



National Research Council of Italy

Institute of Geosciences and Earth Resources

Geothermal Energy

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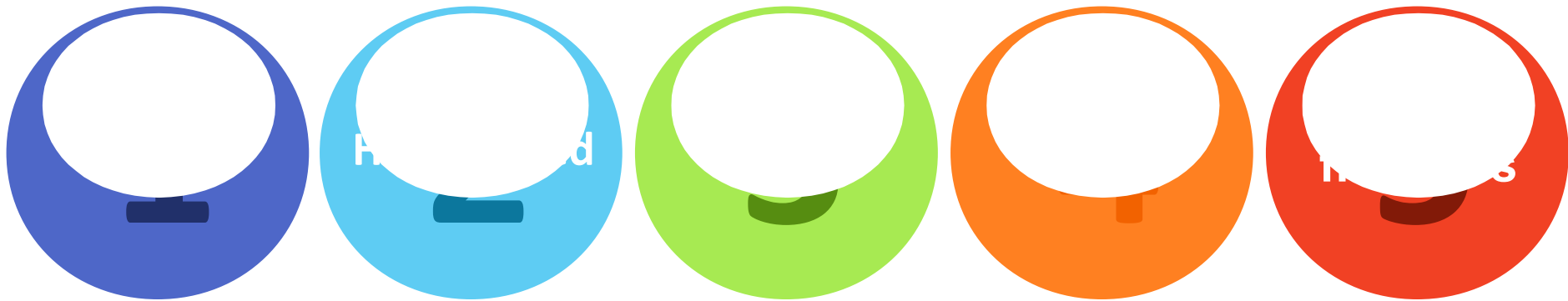
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JOINT EPS-SIF INTERNATIONAL SCHOOL ON ENERGY, Varenna, Italy, July 20-31, 2014



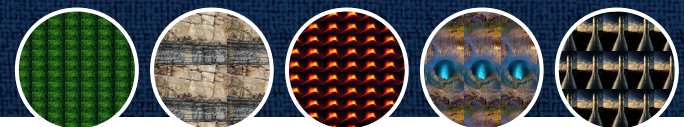
Geothermal Energy



Status and perspectives 



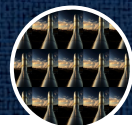
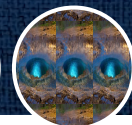
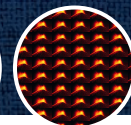
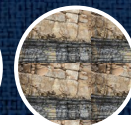
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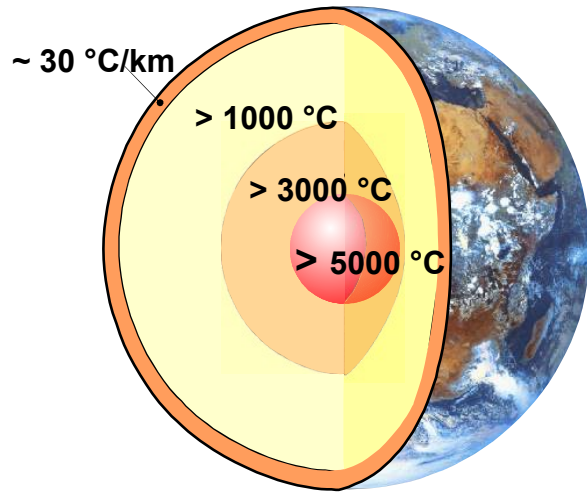


Source of geothermal energy? What part is used?

What is Geothermal Energy

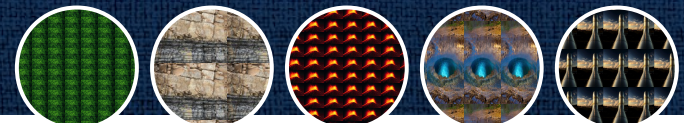


WHAT is Geothermal energy

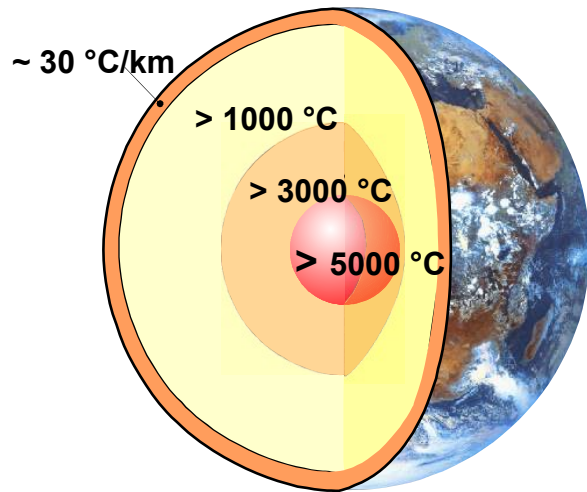


The basis of geothermal energy is the immense heat content of the earth's interior: the Earth is slowly cooling down. Since billions of years the heat in the Earth Crust is constantly supplied by the decay of natural radioactive isotopes or the cooling of hot, shallow magmatic bodies.

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



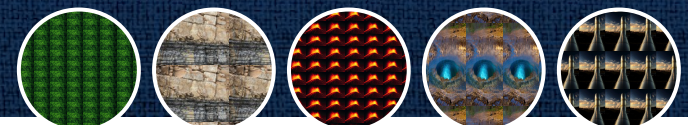
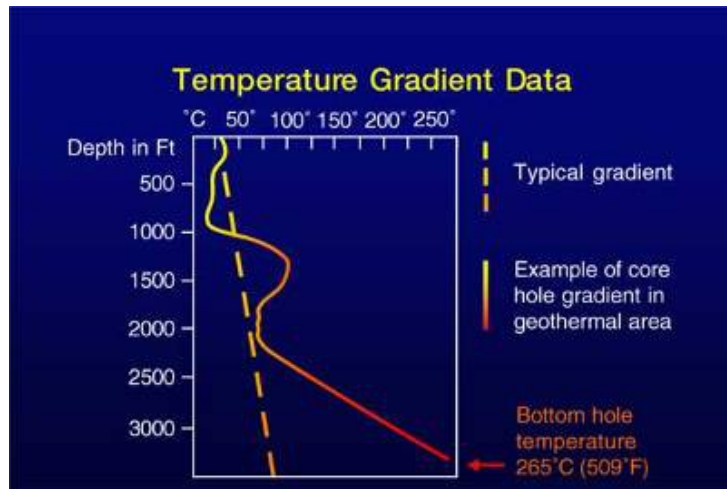
WHAT is Geothermal energy



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

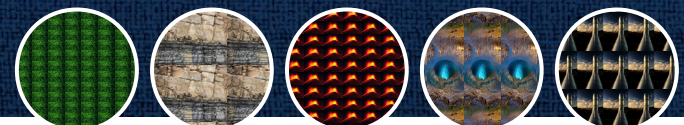
However, only a fraction can be used with actual technology, where a carrier (water in the liquid phase or steam) may "transfer" the heat from deep hot zones to or near the surface, thus giving rise to geothermal resources.

Direct heat exchange is limited.



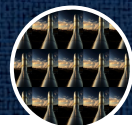
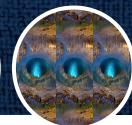
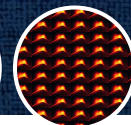
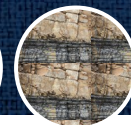
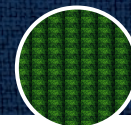
WHAT is Geothermal energy

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 through 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 $4 \times 10^{13} \text{W}$, four times more than the present world energy consumption which is 10^{13}W .

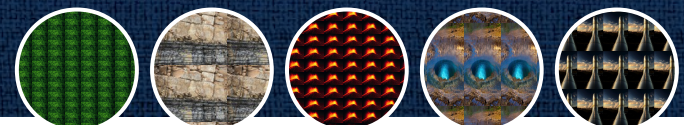
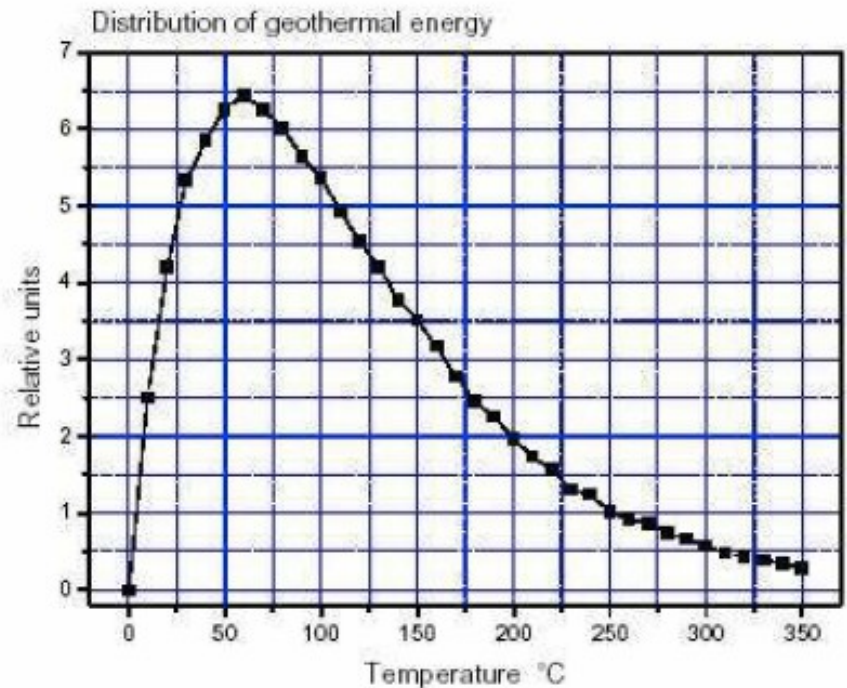
The thermal energy of the Earth is therefore immense, but only a fraction can be utilized by man.



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

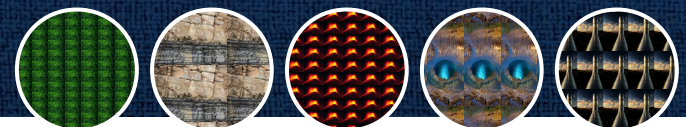
- transfer of random kinetic energy between molecules without transfer of material. Moving molecules strike neighbouring molecules, causing them to vibrate faster and thus transfer heat energy.
- Primary heat transfer mode in **solids**.

Convection

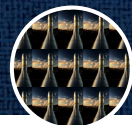
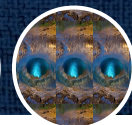
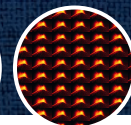
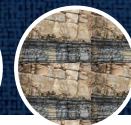
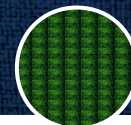
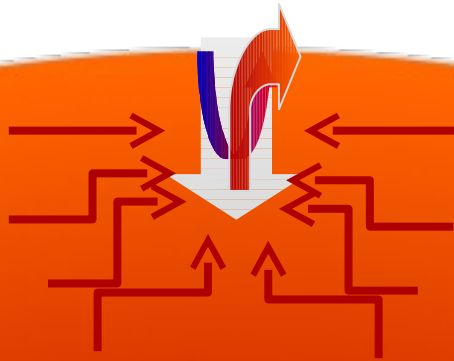
- Movement of hot fluid (liquid or gas) from one place to another. Because motion of material occurs, it is more efficient than conduction.
- Common heat transfer process in **liquids** or **gases**



Figure 1-11 part 1
Understanding Earth, Fifth Edition
© 2011 W. H. Freeman and Company



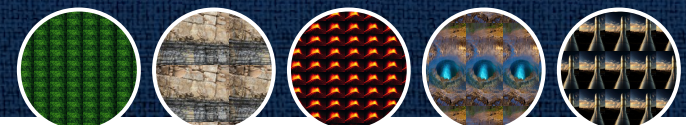
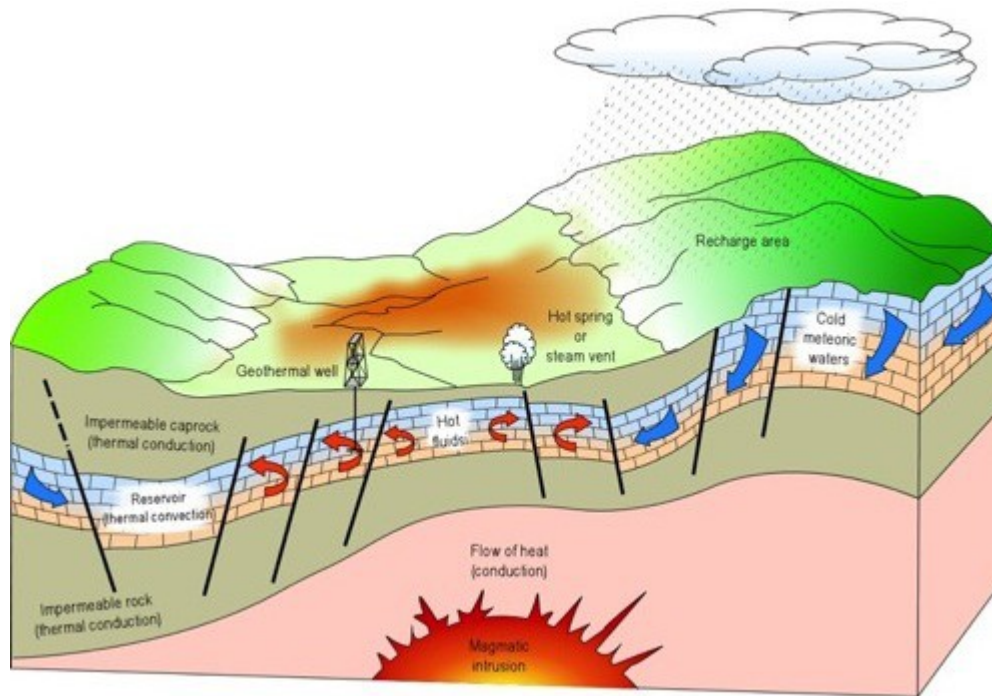
WHAT is Geothermal energy



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:

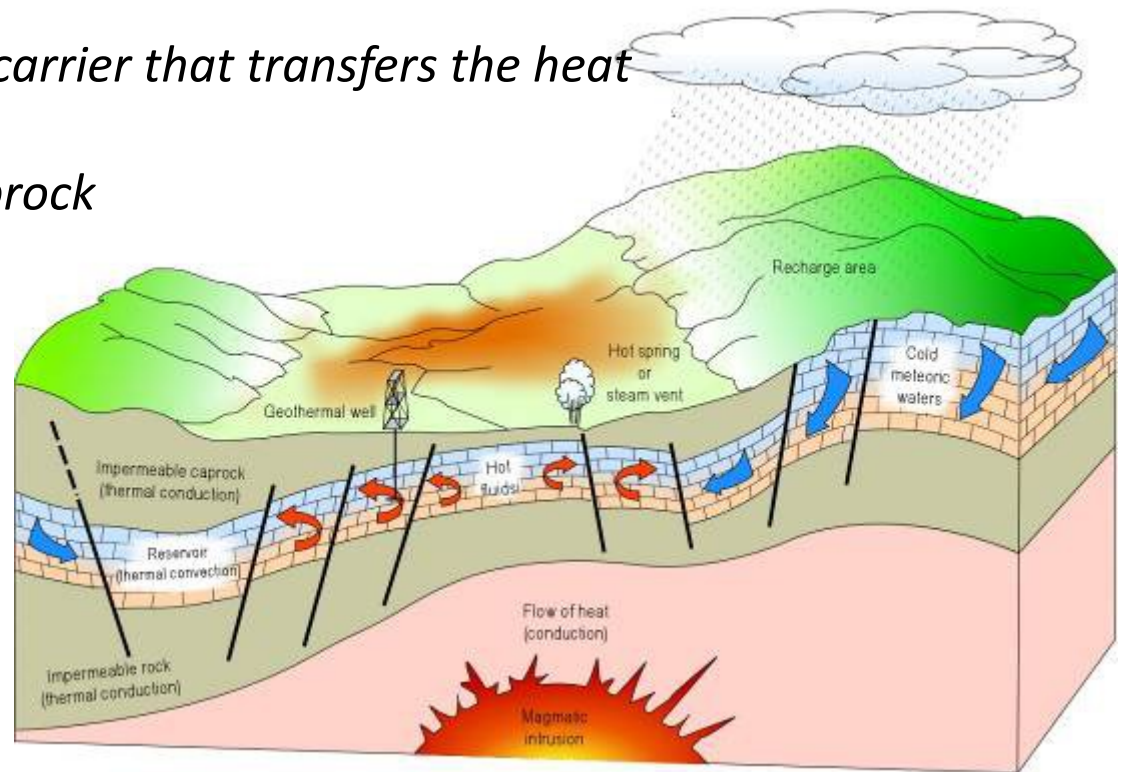
a heat source

a reservoir

a fluid, which is the carrier that transfers the heat

a recharge area

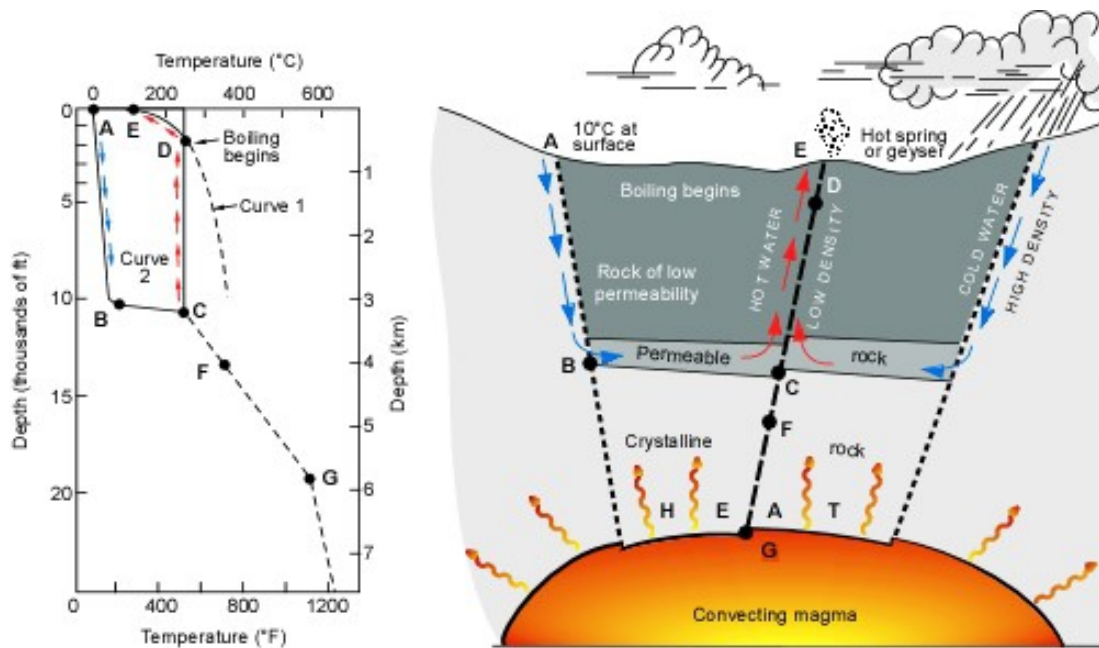
an impermeable caprock



WHAT is Geothermal energy

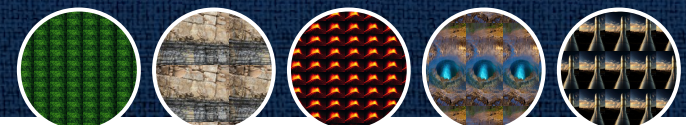
The mechanism underlying geothermal systems is by and large governed by *fluid convection*.

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

Water presence (as carrier medium)

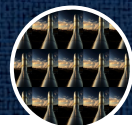
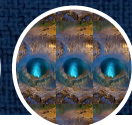
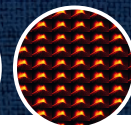
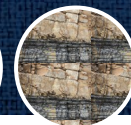
Wet•

Dry•

Conventional hydrothermal systems	Heat exchange
<p>Description: Hot shallow reservoirs are used for generation of electricity in conventional geothermal system</p> <p>Low reservoirs are used for space heating, cooling buildings in summer, and heating in winter</p> <p>Uses: Electricity generation and heat</p>	<ul style="list-style-type: none"> • Description: Heat pumps are used to transfer heat between the surface and subterranean levels • Methods include horizontal loops, borehole heat exchanges, and energy piles • Uses: Heat exchange
Enhanced Geothermal Systems	Enhanced geothermal systems
<p>Description: Super heated ground is heated through geothermal energy and transformed into steam to generate electricity as it travels toward the surface</p> <p>Uses: Electricity generation</p>	<ul style="list-style-type: none"> • Description: Hot dry rock reservoirs are developed by injecting high pressure water into a stressed zone, causing it to fracture. Heat is transferred to the water, used for generation and re-injected into the reservoir, forming a closed-loop system • Uses: Electricity generation

s and Earth

Italy



WHAT is Geothermal energy

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)

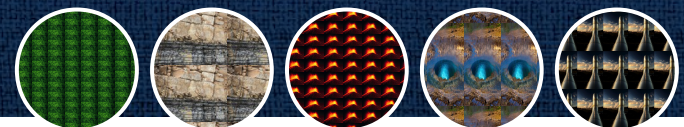
More than
5000 m

Hot deep dry/wet rock
reservoir

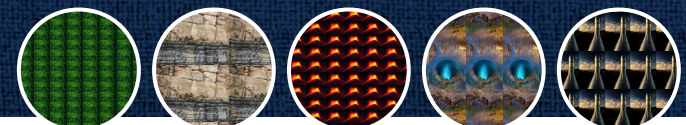
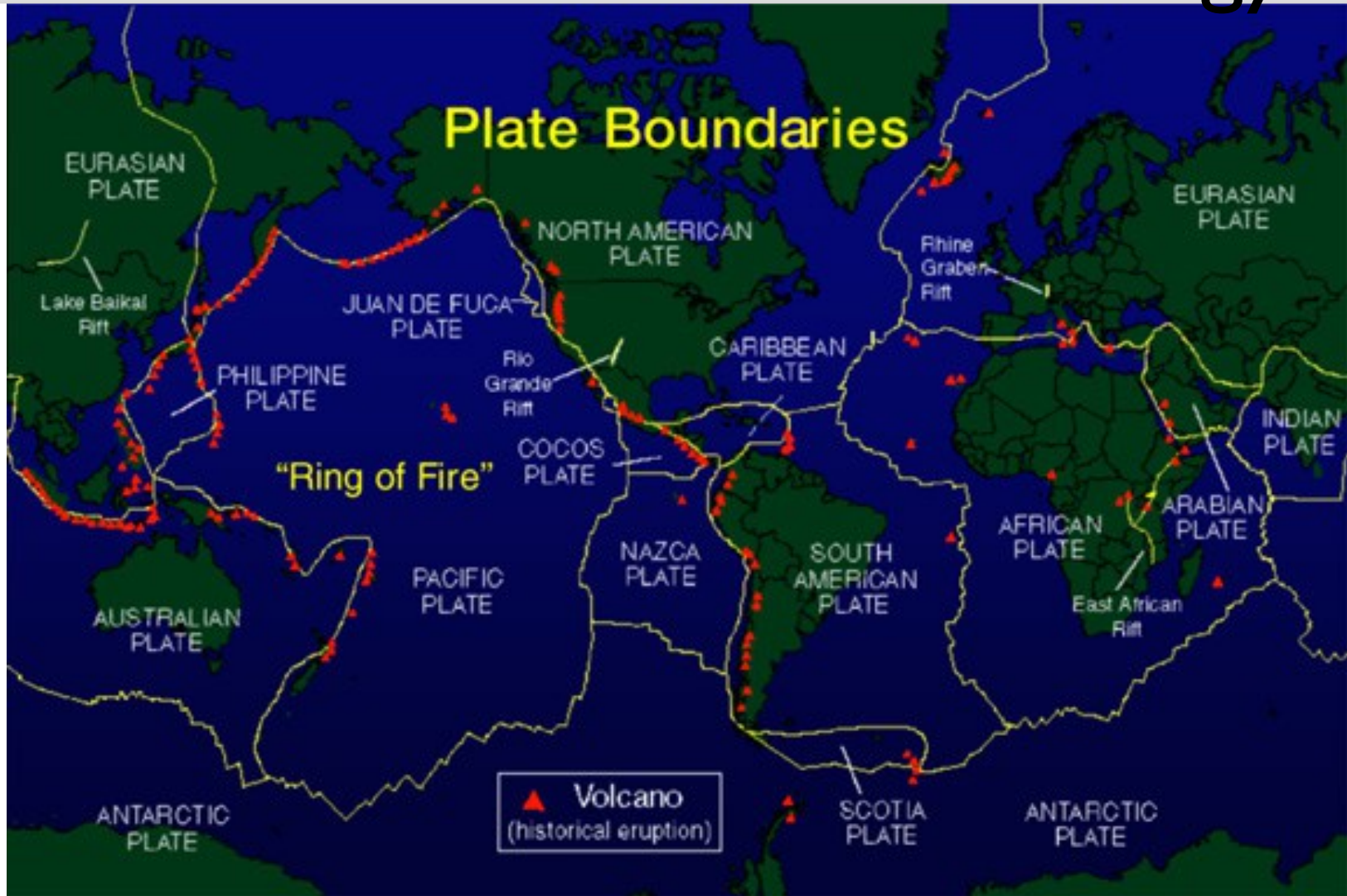
EGS – Supercritical fluids
Future perspectives

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.

