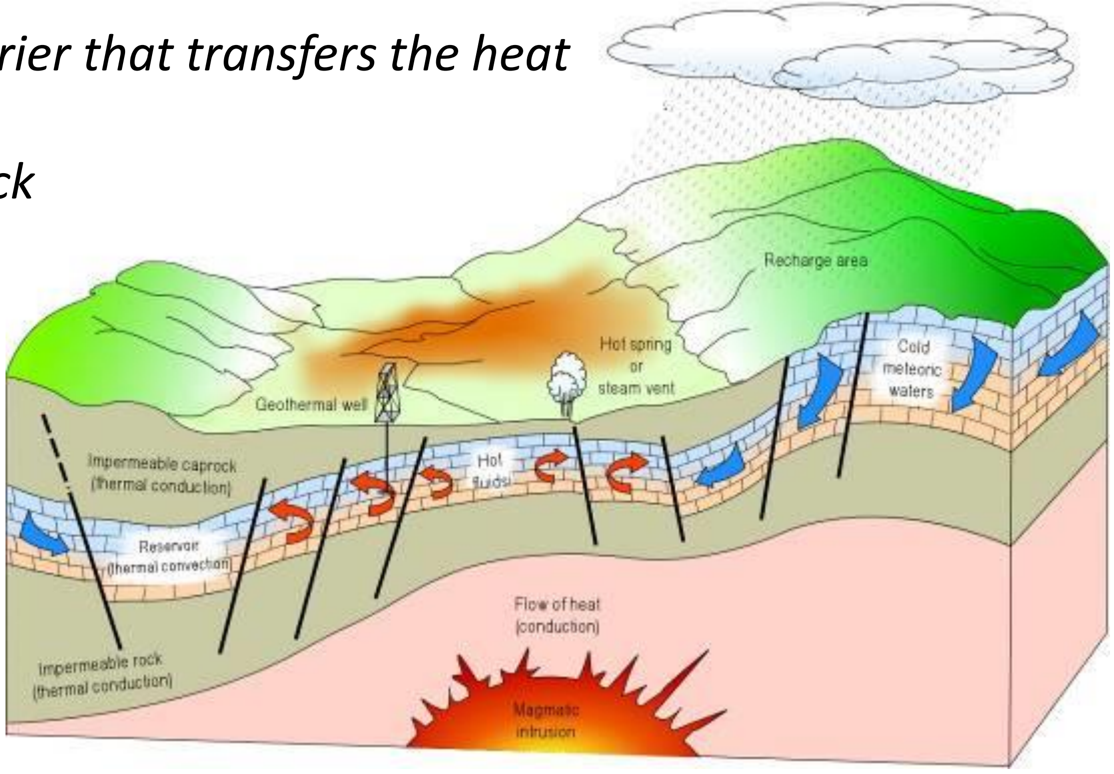
a heat source

a reservoir

a fluid, which is the carrier that transfers the heat

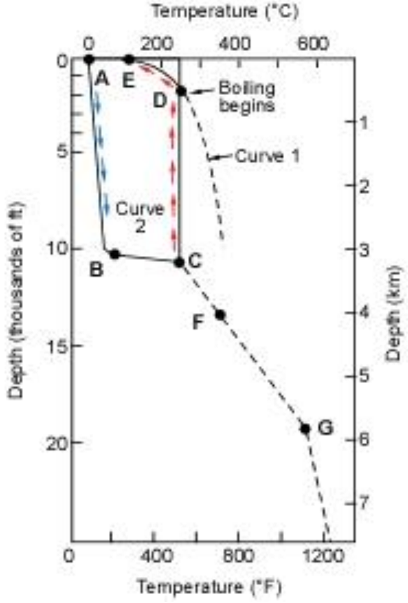
a recharge area

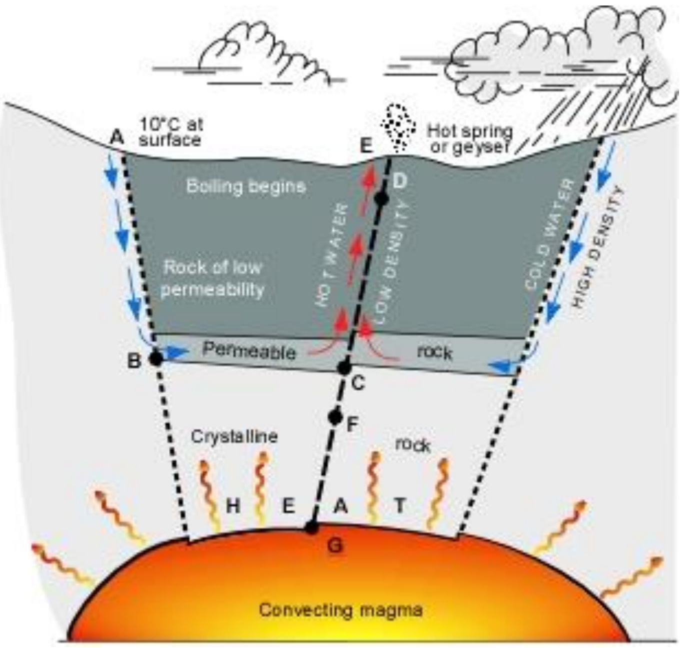
an impermeable caprock



WHAT is Geothermal energy

The mechanism underlying geothermal systems is by and large governed by *fluid convection*.
Convection occurs because of the heating and consequent thermal expansion of fluids in a gravity field.





Model of a geothermal system. Curve 1 is the reference curve for the boiling point of pure water. Curve 2 shows the temperature profile along a typical circulation route from recharge at point A to discharge at point E

(From White, 1973).

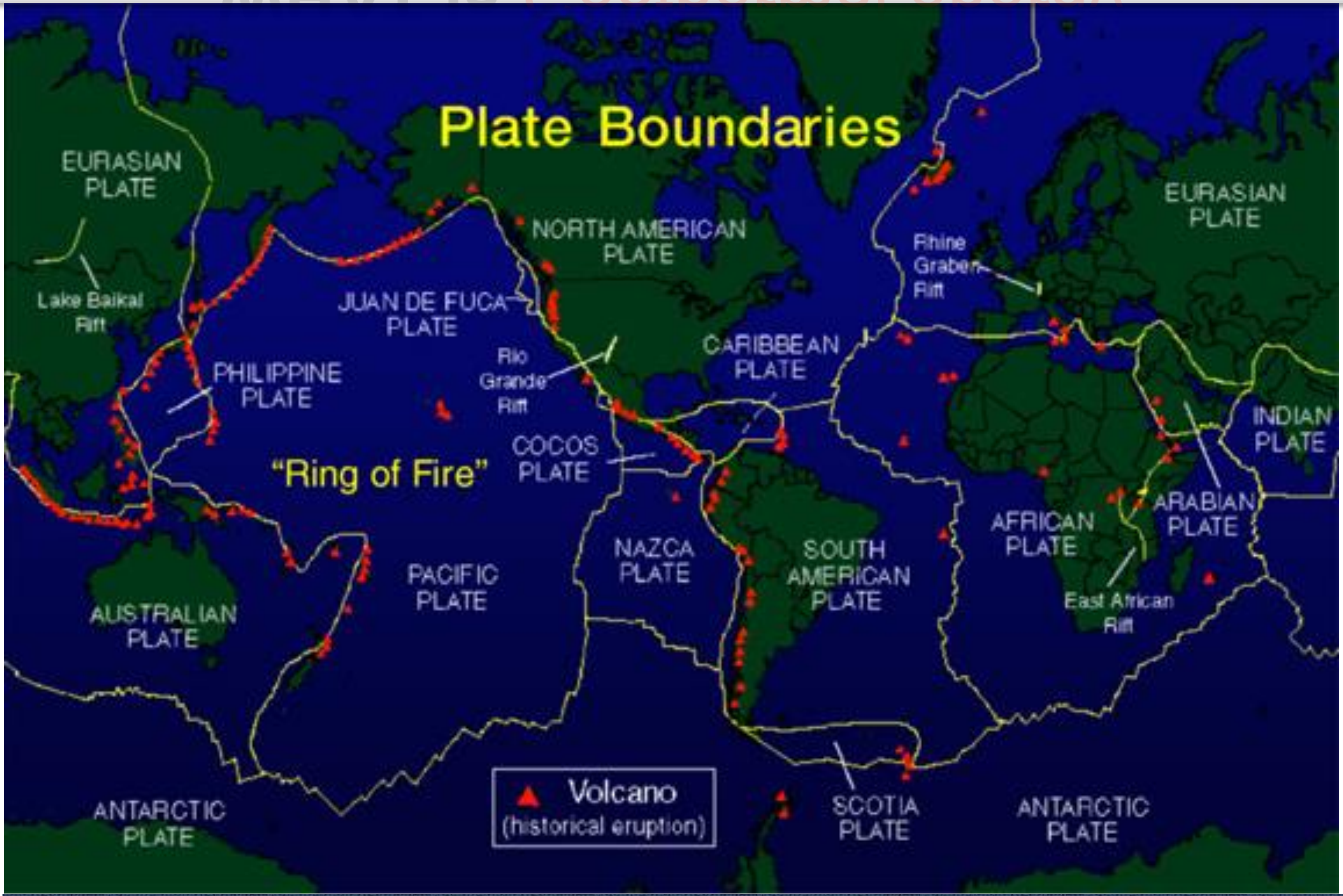
WHAT is Geothermal energy

Depth

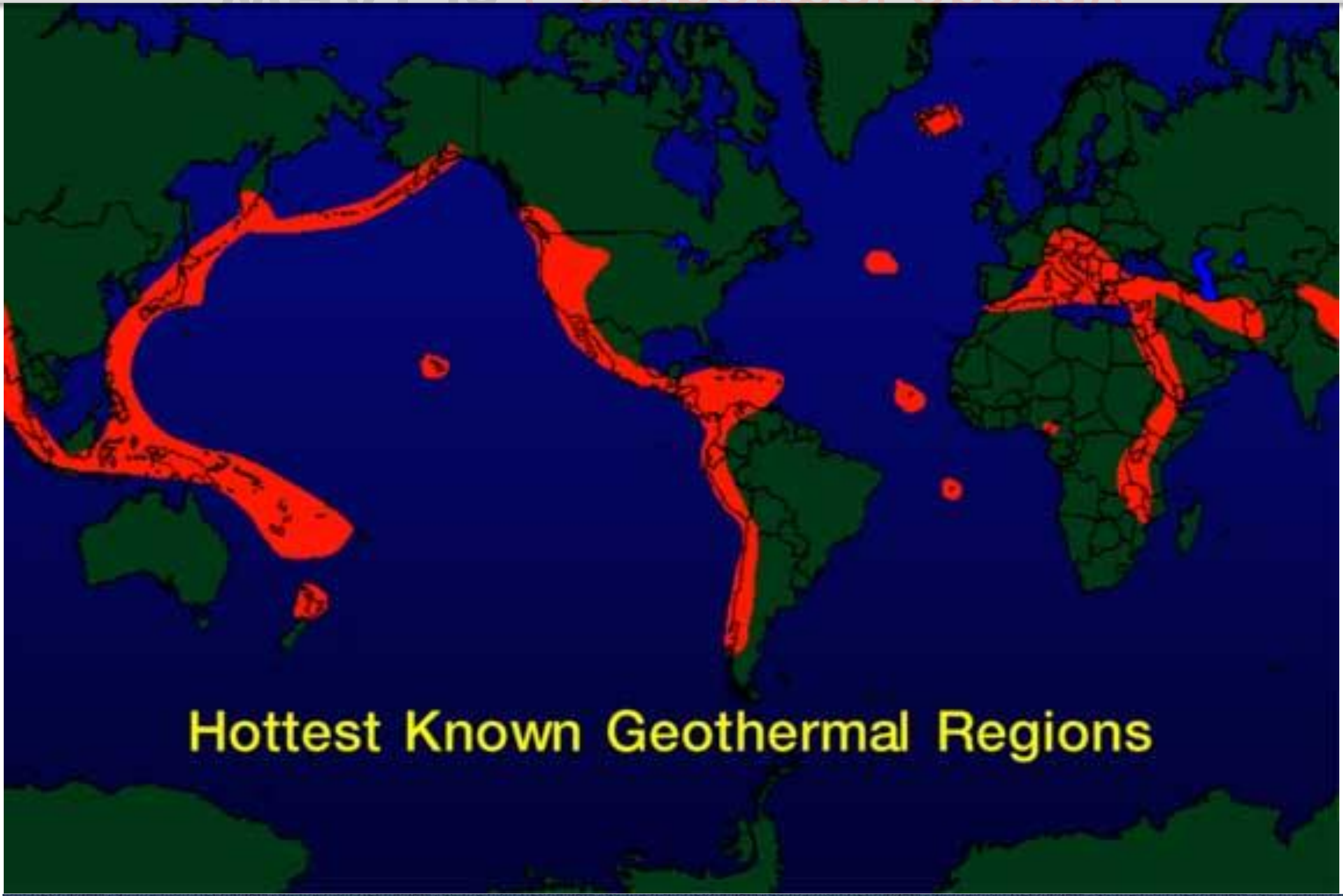
Depth		
0 - 500 m	Dry/hydrothermal Shallow Reservoir	Mostly for Direct uses of heat Borehole Heat Exchanger
500 – 5000 m	Hydrothermal Systems: shallow and deep reservoir	Power generation – Heat&Power generation Conventional technologies – EGS (Engineered Geothermal Systems)
More than 5000 m	Hot deep dry/wet rock reservoir	EGS – Supercritical fluids Future perspectives

Depending on the depth and the physical properties of the resource, the heat&power production, the upfront cost and the appropriate utilization technology may vary.

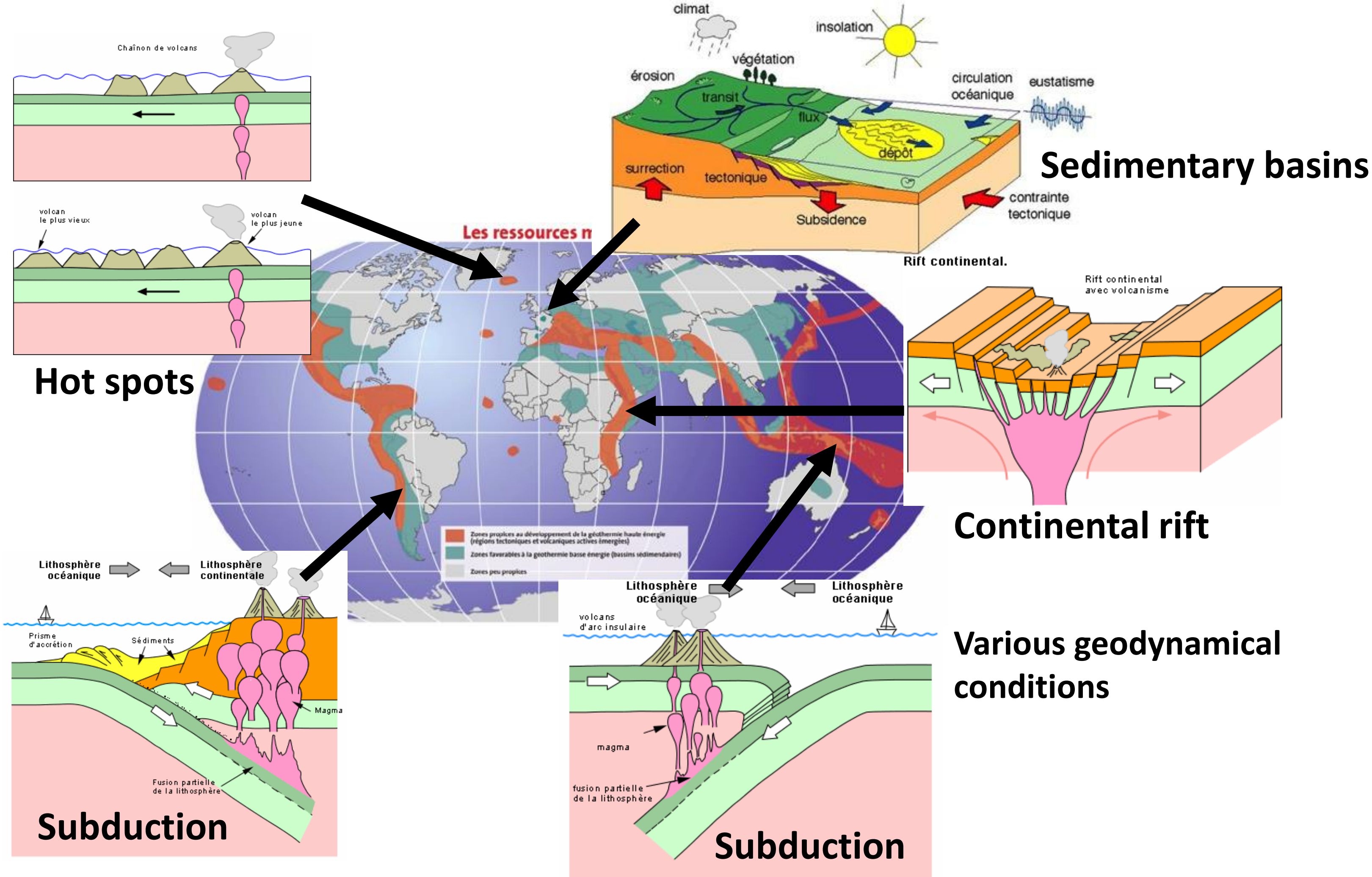
WHAT is Geothermal energy



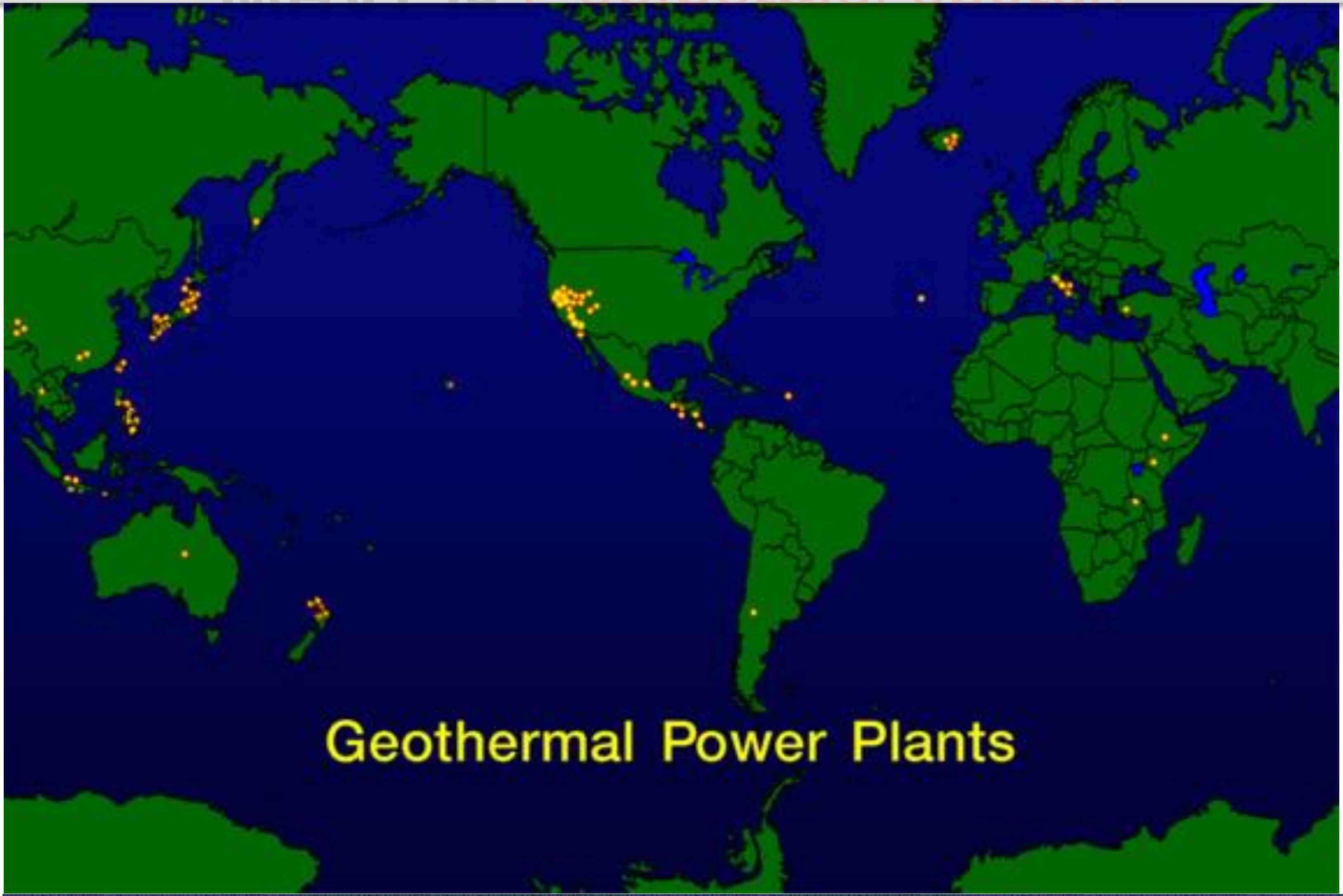
WHAT is Geothermal energy



WHAT is Geothermal energy



WHAT is Geothermal energy



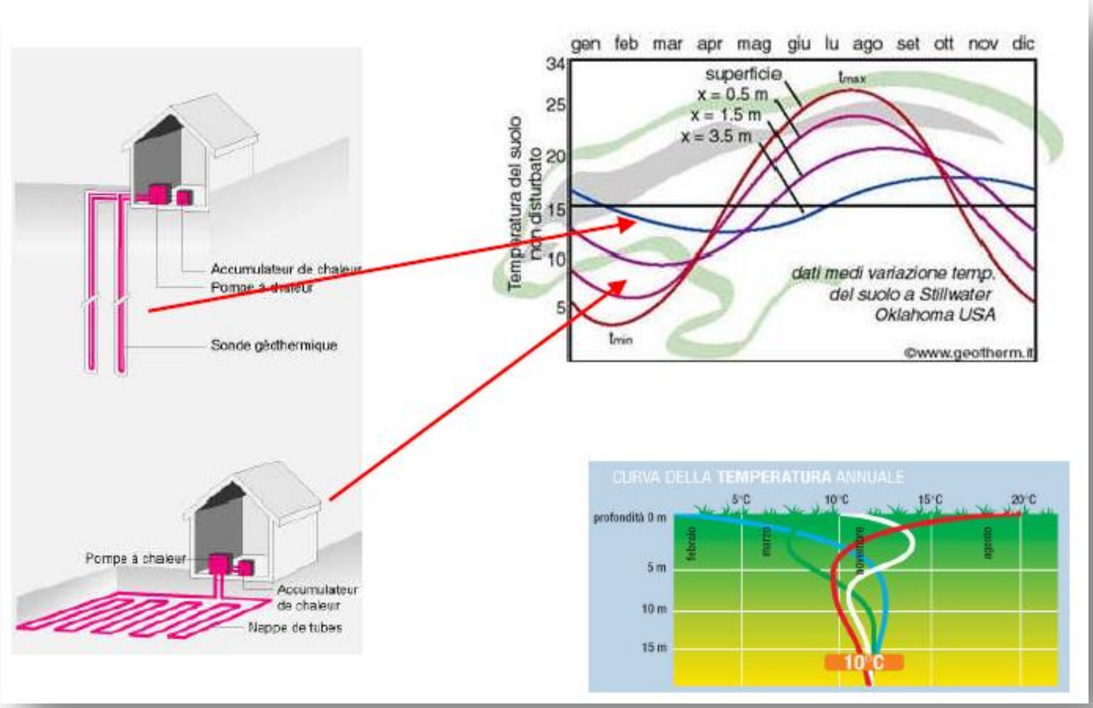
2

Heat? Power? Depending on what?