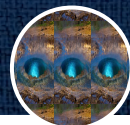
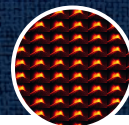
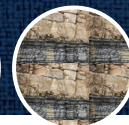
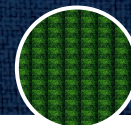
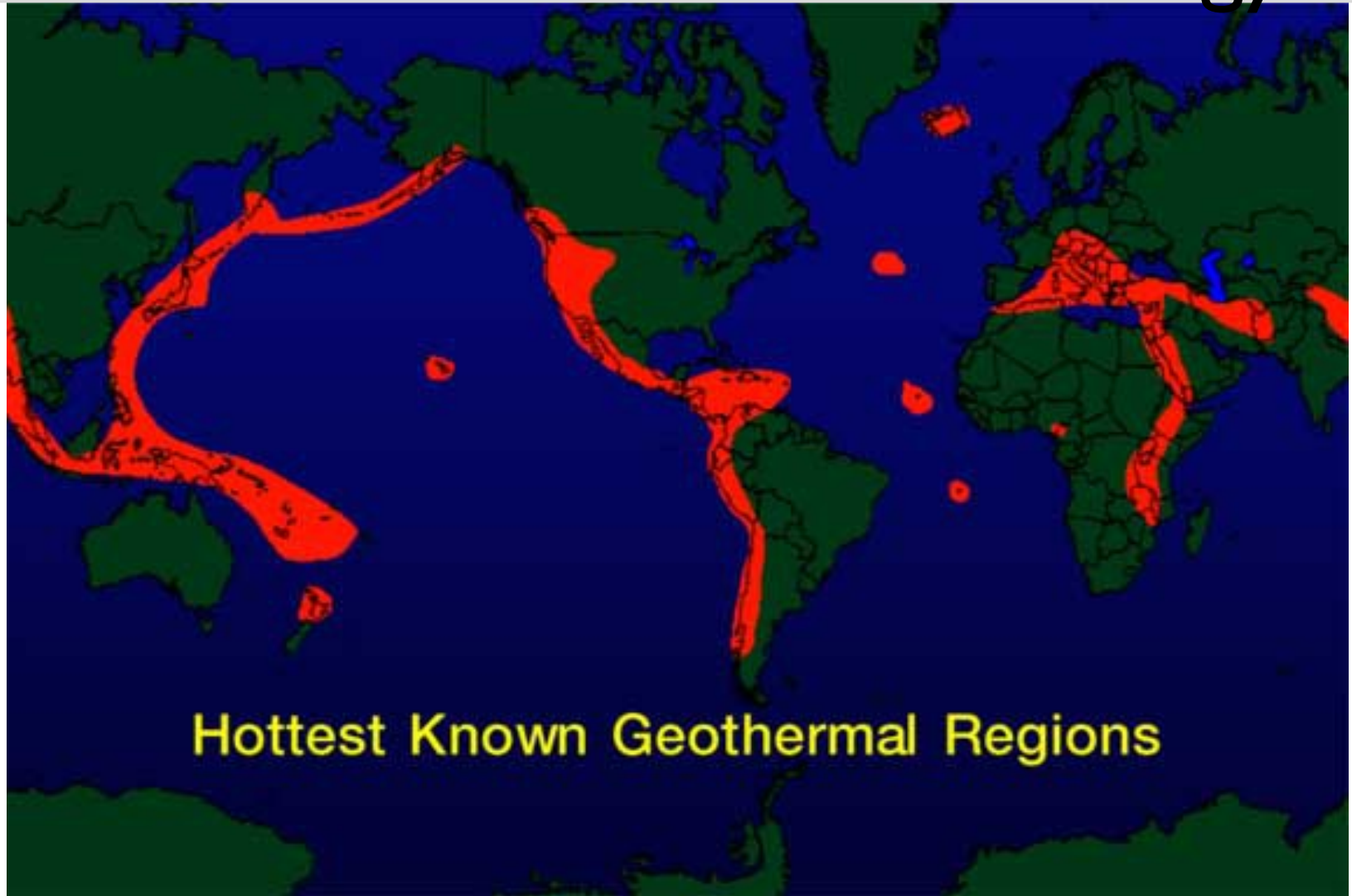
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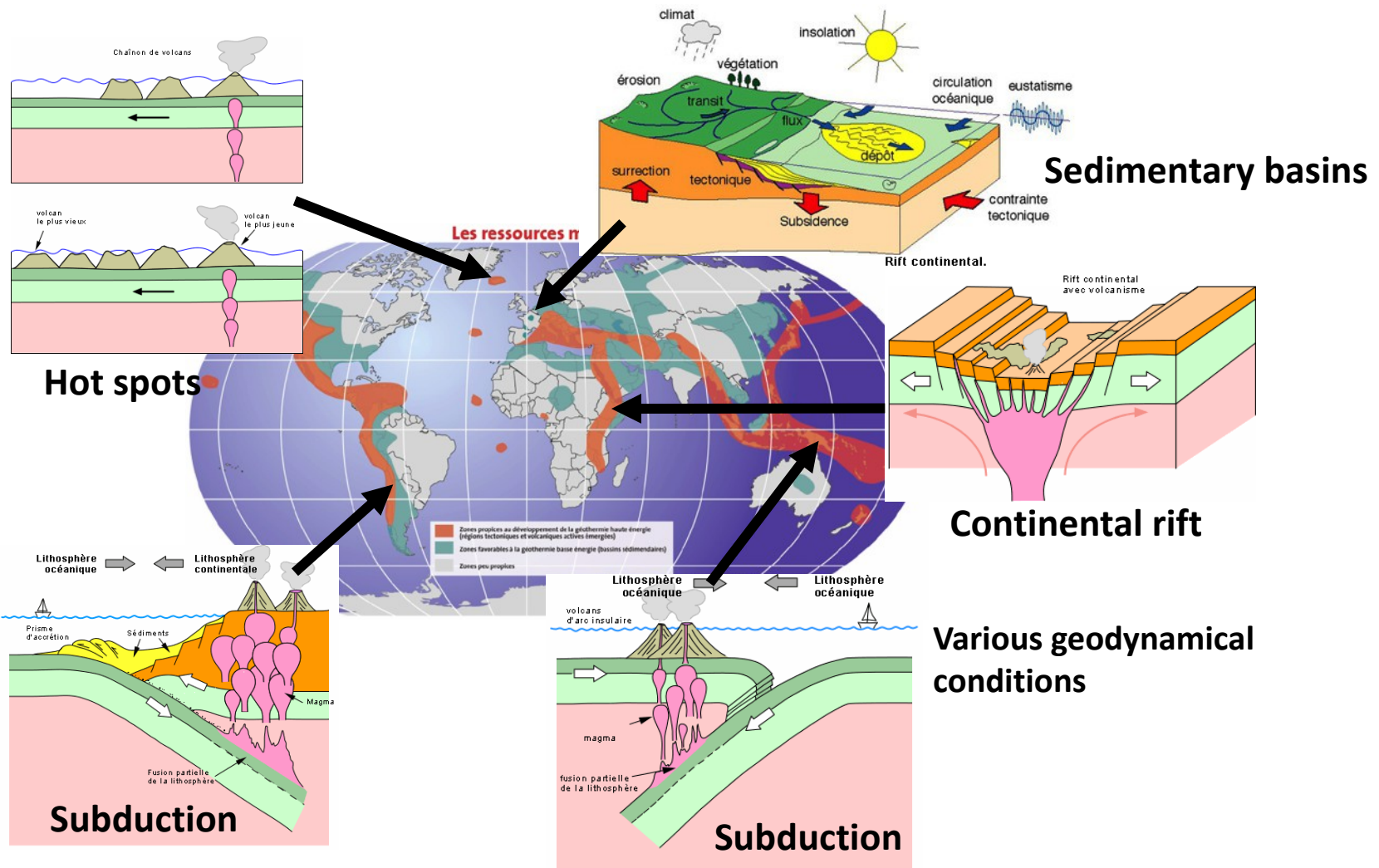
WHAT is Geothermal energy



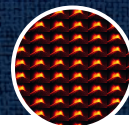
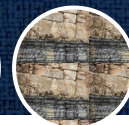
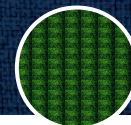
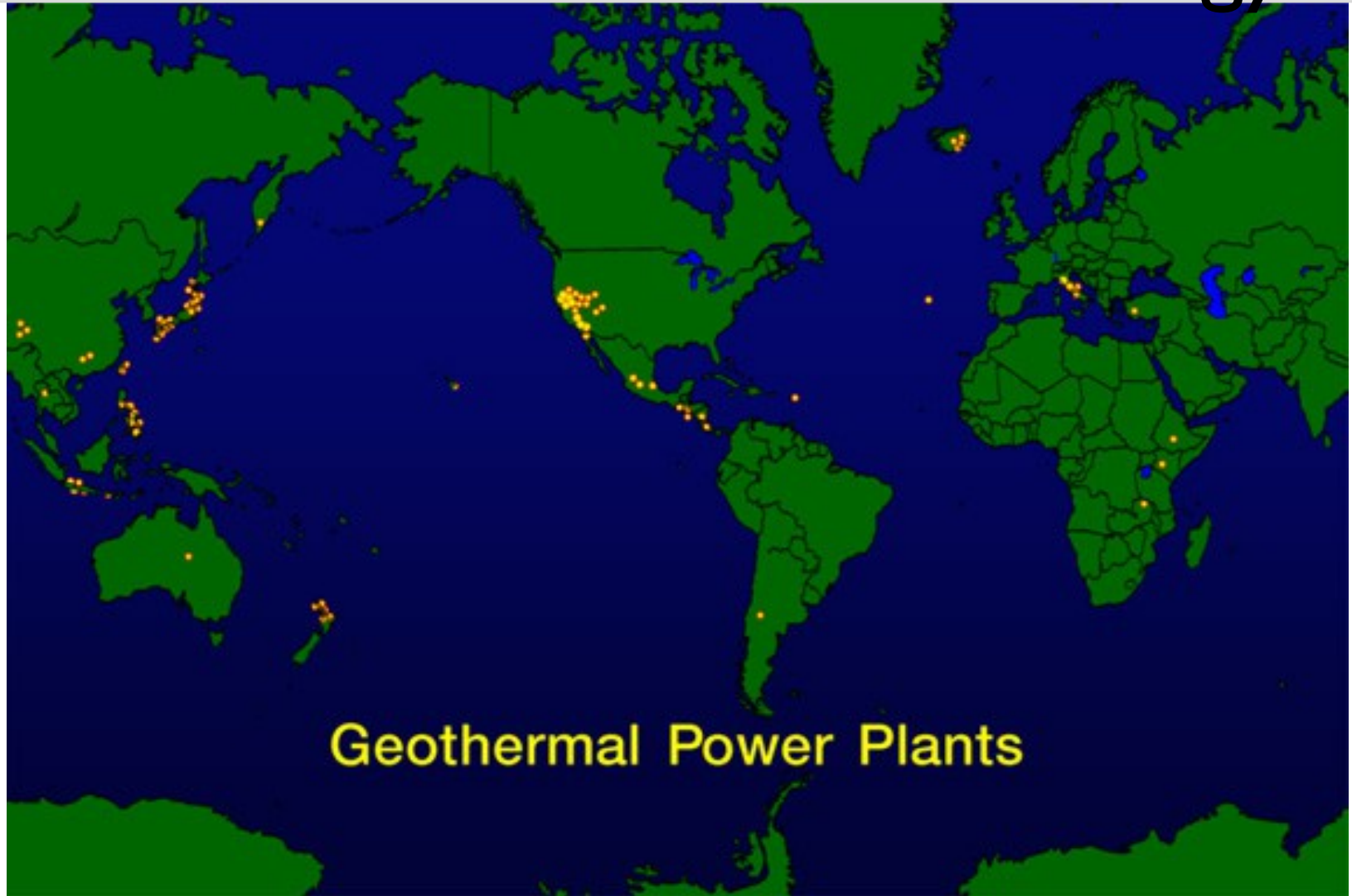
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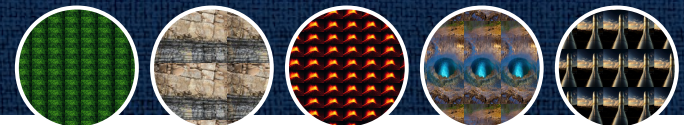
WHAT is Geothermal energy





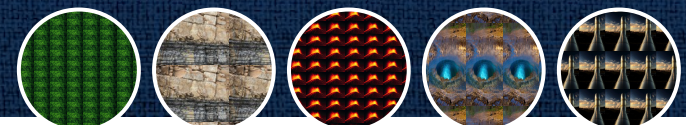
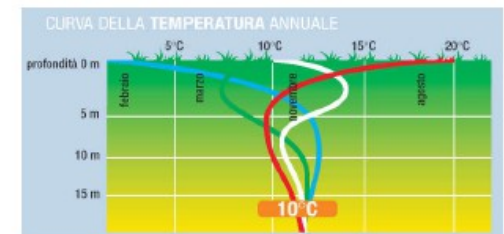
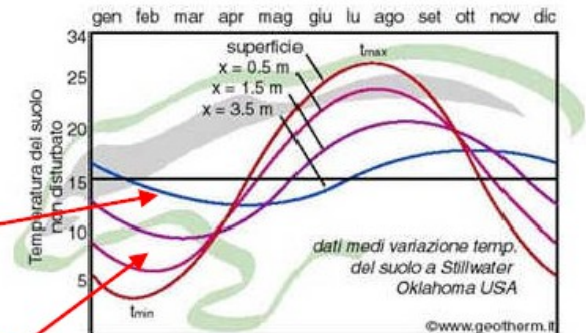
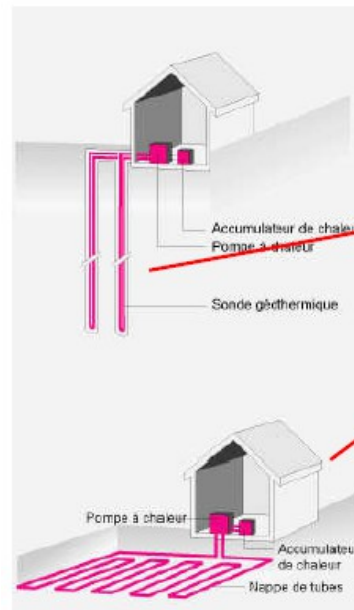
- **Heat? Power? Depending on what?**

How **Geothermal Energy** is used

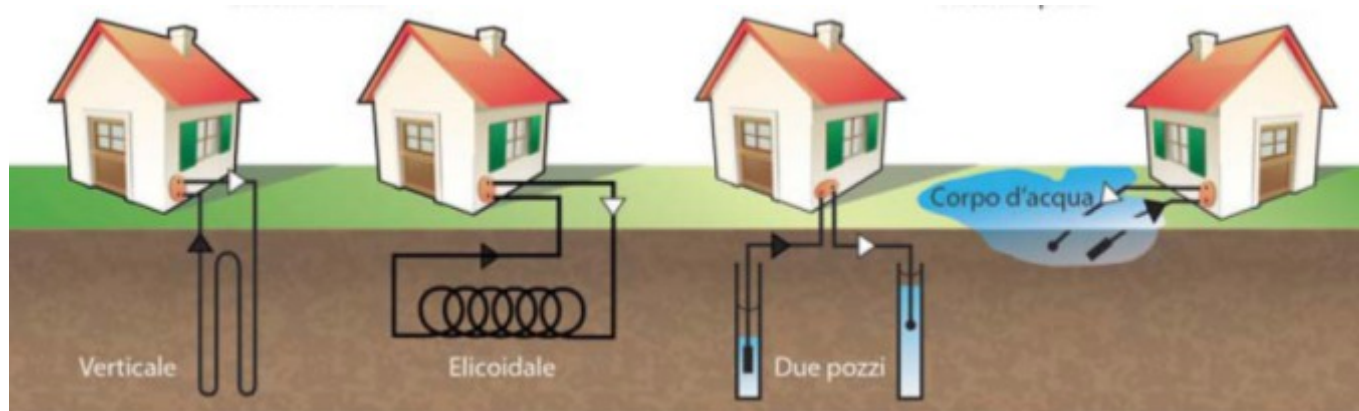


How Geothermal Energy is used

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

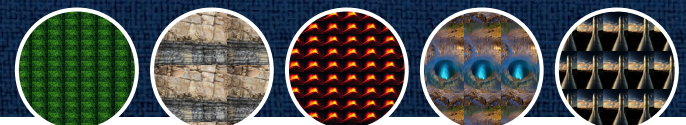


Closed loop systems

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

Open loop systems

Advantages:

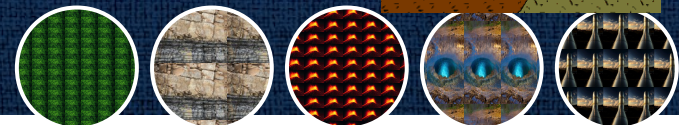
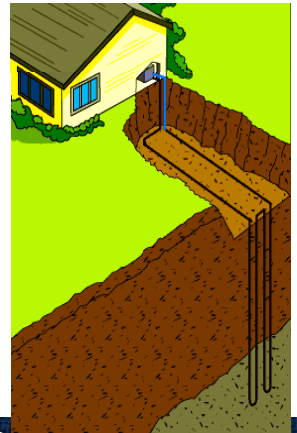
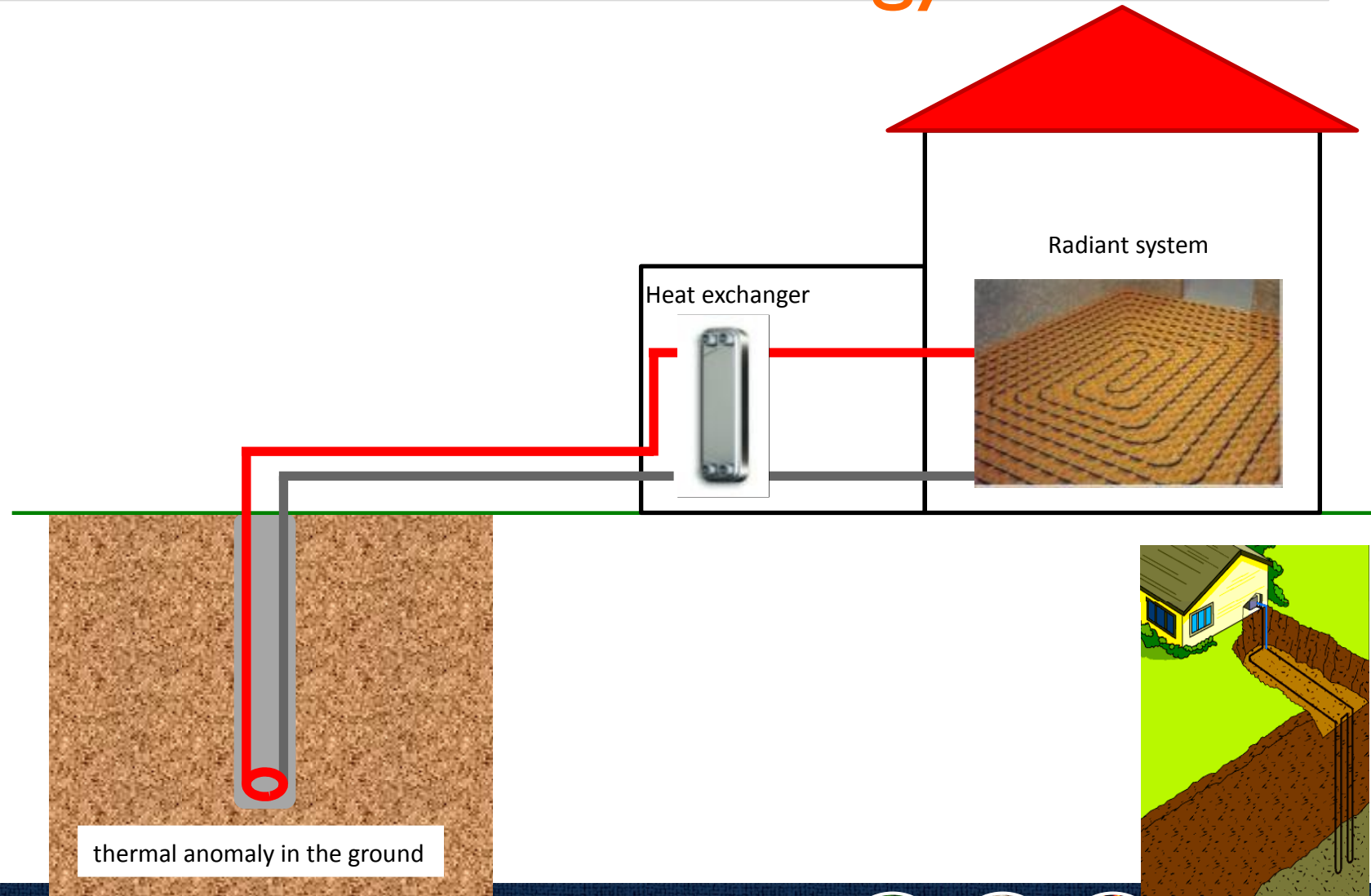
- higher thermal capacity than for CL for each well, therefore less wells
- less wells (low cost and impact)
- lower cost than for Closed Loop (CL)
- efficient exploitation of thermal energy
- relatively easy installation
- zero emissions
- may be used without heat pumps

Disadvantages:

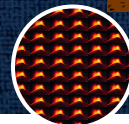
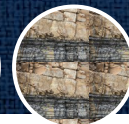
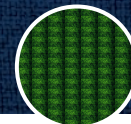
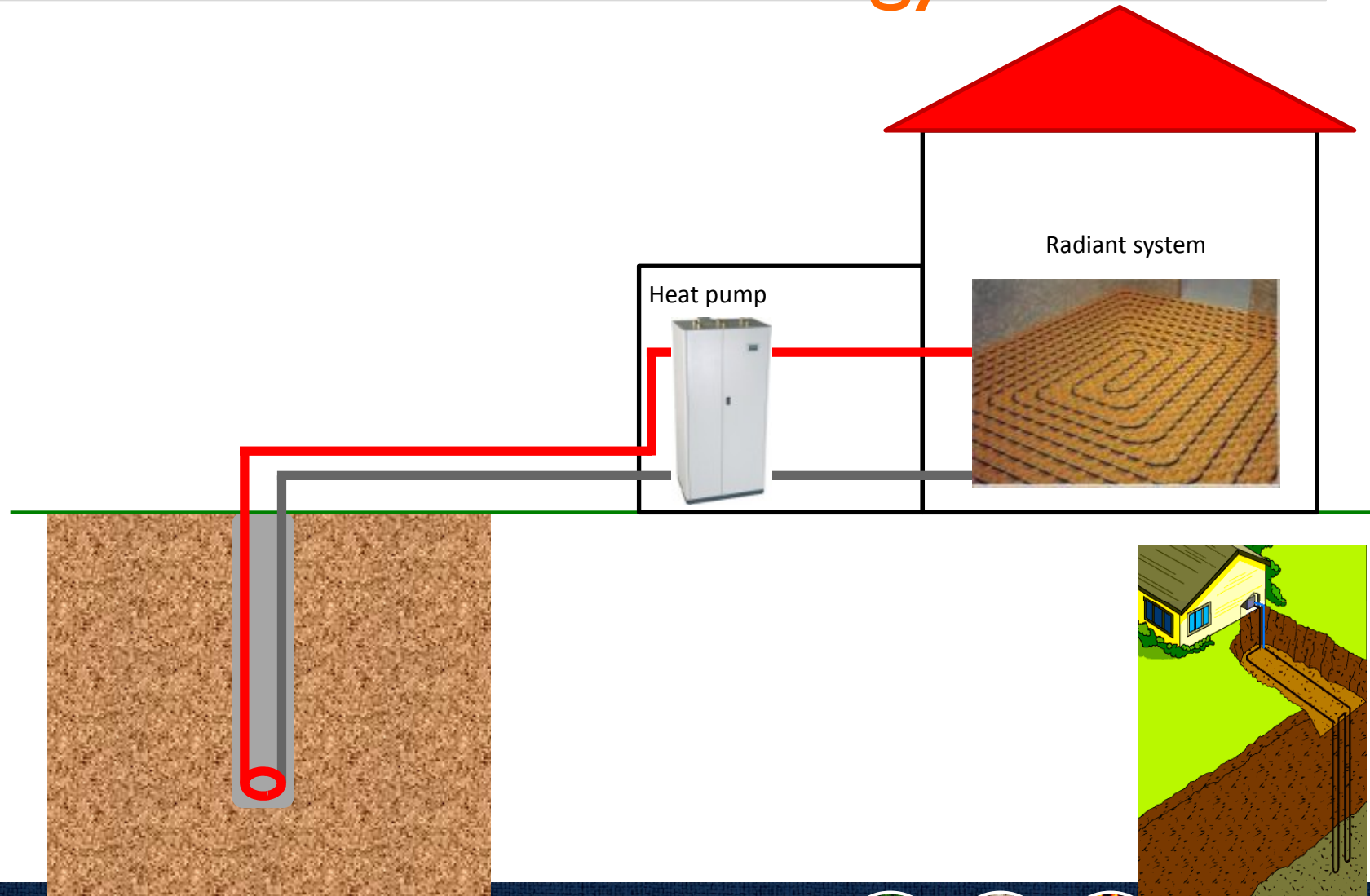
- Complexity of regulation and authorization
- Not always feasible