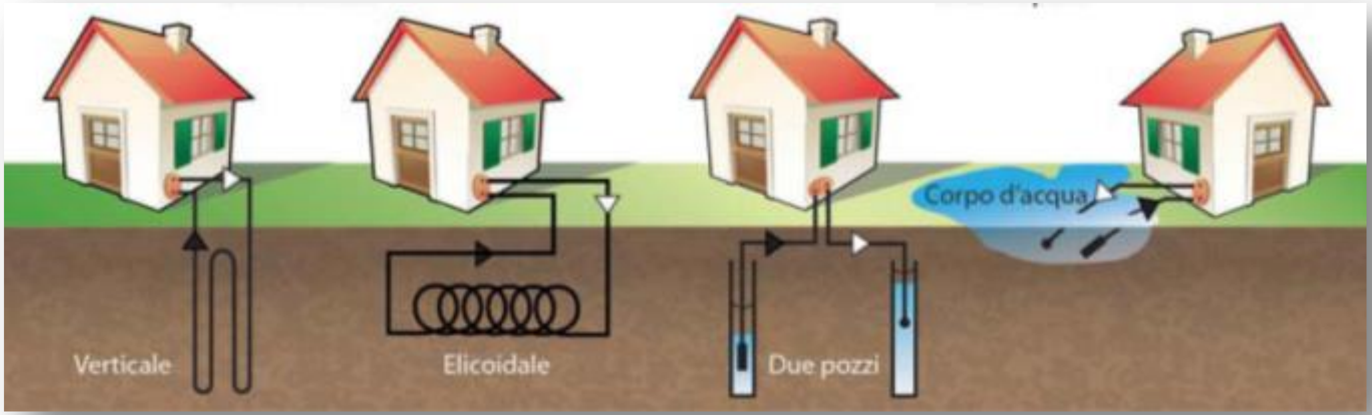
How Geothermal Energy is used

How Geothermal Energy is used

Geothermal heat pump (GHP) or Ground Source Heat Pump (GSHP) is a form for direct use of geothermal energy based on the relatively constant ground or groundwater temperature in the range of 4°C to 30°C available anywhere in the world, to provide space heating, cooling and domestic hot water for homes, schools, factories, public buildings and commercial buildings.



How Geothermal Energy is used



Closed loop systems

A ground-coupled systems where a plastic pipe is placed in the ground, either horizontally at 1-2 m depth or vertically in a borehole down to 50-250 m depth. A water-antifreeze solution is circulated through the pipe collecting heat from the ground in the winter and optionally rejecting heat to the ground in the summer.

Open loop systems

It uses groundwater or lake water as a heat source in a heat exchanger and then discharges it into another well, a stream or lake or even on the ground.

How Geothermal Energy is used

Closed loop systems

Advantages:

- feasible almost everywhere in principle
- efficient exploitation of thermal energy
- more wells (high cost and impact) than for CL
- easy authorization
- zero emissions
- small underground thermal anomaly

Disadvantages:

- High cost
- requires more space
- delicate installation to avoid interference with aquifers
- require heat pump

Open loop systems

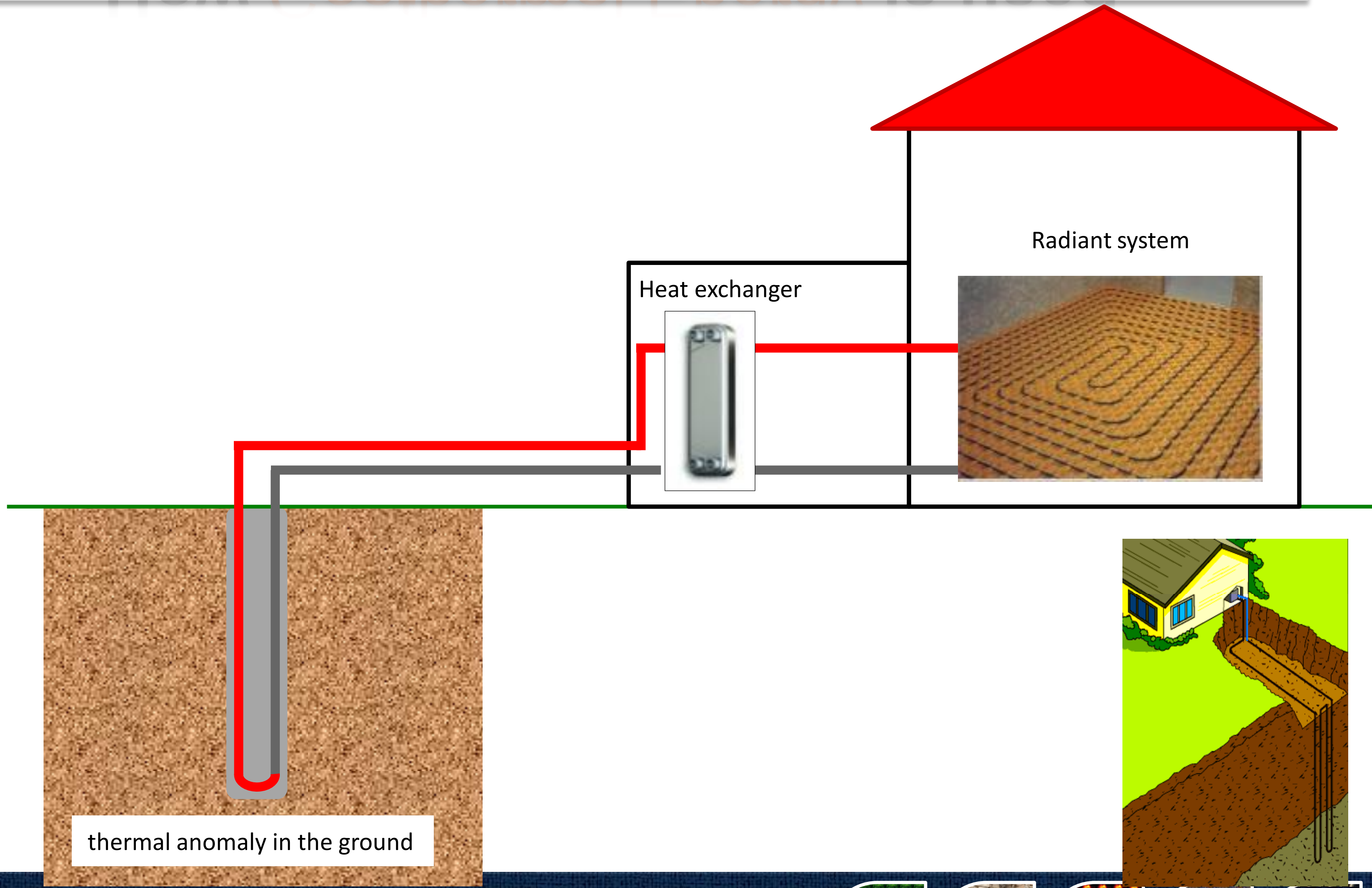
Advantages:

- higher thermal capacity than for CL for each well, therefore less wells
- less wells (low cost and impact)
- lower cost than for Closed Loop (CL)
- efficient exploitation of thermal energy
- relatively easy installation
- zero emissions
- may be used without heat pumps

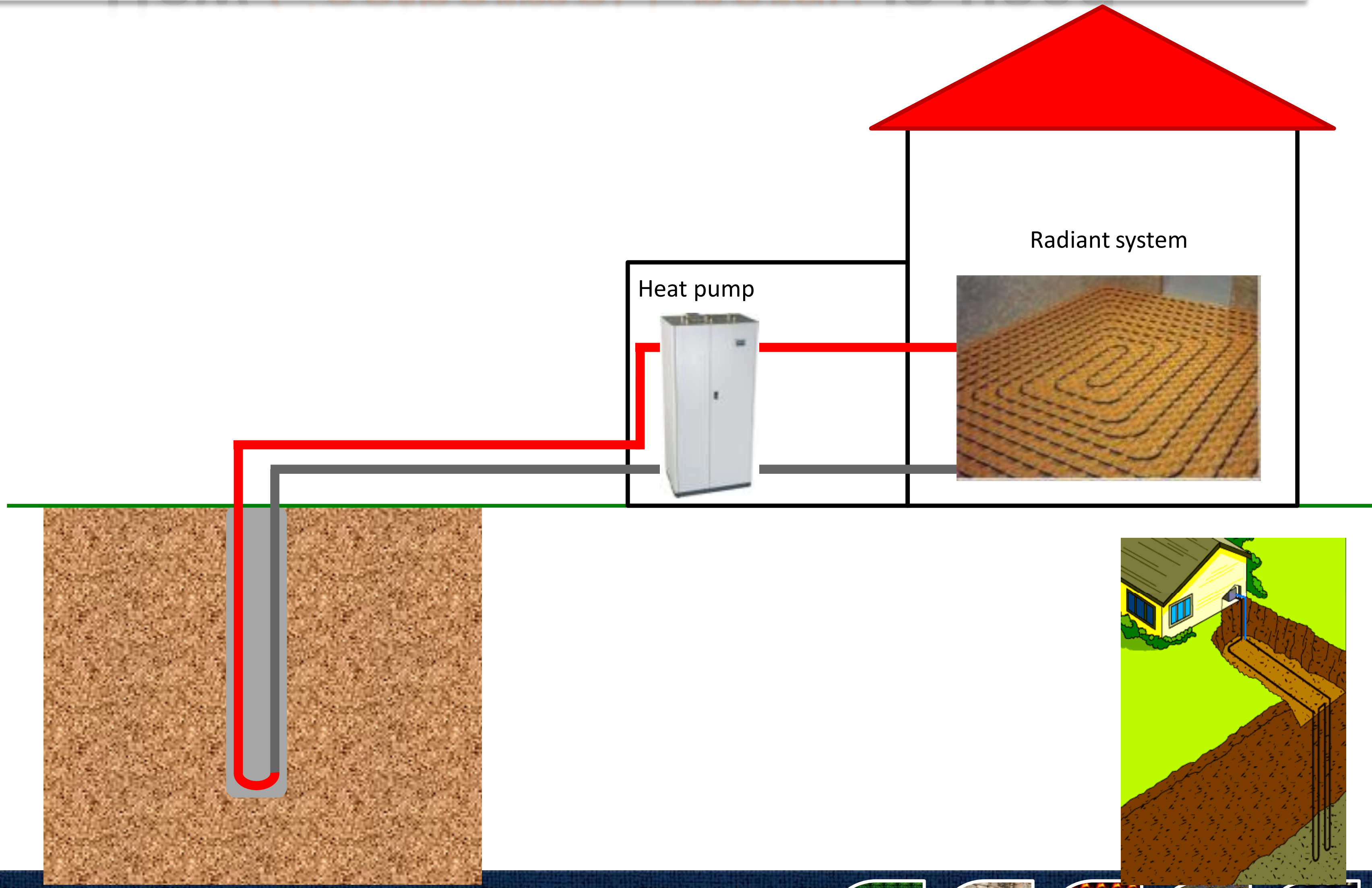
Disadvantages:

- Complexity of regulation and authorization
- Not always feasible
- accurate planning to avoid shortcircuiting

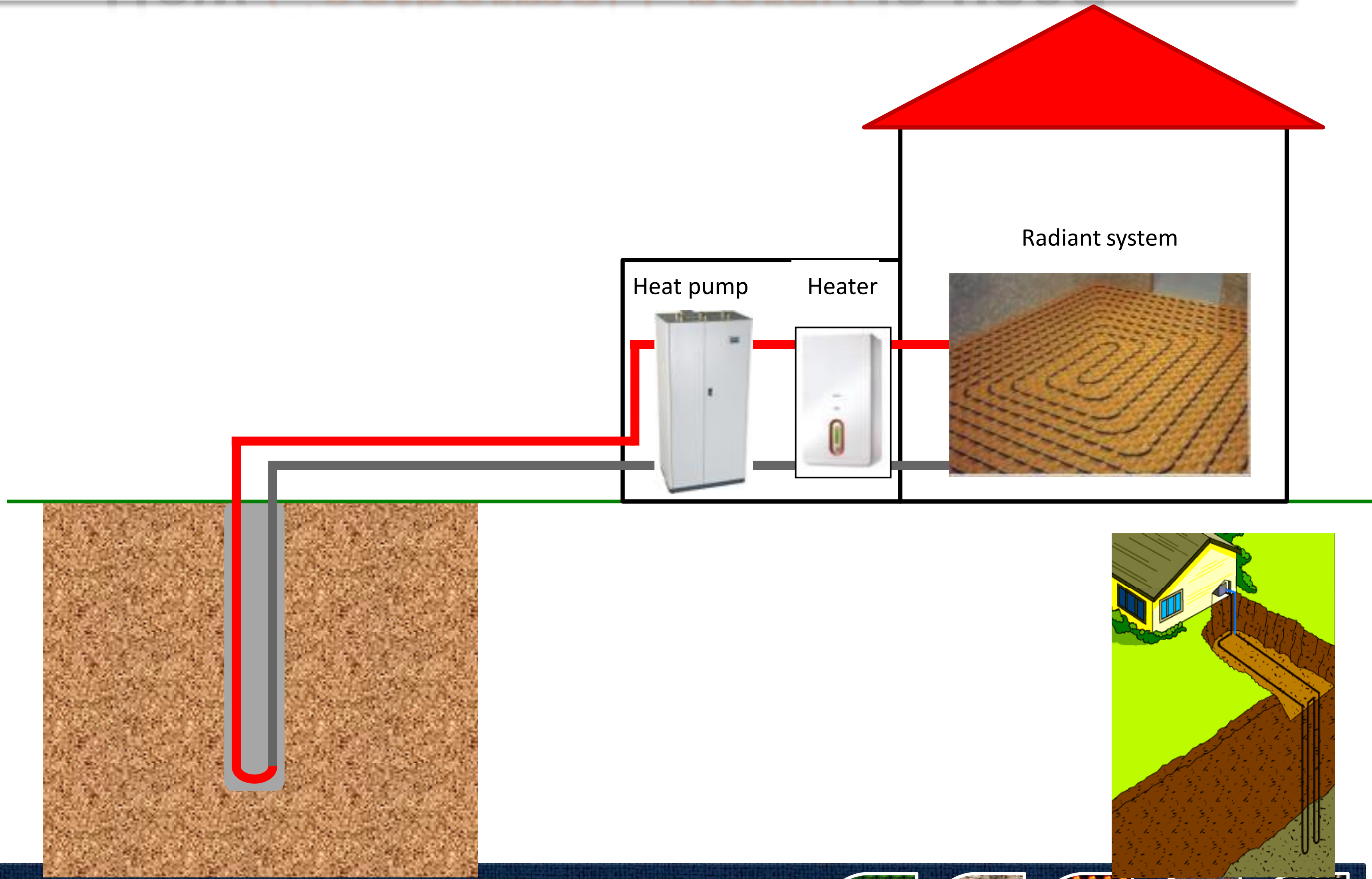
How Geothermal Energy is used



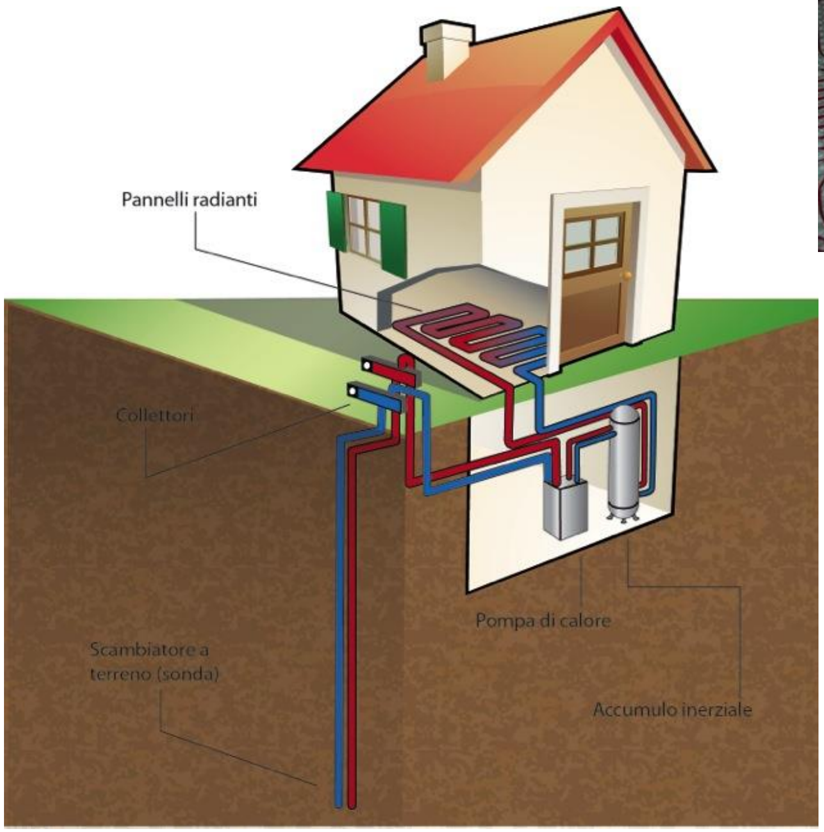
How Geothermal Energy is used



How Geothermal Energy is used



How Geothermal Energy is used



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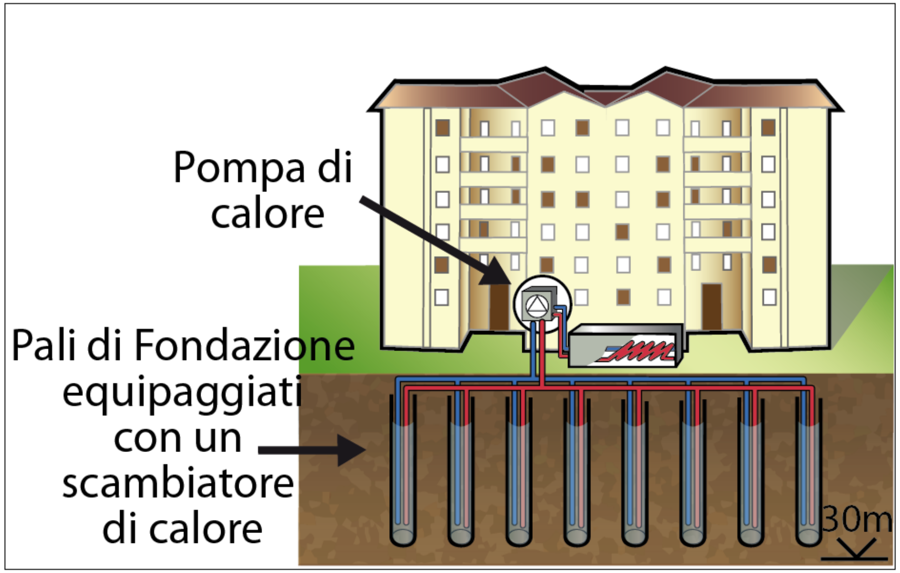
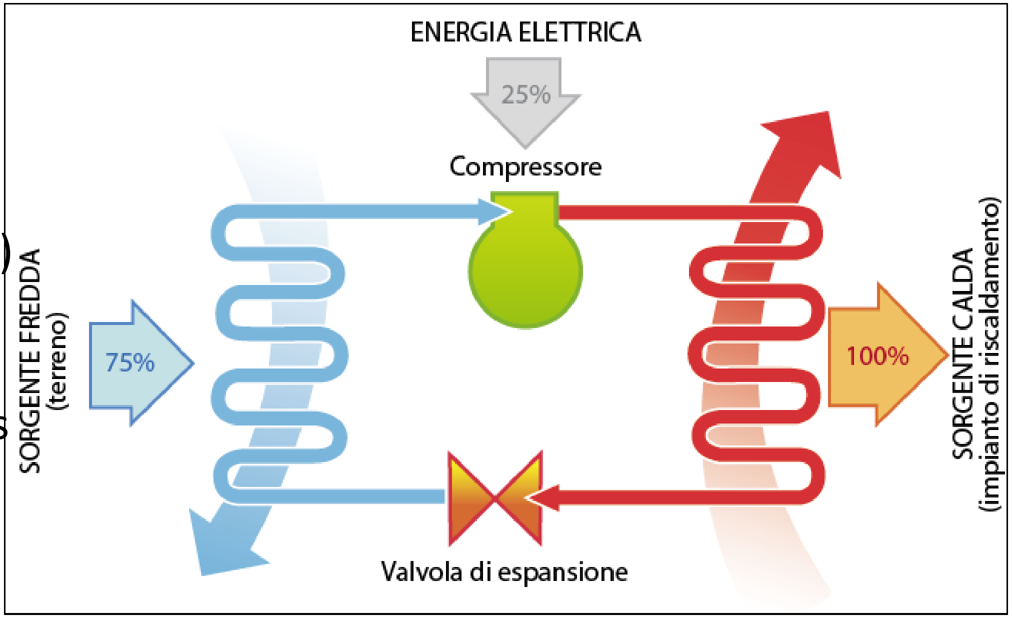


How Geothermal Energy is used

compressor
(power consumption)
to compress the vapour

cold source (ground)
evaporator
the fluid absorbs
heat and evaporates

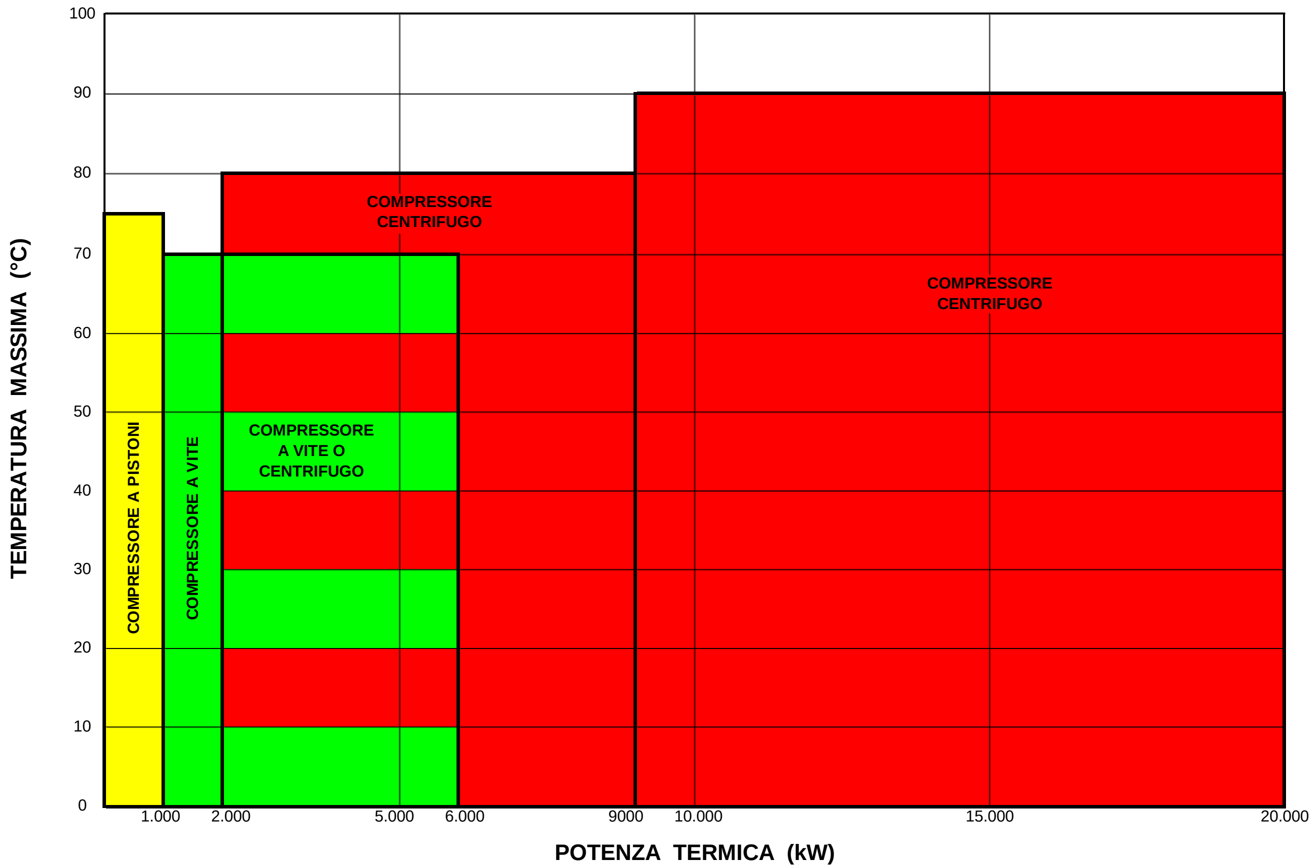


condenser where the
warm vapour
releases heat
and becomes liquid
while heating

expansion valve

How Geothermal Energy is used

Depending on the compressor type, various temperatures and thermal capacity may be obtained



How Geothermal Energy is used

For single units requiring a thermal capacity within 35 kW one heat pump is enough. The energy efficiency may reach 150% (it is 80% for a gas heater, and energy consumption is almost halved).
For larger volumes the units are installed in parallel.

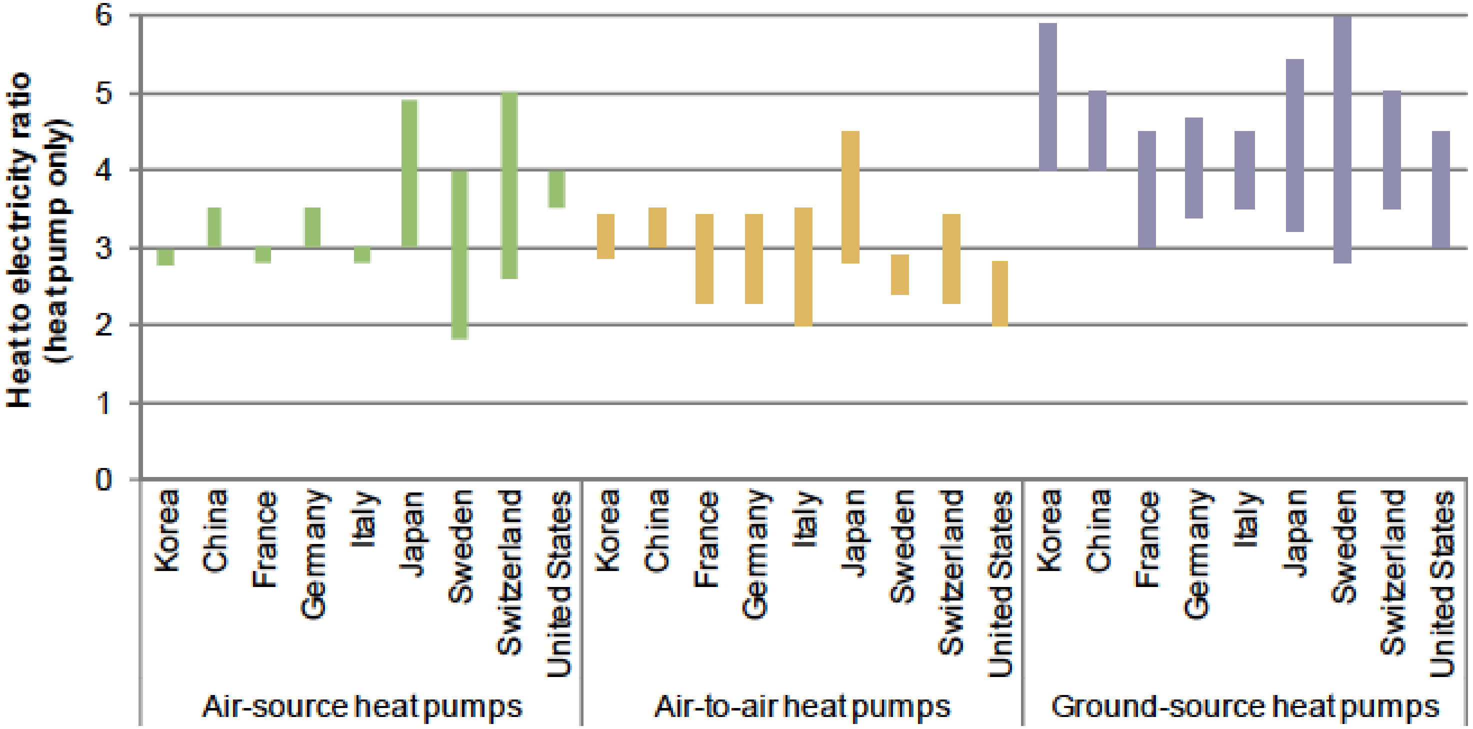
The process may be inverted (reversable units), obtaining heating and cooling systems. Single units may provide 18 kW (cold).

District heating using heat pumps is becoming very popular, and may provide temperature up to 90°C

Heat pumps may have one (40°C) or two (85°C) blocks. COP (coefficient of production, ratio heat/power) is 2.6-3

How Geothermal Energy is used

Figure 28 • Representative efficiencies of air- and ground-source heat pump installations in selected countries



Note: The COP (heat to electricity ratio) values above are based on values provided by the manufacturers, and refer to the heat pump only. Heat to electricity ratios for the whole heat pump cycle typically lie well below the values indicated of the heat pump only.

Source: IEA (2012a), *Energy Technology Perspectives 2012*, OECD/IEA, Paris.

How Geothermal Energy is used

In the European Union, heat generated by hydrothermal, air- and ground-source heat pumps is considered renewable under the Renewable Energy Directive (Directive 2009/28/EC).

According to the EU Directive 2009/28/EC, heat pumps can be considered a renewable technology as long as they result in a primary energy efficiency of at least 115%, which corresponds to a seasonal performance factor of 2.875 at an average efficiency of the electricity production of 40% (EC/RHC Platform, 2012).

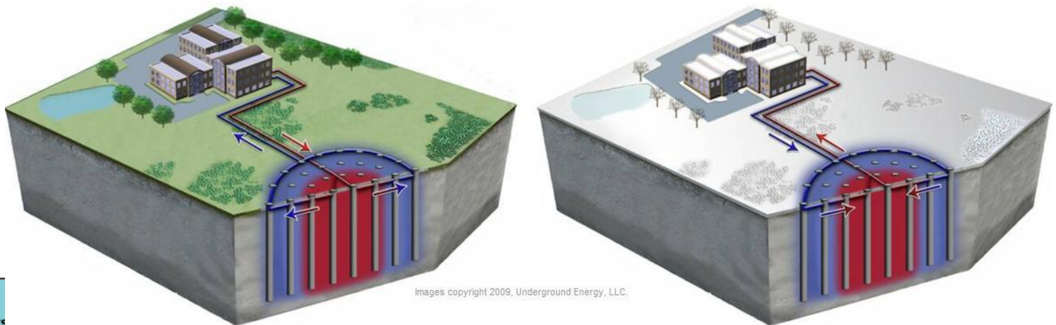
The energy considered renewable is the heat delivered, minus the electricity consumption of the pump.

How Geothermal Energy is used

Heating and cooling system of Palazzo Lombardia, Milan, by geothermal heat pump

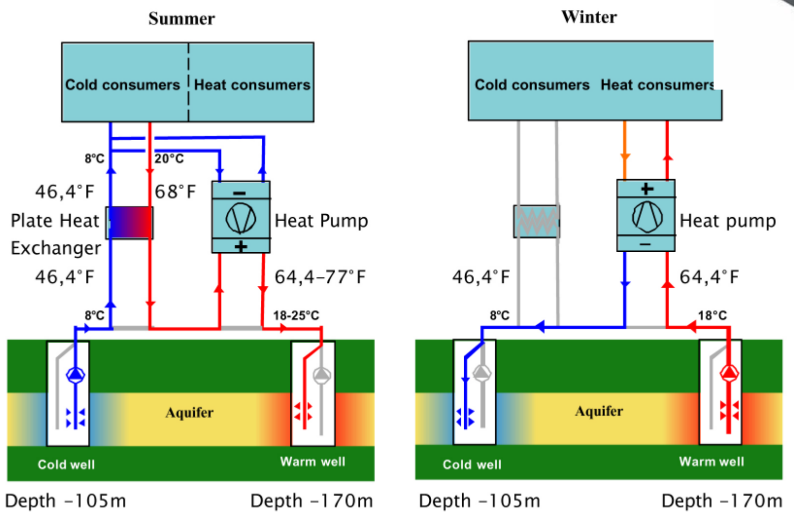
How Geothermal Energy is used

UTES (*Underground Thermal Energy Storage*) is an increasing research field for storing heat/cold and use it when necessary



BTES
Borehole Thermal Energy System

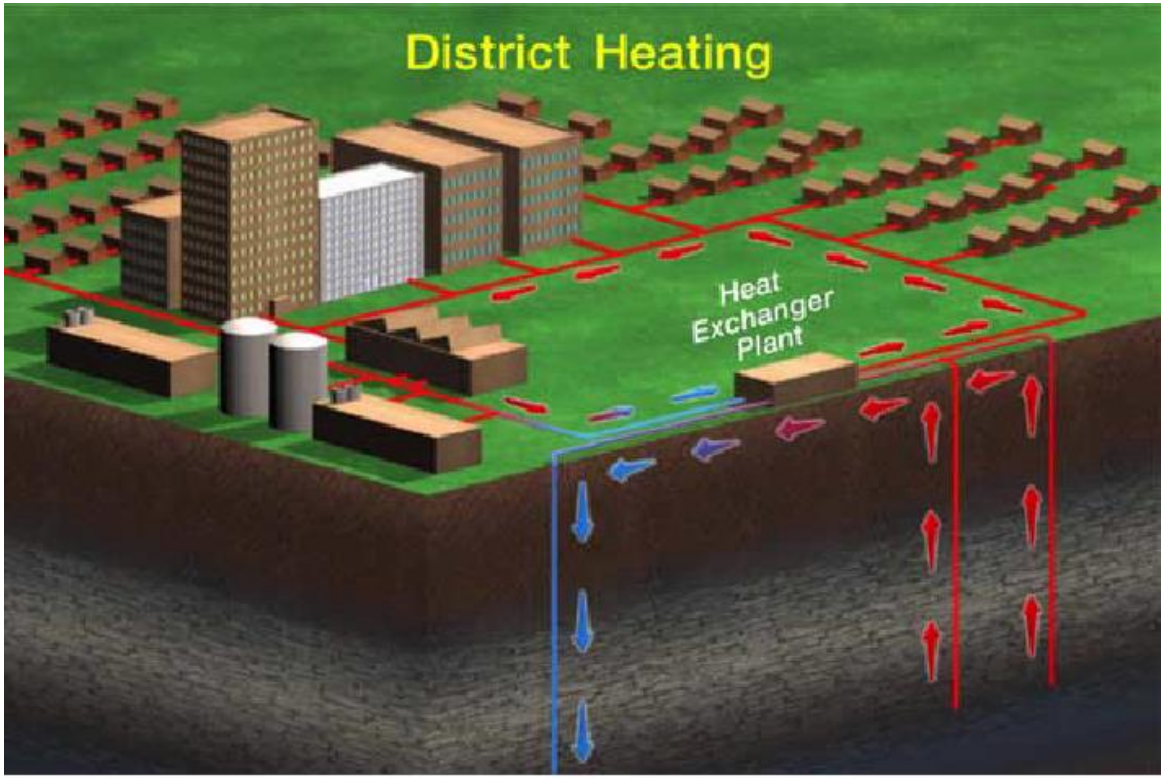
ATES
Aquifer Thermal Energy Storage



How Geothermal Energy is used

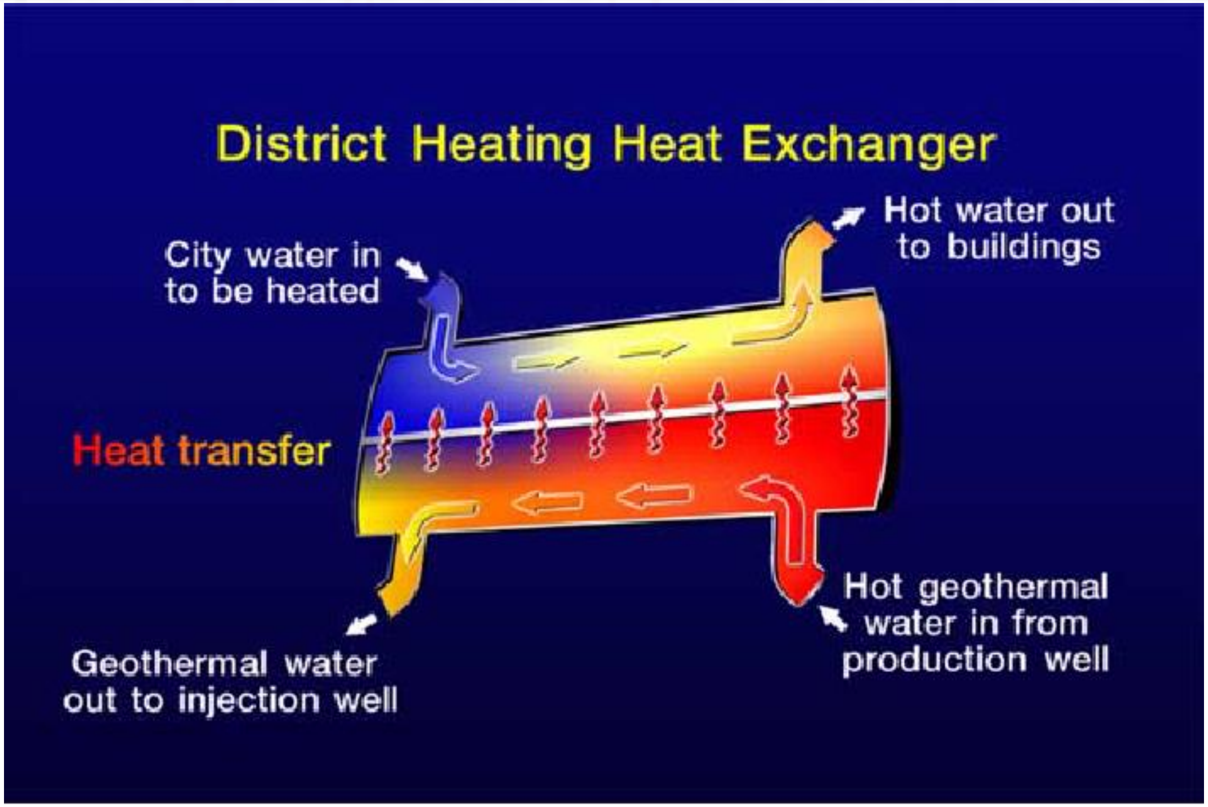
Space heating, of which more than 80% are district heating, is among the most important direct uses of geothermal energy

Open loop (single pipe) distribution systems are used where the water quality is good and recharge into the geothermal system adequate (fluids are wasted). In the more commonly used closed loop (double pipe) systems the spent water is disposed into reinjection wells.



Hot water from one or more geothermal wells is piped through a heat exchanger plant to heat city water in separate pipes. Hot city water is piped to heat exchangers in buildings to warm the air.

How Geothermal Energy is used

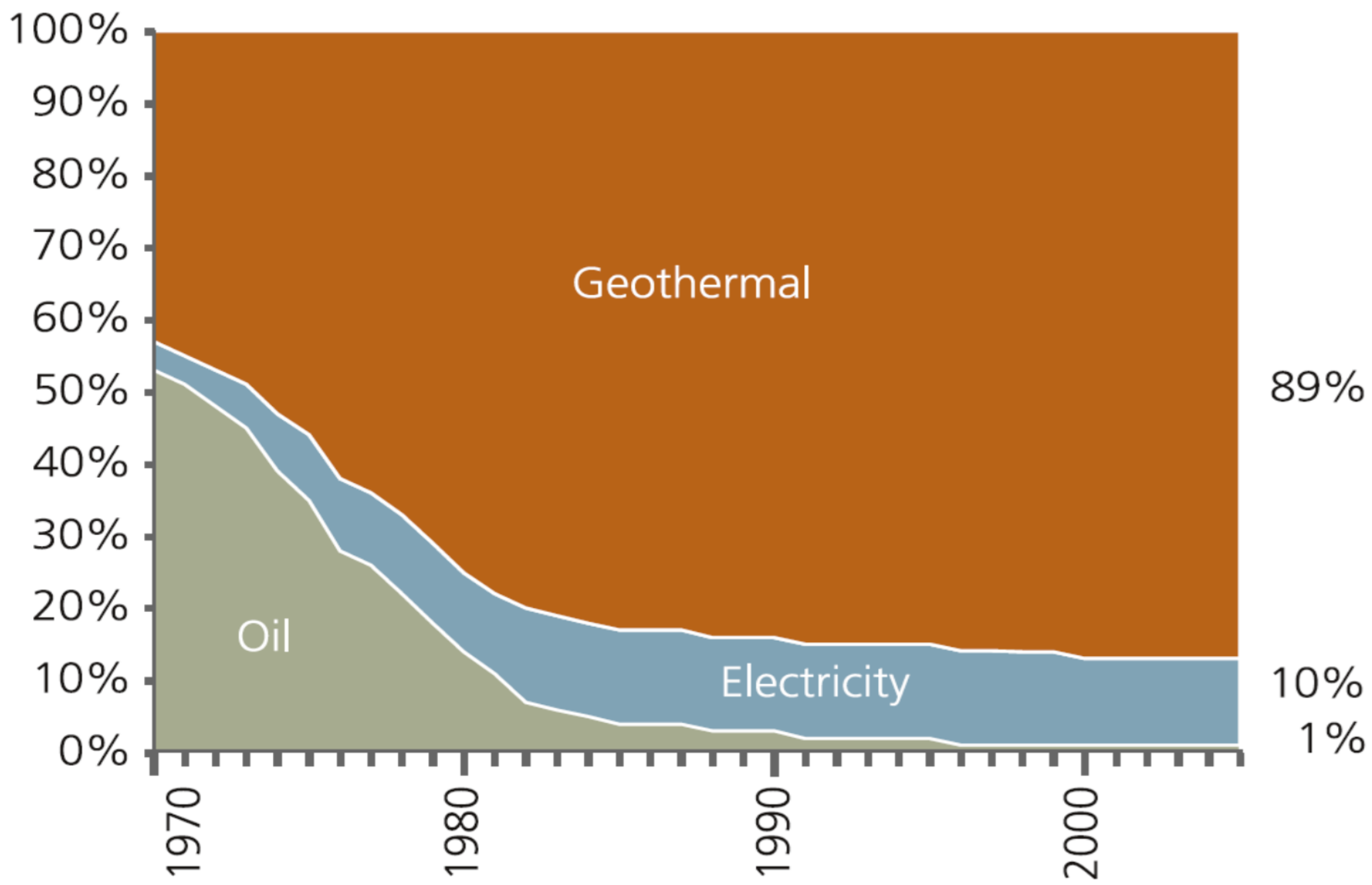


The geothermal water never mixes with the city water. Once its heat is transferred to the city water, the geothermal water is injected back into the reservoir to be reheated and recycled.

How Geothermal Energy is used

These pumps are used to pump the heated water to buildings in a district heating system, after it has passed through the heat exchanger.