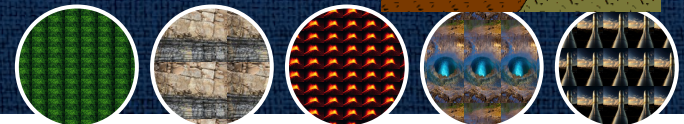
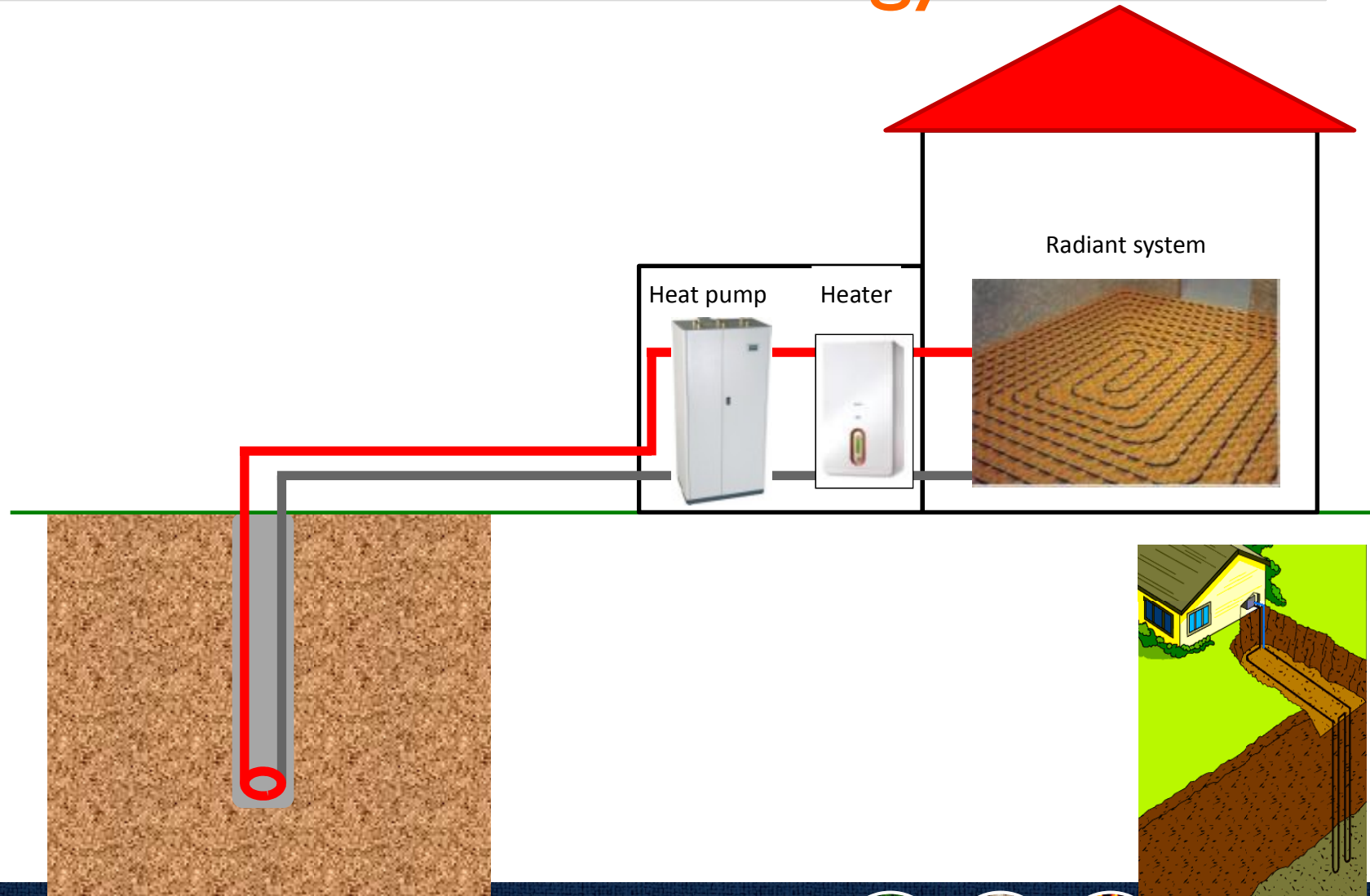
How Geothermal Energy is used



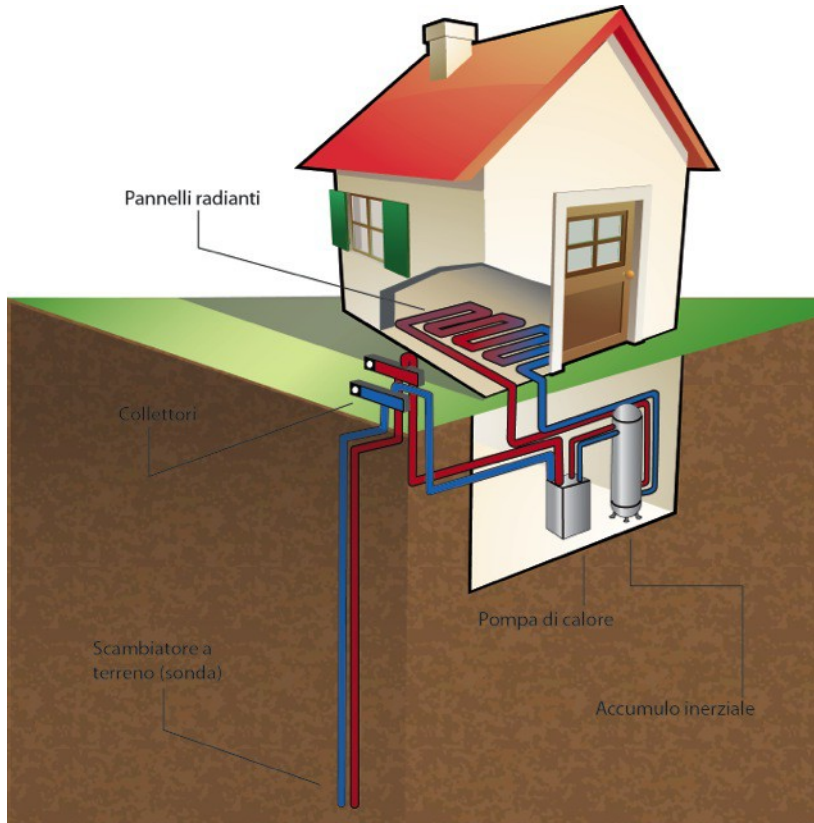
How Geothermal Energy is used



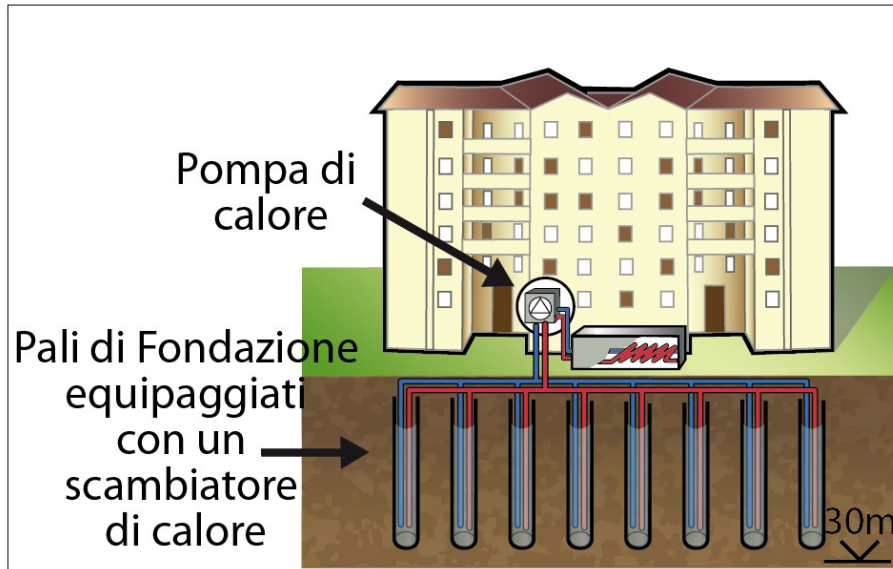
How Geothermal Energy is used



How Geothermal Energy is used

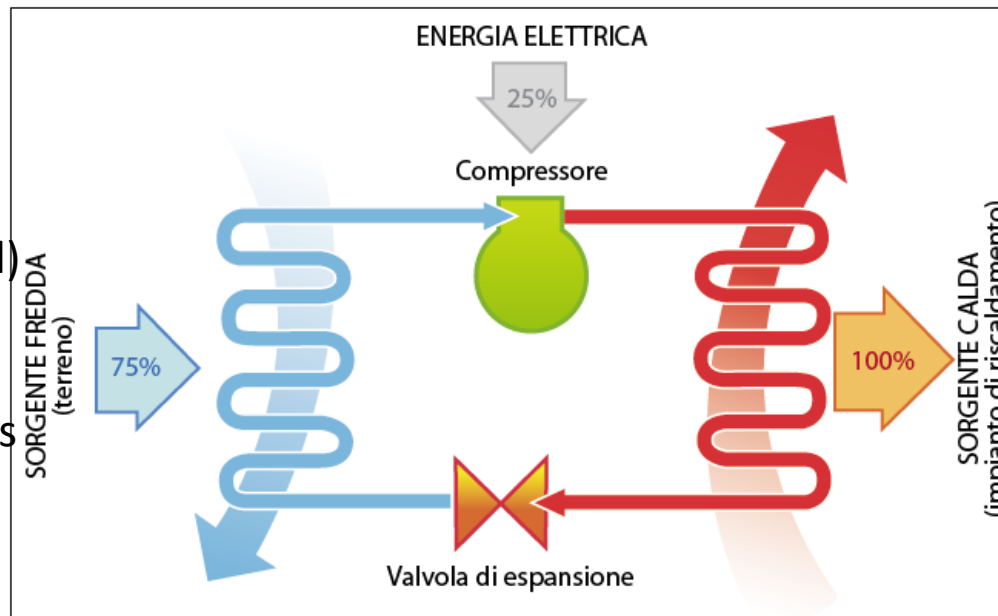


How Geothermal Energy is used



How Geothermal Energy is used

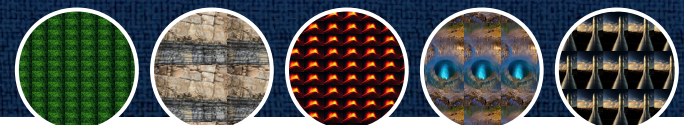
compressor
(power consumption)
to compress the vapour



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

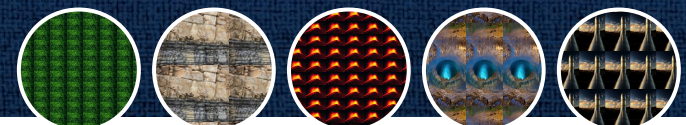
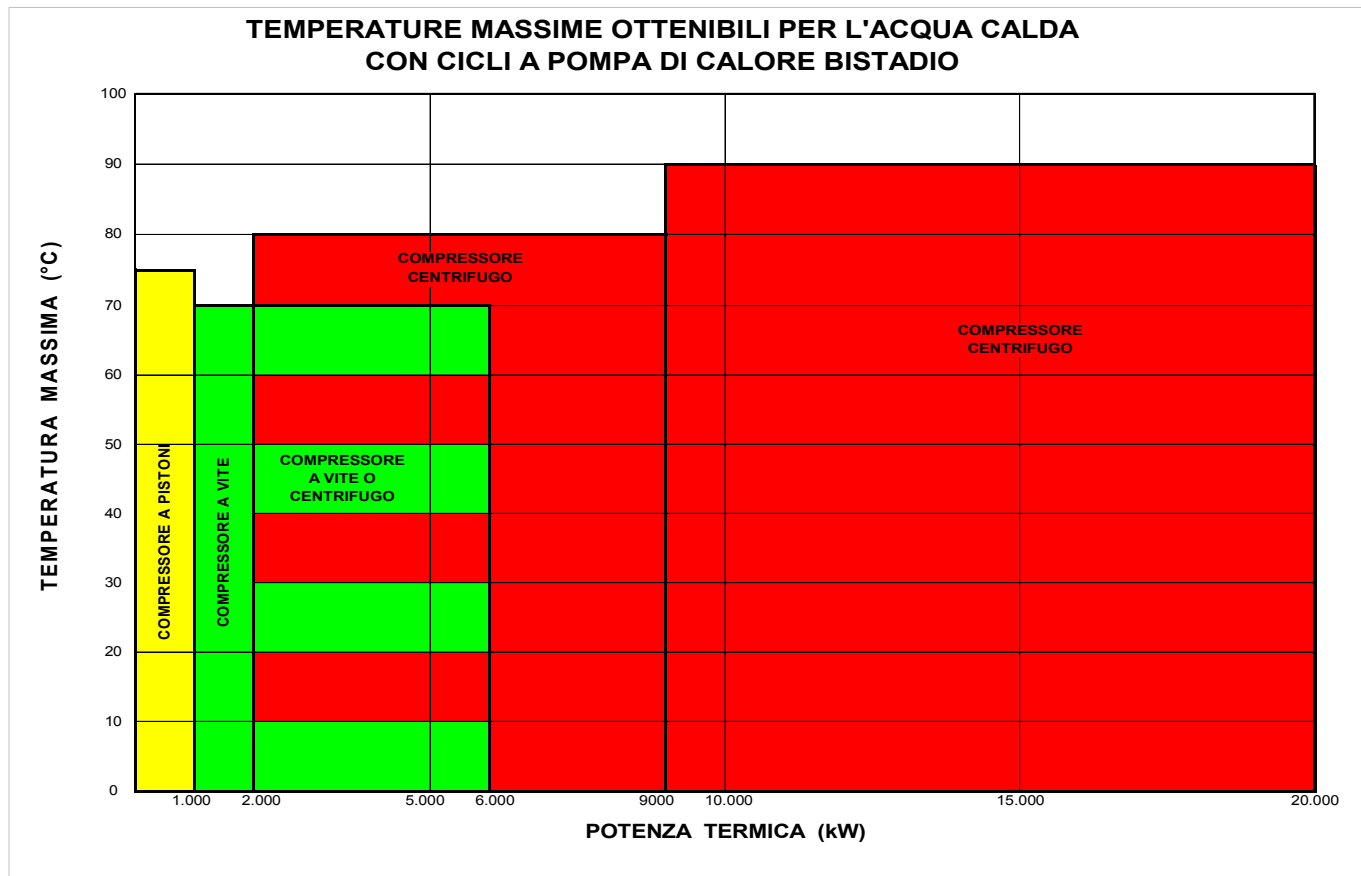
expansion valve

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



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 (reversible units), obtaining heating and cooling systems. Single units may provide 18 kW (cold).

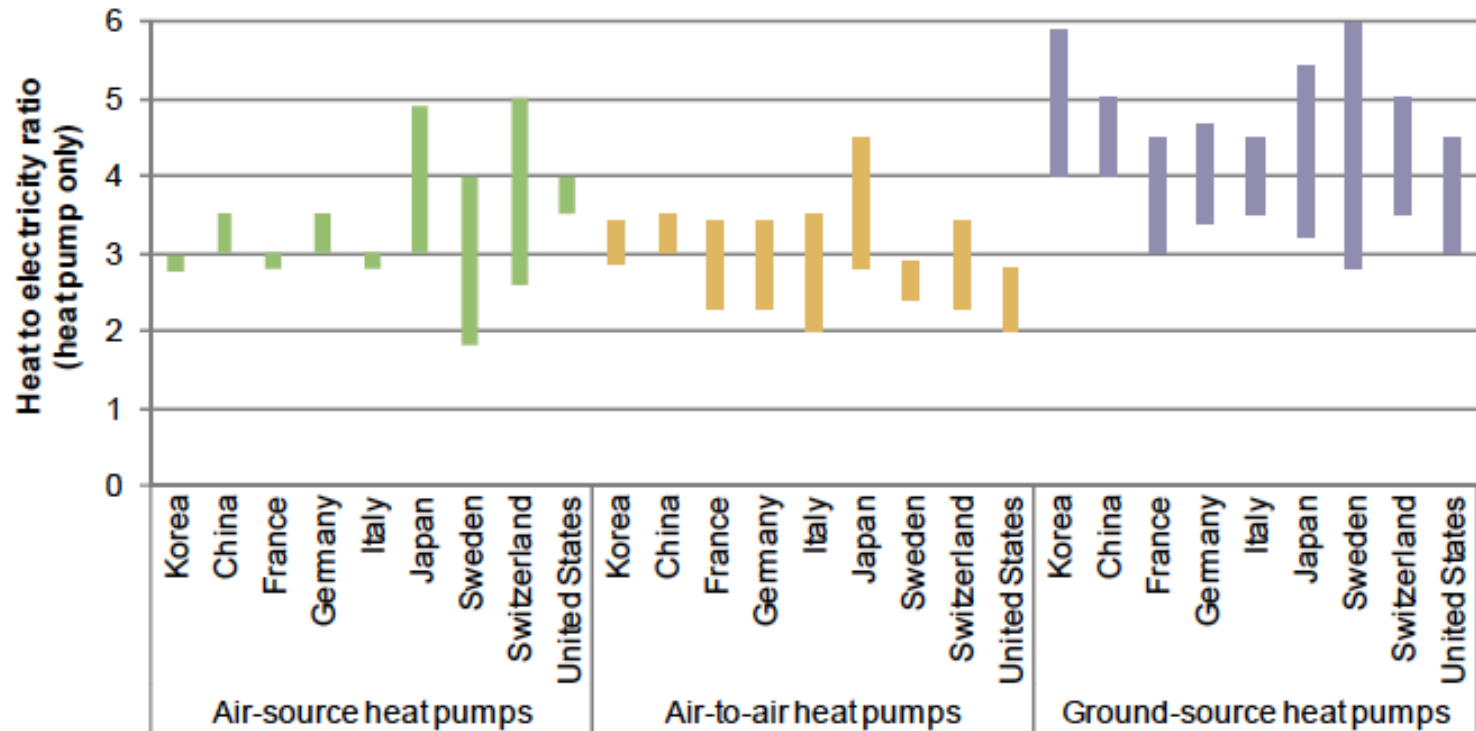
District heating using heat pumps is becoming very popular, and may provide temperature up to 90°C

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



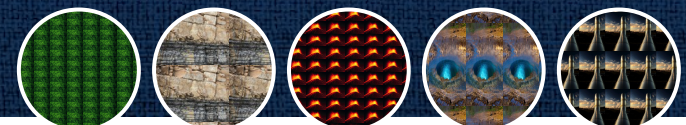
How Geothermal Energy is used

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.

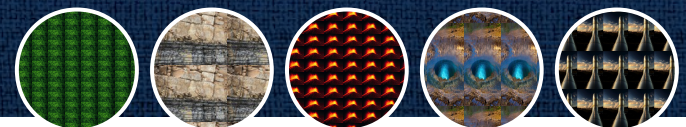


How Geothermal Energy is used

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).

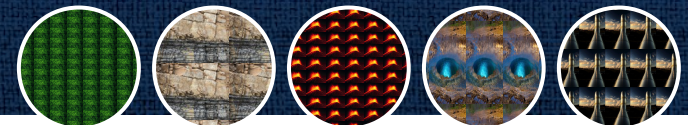
According to the EU Directive 2009/28/EC, heat pumps can be considered a renewable technology as long as they result in a primary energy efficiency of at least 115%, which corresponds to a seasonal performance factor of 2.875 at an average efficiency of the electricity production of 40% (EC/RHC Platform,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

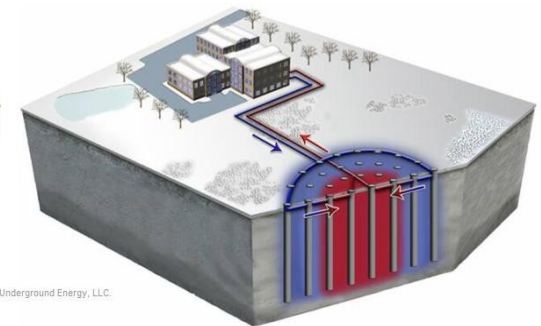
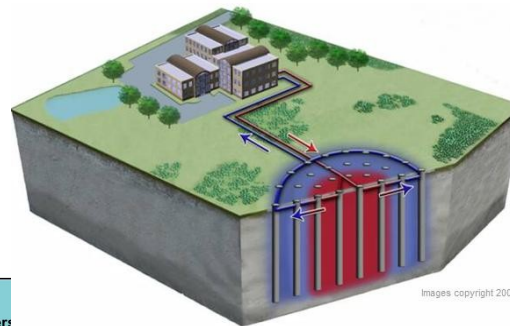
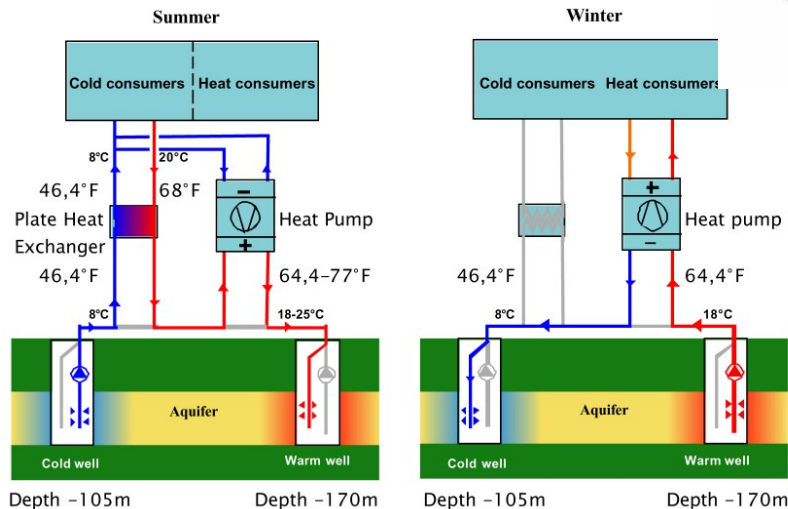


How Geothermal Energy is used

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

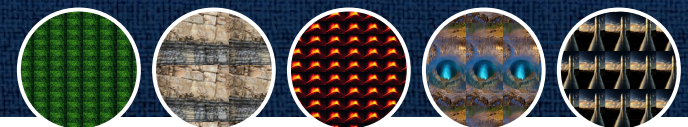
ATES

Aquifer Thermal Energy Storage



BTES

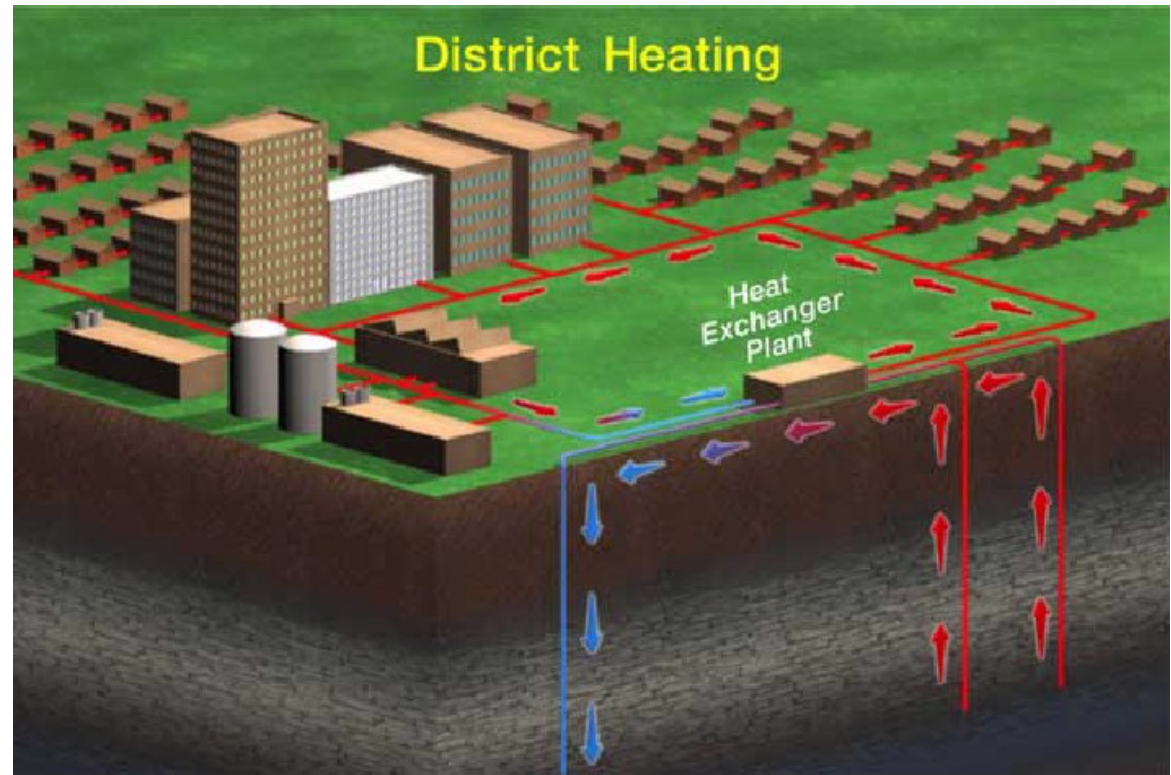
Borehole Thermal Energy System



How Geothermal Energy is used

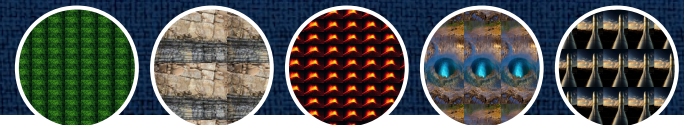
Space heating, of which more than 80% are district heating, is among the most important direct uses of geothermal energy

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.