How Geothermal Energy is used

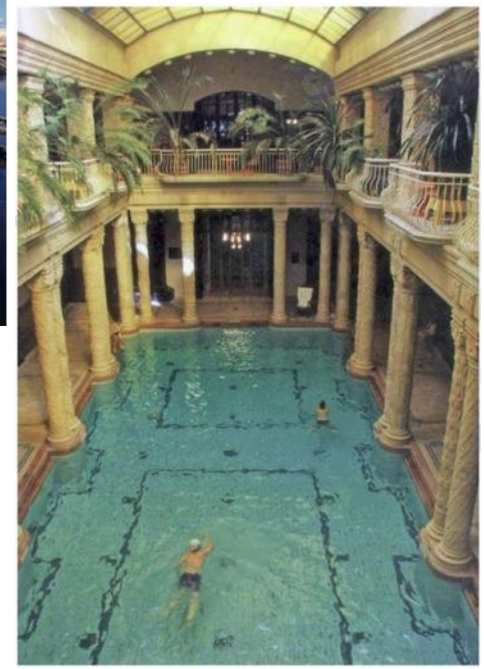


Energy source for district heating in Iceland

How Geothermal Energy is used

Fish and other animal farming farming

Greenhouse heating



Bathing and balneology

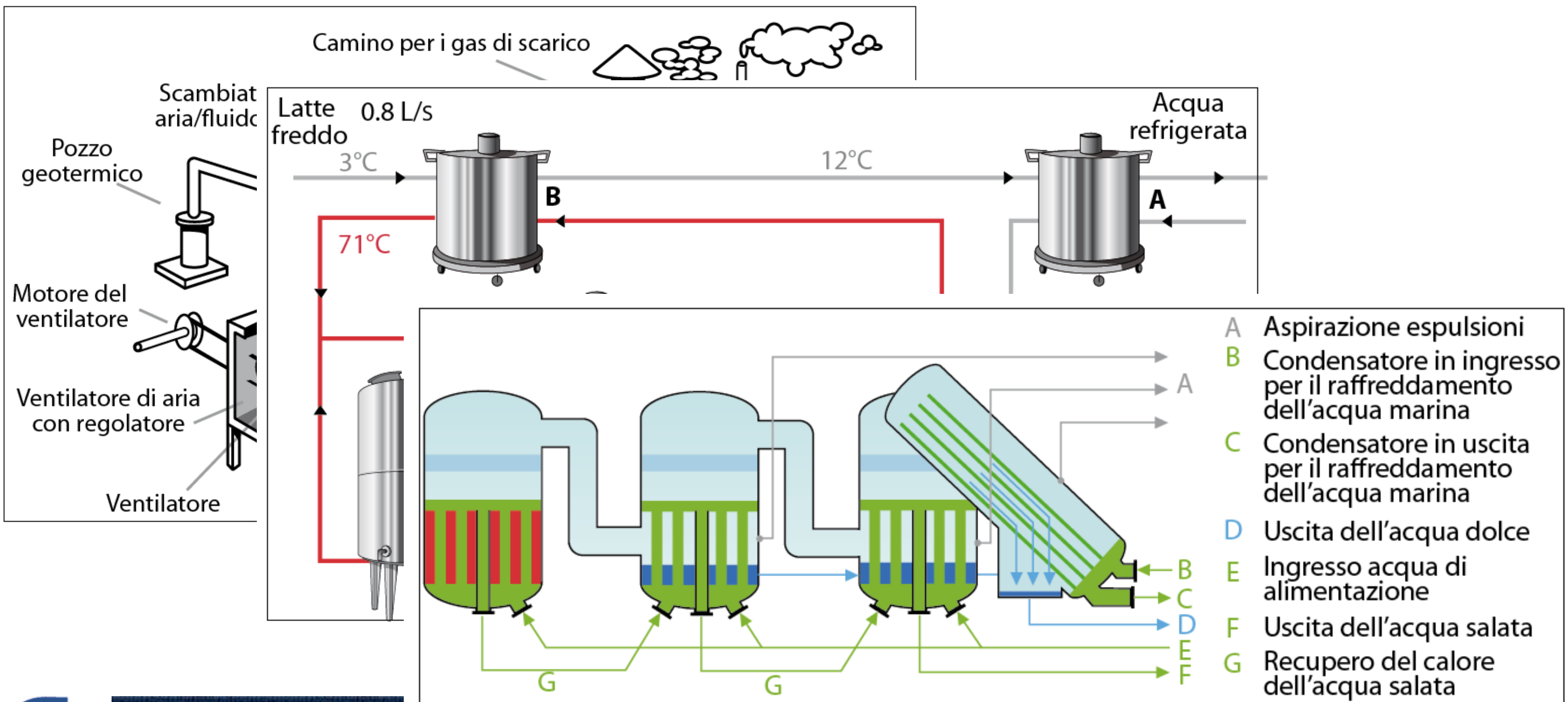
The most common direct uses of geothermal heat

How Geothermal Energy is used

Food processes using heated fluids or heating&cooling may benefit from geothermal energy

How Geothermal Energy is used

Industrial processes using heated fluids may benefit from geothermal energy, as well as evaporative, drying, distilling, sterilizing, washing, freezing and de-freezing processes, and hydrocarbon extraction.



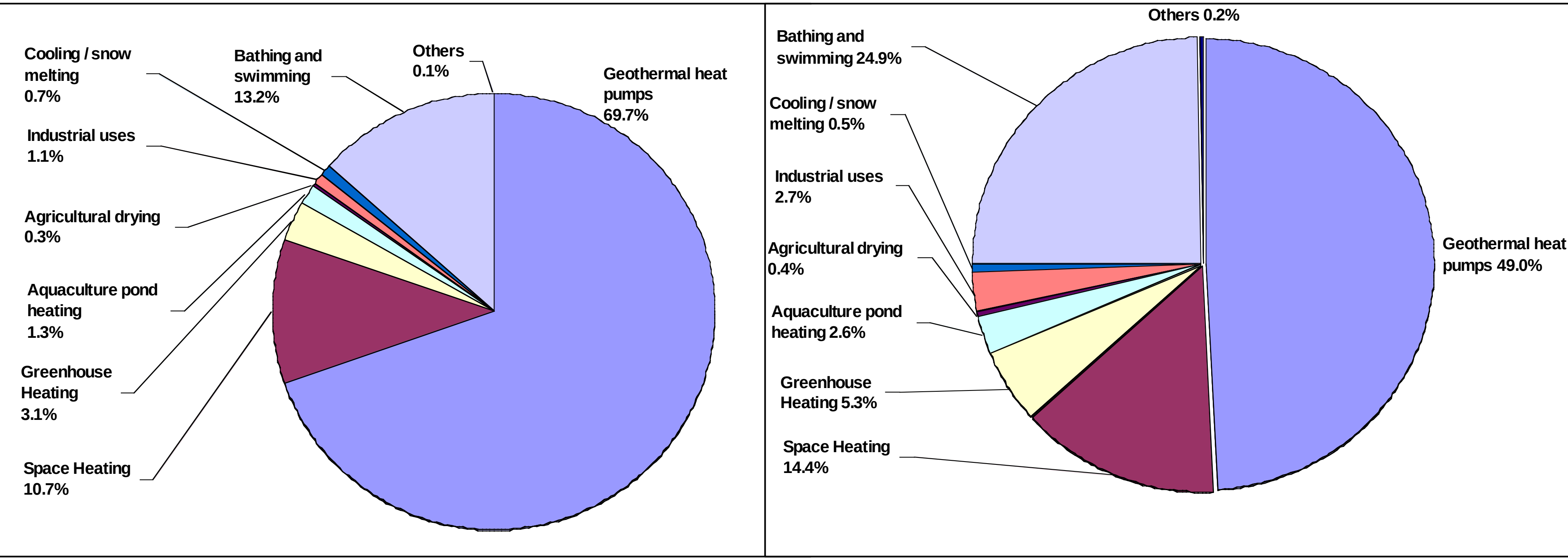
How Geothermal Energy is used

Pipes of geothermal water can be installed under sidewalks and roads to keep them from icing over in winter, like this sidewalk.

Slide 88 of 122, © 2000 Geothermal Education Office

How Geothermal Energy is used

Geothermal direct applications worldwide in 2010, distributed by percentage of total installed capacity (left) and percentage of total energy use (right).



How Geothermal Energy is used

Country	Capacity, MWt	Annual Use, TJ/yr	Annual Use, GWh/yr
United States	12611.46	56551.80	15710.10
China	8898.00	75348.30	20931.80
Sweden	4460.00	45301.00	12584.60
Norway	3300.00	25200.00	7000.60
Germany	2485.40	12764.50	3546.00
Japan	2099.53	15697.94	7138.90
Iceland	1826.00	24361.00	6,767,5
Netherlands	1410.26	10699.40	2972.30
France	1345.00	12929.00	3591.70
Canada	1126.00	8873.00	2464.90
Switzerland	1060.90	7714.60	2143.10
Italy	867.00	9941.00	2,761,6
Finland	857.90	8370.00	2325.20
Austria	662.85	3727.70	1035.60
Hungary	654.60	9767.00	2713.30
New Zealand	393.22	9552.00	2653.50
Brazil	360.10	6622.40	1839.70
Russia	308.20	6143.50	1706.70
Argentina	307.47	3906.74	1085.30
Poland	281.05	1501.10	417.00
total	48501.20	428070.66	112166.80

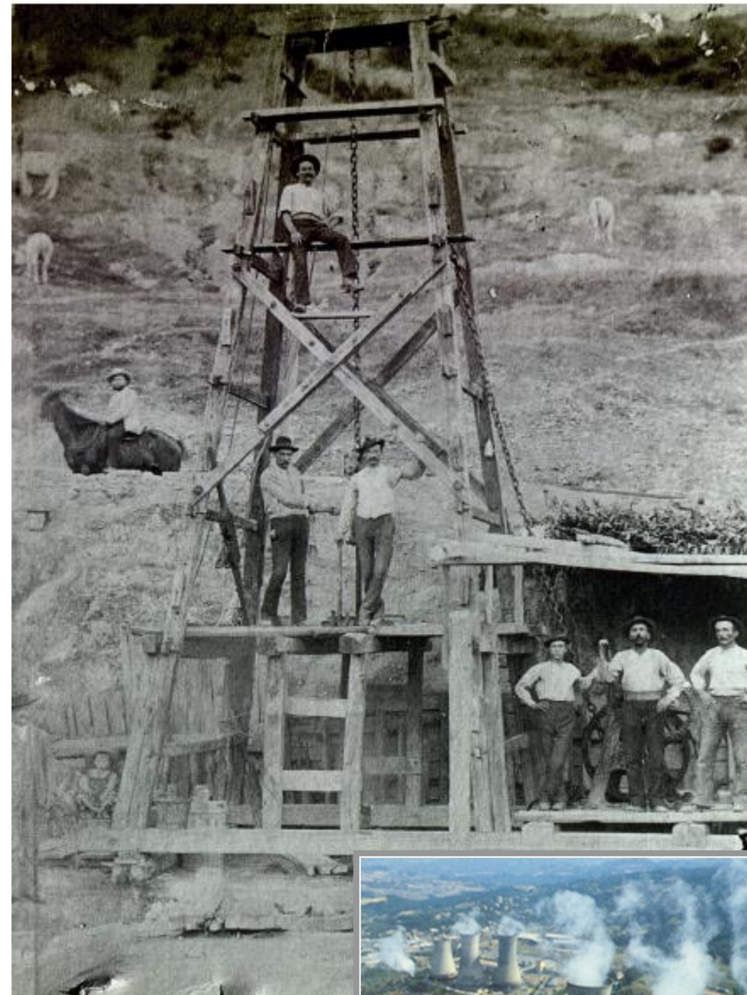
78 countries in the list (WGC2010)

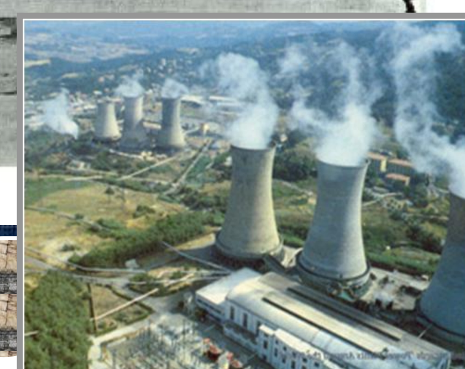
How Geothermal Energy is used

Italy has been the first country in the world to produce **electricity by geothermal energy** on 1904.

Power production started on 1908 and increased in Italy and the world since then.

Larderello, 1904

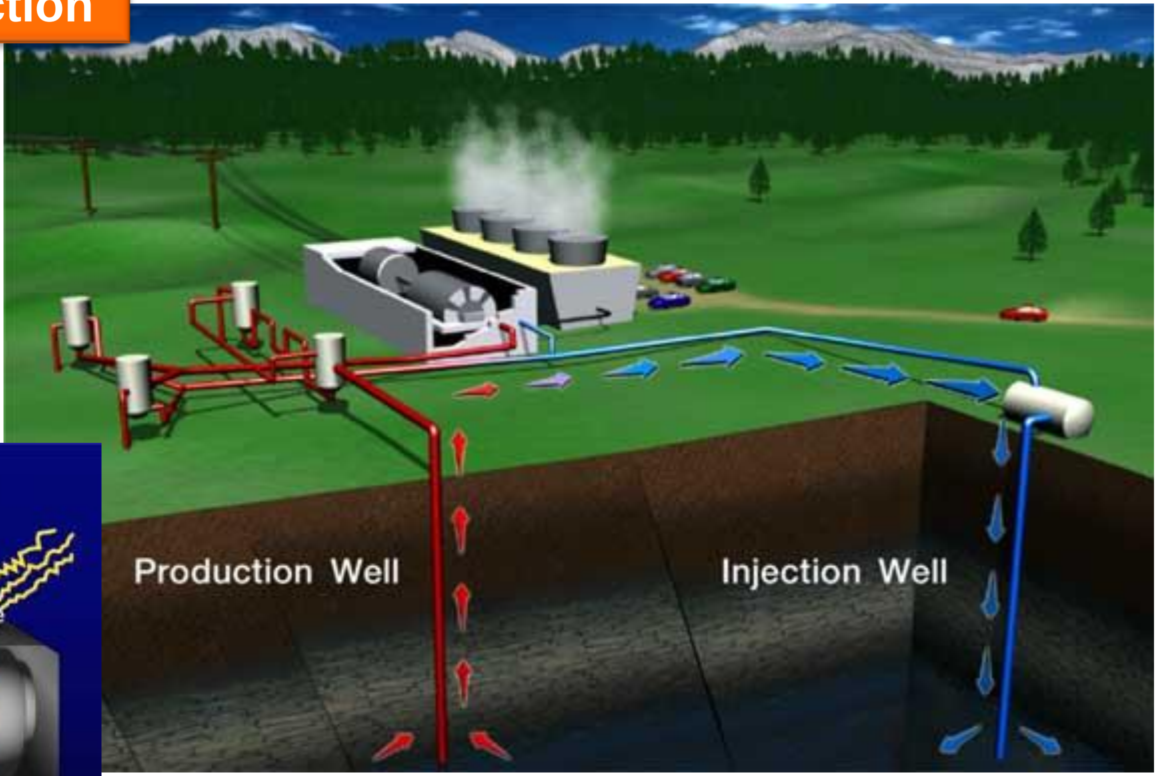


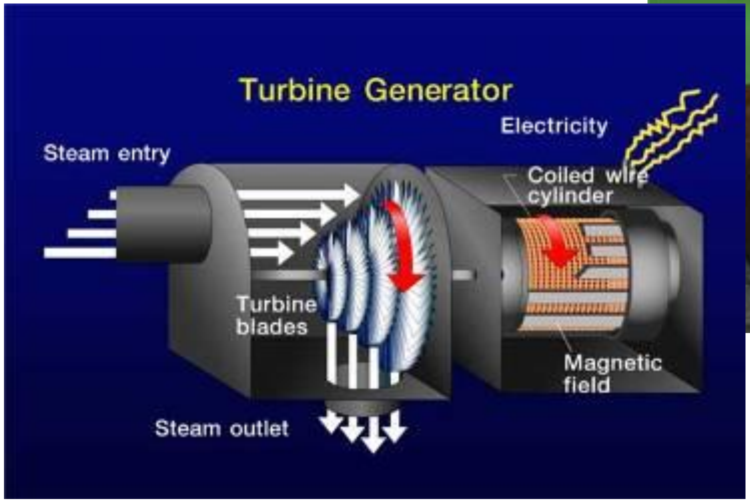


How Geothermal Energy is used

Geothermal power production

By means of turbine generators, geothermal heat (high temperature) is converted in mechanical energy and then in electrical energy





How Geothermal Energy is used

Steam Dominated systems
vapourstatic pressure

Dry steam plants

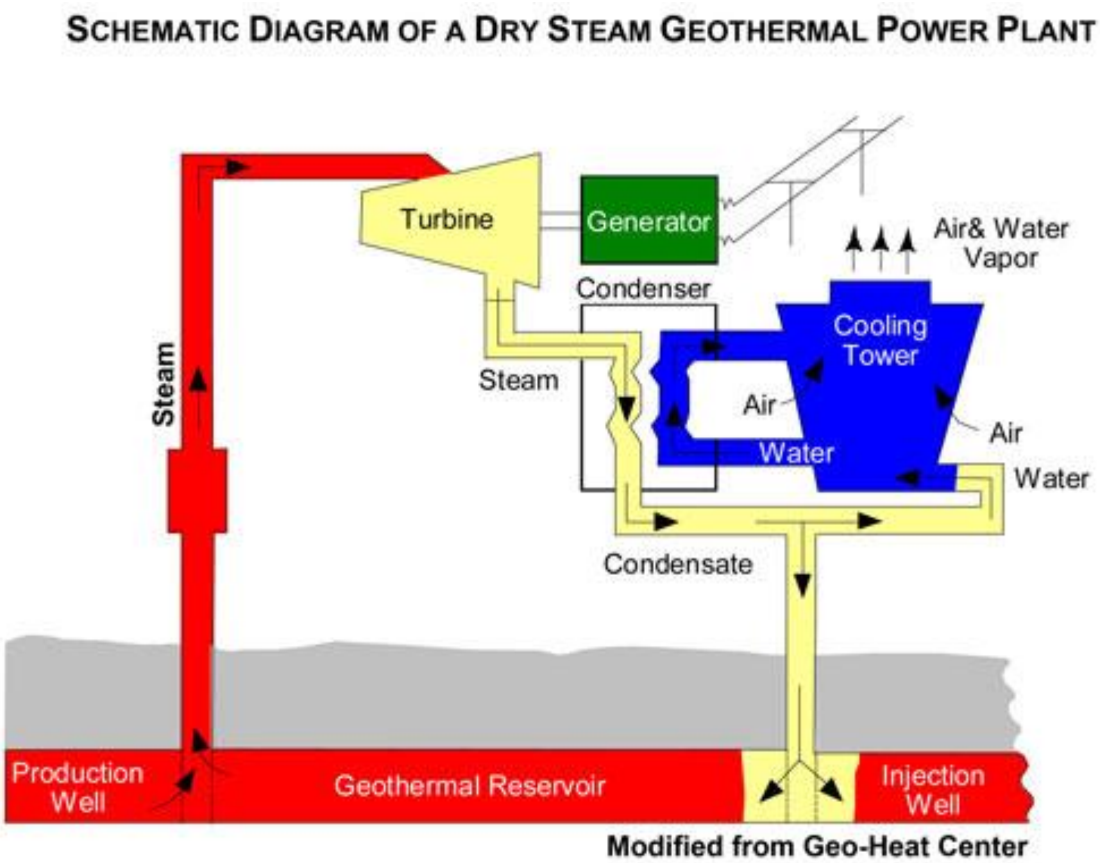
Liquid dominated systems
hydrostatic pressure

Single or double flash plants
separation of steam and liquid phase

Binary plants

Combined plants
flash and binary, cascade

How Geothermal Energy is used



Dry steam plants

use hydrothermal fluids that are primarily steam. The steam goes directly to a turbine, which drives a generator that produces electricity.

How Geothermal Energy is used

Technology Advantages

- Resembles a typical Steam Cycle Power Plant
- Most equipment can be obtained from a variety of suppliers
- Condensing Steam Turbines have a high power conversion efficiency (+75%)

Technology Disadvantages

- Since 2/3 of the steam is lost in the cooling tower, geothermal fields get depleted with time
- Use of Steam Ejectors more suitable for low NCG concentrations – high steam usage
- Gas Compressors have high parasitic load and high maintenance

Main Equipment Suppliers

Steam Turbine: GE; Mitsubishi; Sumitomo; Ansaldo

Generator: GE; Alstom; Siemens

Cooling Tower: Marley; Niagara

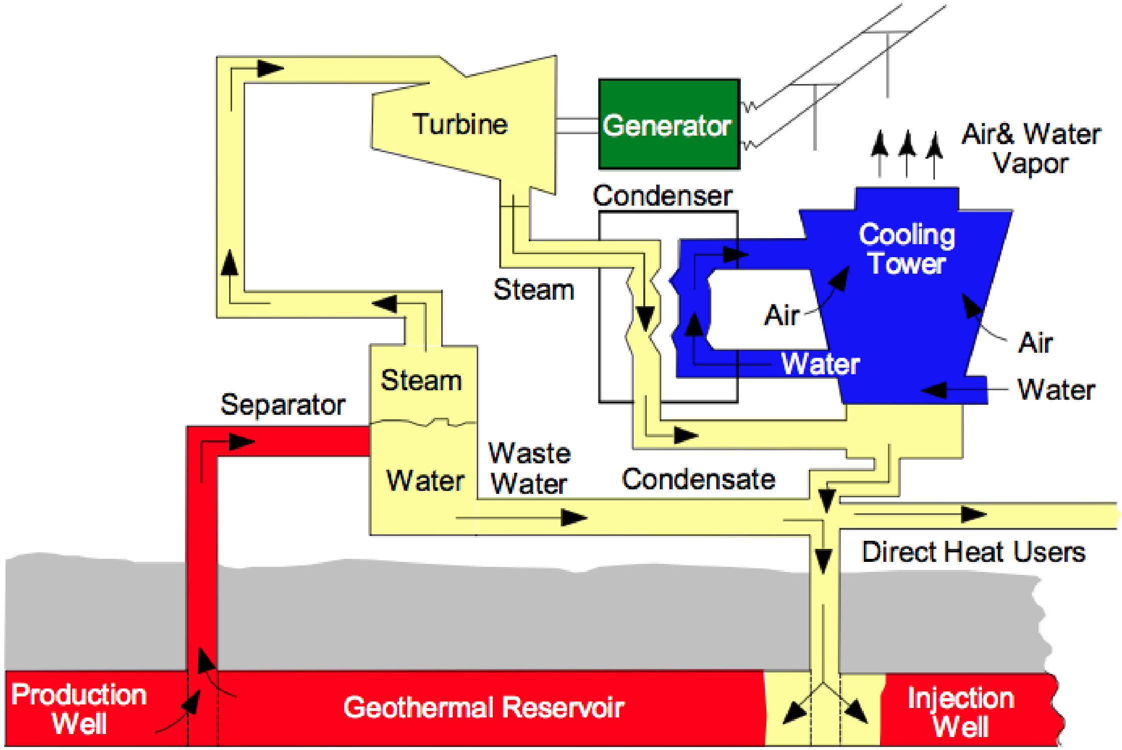
Economics

Power Plant Construction Cost: $1,000 – $1,500 / kW

O&M Cost: $10 - $20 / MWh

How Geothermal Energy is used

Figure 27: Single Flash Steam Power Plant Schematic



Flash steam power plants tap into reservoirs of water with temperatures higher than **180ºC**. As it flows, the fluid pressure decreases and some of the hot water boils or "flashes" into steam. The steam is then separated at the surface and is used to power a turbine/generator unit

How Geothermal Energy is used

Technology Advantages

- Most equipment can be obtained from a variety of suppliers

- Most of the water drawn from the reservoir is return. Source generally have a higher useful life

Technology Disadvantages

- Use of Steam Ejectors more suitable for low NCG concentrations

- Brines may have high concentrations of silica and/or Calcium salts which can cause troublesome scaling requiring frequent clean-ups of separators and wells.

- Single Flash preferred when high solids concentration are found in the brine

Main Equipment Suppliers

Steam Turbine: GE; Mitsubishi; Sumitomo; Ansaldo

Generator: GE; Alstom; Siemens

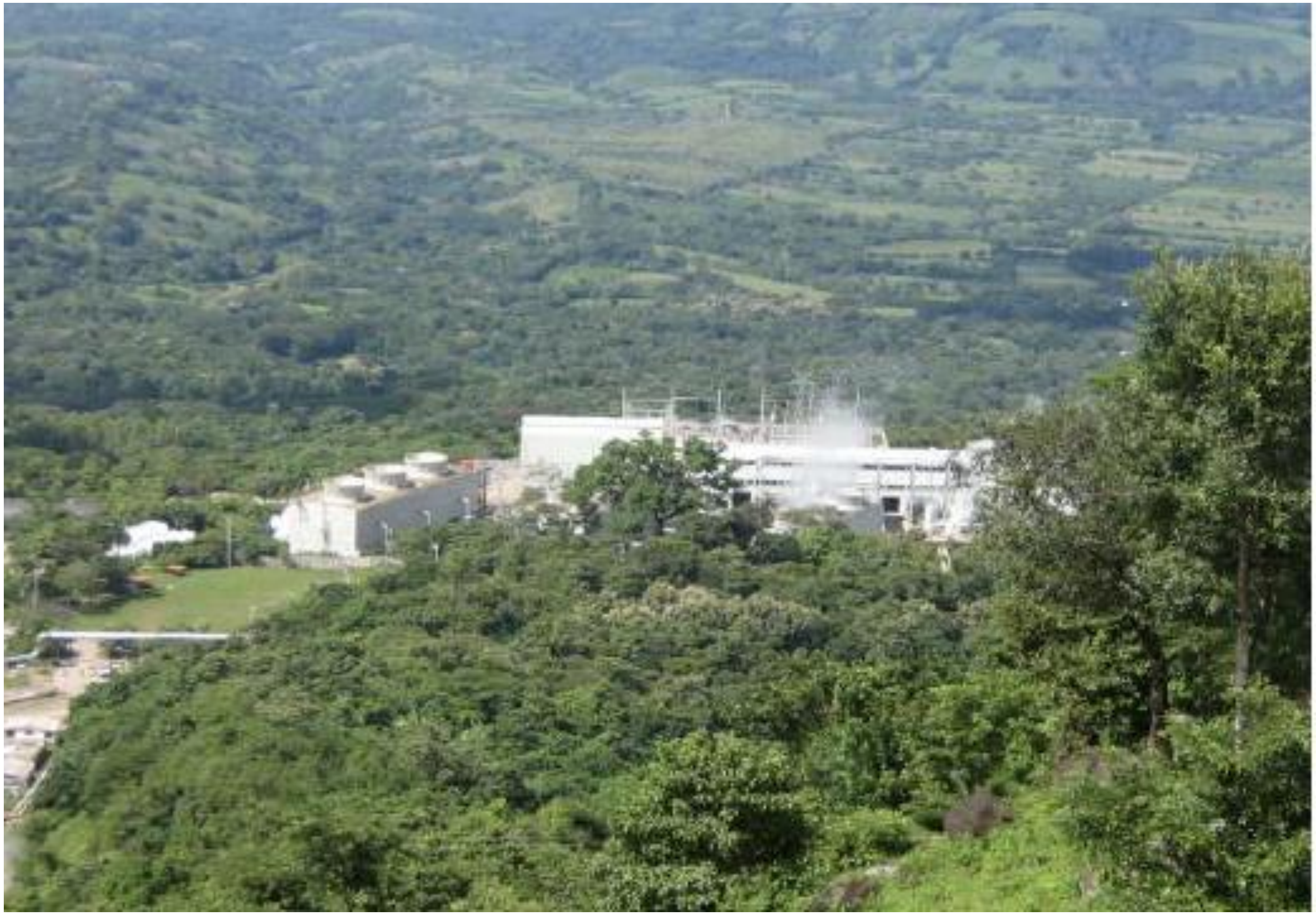
Cooling Tower: Marley; Niagara;

Economics

Power Plant Construction Cost:
$1,500 – $2,000 / kW

O&M Cost (direct): $15 - 20 / MWh

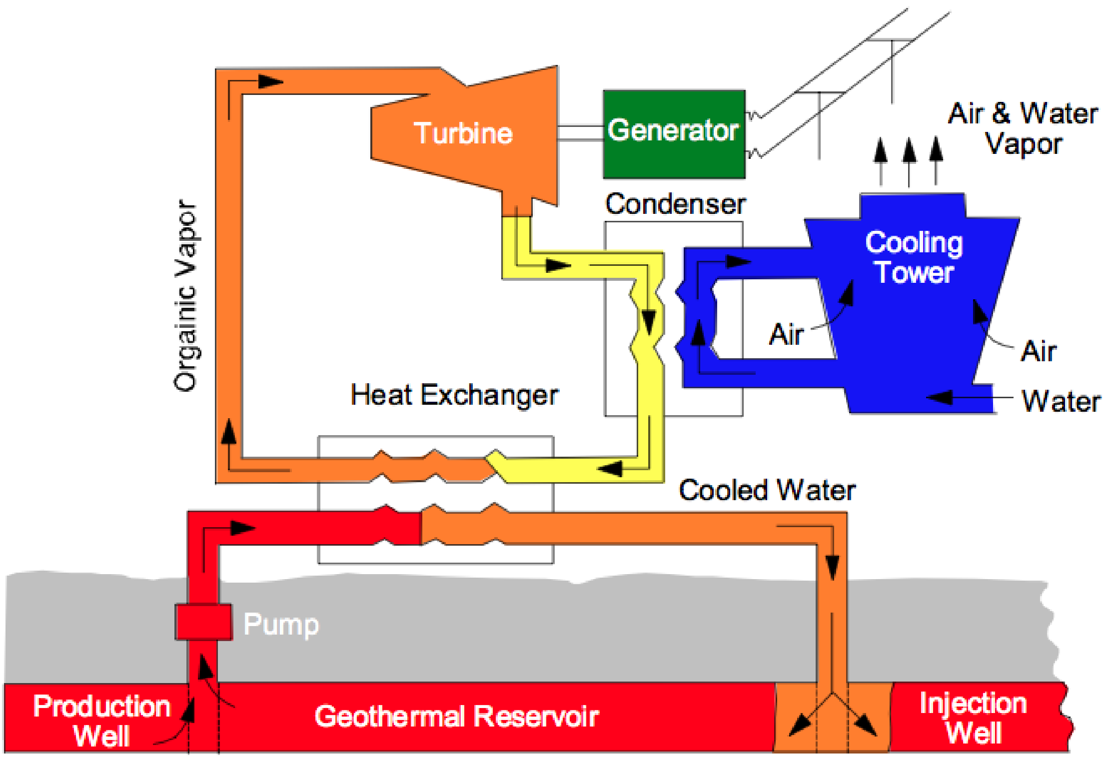
How Geothermal Energy is used



Berlin, El Salvador

How Geothermal Energy is used

Figure 30: Binary Power Plant Schematic



Source: Geo-Heat Center

Binary cycle power plants operate on water at lower temperatures of about **105-180ºC**. These plants use the heat from the geothermal water to boil a working fluid, usually an organic compound with a low boiling point.

How Geothermal Energy is used

Technology Advantages

- Can exploit low temperature heat sources
- Most equipment can be obtained from a variety of suppliers
- Plant can be constructed in shops on skid mounted modules for easy shipping and field assembly
  - Negligible emissions from NCGs
- All of the water drawn from the reservoir is return. Source generally have a higher useful life.

Technology Disadvantages

- Lower energy conversion rate than steam turbine plants
- More process equipment thus requiring more maintenance effort and expense
- Brines may have high concentrations of silica and/or Calcium salts which can cause troublesome scaling requiring frequent clean-ups of heat exchangers and wells.

used in cascade to flash plants improve the overall efficiency

Main Equipment Suppliers

Turbine/Expanders: Rotoflow; Elliott Turbines
Texas Turbines; Mafi-Trench
Air Products; Ormat, Turboden

Generators: GE; Alstom; Siemens, Kato

Condensers: Marley; Aerofin; BAltimore Coil

Economics

Power Plant Construction Cost:
$2,000 – $3,000 / kW

O&M Cost (direct): $15 - $20 /MWh

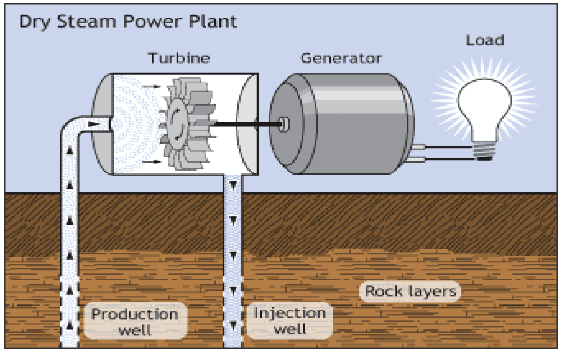
How Geothermal Energy is used

Typical Ormat Binary Power Plant Arrangement

Ormat SIGC Binary Plant (SIGC)
with Water Cooled Condensers

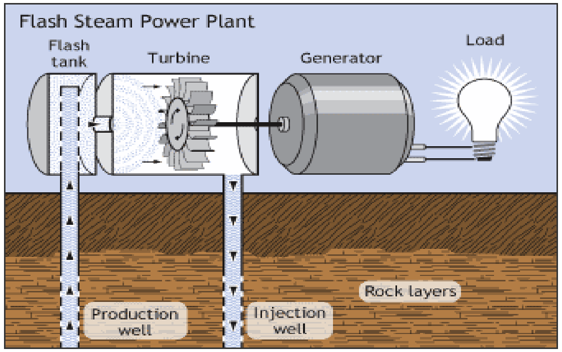
Ormat SIGC Binary Plant (Soda Lake II)
with Air Cooled Condensers

How Geothermal Energy is used



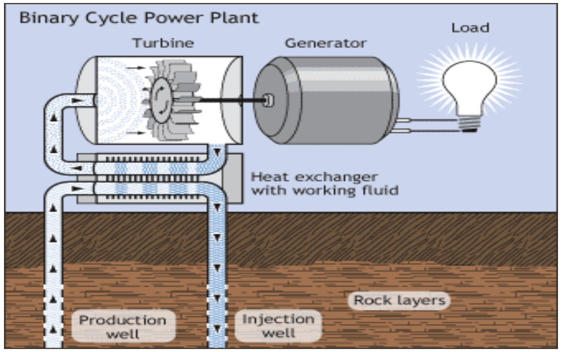
Dry steam plants

Highly cost competitive but geographically limited



Flash steam power plants

Most dominant in terms of global capacity



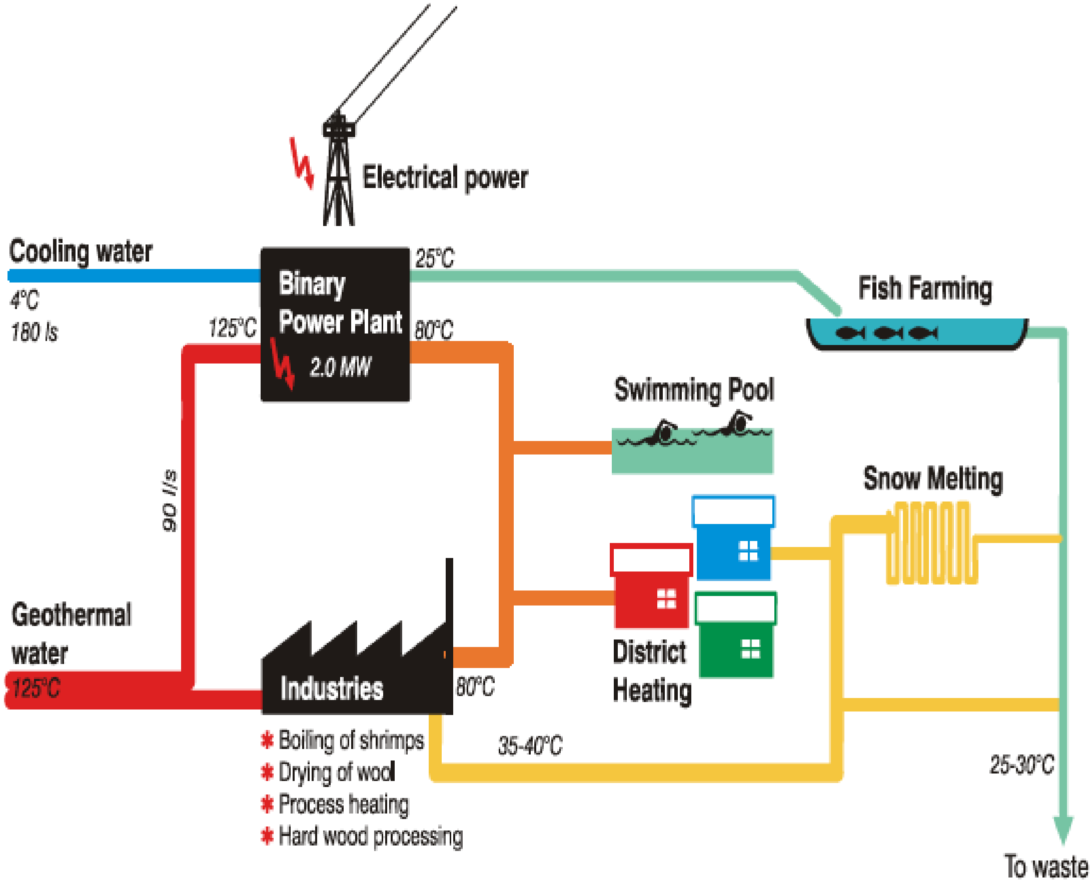
Binary cycle power plants

Useful alongside geothermal heating, hot springs, etc

Global Installed capacity 2010		Dry steam plants	Flash steam power plants	Binary cycle power plants
	Units	61	209	239
	Capacity (GW)	2.8	6.7	1.2
	Average size (MW)	~45	~29	~3

How Geothermal Energy is used

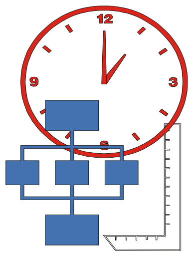
The efficiency of geothermal utilisation is enhanced considerably by cogeneration plants (combined heat and power plants), compared with conventional geothermal plants. A cogeneration plant produces both electricity and hot water which can be used for district heating as well as other direct uses. A necessary condition for the operation of a cogeneration power plant is that a relatively large market for hot water exists at a distance not too far from the plant.



How Geothermal Energy is used

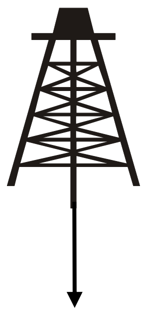
Investigation | Drilling, stimulation and reservoir assessment | Exploitation, economic, environmental and social impacts

Concept



General planning / geological screening
- conceptual
- technical
- political and environmental
- financial

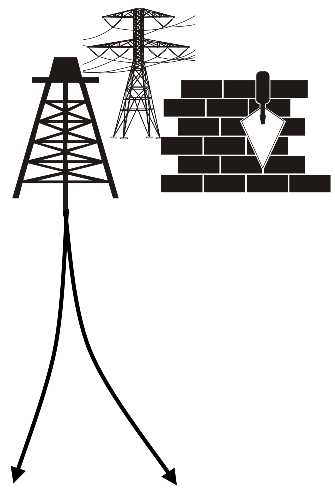
Site exploration



?

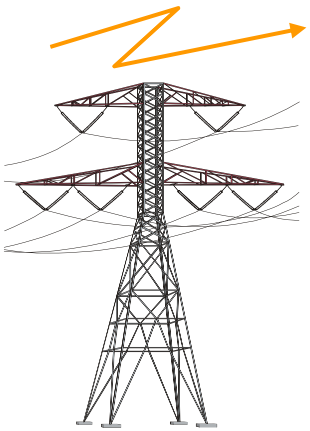
- Site screening
- Pilot borehole
- Stimulation tests
- Production modelling

Site development



- Inj./Prod boreholes
- Intensive stimulation
- Production tests
- Surface installations

Production



- Power/Heat production
- Maintenance

Abandonment

If no re-investment for this site: Deconstruction

Milestones

- Site selected
- Feasibility of resource demonstrated
- Installations and reservoir ready for production
- Production lifetime reached

From ENGINE

How Geothermal Energy is used

10 MW_t (thermal) ≈➔ 1MW_e (electric)

1 MW_e requires :

- 7 - 10 t/h of dry steam
- 30-40 t/h of bi-phase fluids at 200-250° C (flash technology)
- 400 - 600 t/h of water when using low enthalpy ORC binary cycles (120-160° C)

How Geothermal Energy is used

A economically feasible geothermal reservoir should lie at depths that can be reached by drilling, possibly less than 4 km (**accessibility requirement**).

A geothermal system must contain great volumes of fluid at high temperatures - a reservoir - that can be recharged with fluids that are heated by contact with the rock.

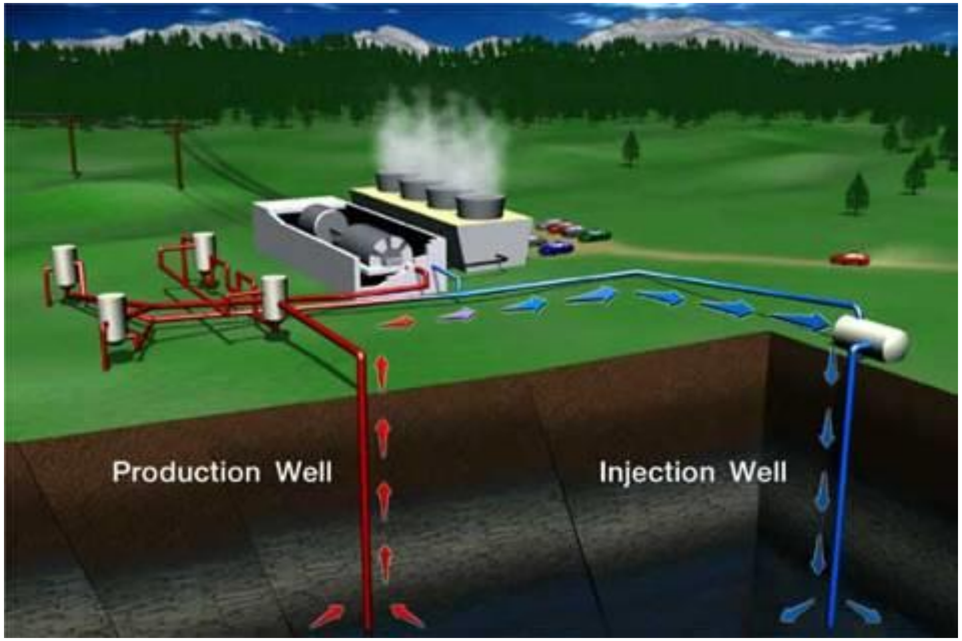
productivity requirement

For most uses, a well must penetrate permeable zones, usually fractures, that can support a high flow rate.

How Geothermal Energy is used

When sufficient natural recharge to the hydrothermal system does not occur, which is often the case, a reinjection scheme is necessary to ensure production rates will be maintained.

This would ensure the **sustainability** of the resource.

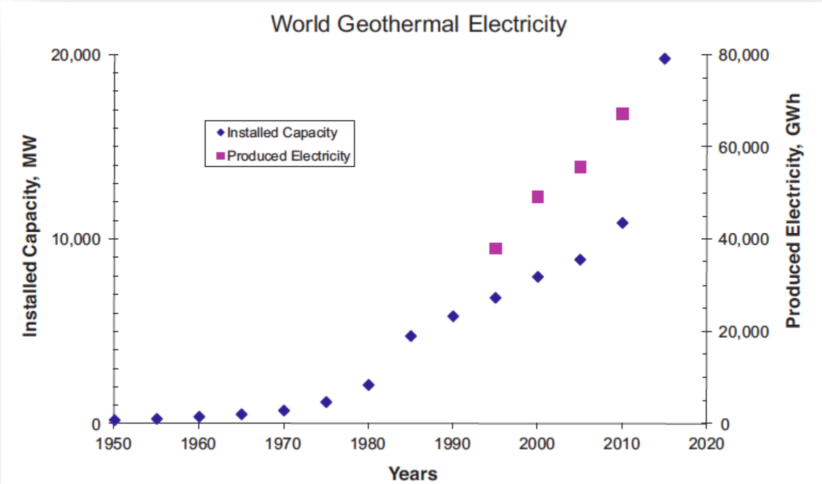


3

What is the production? What about the cost? And emissions?

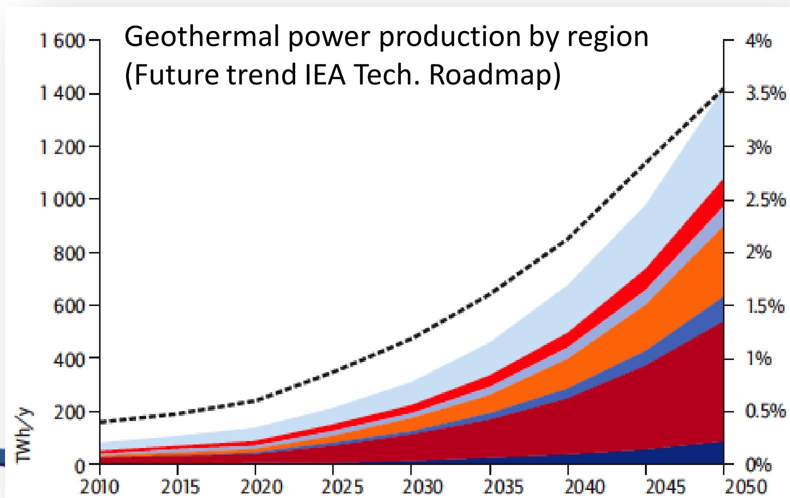
The advantages of using Geothermal Energy

Geothermal Energy **pros**



Bertani, 2012

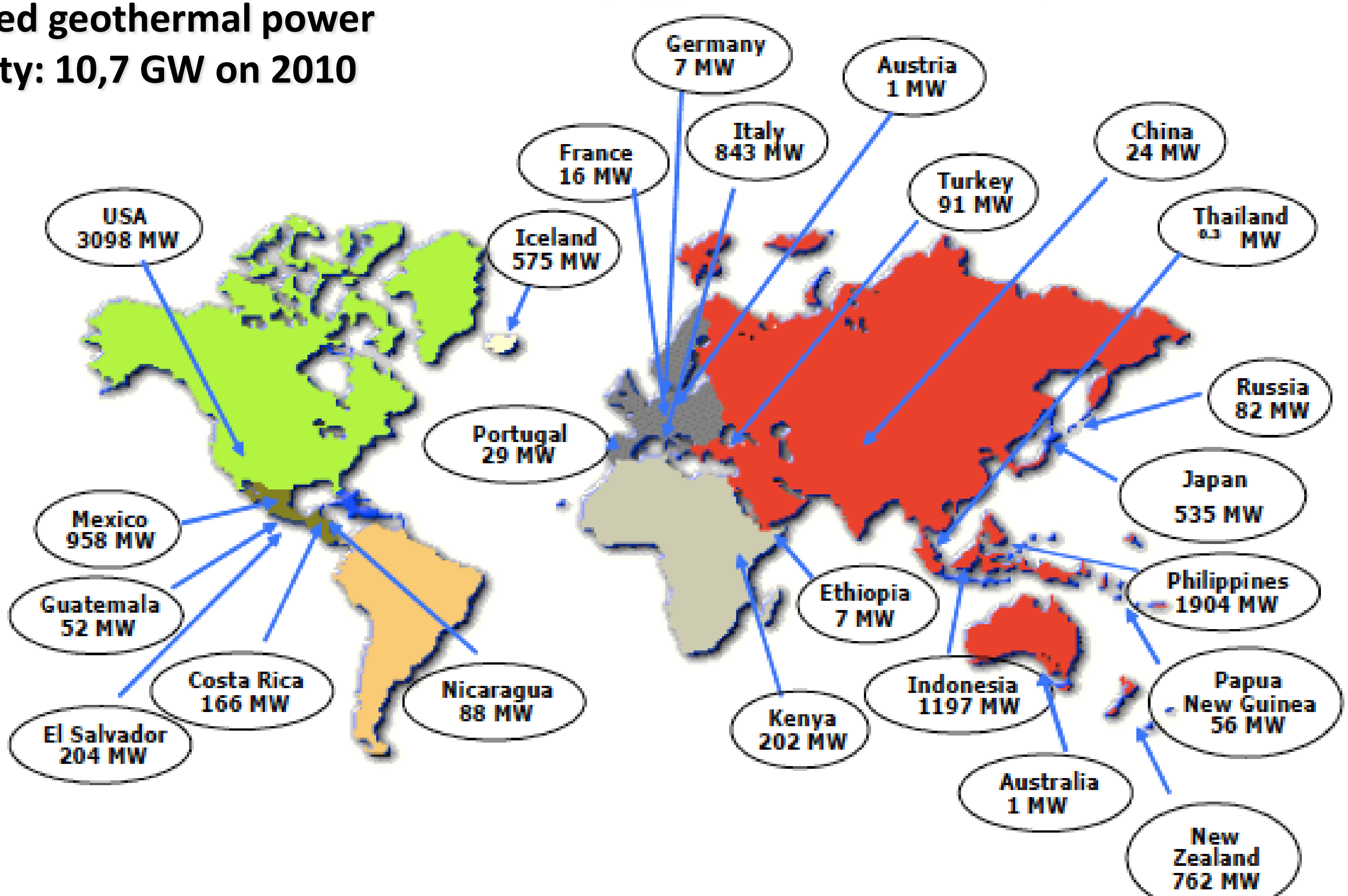
The two main applications of geothermal energy, electric power generation and direct use of heat, are currently producing more than 67 TWh/a$_e$ and 10 GW$_e$ of installed capacity, and about 300 TJ/yr with 30 GW$_{th}$



And are **constantly growing**.