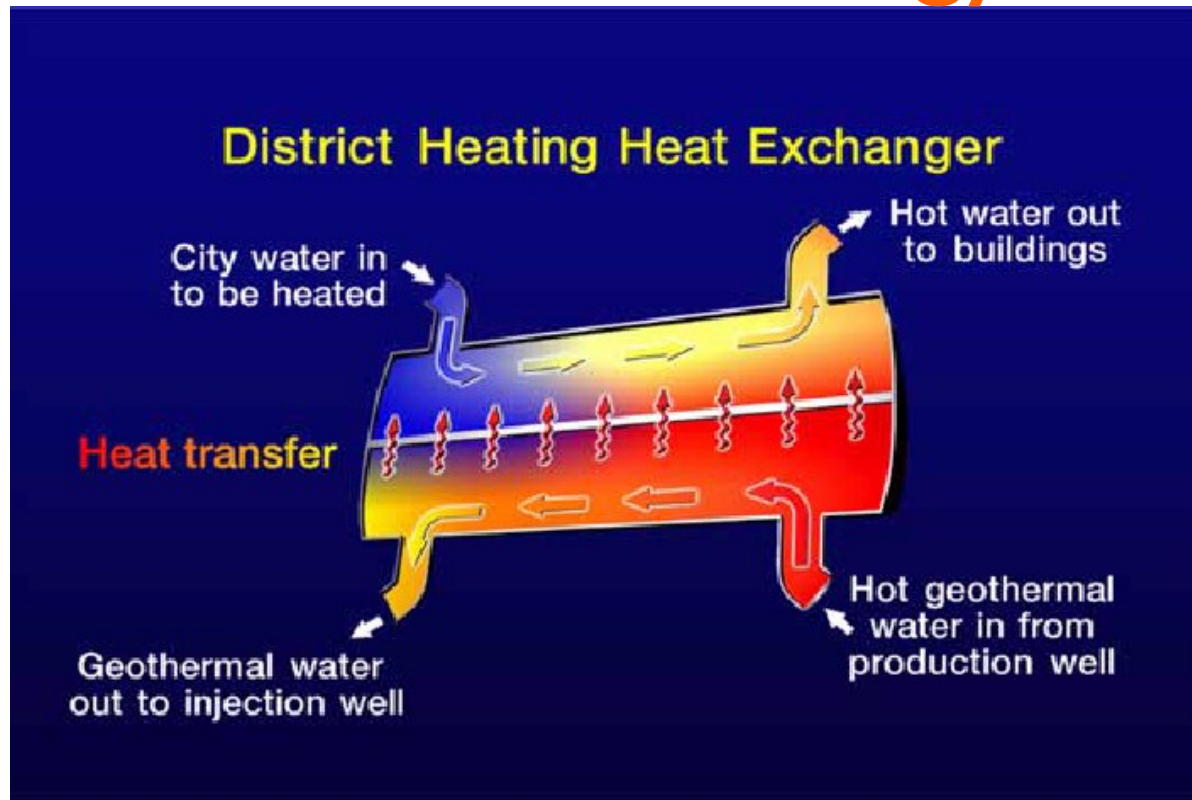


Hot water from one or more geothermal wells is piped through a heat exchanger plant to heat city water in separate pipes. Hot city water is piped to heat exchangers in buildings to warm the air.

Slide 90 of 122, © 2000 Geothermal Education Office



How Geothermal Energy is used

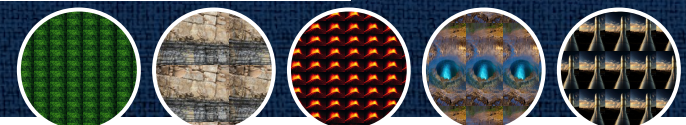


The geothermal water never mixes with the city water. Once its heat is transferred to the city water, the geothermal water is injected back into the reservoir to be reheated and recycled.

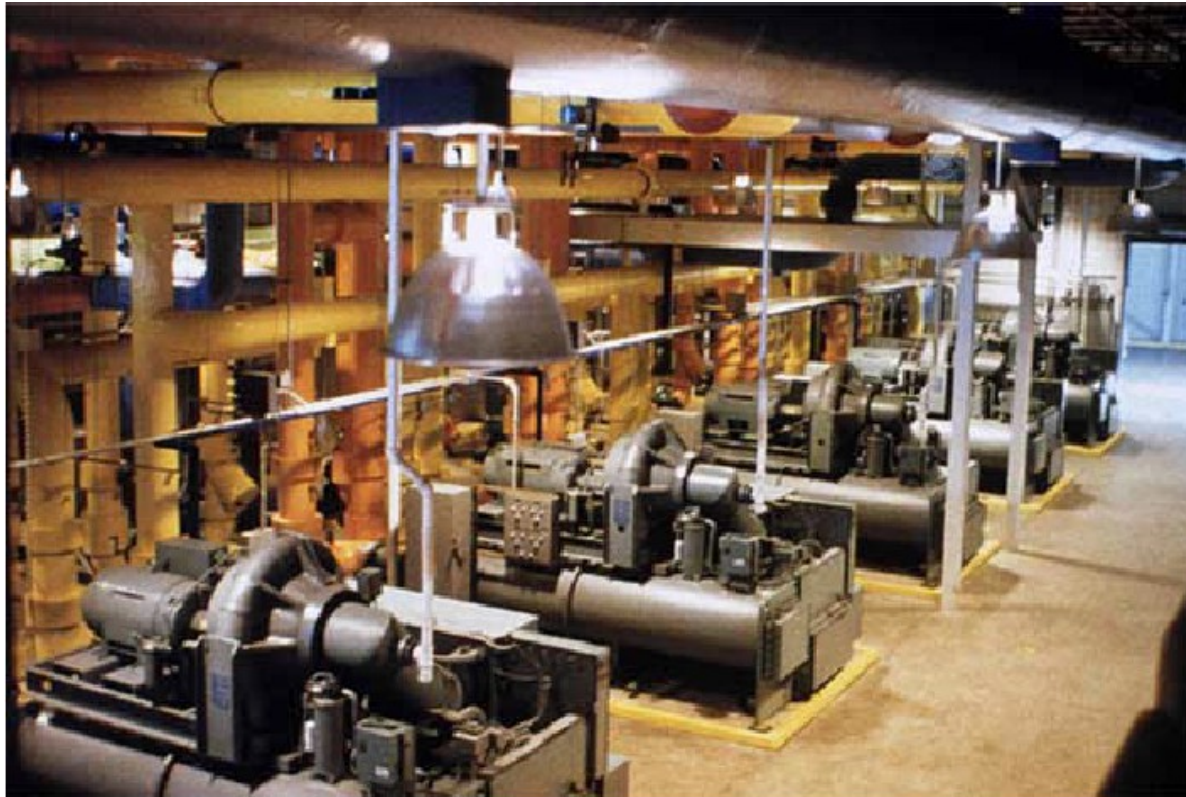
Slide 91 of 122, © 2000 Geothermal Education Office



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How Geothermal Energy is used

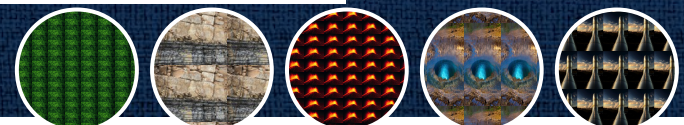


These pumps are used to pump the heated water to buildings in a district heating system, after it has passed through the heat exchanger.

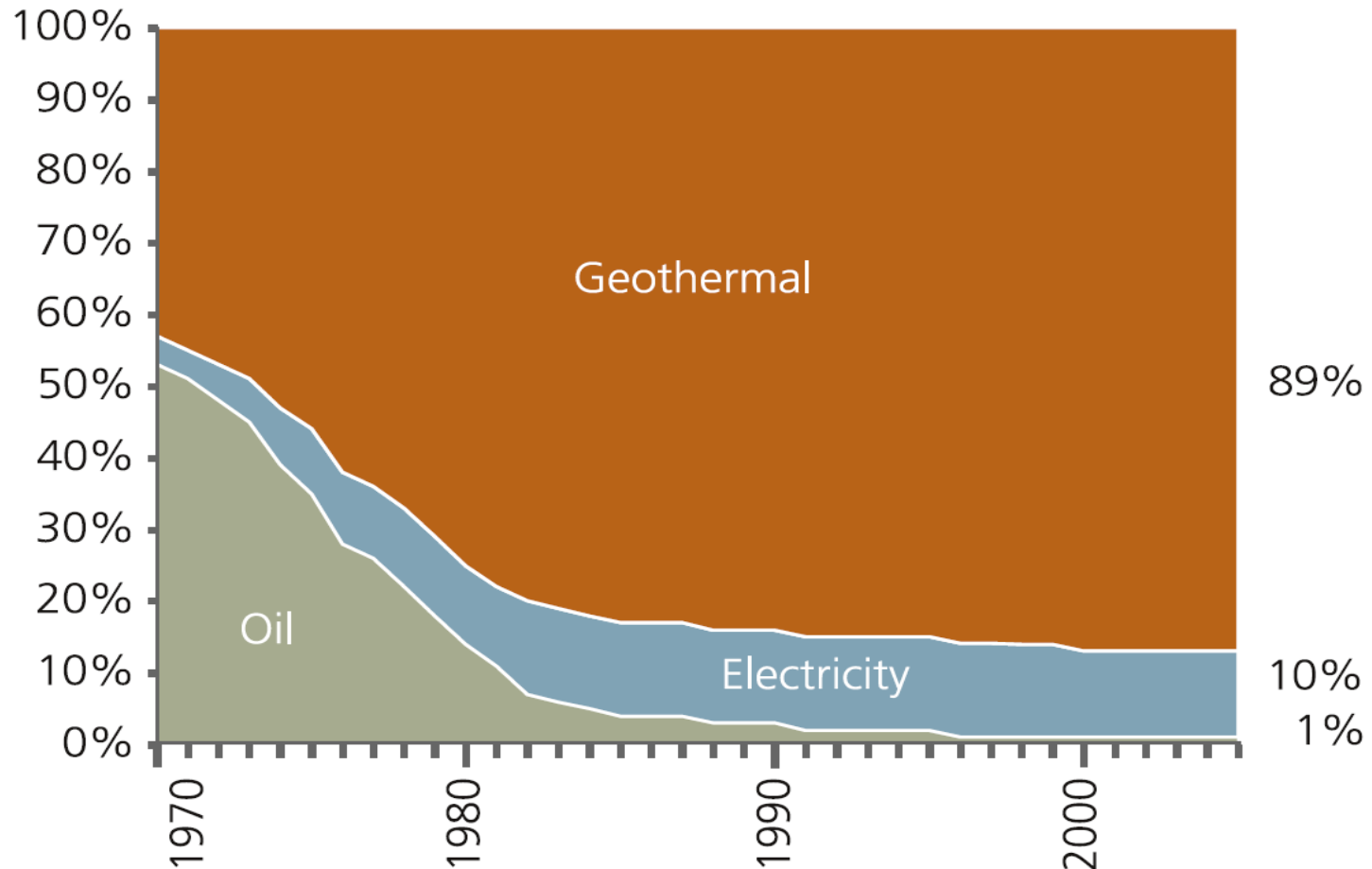
Slide 93 of 122, © 2000 Geothermal Education Office



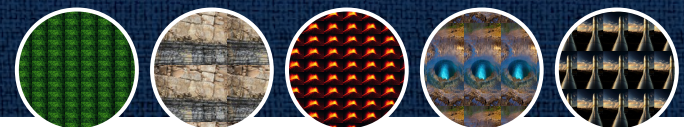
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How Geothermal Energy is used



Energy source for district heating in Iceland



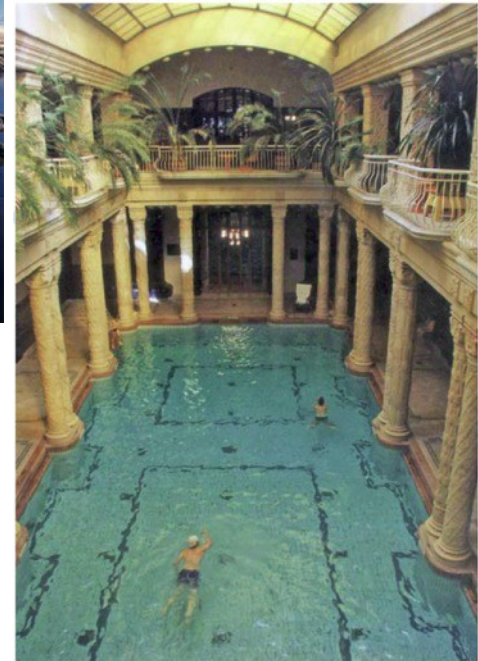
How Geothermal Energy is used



Fish and other animal farming

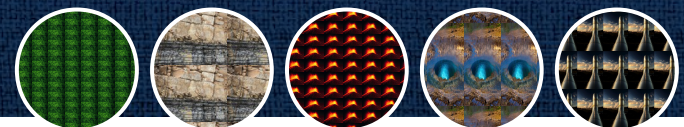


Greenhouse heating



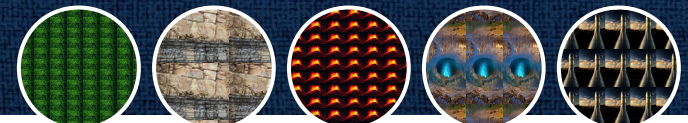
Bathing and balneology

**The most common
direct uses of
geothermal heat**



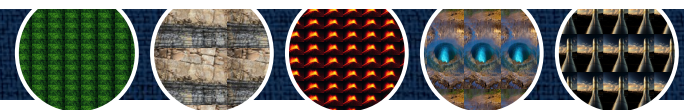
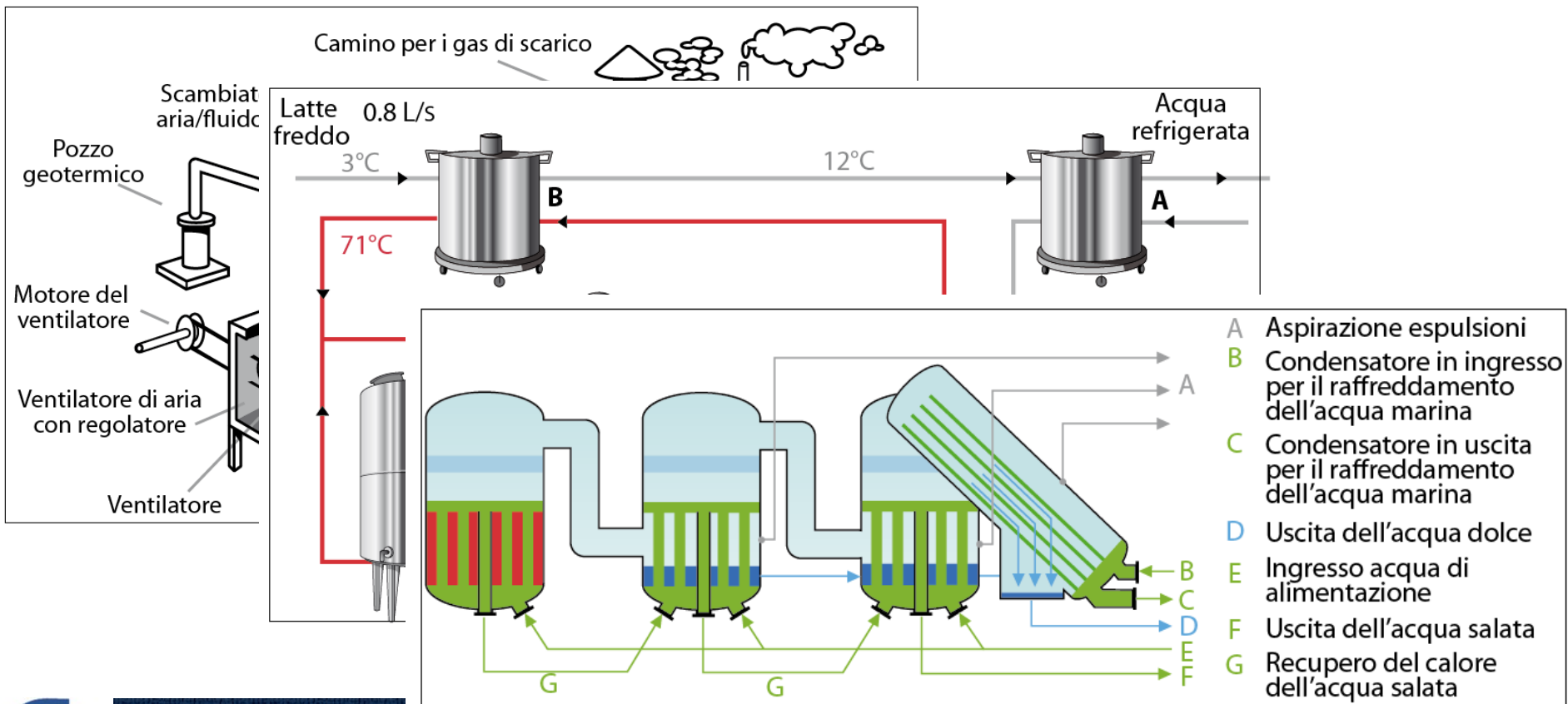
How Geothermal Energy is used

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

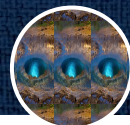
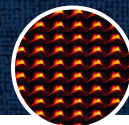
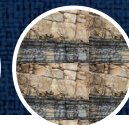
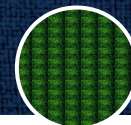


Pipes of geothermal water can be installed under sidewalks and roads to keep them from icing over in winter, like this sidewalk.

Slide 88 of 122, © 2000 Geothermal Education Office

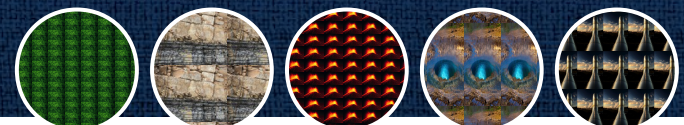
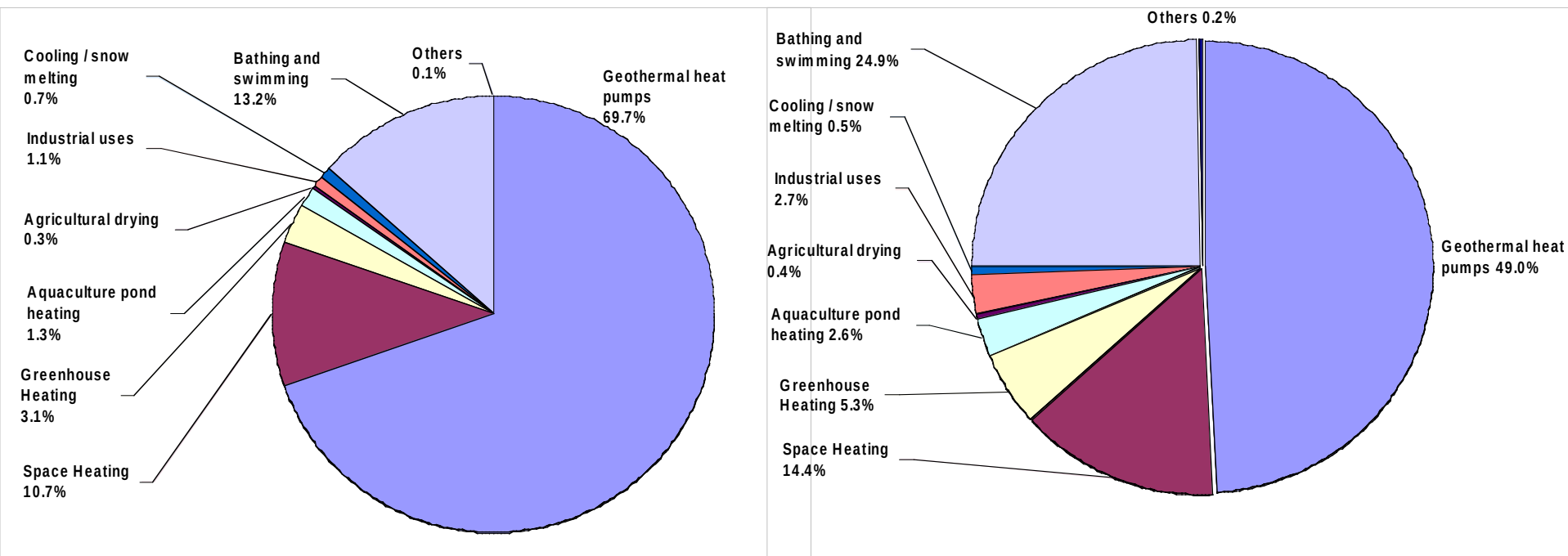


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How Geothermal Energy is used

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

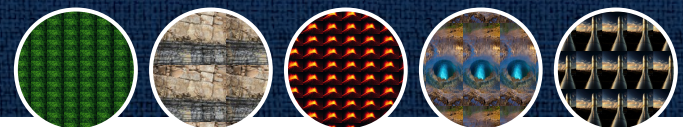


How Geothermal Energy is used

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

78 countries
in the list
(WGC2010)