Geothermal Energy pros

Installed geothermal power capacity: 10,7 GW on 2010



From Bertani, WGC 2010

Geothermal Energy pros

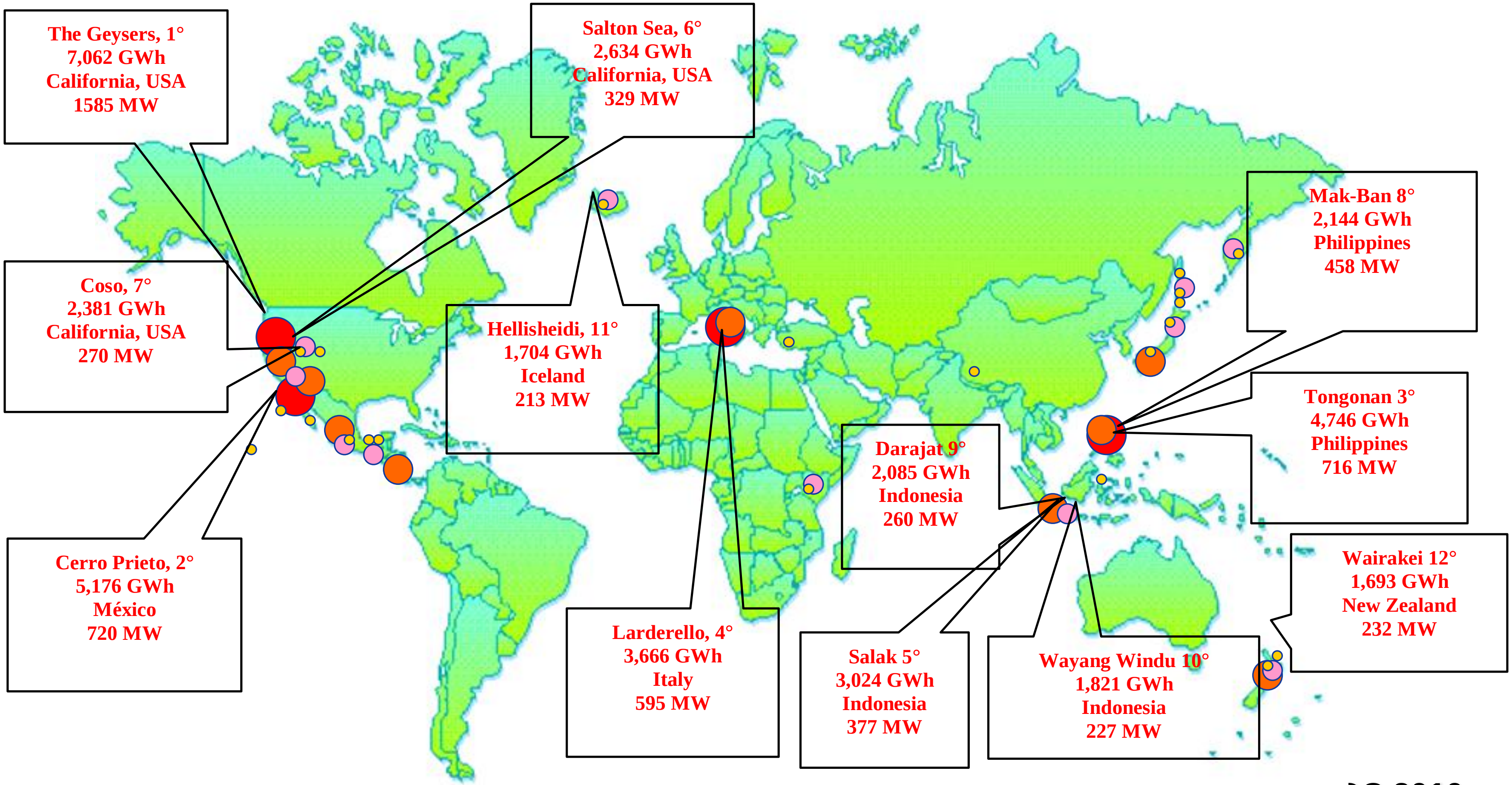
Installed geothermal power capacity: 10,7 GW on 2010

COUNTRY	2005 MW	2005 GWh	2010 MW	2010 GWh
USA	2,564	16,840	3,093	16,603
PHILIPPINES	1,930	9,253	1,904	10,311
INDONESIA	797	6,085	1,197	9,600
MEXICO	953	6,282	958	7,047
ITALY	791	5,340	843	5,520
NEW ZEALAND	435	2,774	628	4,055
ICELAND	202	1,483	575	4,597
JAPAN	535	3,467	536	3,064

From Bertani, WGC 2010

Geothermal Energy pros

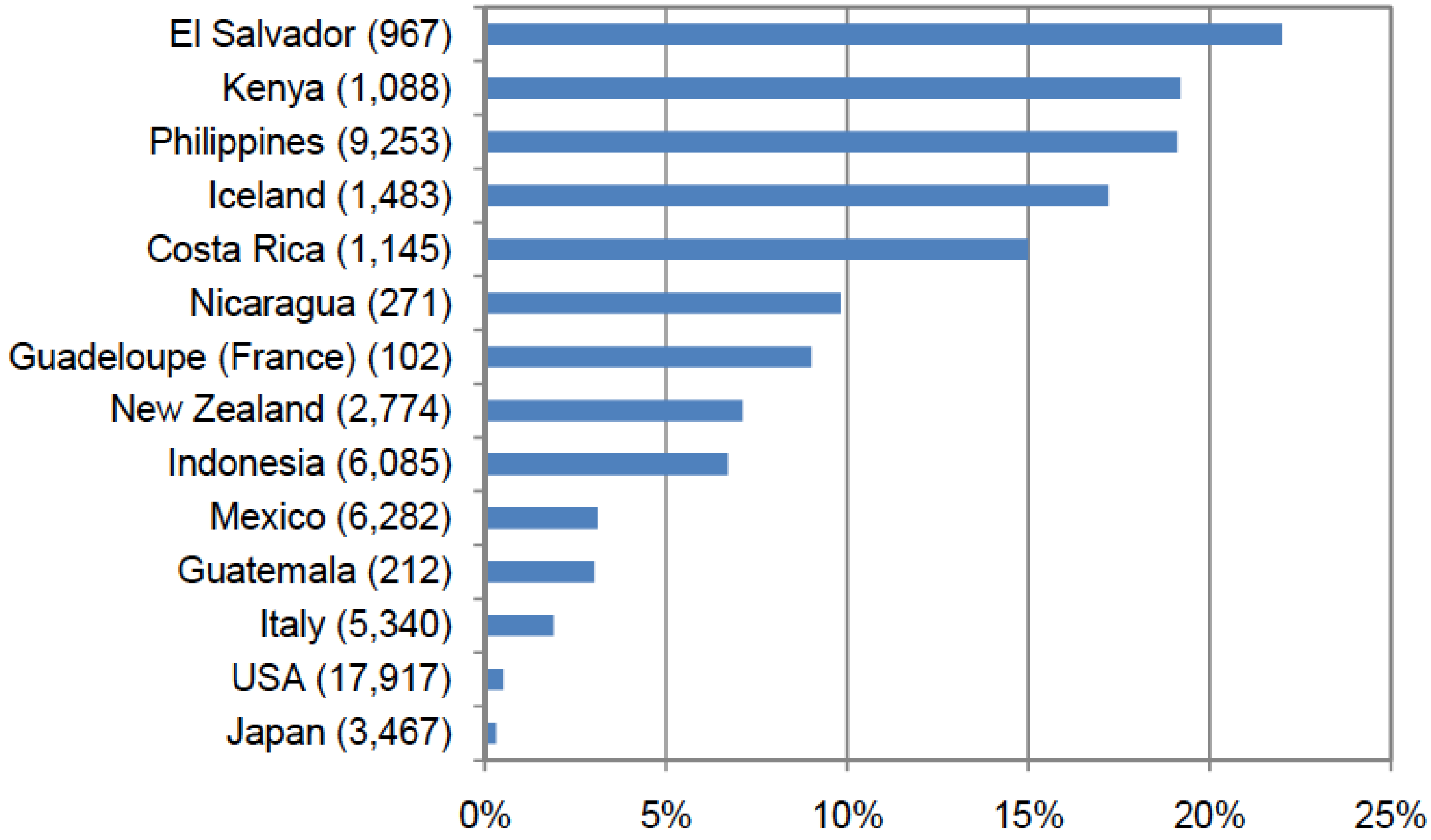
Geothermal power production by main field



From Bertani, WGC 2010

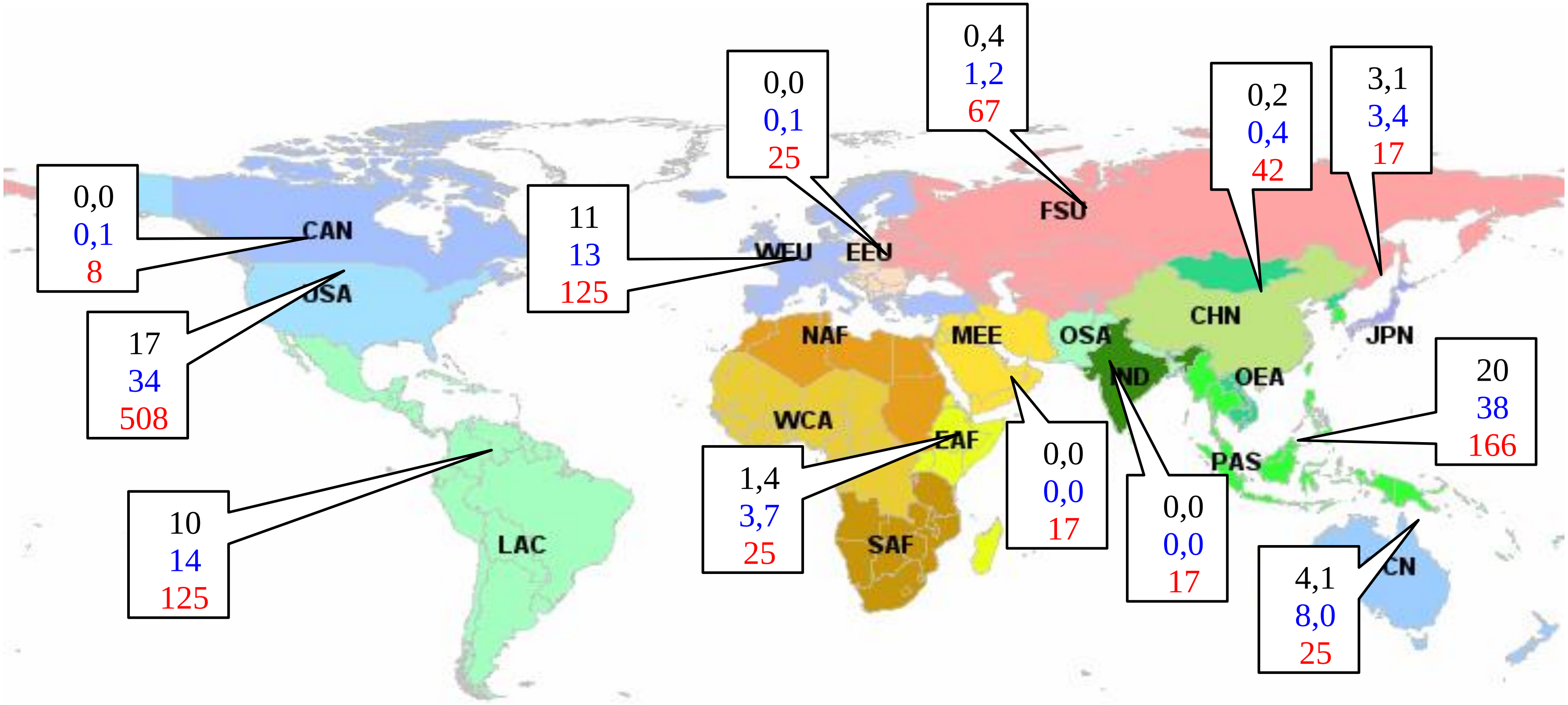
Geothermal Energy **pros**

Share of geothermal energy in national electricity production



Geothermal Energy **pros**

Foreseen growth of geothermal power production (TWh/a)

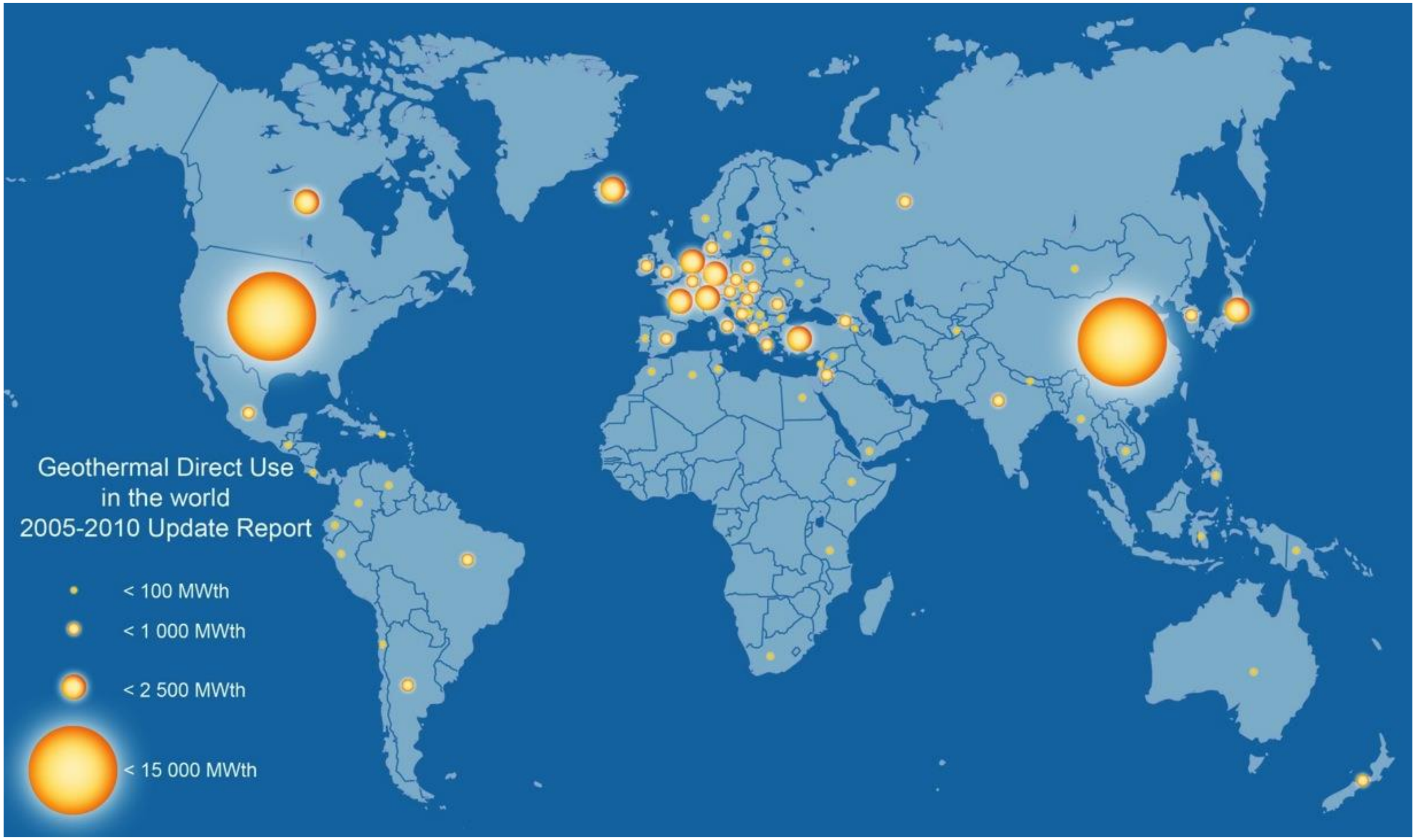


Color legend: 2010, 2015, 2050

Corrisponding to 10.7 GW on 2010, 18.5 GW on 2015 and 140 GW on 2050 (including 70 GW from EGS)

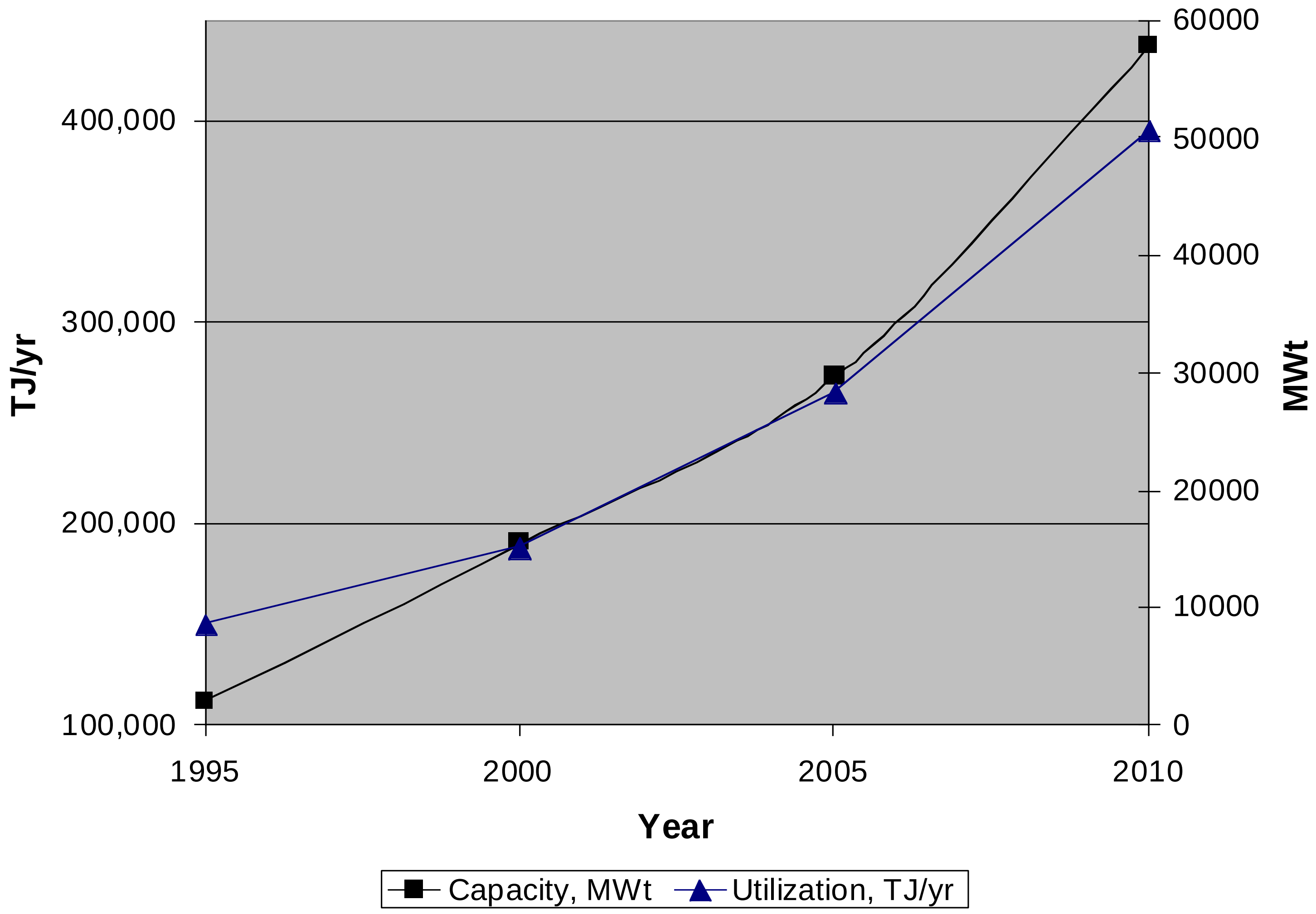
From Bertani, WGC 2010

Geothermal Energy **pros**

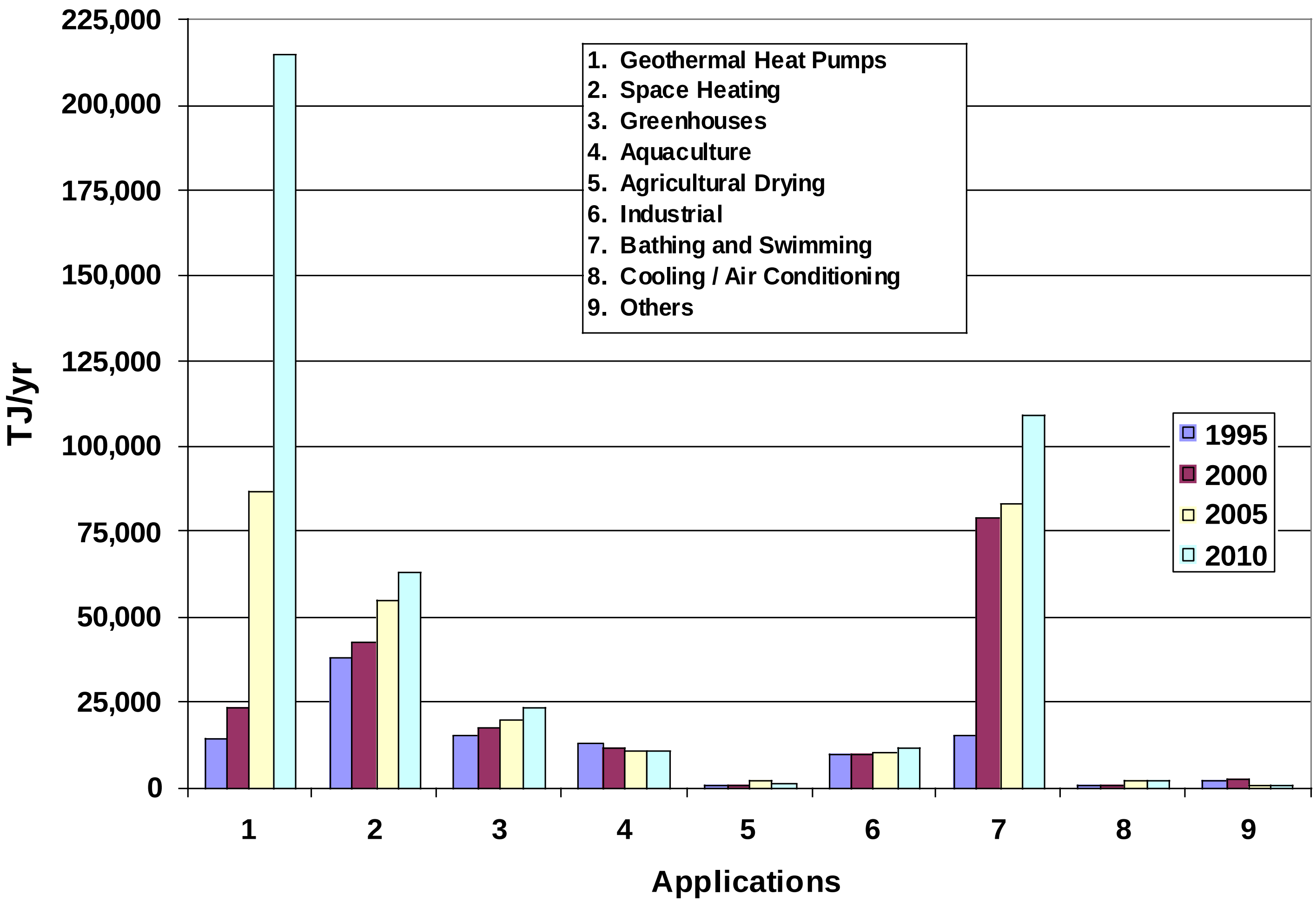


Installed heat capacity in the **79 countries** using geothermal heat was estimated at **43 GWt on 2010**

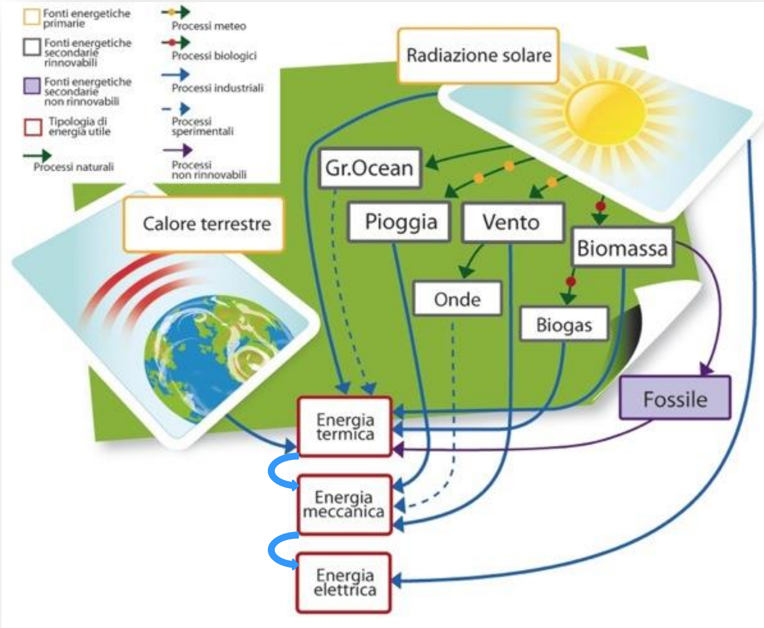
Geothermal Energy **pros**



Geothermal Energy pros

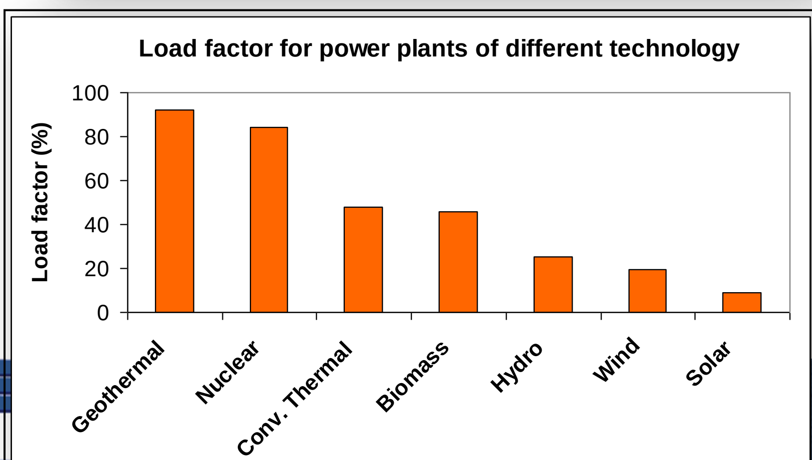


Geothermal Energy **pros**

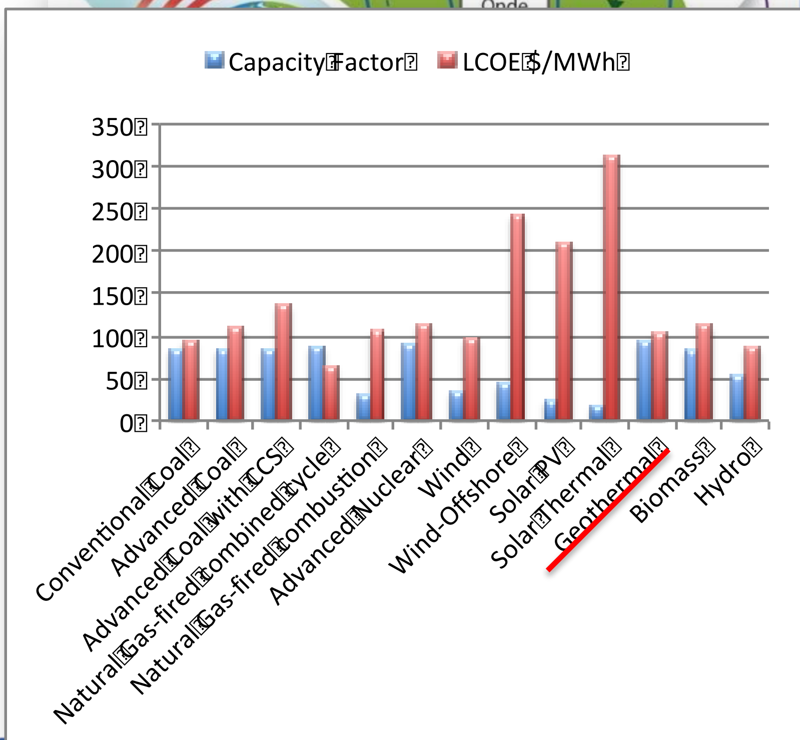


Not depending, directly or undirectly, on sun, geothermal may produce 24 hours per day:
a **base-load energy** like fossil and nuclear sources.

It is most economical for geothermal power stations to serve as **base load** throughout the year.



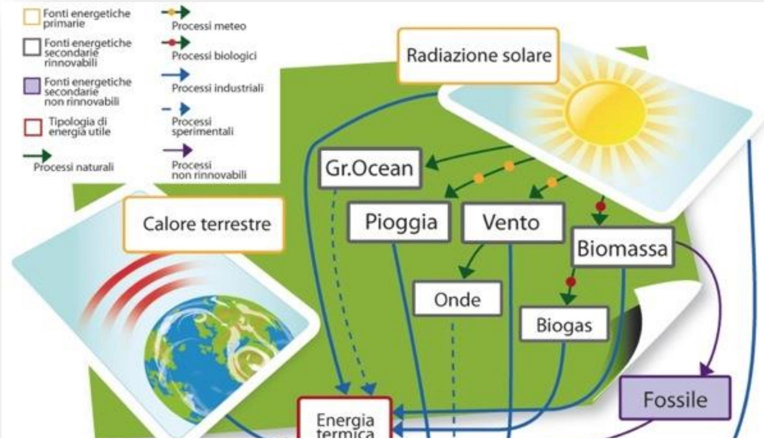
Geothermal Energy **pros**



The **total cost (LCOE)** of geothermal power production is **cheap** if compared to those of others renewables

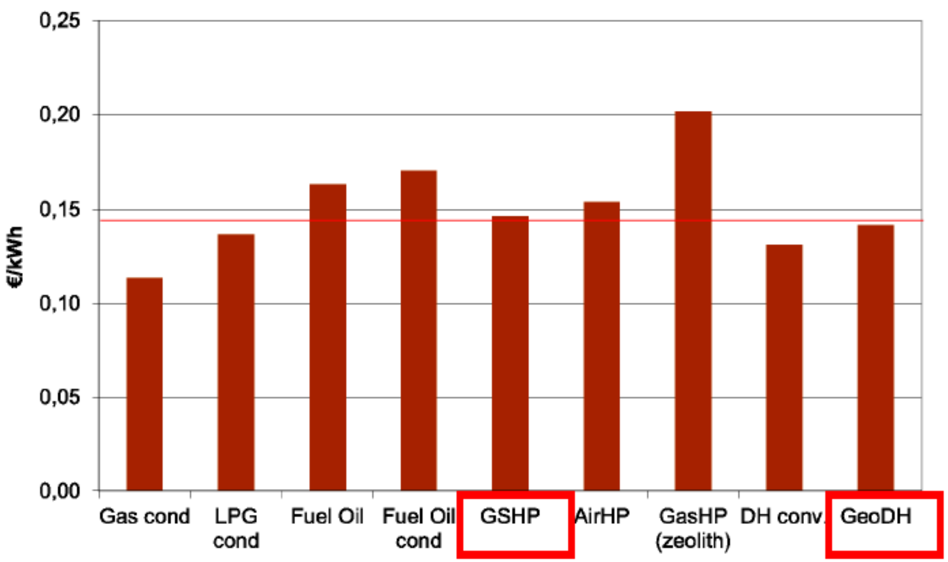
Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011, EIA

Geothermal Energy **pros**

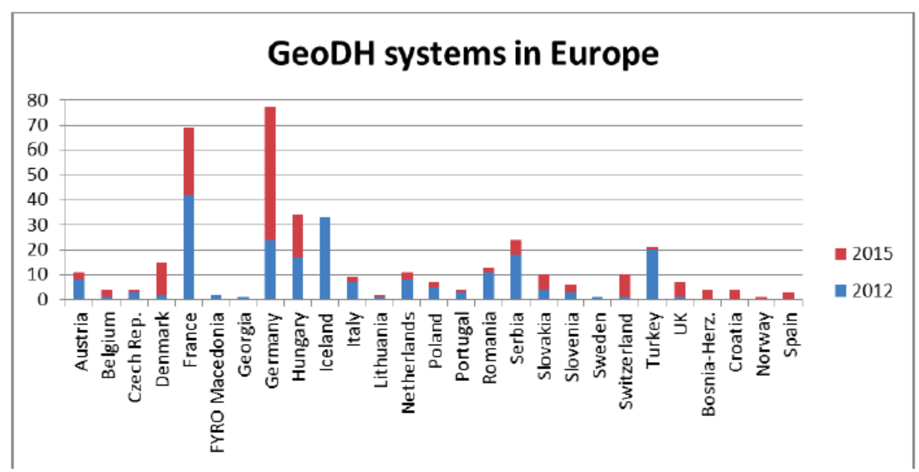


The **total cost (LCOE)** of geothermal power production is **cheap** if compared to those of others renewables and fuels

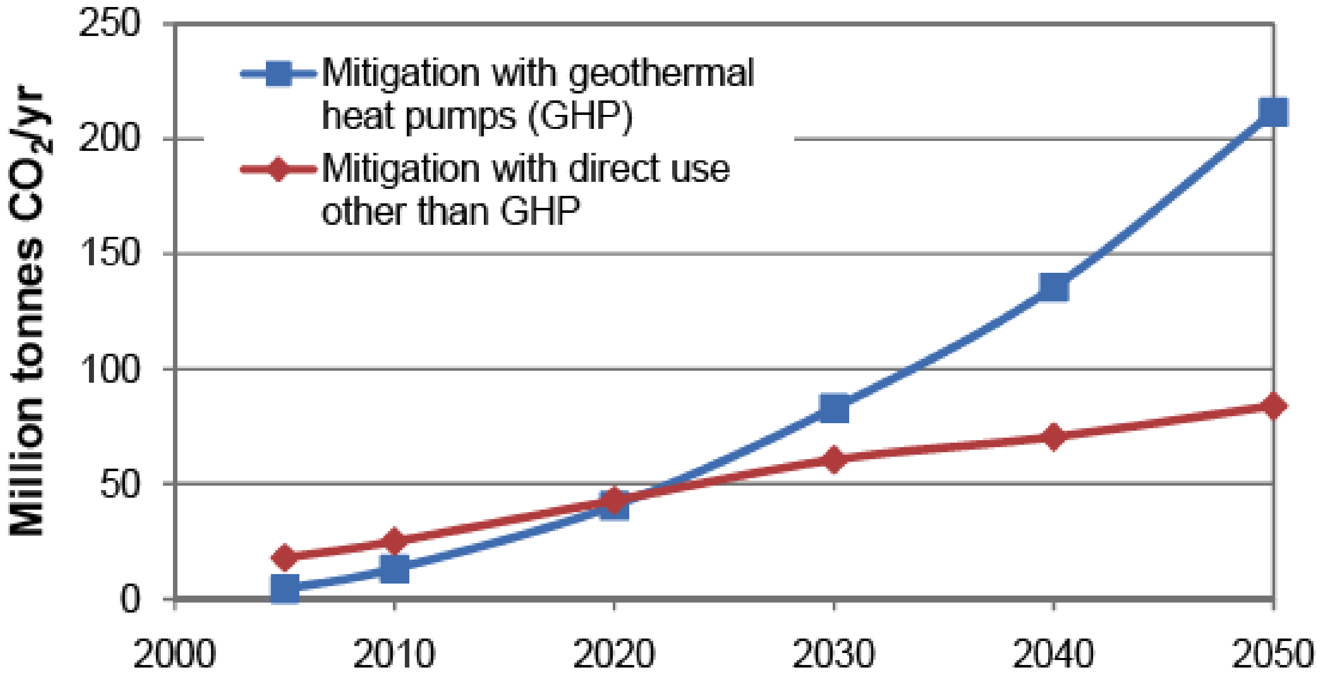
Full cost of Heat, calculated for small building or flat



GeoDH Systems in Europe



Geothermal Energy **pros**



CO_2 emission mitigation of Geothermal Heat. For each Geothermal Heat Pump (blue) it assumes an emission of 50 tonnes CO_2-equivalent/TJ. For other sources of geothermal heating (red) it assumes an emission of 4 tonnes CO_2-equivalent/TJ. Both assume an emission of 100 tonnes CO_2 equivalent/TJ for fossil heat provision. Fridleifsson et al., 2008

4

What are the risks? Environmental impact?

Disadvantages, needs and gaps of Geothermal Energy

Geothermal Energy **cons**

Thanks to the high capacity factor, the total cost (LCOE) of geothermal power production is comparable or cheap if compared to those of others renewables.

However, the **capital, up-front costs remain too high**, due to the scarcity of on-site data, the difficulty to forecast the production prior to drill combined with the high drilling costs.

Geothermal Energy **cons**

The average geothermal capacity on the entire 526 units in operation is 20.6 MW

BIG

Only 48 units with capacity >55 MW, with an average of 79.5 MW.

SMALL

There are 259 units with capacity < 10 MW, with an average capacity of 3.2 MW. The majority of them is binary (196 units), 22 are back pressure, 22 are single flash and 17 double flash.

Geothermal Energy **cons**

- The economics of electricity production is influenced by the drilling costs and resource development;
- The productivity of electricity per well is a function of reservoir fluid thermodynamic characteristics (phase and temperature);
- The higher the energy content of the reservoir fluid, the lesser is the number of required wells and as a consequence the reservoir CAPEX quota is reduced
- The small dimention of most plants enhance the risk of investment

Geothermal Energy **cons**

Environmental impact – main categories

- Surface disturbances
  - Landscape, surface water
- Physical effects
  - Fluid withdrawal on natural manifestations, land subsidence, induced seismicity, visual effect (buildings, cooling towers, surface pipelines, power transmission lines etc.)
- Noise
- Thermal pollution
  - liquid and steam release on the surface
- Chemical pollution
  - Liquid and solid waste disposal, gas emissions to the atmosphere
- Ecological protection
  - Flora and fauna

Geothermal Energy **cons**

Activities causing environmental impacts

- Building of access roads and drilling pads

Geothermal Energy **cons**

Activities causing environmental impacts

- Building of access roads and drilling pads
- **Well drilling, repairs, stimulation and testing phase**

Geothermal Energy **cons**

Activities causing environmental impacts

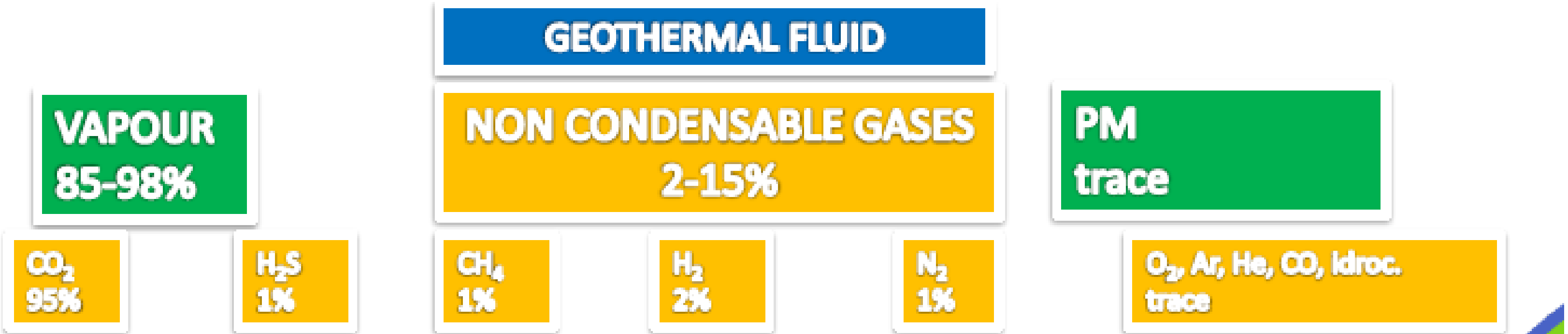
- Building of access roads and drilling pads
- **Well drilling, repairs, stimulation and testing phase**
- Laying of pipelines, electric power transformation and transmission lines

Geothermal Energy **cons**

Activities causing environmental impacts

- Building of access roads and drilling pads
- **Well drilling, repairs, stimulation and testing phase**
- Laying of pipelines, electric power transformation and transmission lines
- Plant construction and equipment installation
- Power plant commissioning and operation
- Decommissioning of facilities

Geothermal Energy **cons**



kg/MWh net	NO_x	SO_2	PM	H_2S	CO_2
Fossil fuels	0.49	0.54	0.024	0	691
Geothermal	0	0	0	3.09 in 2007 1.73 in 2011	372 in 2007 340 in 2011

ENVIRONMENTAL REPORT _ENEL_2011

Geothermal Energy **cons**

Enel, in order to mitigate the H_2S and Hg effluent to the environment with a specific treatment, uses a technology fully designed and developed by Enel: AMIS plant, reaching a very high efficiency in H_2S and Hg removal, lower capital and O&M costs in comparison with commercial process, no solid sulphur by-products (liquid streams reinjected in the reservoir) and unattended operation (remote control).

Approximately 80% of the effluents are currently treated by AMIS systems.

Geothermal Energy **cons**

The real **geothermal potential is scarcely known**, it is seldom defined in detail by the countries and properly introduced in the Energy Plans

Larderello, 1904

Although geothermal energy has a long tradition for application in Italy, there is little **awareness** of its potential, and the role it might play for energy production among renewables.

Geothermal Energy **cons**

Thanks to the high capacity factor, the total cost (LCOE) of geothermal power production is comparable or cheap if compared to those of others renewables.

However, the capital, up-front costs remain too high, due to the scarcity of on-site data, the difficulty to forecast the production prior to drill combined with the high drilling costs.

The real geothermal potential is scarcely known, it is seldom defined in detail by the countries and is not properly introduced in the Energy Plans

Geothermal Energy **cons**

- A comprehensive identification of resources and opportunities, as well as an accessible collection of data and information
- A clear and easy to follow regulation for authorizations in the exploration, drilling and exploitation phases of the project
- The promotion and dissemination of technology, values, economics
- Research and technological development

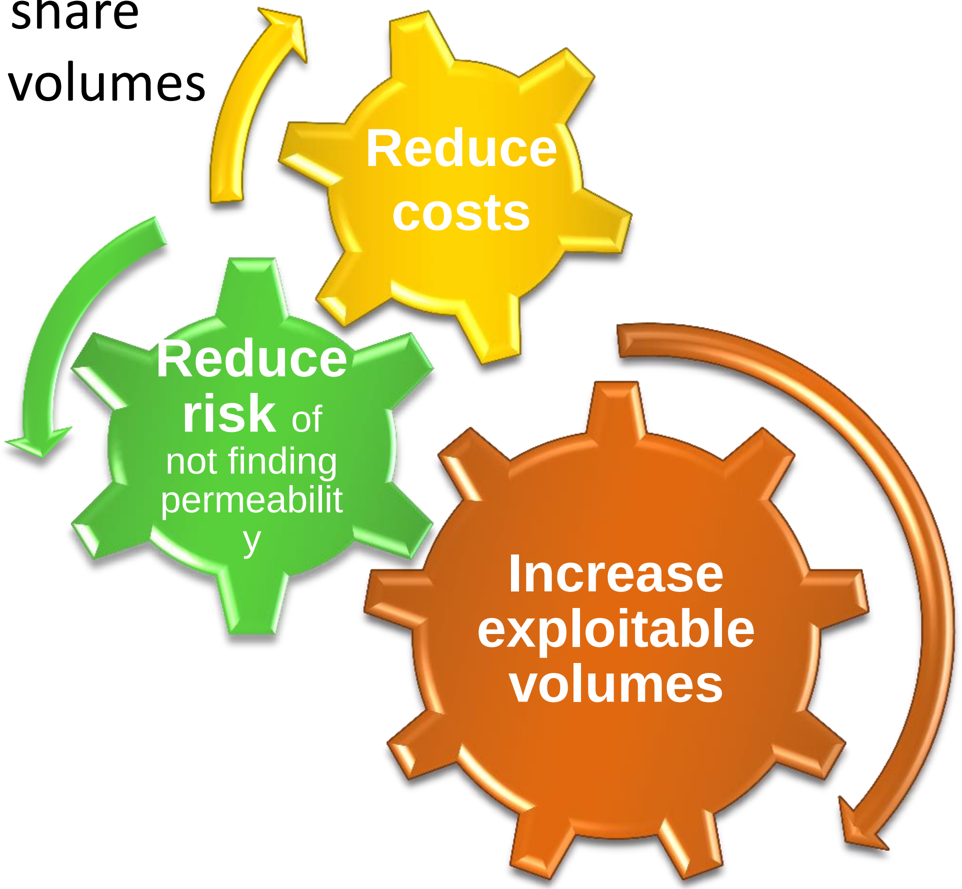
5

Reducing cons while increasing pros: how?