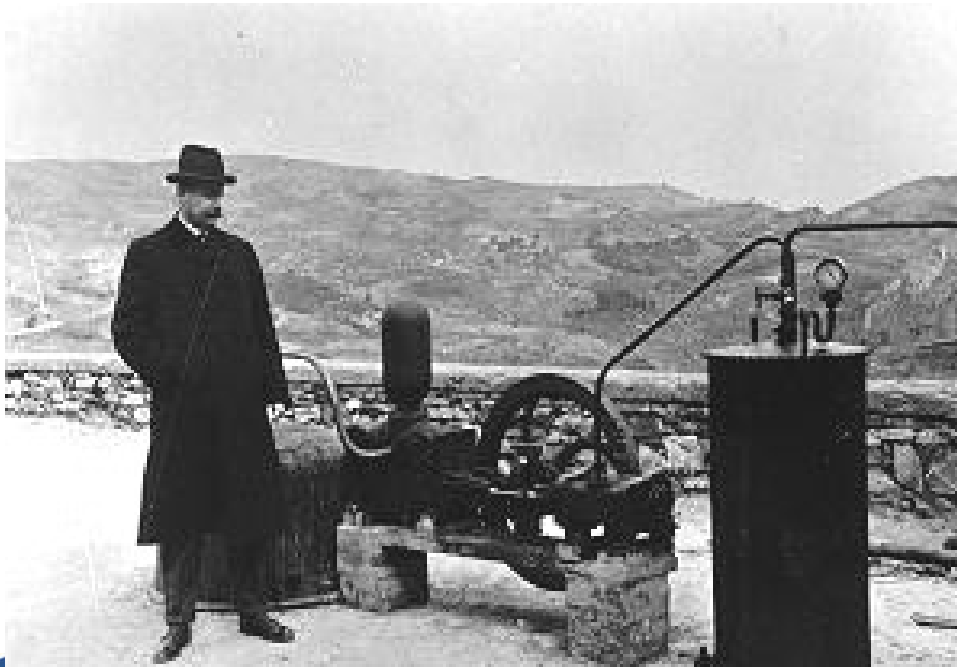
total	48501.20	428070.66	112166.80
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How Geothermal Energy is used

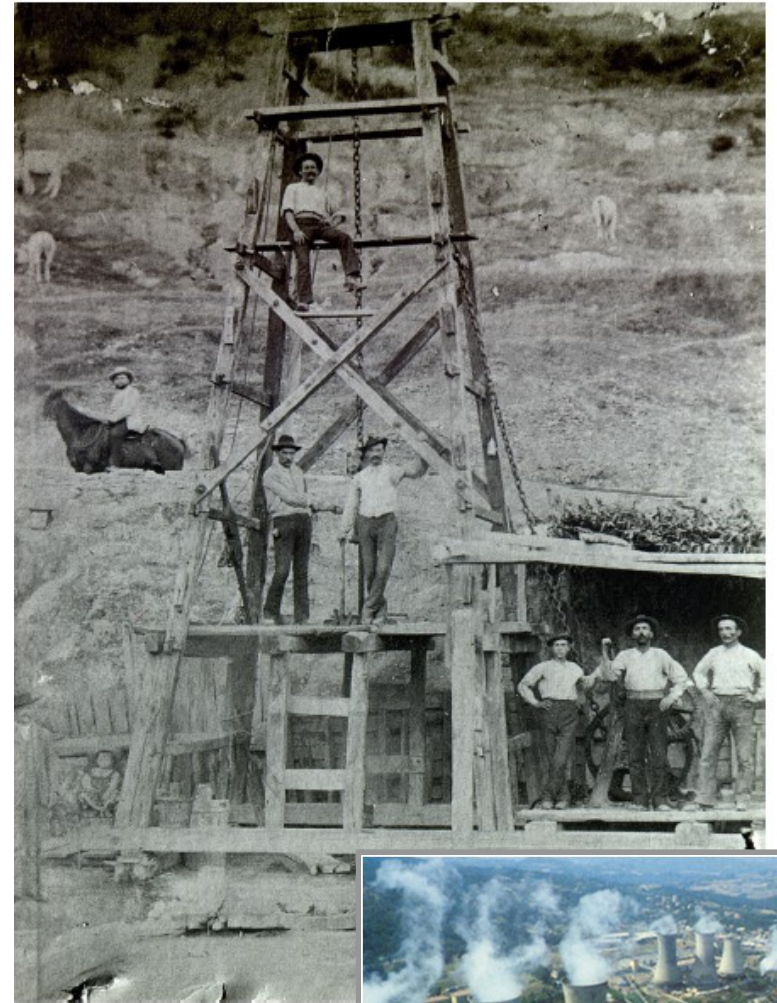
Italy has been the first country in the world to produce **electricity by geothermal energy** on 1904.

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



Larderello, 1904

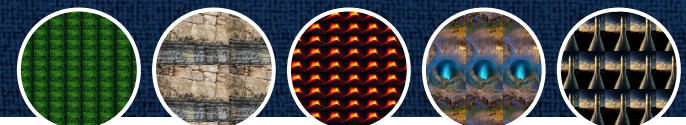
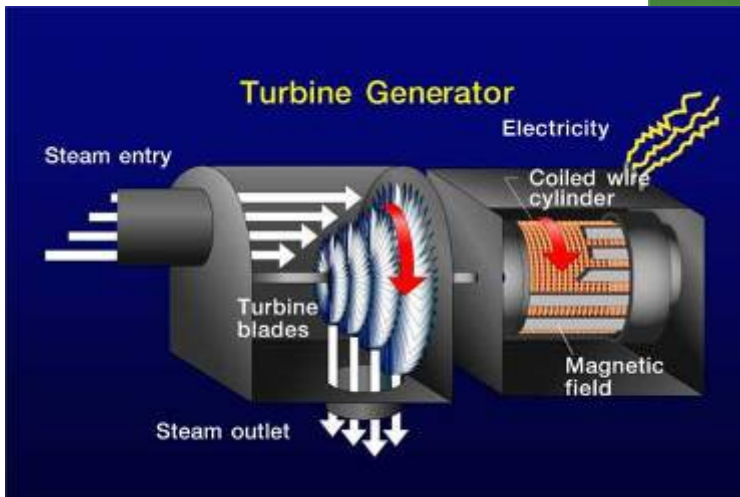
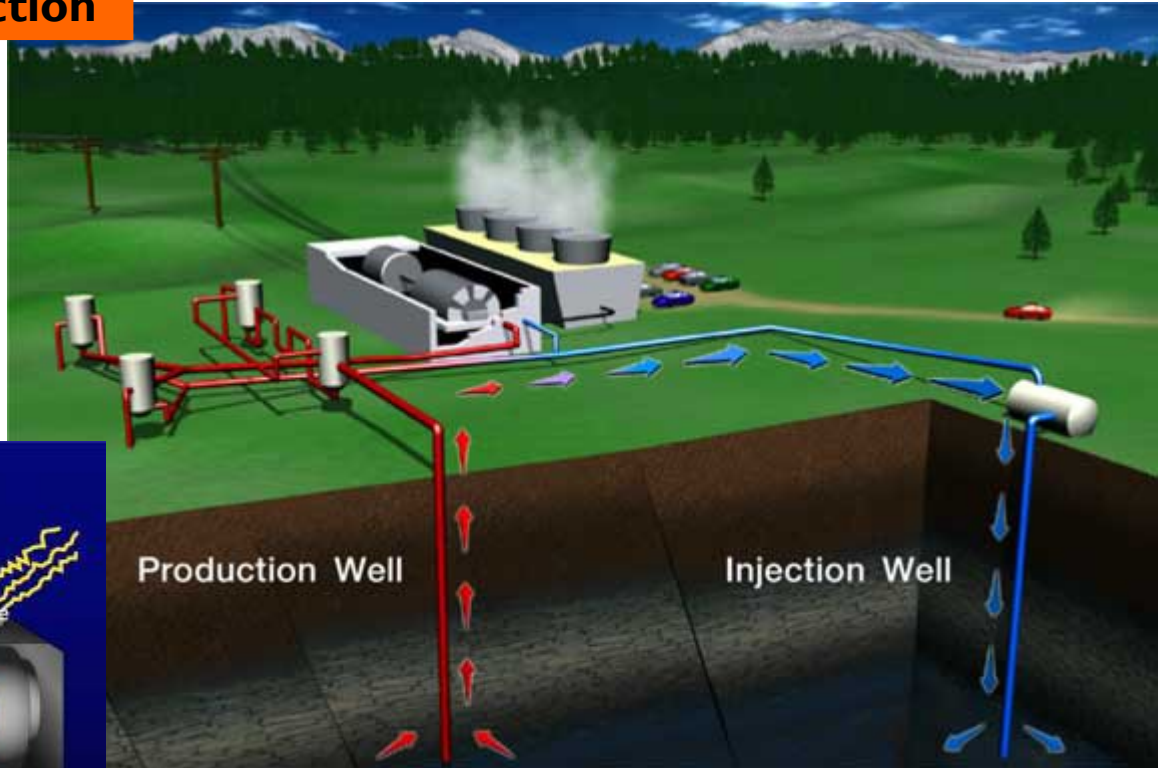
National Research Council of Italy



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

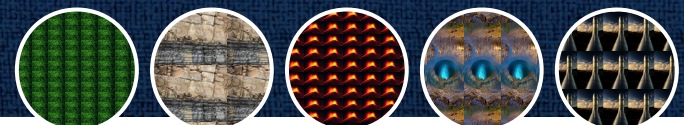
Single or double flash plants
separation of steam and liquid phase

Liquid dominated systems

hydrostatic pressure

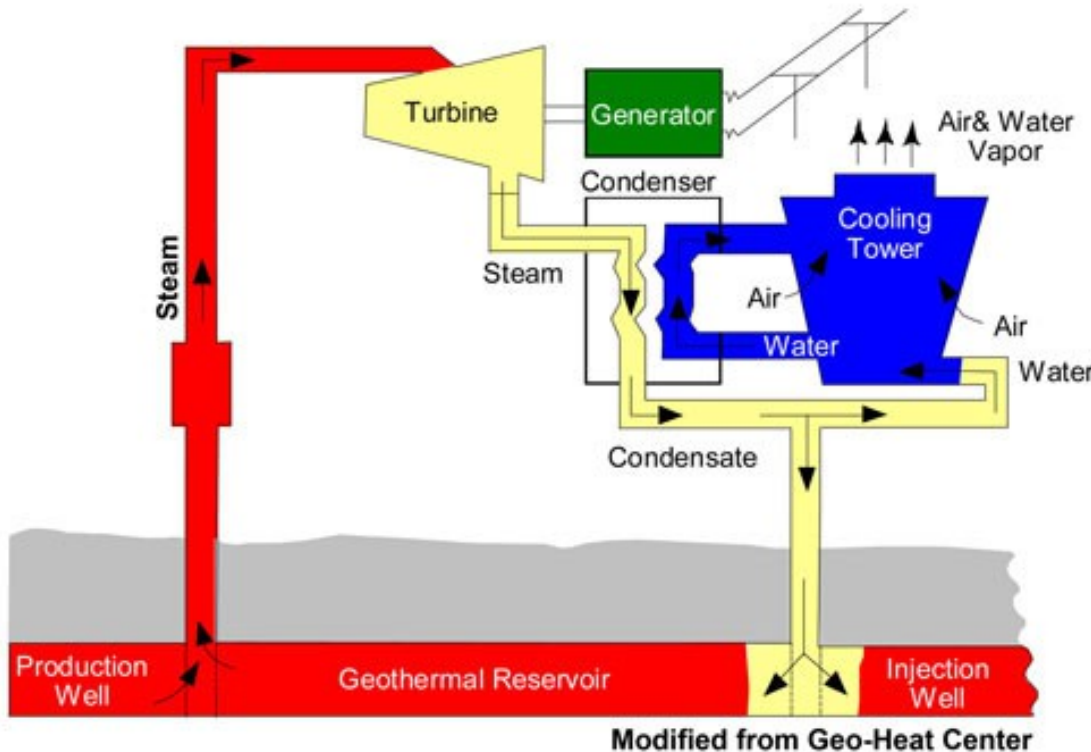
Binary plants

Combined plants
flash and binary,
cascade

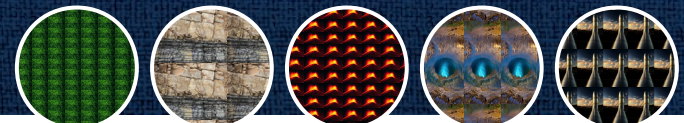


How Geothermal Energy is used

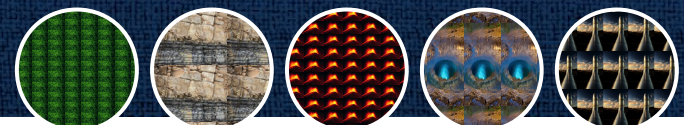
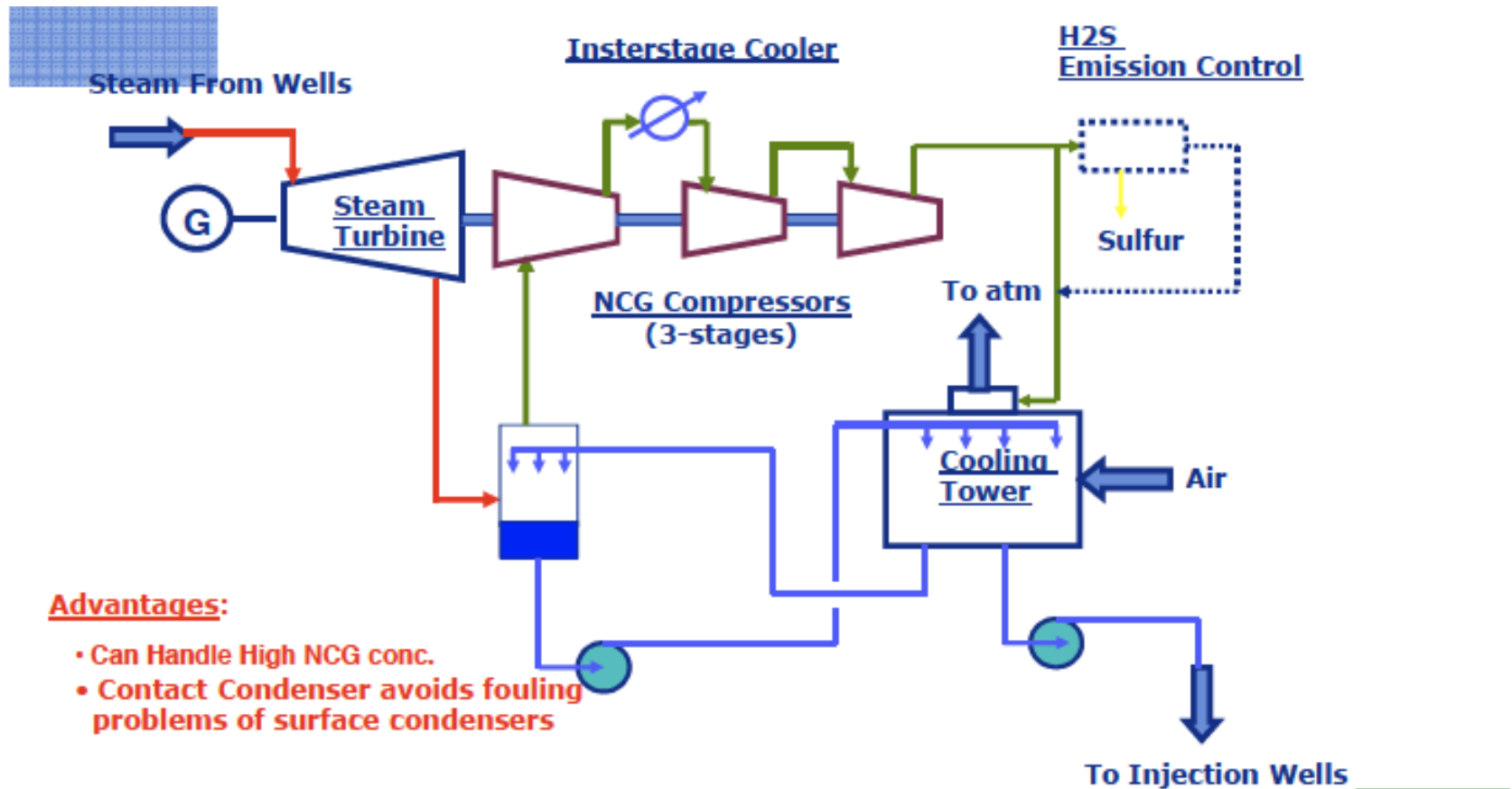
SCHEMATIC DIAGRAM OF A DRY STEAM GEOTHERMAL POWER PLANT



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



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

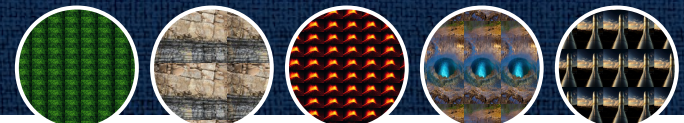
Generator: GE; Alstom; Siemens

Cooling Tower: Marley; Niagara

Economics

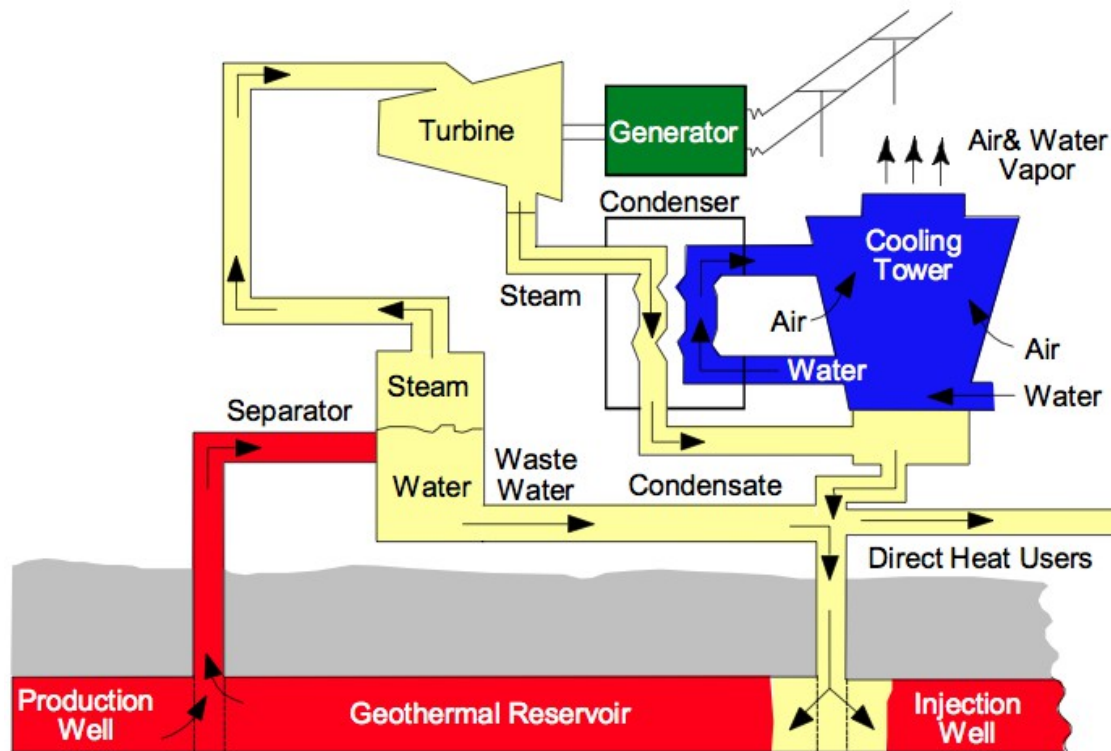
Power Plant Construction Cost:
\$1,000 – \$1,500 / kW

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

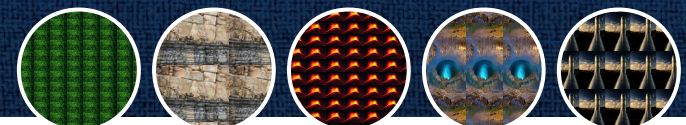


How Geothermal Energy is used

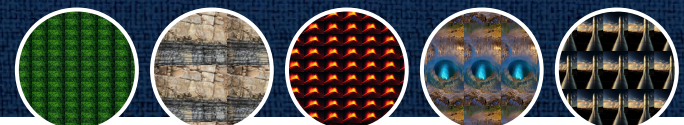
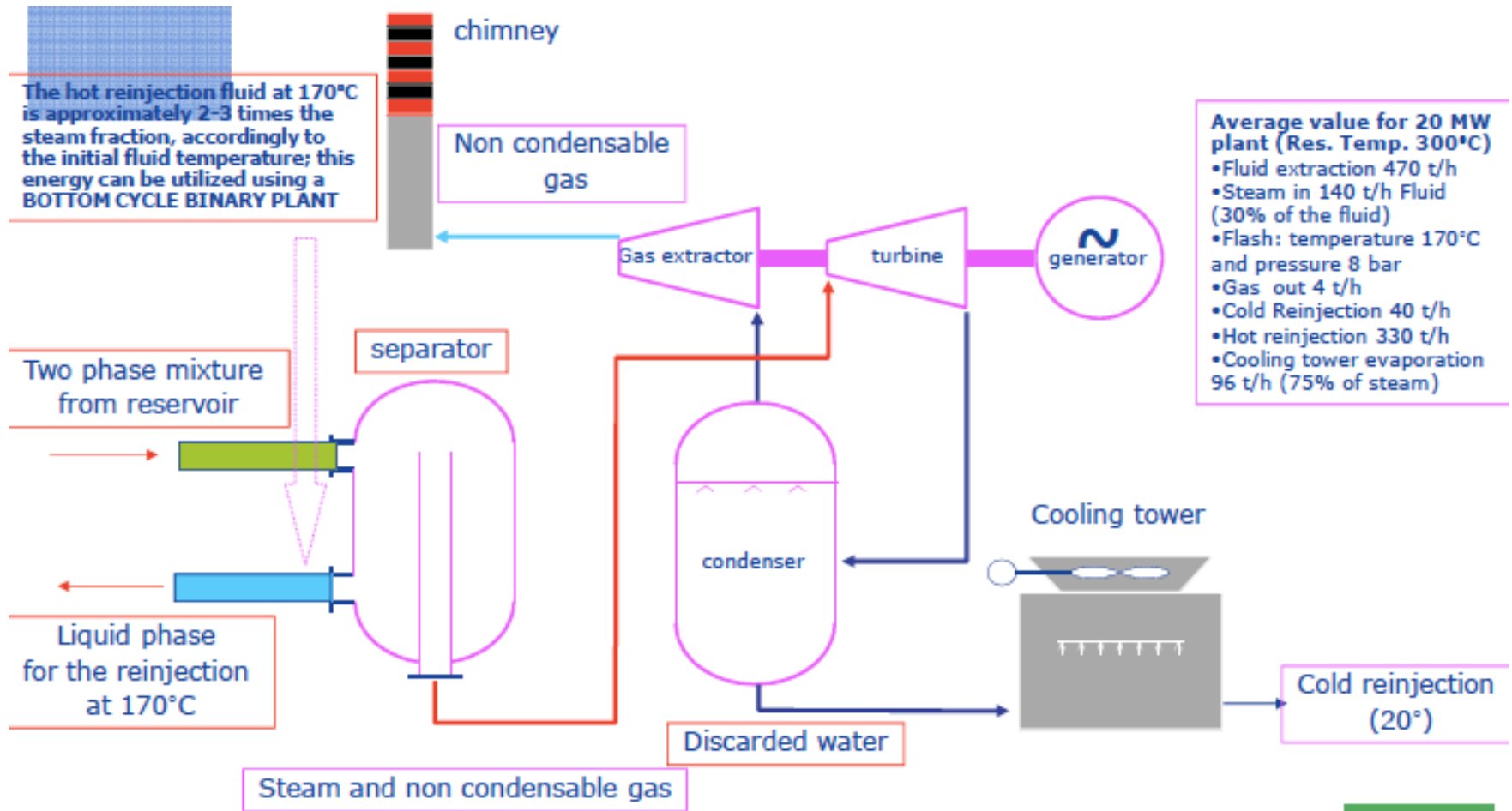
Figure 27: Single Flash Steam Power Plant Schematic



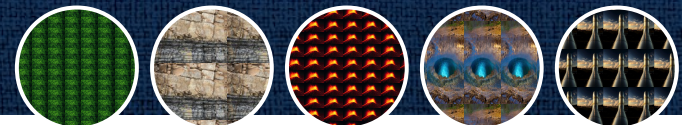
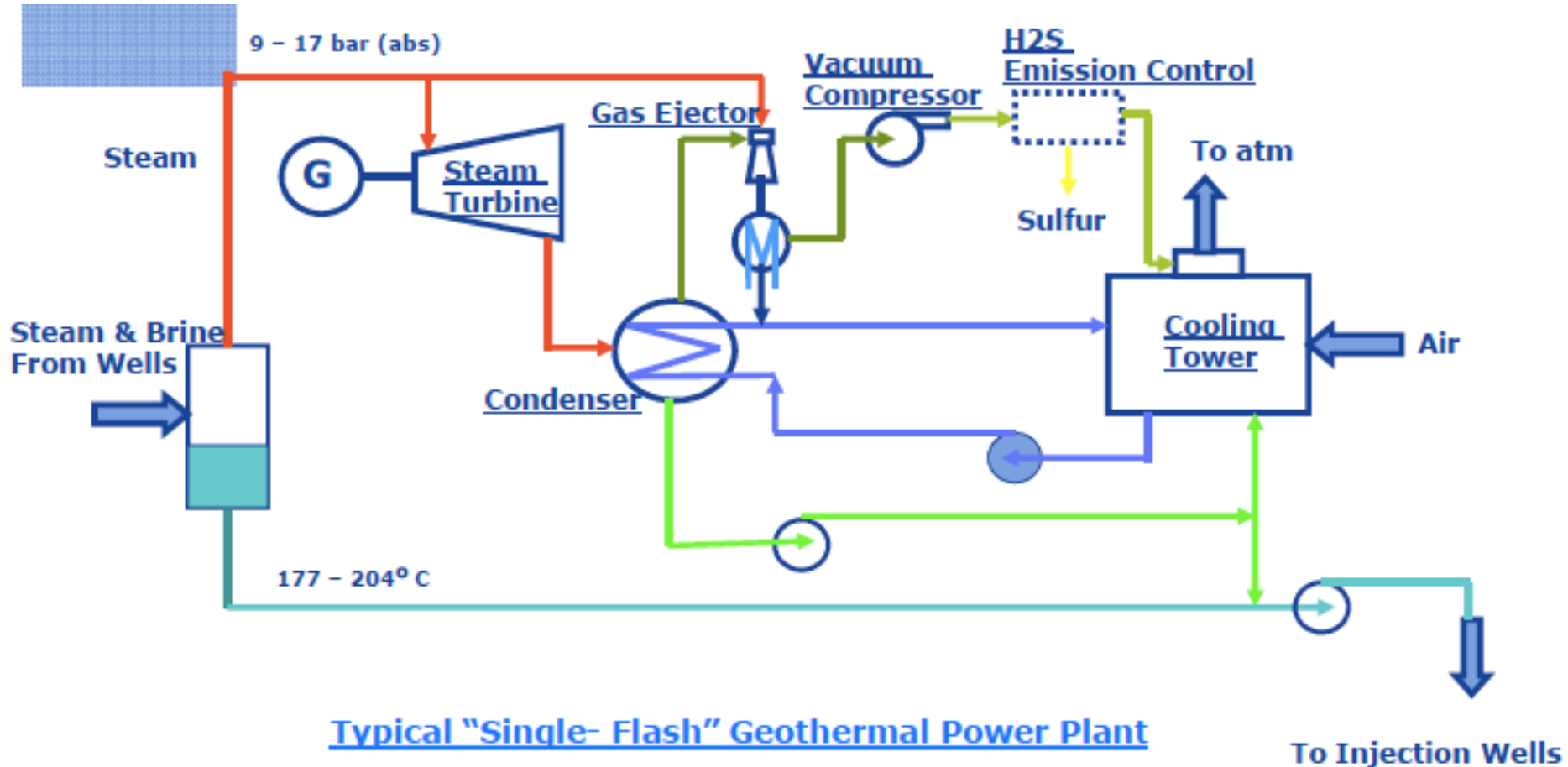
Flash steam power plants tap into reservoirs of water with temperatures higher than **180°C**. As it flows, the fluid pressure decreases and some of the hot water boils or "flashes" into steam. The steam is then separated at the surface and is used to power a turbine/generator unit



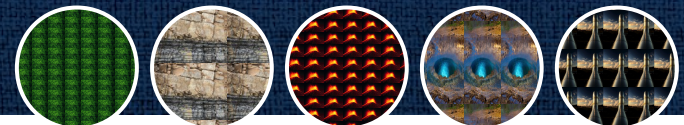
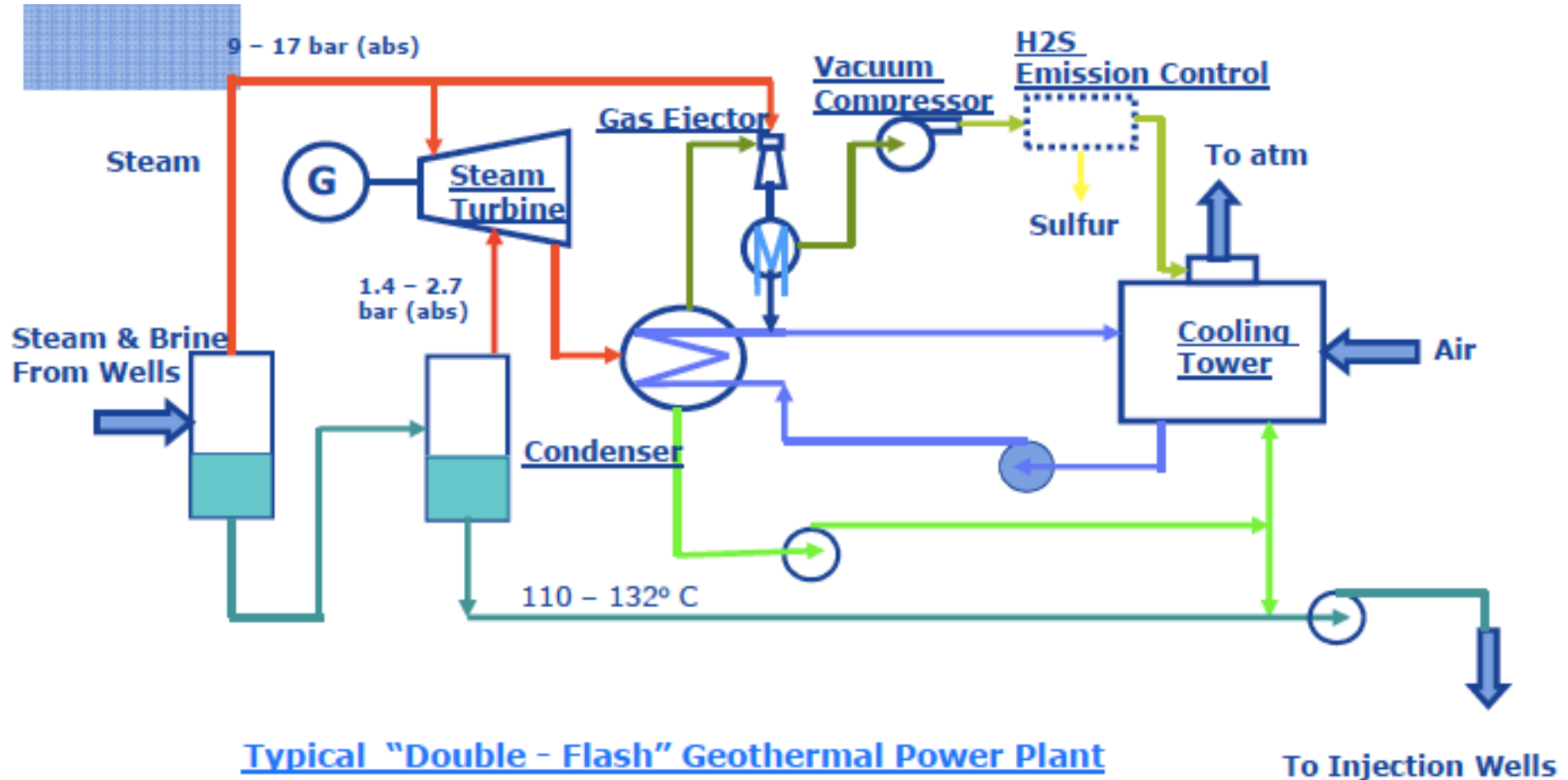
How Geothermal Energy is used



How Geothermal Energy is used



How Geothermal Energy is used



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

Main Equipment Suppliers

Steam Turbine: GE; Mitsubishi; Sumitomo; Ansaldo

Generator: GE; Alstom; Siemens

Cooling Tower: Marley; Niagara;

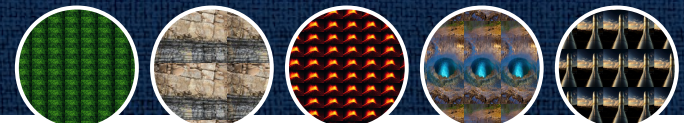
Technology Disadvantages

- 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

Economics

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

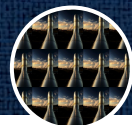
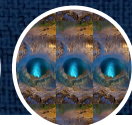
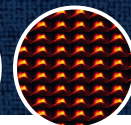
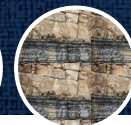
O&M Cost (direct): \$15 - 20 / MWh



How Geothermal Energy is used

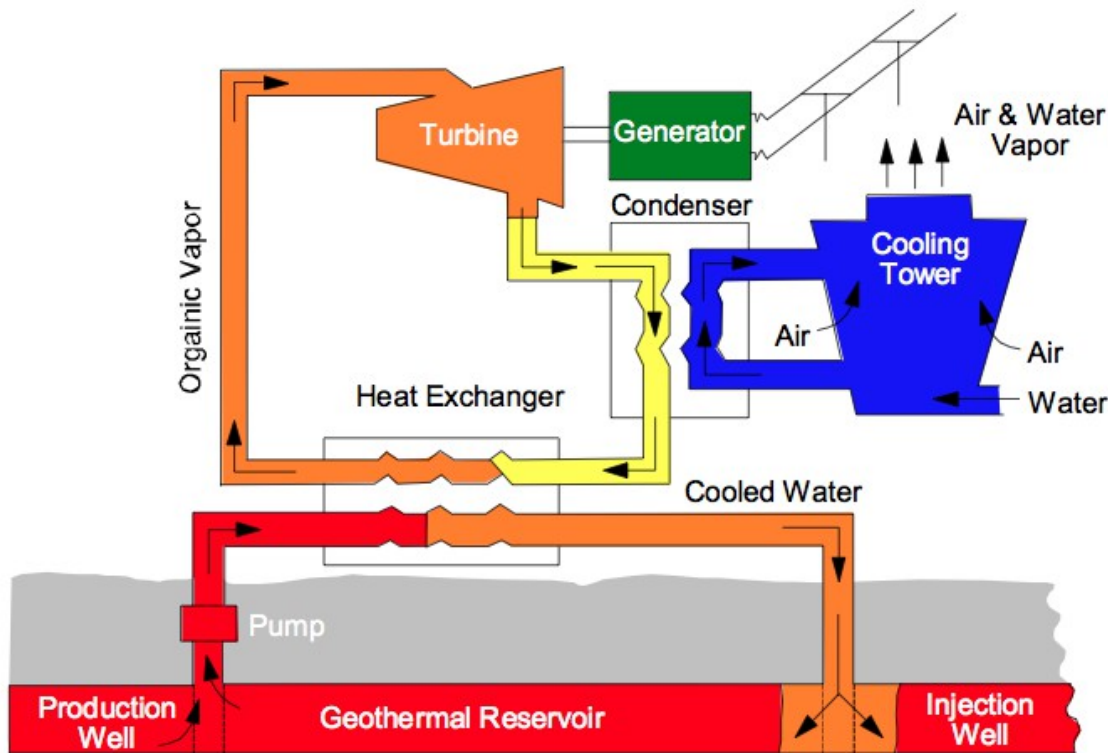


Berlin, El Salvador



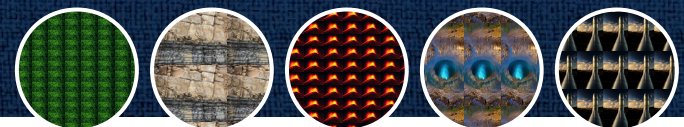
How Geothermal Energy is used

Figure 30: Binary Power Plant Schematic

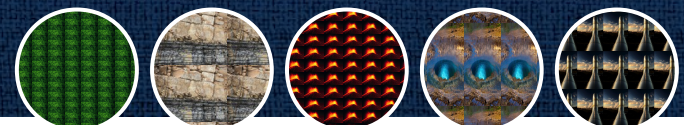
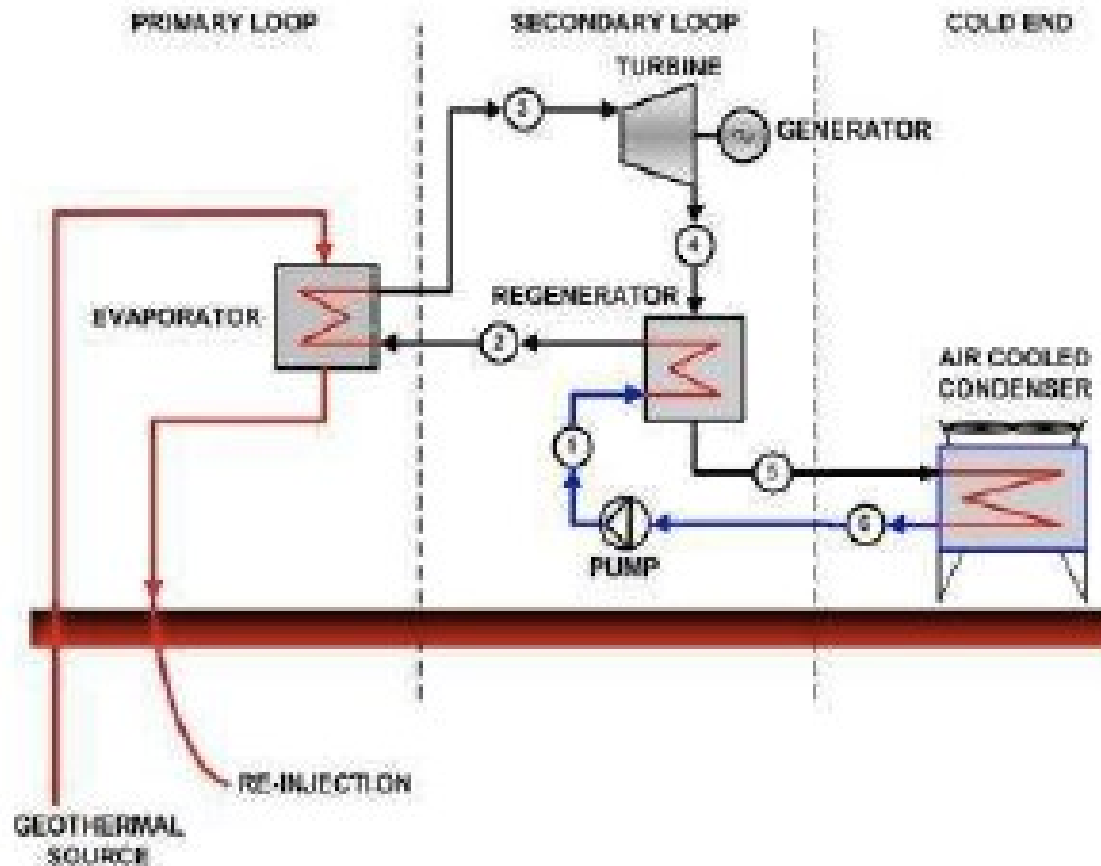


Source: Geo-Heat Center

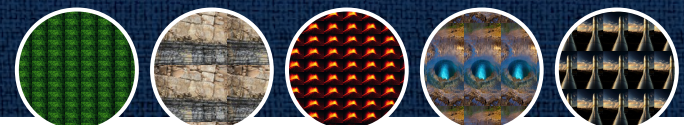
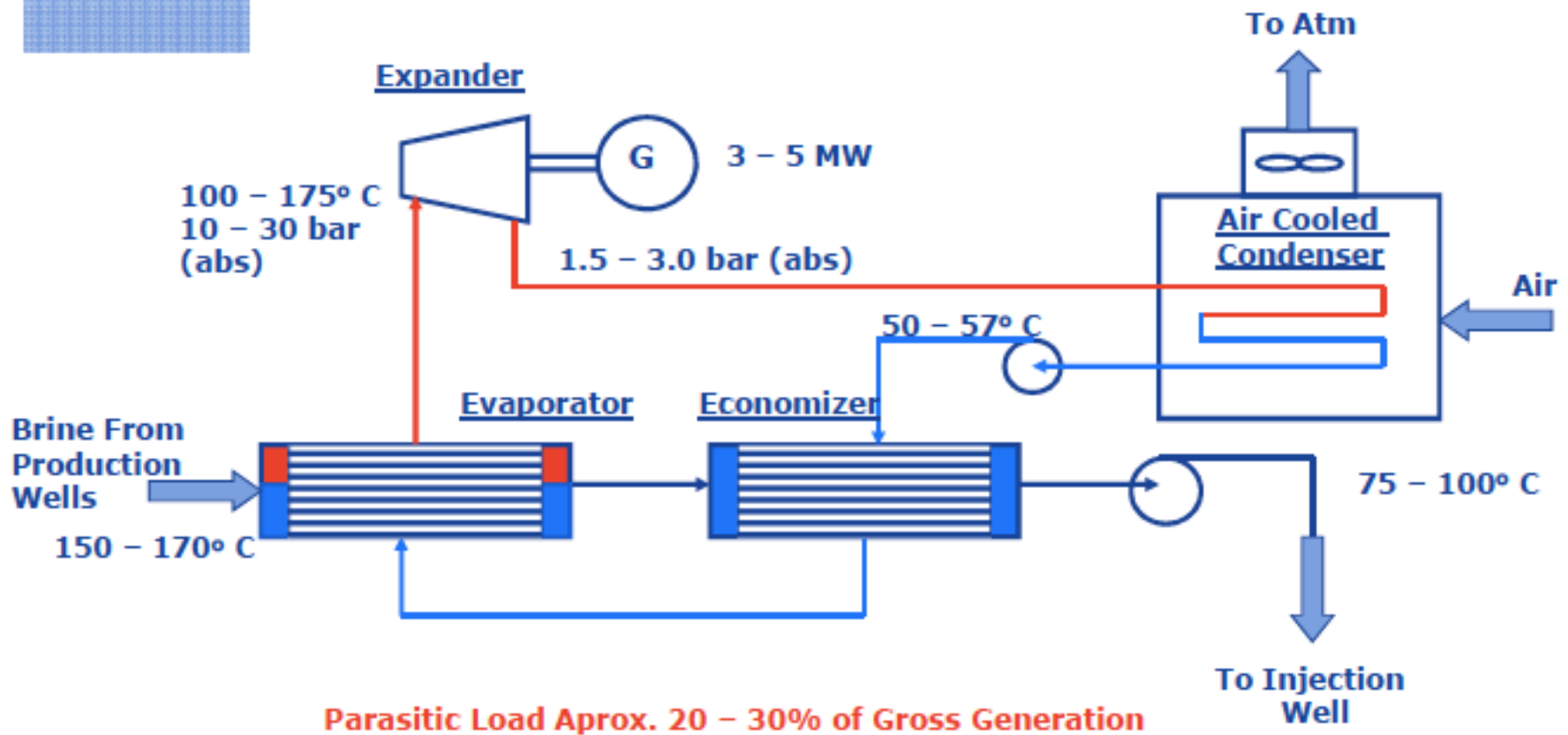
Binary cycle power plants operate on water at lower temperatures of about **105-180°C**. These plants use the heat from the geothermal water to boil a working fluid, usually an organic compound with a low boiling point.



How Geothermal Energy is used



How Geothermal Energy is used



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

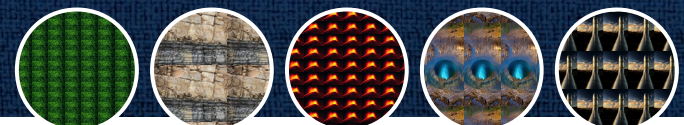
Generators: GE; Alstom; Siemens, Kato

Condensers: Marley; Aerofin; Baltimore Coil

Economics

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

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



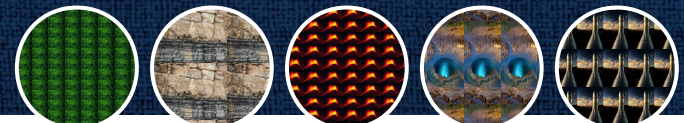
How Geothermal Energy is used

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**

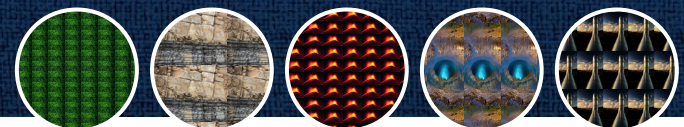


How Geothermal Energy is used

LOW TEMPERATURE

- For temperature below 150°C, the conventional flash is not able to reach satisfactory efficiency: at this temperature, only 10% of steam can be produced at about 1 bar of separation pressure; the steam will have a very low efficiency, due to its low pressure and temperature: for producing 20 MW it is necessary to mine up to 3,000 t/h of fluid; on the other hand, with a binary process, only 1,800 t/h are necessary (from 300°C liquid reservoir for flash plant only 500 t/h).
- The unique way to exploit the geothermal energy for producing electricity is the use of a binary plant on the pressurized fluid, which will be handled through a closed loop from production and reinjection; it is a zero emission cycle.

The total installed capacity of such binary plants is about 600 MW worldwide.



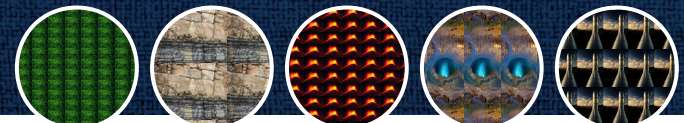
How Geothermal Energy is used

OPTIMIZATION

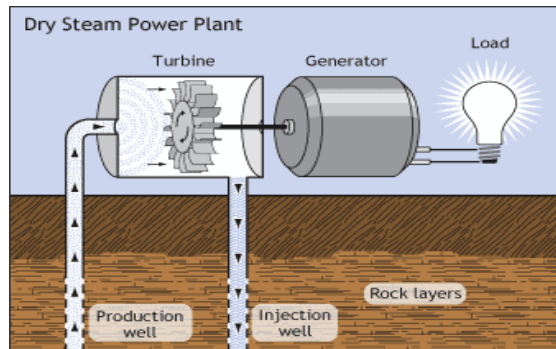
- Bottoming cycle technique is widely used worldwide, as shown in the attached table;
- This electricity is produced using the waste water from the separated brine: it can be considered as an unexpensive and rich of value by-product of the primary flash power plant.

The total installed capacity of such binary plants is about 160 MW worldwide.