Research frontiers of Geothermal Energy

Research in Geothermal Energy

Ultimate goal: Increase the share by increasing the exploitable volumes



Technology & research efforts

Exploration and investigation technology: Improvement of the probability of finding an unknown geothermal reservoir and better characterize known reservoir, optimizing exploration and modeling of the underground prior to drill. Require also clear terminology, methodology and guidelines for the assessment of geothermal potential. It will result in an ***increased success rate***.

Drilling technology: improvements on conventional approaches to drilling such as more robust drill bits, innovative casing methods, better cementing techniques for high temperature, improved sensors, electronic capable of operating at higher temperature in downhole tools, revolutionary improvements utilizing new methods of rock penetration. It will result in ***reducing the drilling cost*** and it will allow to ***access deep and hot regions***.

Power conversion technology: improving heat-transfer performance for low temperature fluid, developing plant design with high efficiency and low parasitic losses. It will ***increase the available resource basis*** to the huge low-temperature regions, not only those having favorable geological conditions.

Technology & research efforts

Operation technology: increasing production flow rate by targeting specific zones for stimulation, improving heat-removal efficiency in fractured rock system. Refine stimulation methods (permeability enhancement) for Engineered Geothermal Systems (EGS) and reduce the risk associated with induced seismicity. It will lead to an immediate ***cost reduction increasing the output per well and extending reservoir operating life***.

Management technology: retrieve, simulate and monitor geothermally relevant reservoir parameters that influence the potential performance and long-term behavior. It includes the development of a **Zero-emission technology**, by mean of the total reinjection of fluid (and gases) within the reservoir without cooling and secondary effects.

It will secure the ***sustainable production*** achieved by using the correct production rates, taking into account the local resource characteristics (field size, natural recharge rate, etc.), extending the reservoir operating life and producing a benefit for the environment.

Technology & research efforts

Unconventional Geothermal Systems (UGR) technology: emerging activities to harness energy from nowadays non-economic reservoir would make significant progress with qualified input from research. in particular, reservoirs with ***supercritical fluids*** (fluids in the thermodynamic area above the critical temperature and pressure) and ***geopressurized reservoirs*** (deep sedimentary basins where fluids show high pressure and are rich of chemical elements or gases). This includes, beside peculiar power conversion and reservoir technology, also Operation & Maintenance techniques in aggressive geothermal environments, since they require specific solutions for corrosion and scaling problems. It will lead to an ***overall increase in power production***

Research in Geothermal Energy

Goal: increase production

Increase the heated mass of fluid

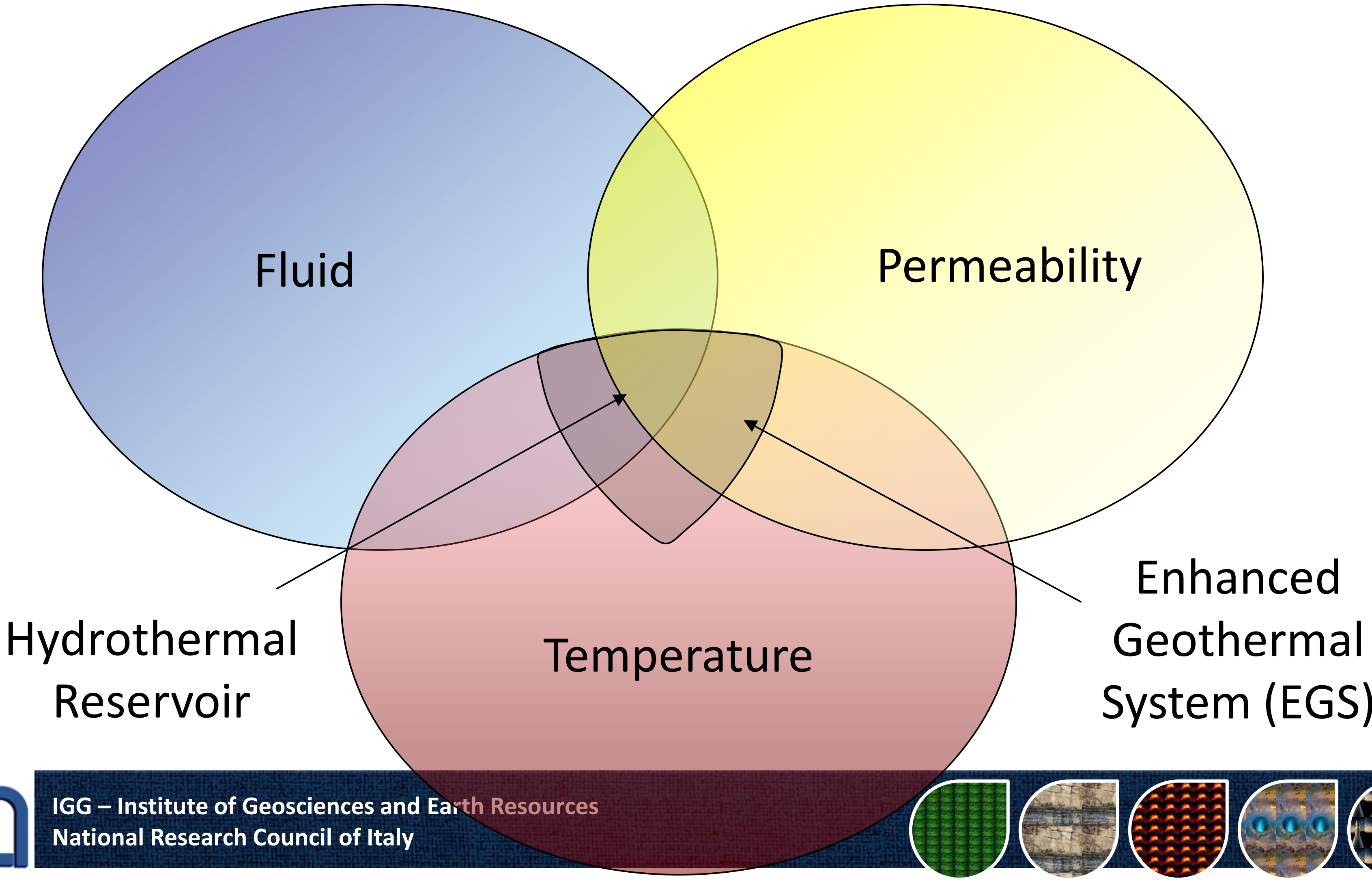
Target1: > permeability (EGS)

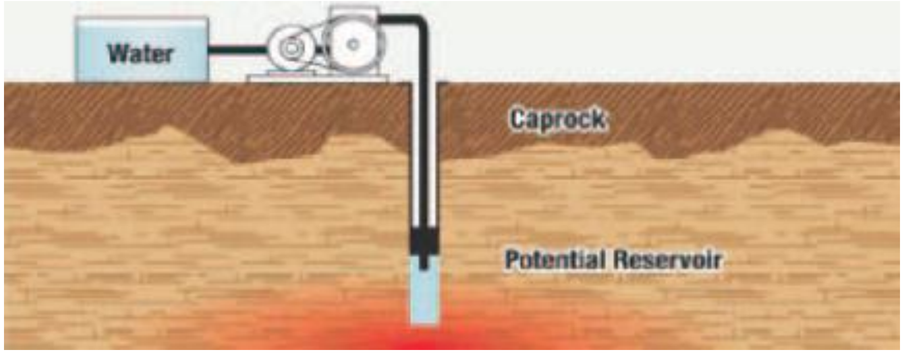
Target2: > number of sites

Target3: Increase efficiency of power and heating&cooling production per unit mass of fluid

Research in Geothermal Energy

Target1: > fluid mass, > permeability

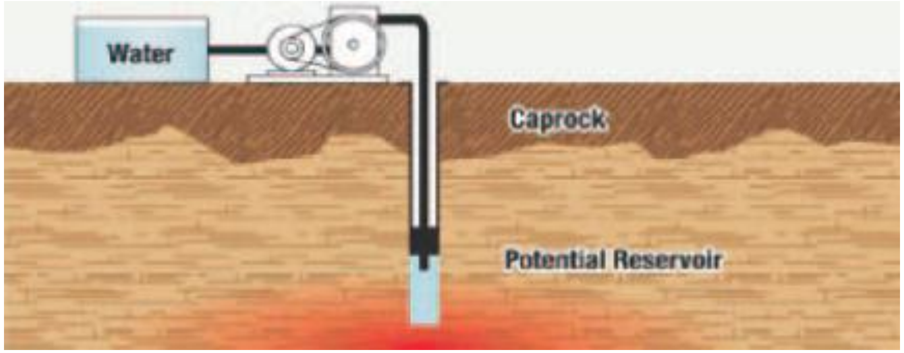


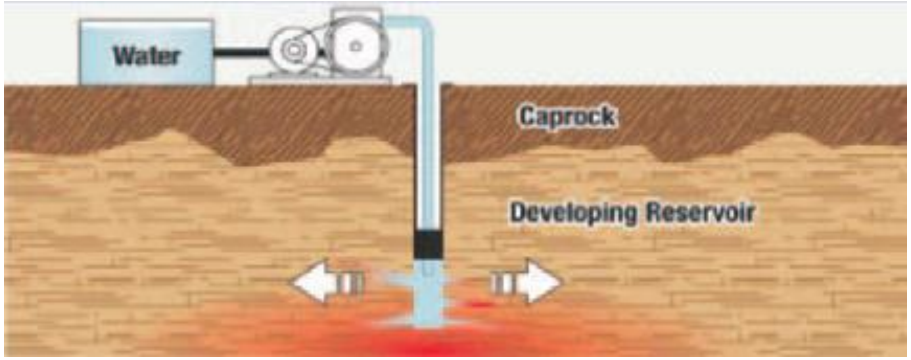


How it works

Injection well in low permeability rocks and useful T°

International Energy Agency

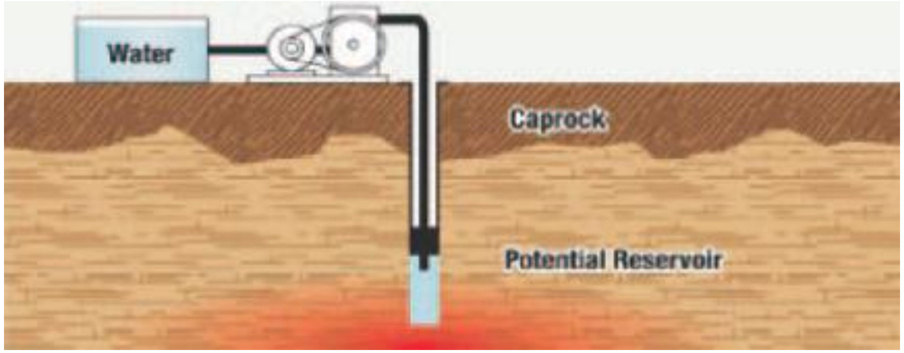


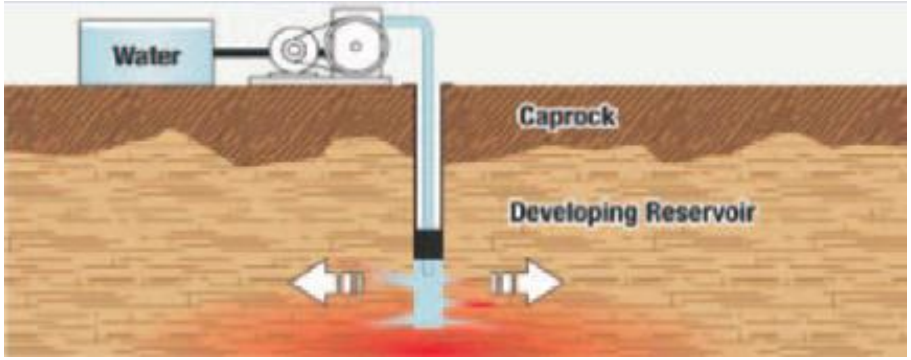


How it works

Water is injected at P able to fracture or expand existing fractures

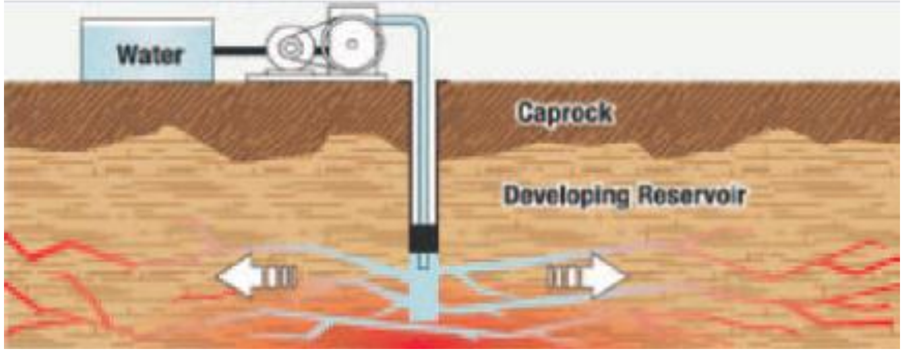
International Energy Agency



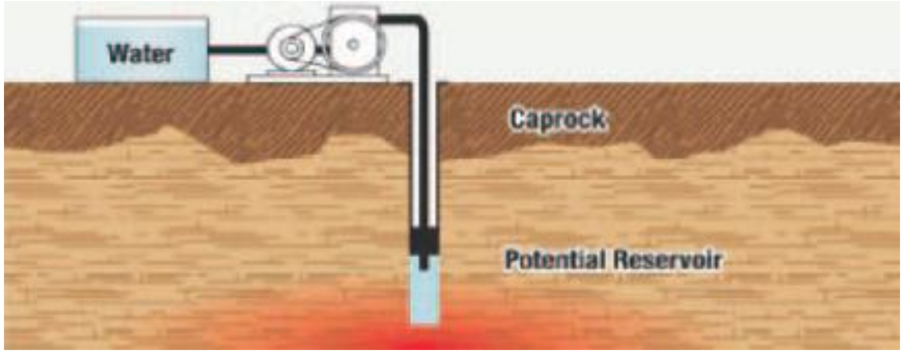


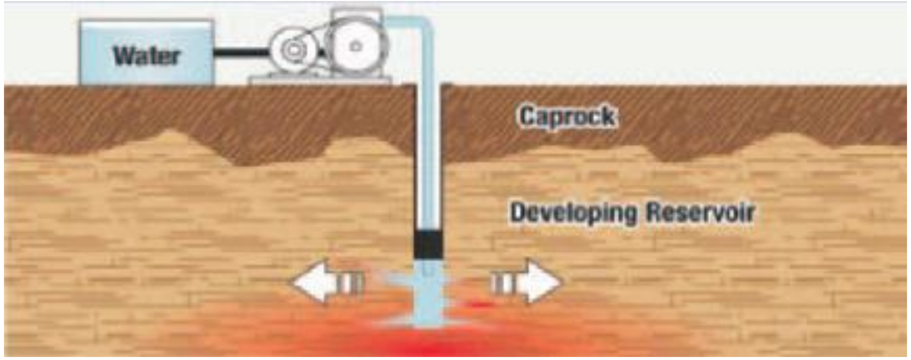
How it works

Hydrofracturing expand fractures



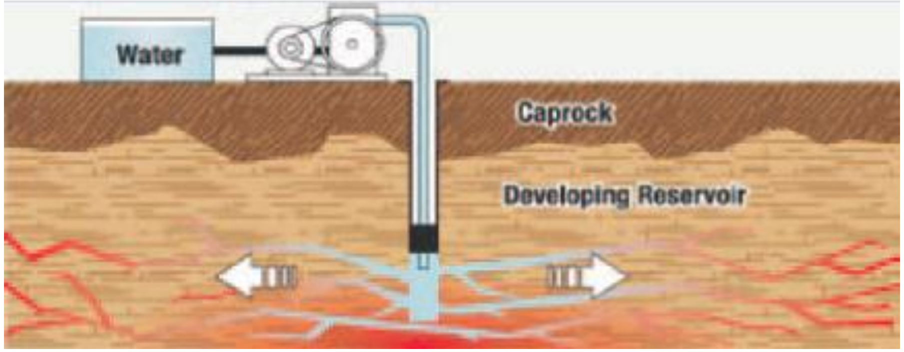
International Energy Agency

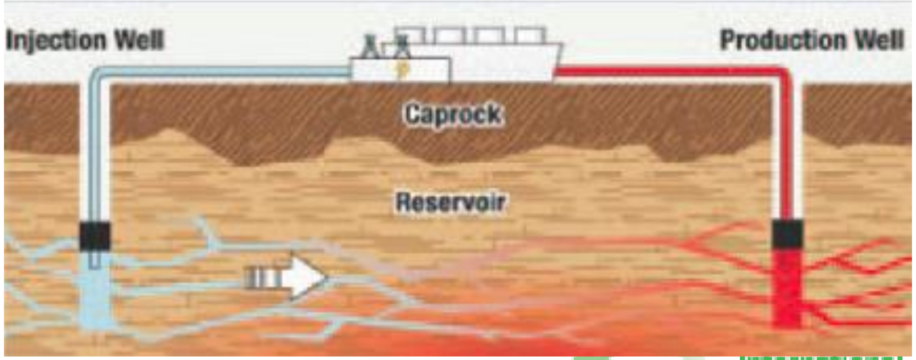




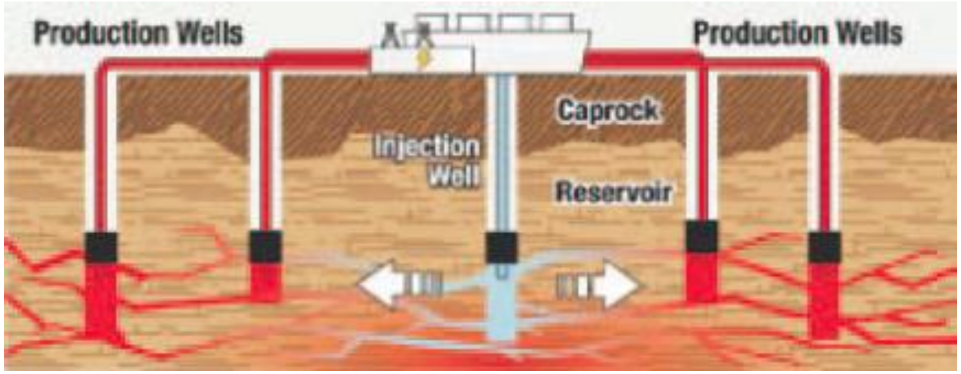
How it works

Through a **production well** fractures are intercepted and water is circulated and heated





International Energy Agency

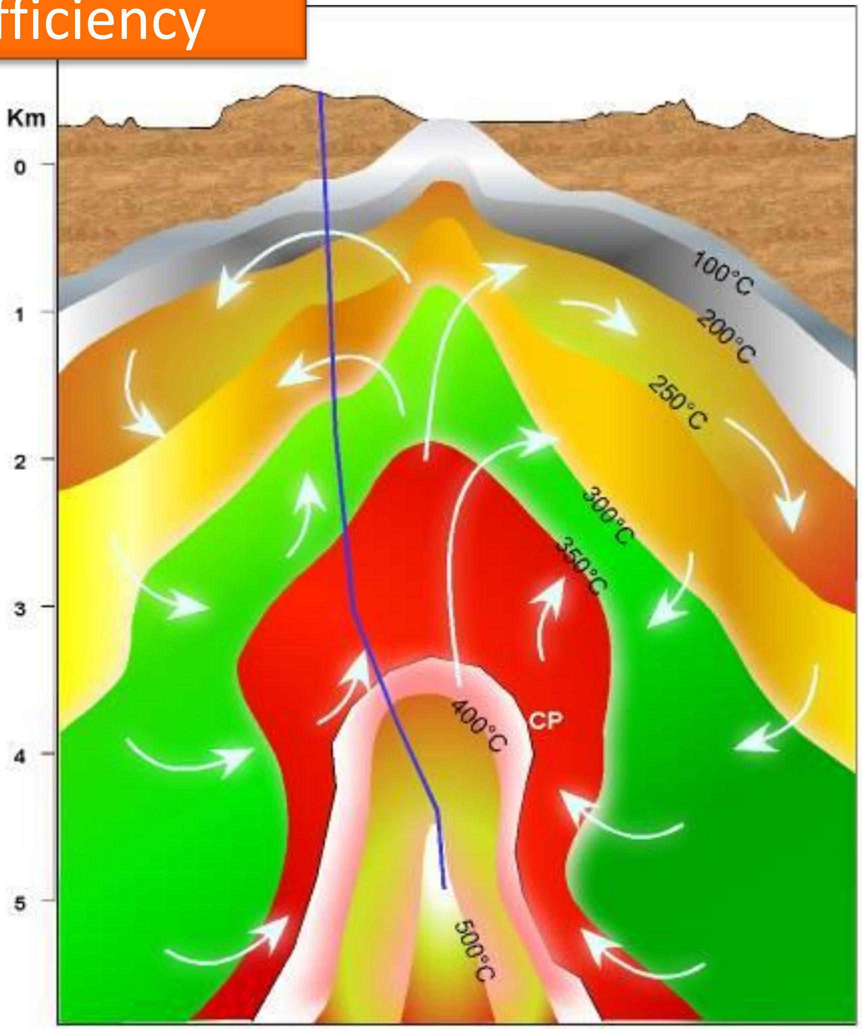


Production by new wells and enhanced fracturation/circulation

Research frontiers of Geothermal Energy

Target2: > sites, Target 3 > efficiency

Supercritical fluid resources.
A deep well producing 2500 m^3/h of steam from a reservoir with a temperature significantly above 450°C could yield enough high-enthalpy steam to generate 40-50 MW of electric power.
This exceeds by an order of magnitude the power typically obtained from conventional geothermal wells. This would mean that much more energy could be obtained from presently exploited high-temperature geothermal fields from a smaller number of wells.



Conclusions

Geothermal is a "cheap", sustainable, clean, flexible and base load energy

when we are lucky enough to produce it economically (T and fluid)

Geothermal is an energy known and used since the dawn of civilization

but very few are aware of it

Geothermal energy still require a lot of efforts in research, to optimize technology and reduce the investment risk

Geothermal energy may provide an important contribution to energy efficiency in many processes (most of our energy consumption is for heating!)

Geothermal areas are all beautiful!!!!

Jigokudani Hot Springs – Giappone