Country	Plant	Capacity (MW)
Iceland	Svartsenegi	8
El Salvador	Berlin	9
Mexico	Los Azufres	3
New Zealand	Kawerau	6
New Zealand	Mokai	27
New Zealand	Rotokawa	13
New Zealand	Wairakei	14
Nicaragua	Momotombo	7
Philippines	Mak-Ban	16
Philippines	Tongonang	19
Philippines	Mahandong	19
Philippines	Mahiaio	5
Philippines	Malitbog	12
TOTAL		160

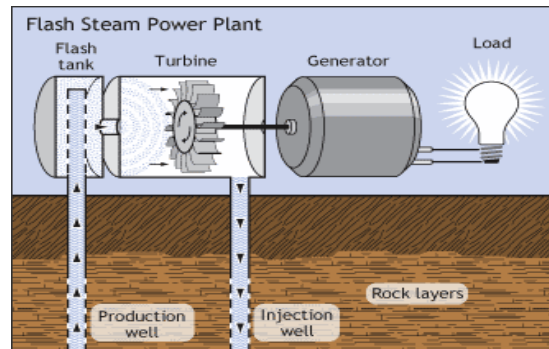


How Geothermal Energy is used



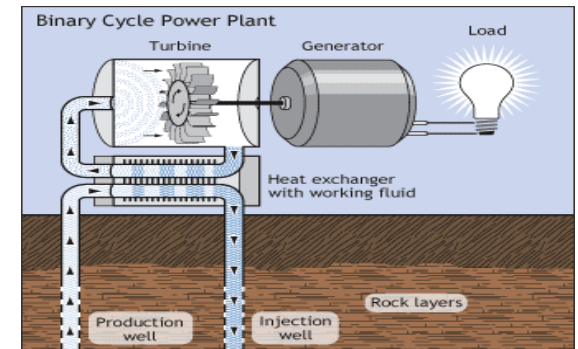
Dry steam plants

Highly cost competitive
but geographically limited



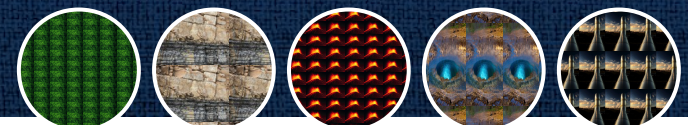
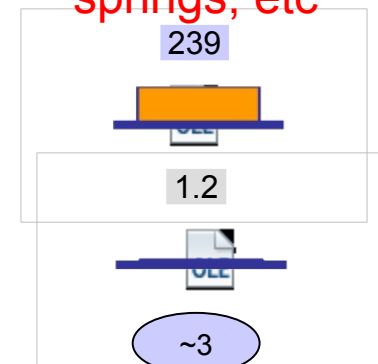
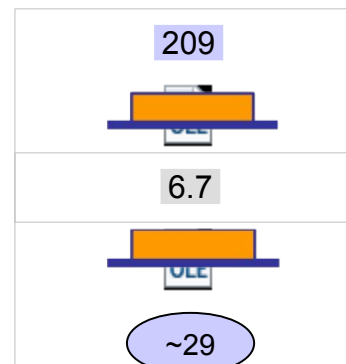
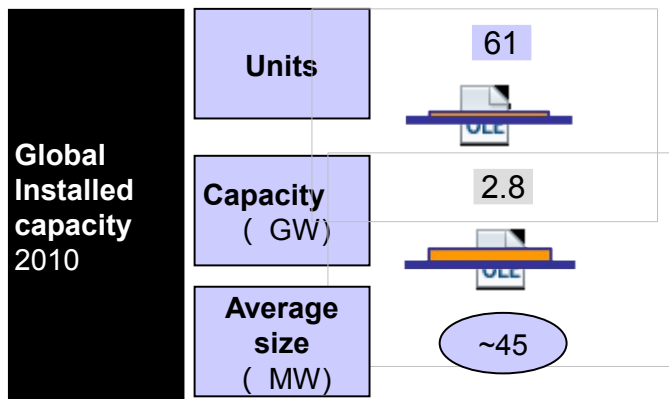
Flash steam power plants

Most dominant in terms
of global capacity



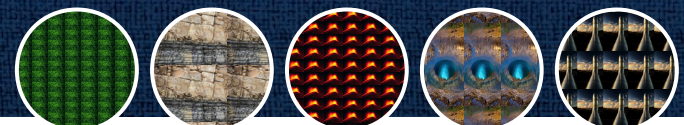
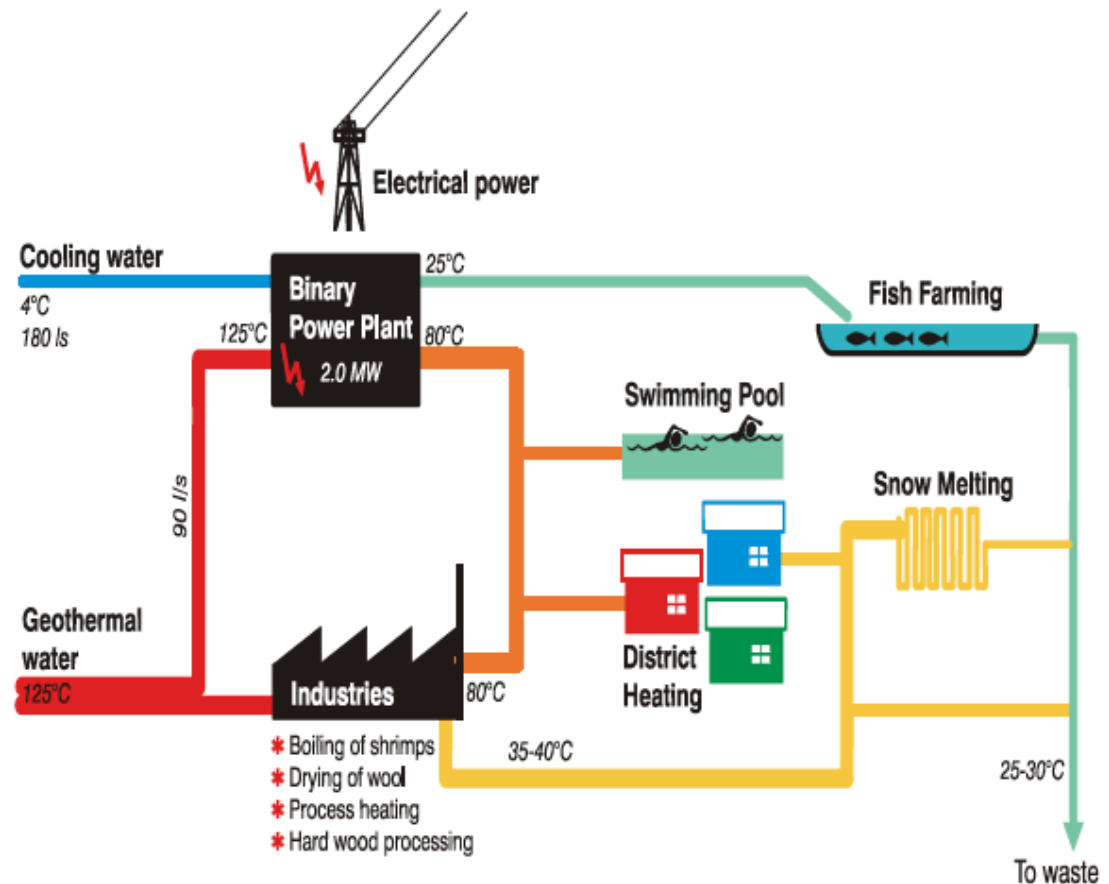
Binary cycle power plants

Useful alongside
geothermal heating, hot
springs, etc



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.

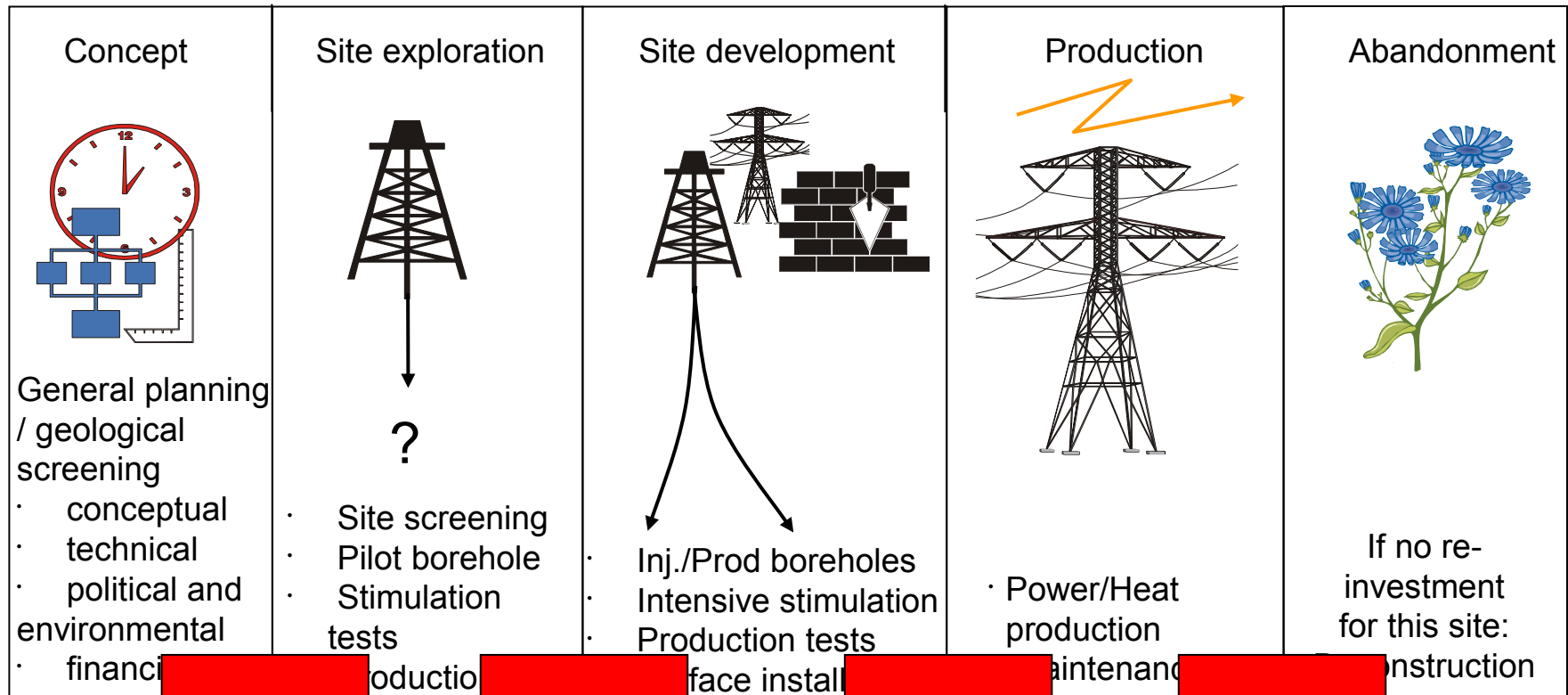


How Geothermal Energy is used

Investigation

Drilling, stimulation and reservoir
assessment

Exploitation, economic, environmental
and social impacts



Milestone

From ENGINE



IGG – Institute of Geosciences and Earth
Resources
National Research Council of Italy



How Geothermal Energy is used

10 MWt (thermal) $\approx \rightarrow$ 1MWe (electric)

1 MWe 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)



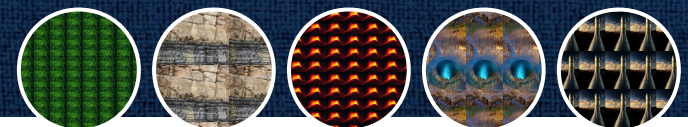
How Geothermal Energy is used

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

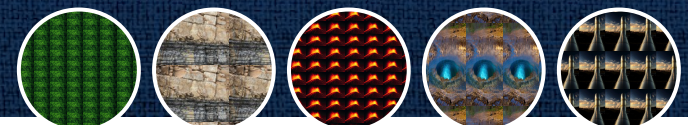
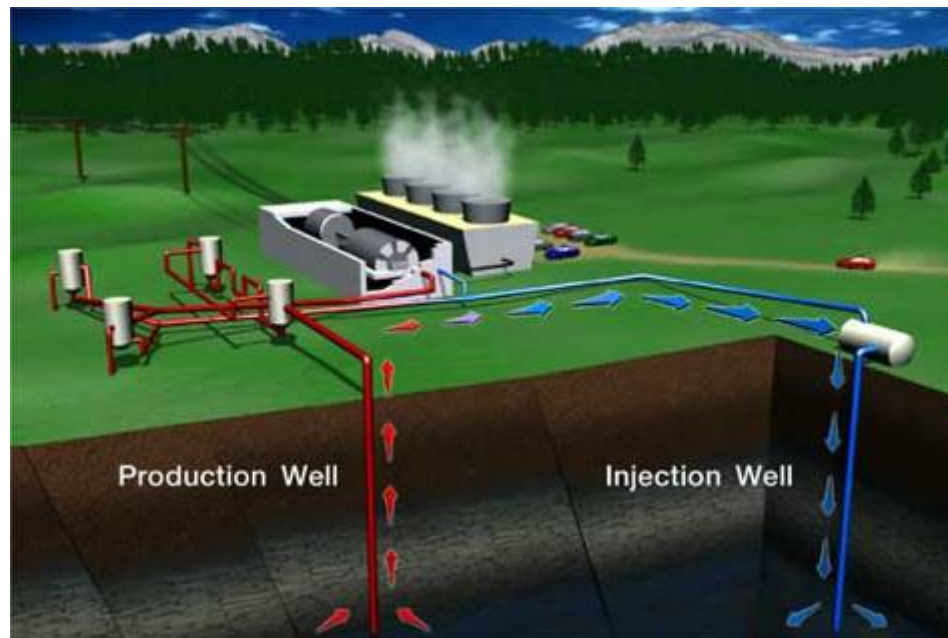
For most uses, a well must penetrate permeable zones, usually fractures, that can support a high flow rate.



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.



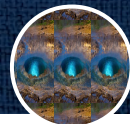
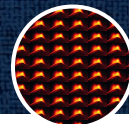
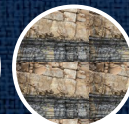
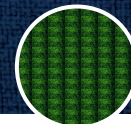


duction? What about the cost? And emissions?

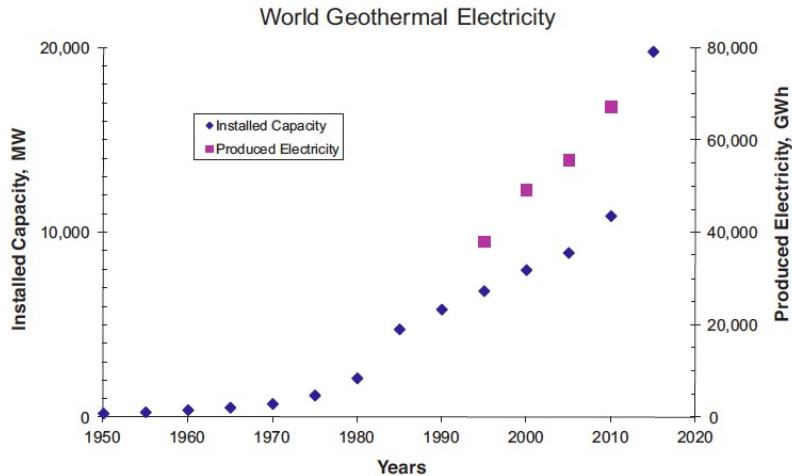
The advantages of using Geothermal Energy



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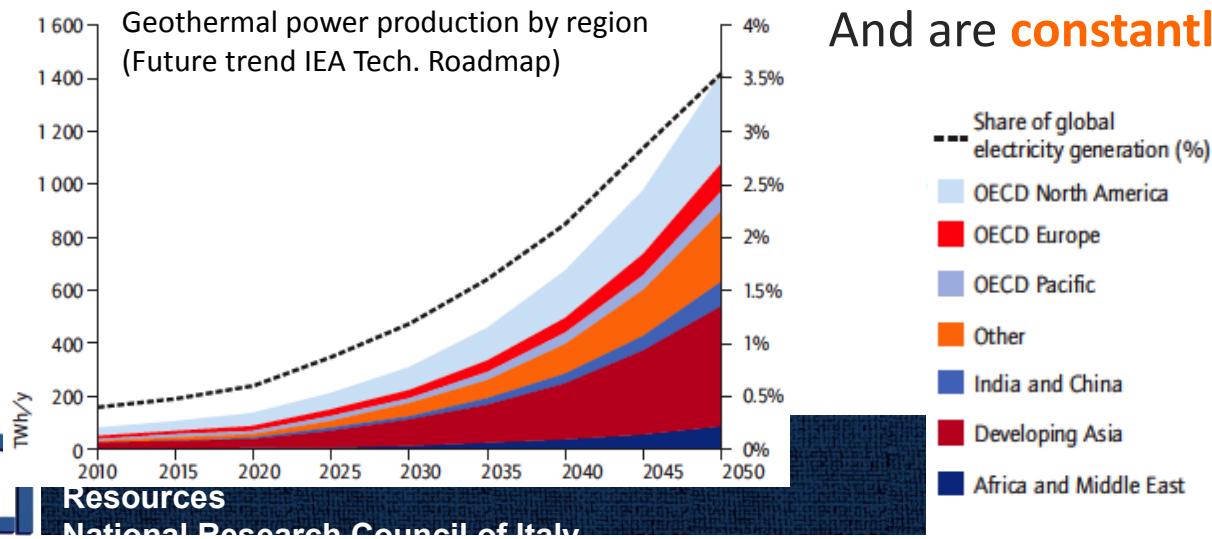


Geothermal Energy pros

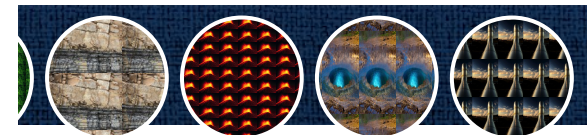


Bertani, 2012

The two main applications of geothermal energy, electric power generation and direct use of heat, are currently producing more than 67 TWh/ae and 10 GWe of installed capacity, and about 300 TJ/yr with 30 GWth

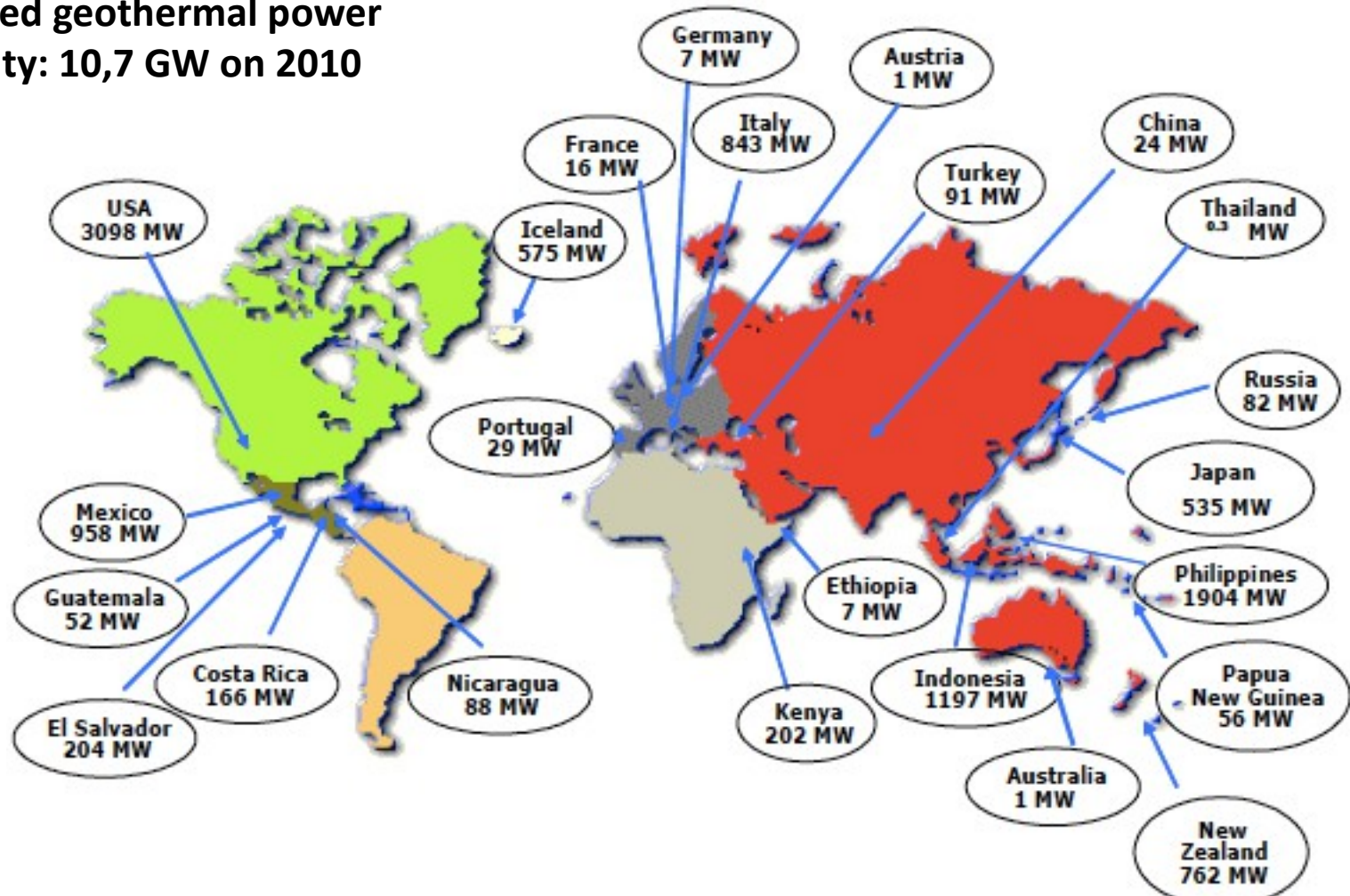


And are **constantly growing**.

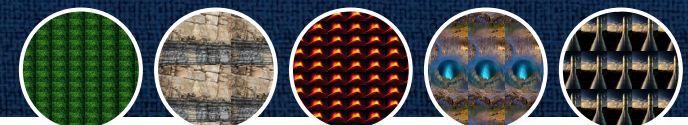


Geothermal Energy pros

Installed geothermal power capacity: 10,7 GW on 2010








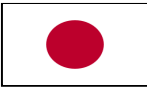


From Bertani, WGC 2010



Geothermal Energy pros

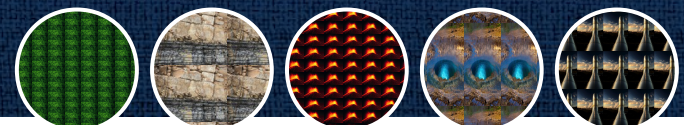
Installed geothermal power capacity: 10,7 GW on 2010

	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

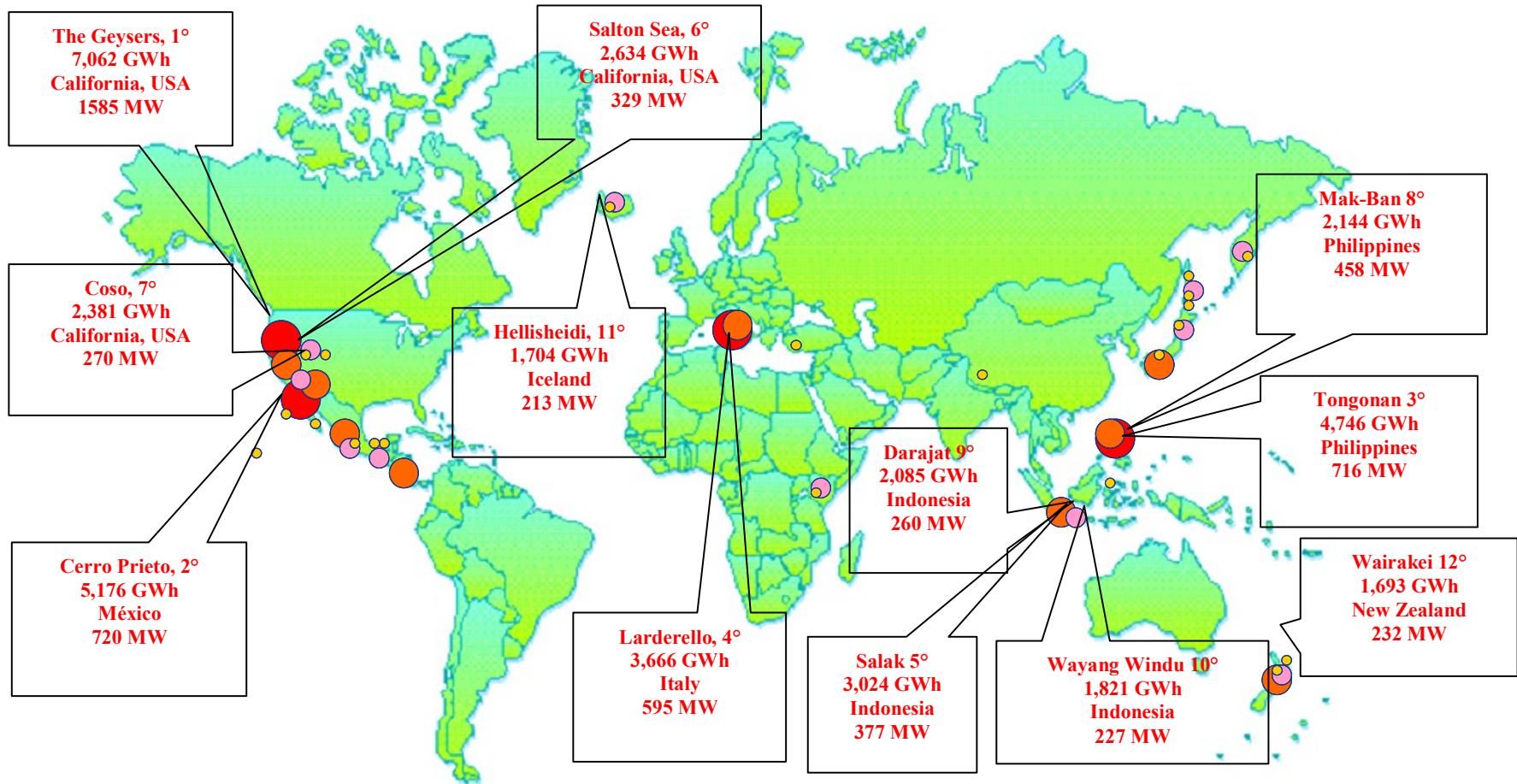


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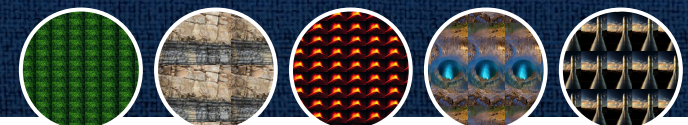


Geothermal Energy pros

Geothermal power production by main field

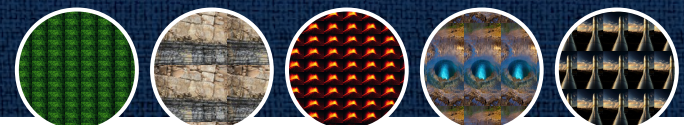
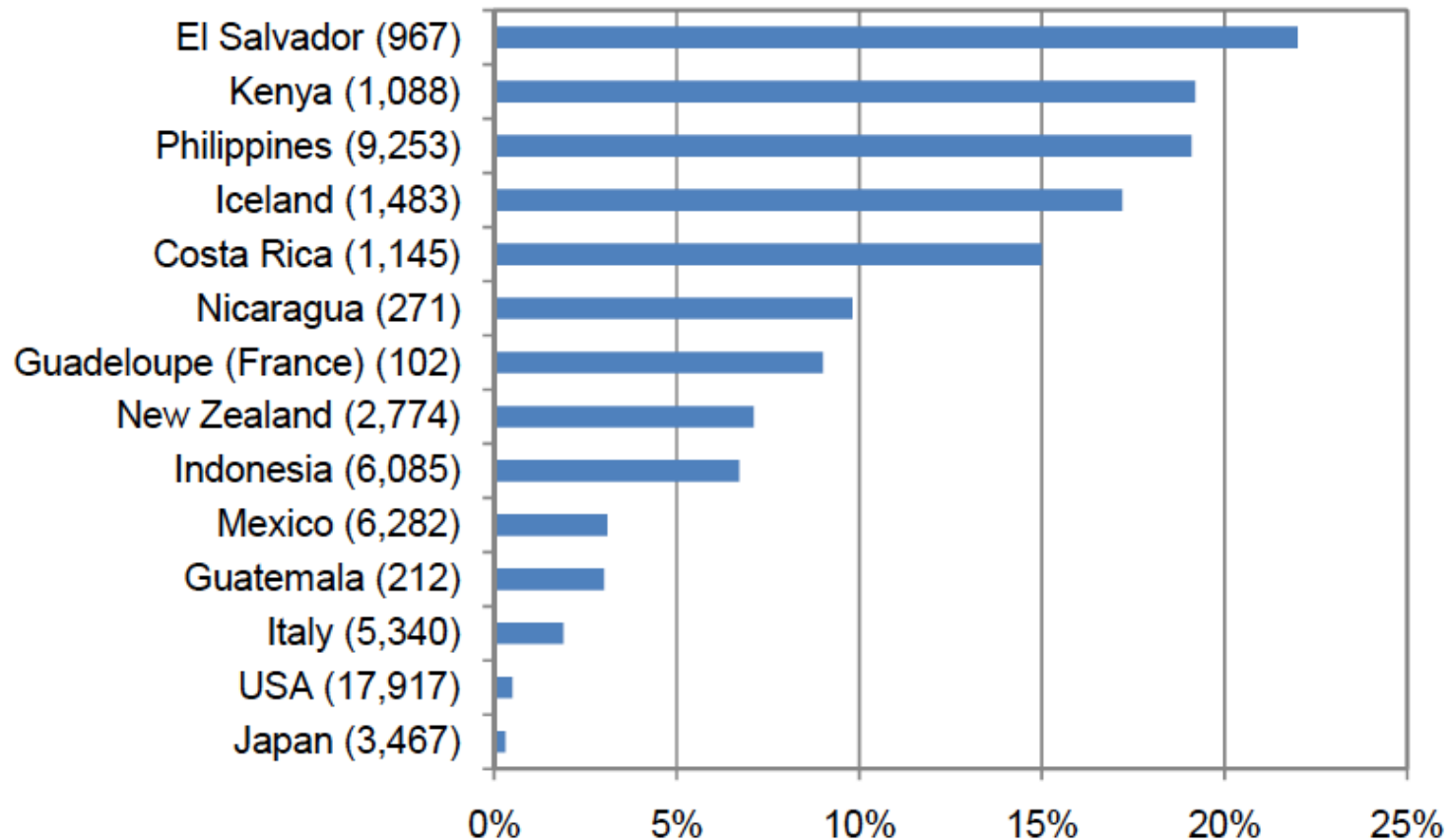


From Bertani, WGC 2010



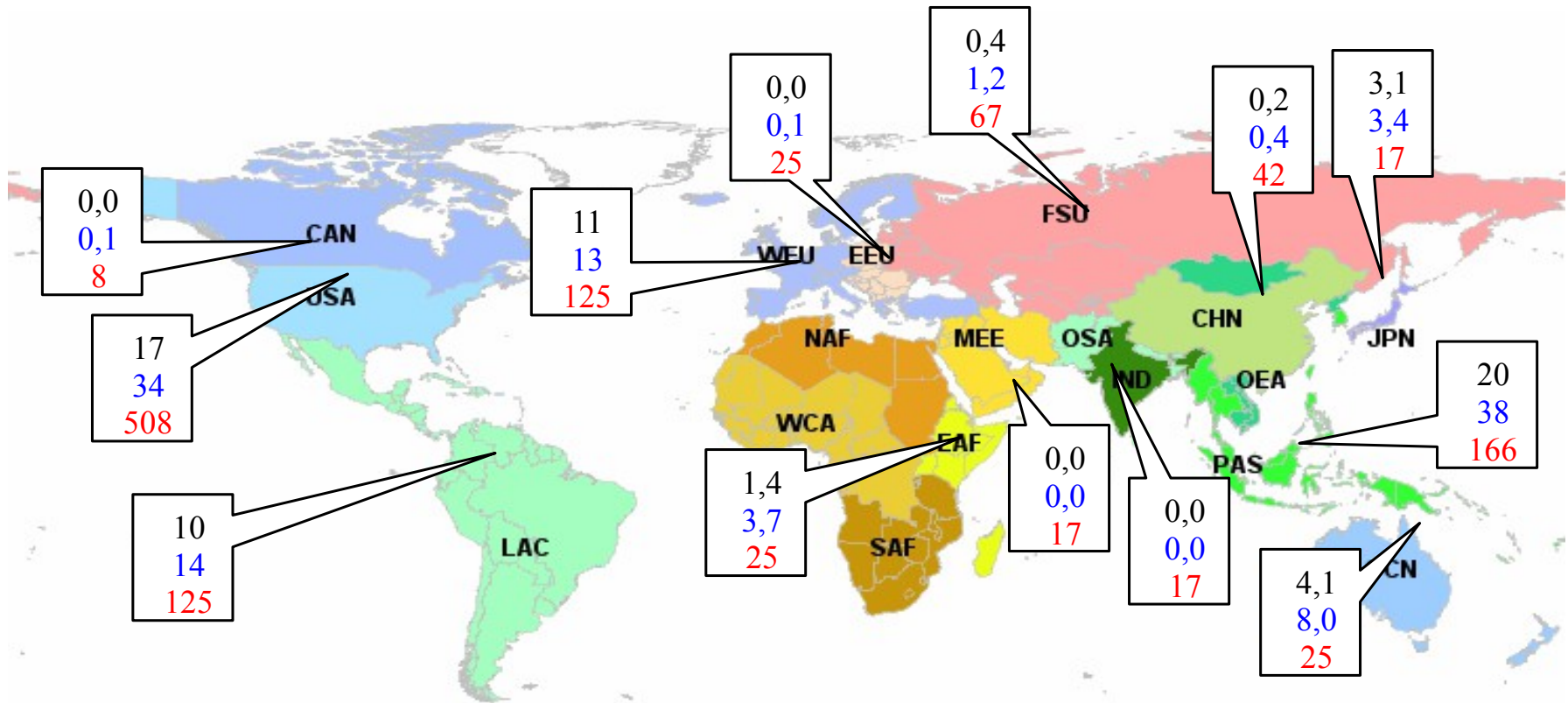
Geothermal Energy pros

Share of geothermal energy in national electricity production



Geothermal Energy pros

Foreseen growth of geothermal power production (TWh/a)



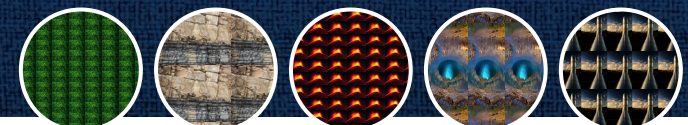
Color legend: 2010, 2015, 2050

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

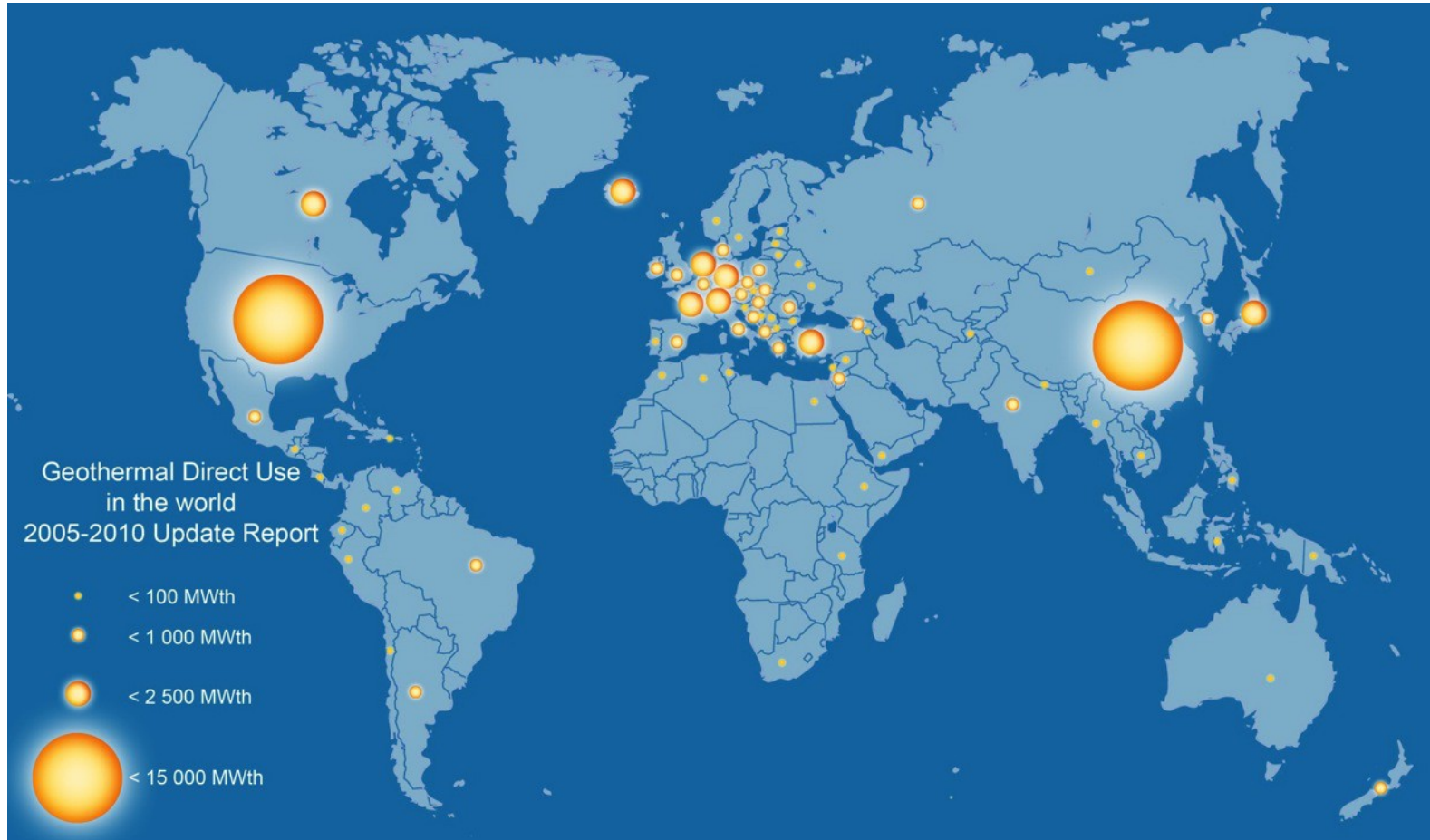
From Bertani, WGC 2010



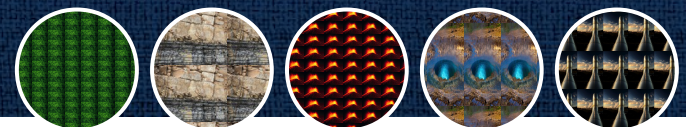
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National Research Council of Italy



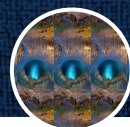
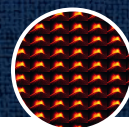
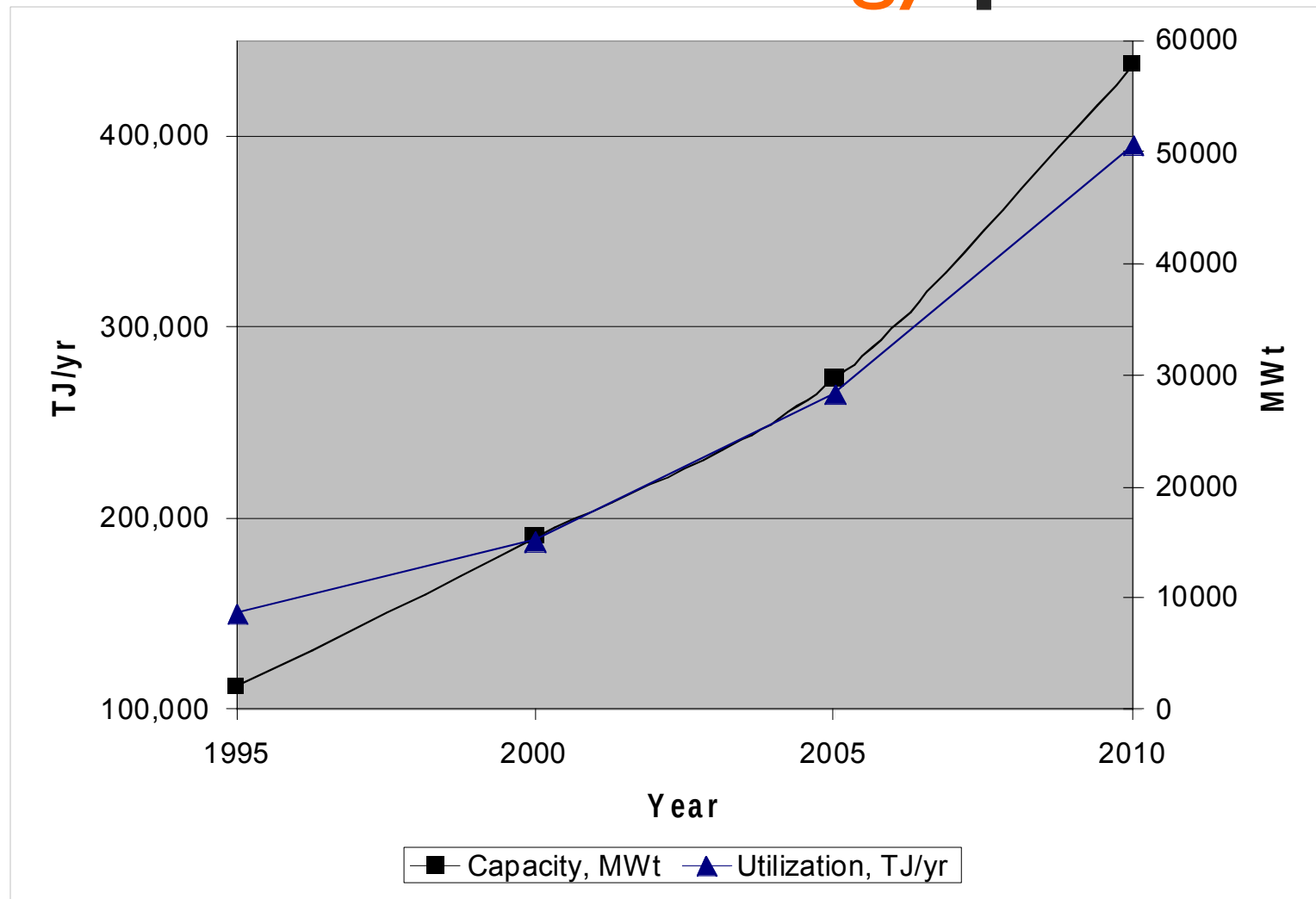
Geothermal Energy pros



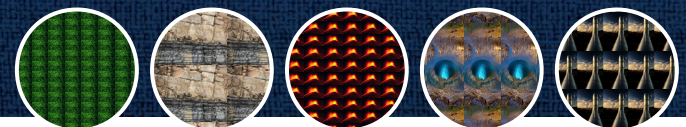
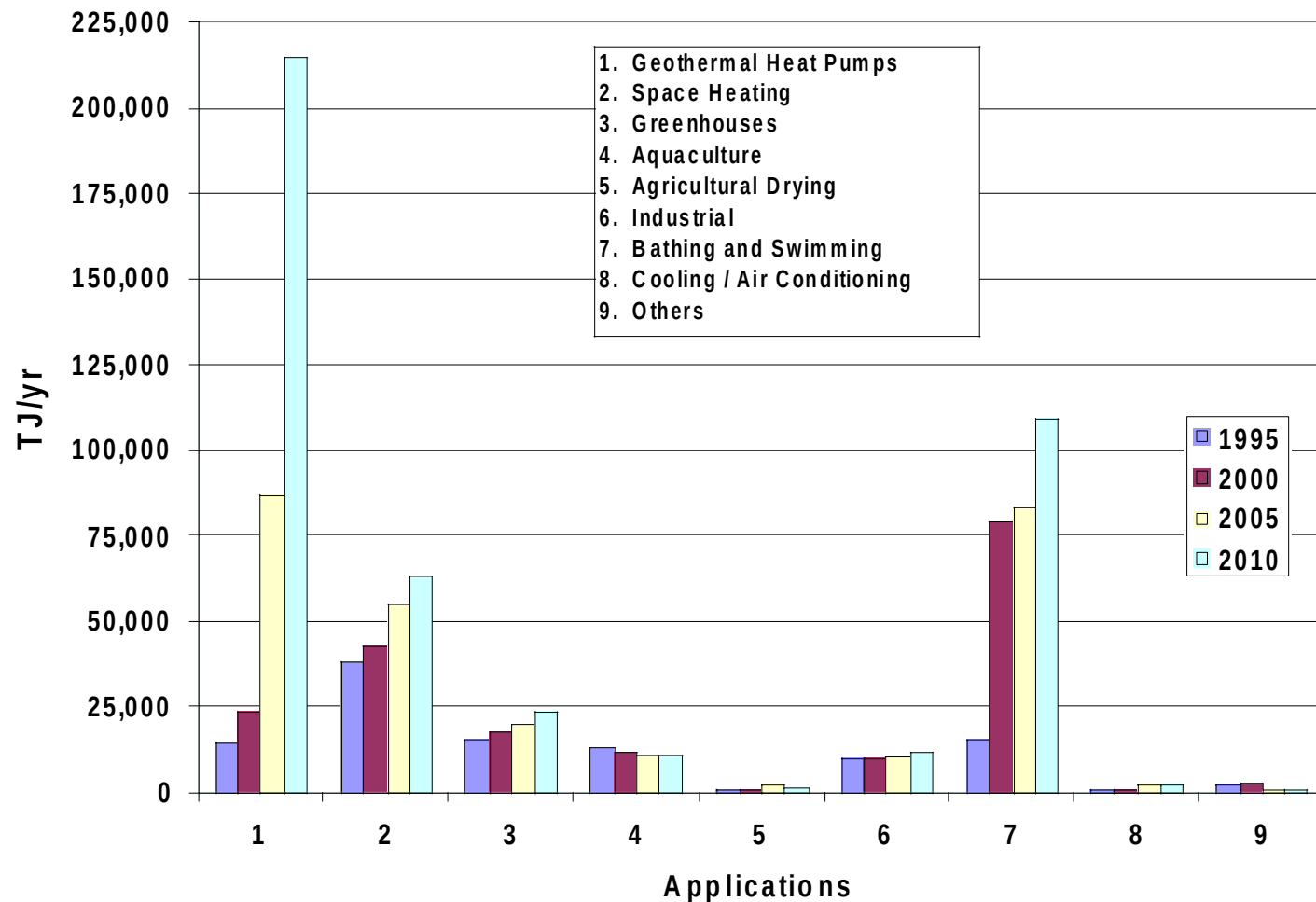
Installed heat capacity in the **79 countries** using geothermal heat was estimated at **43 GWt on 2010**



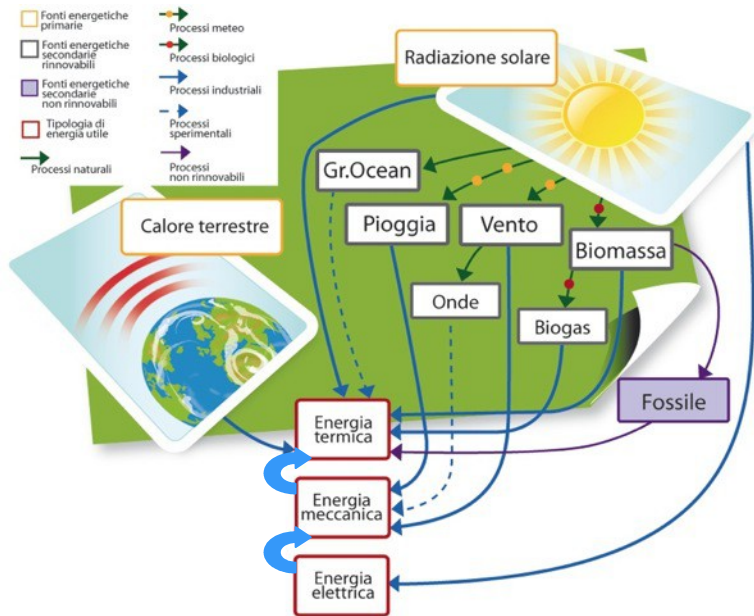
Geothermal Energy pros



Geothermal Energy pros

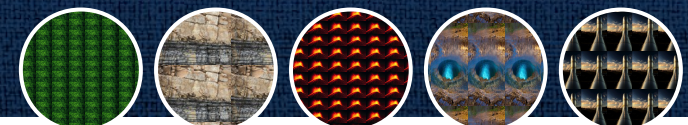
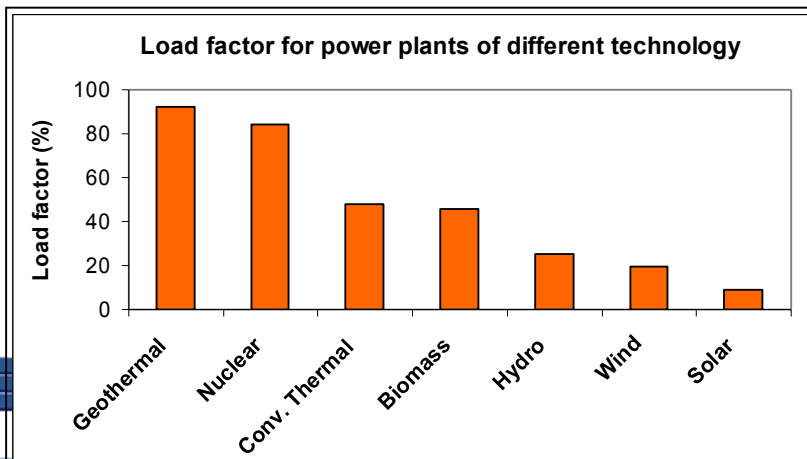


Geothermal Energy pros



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

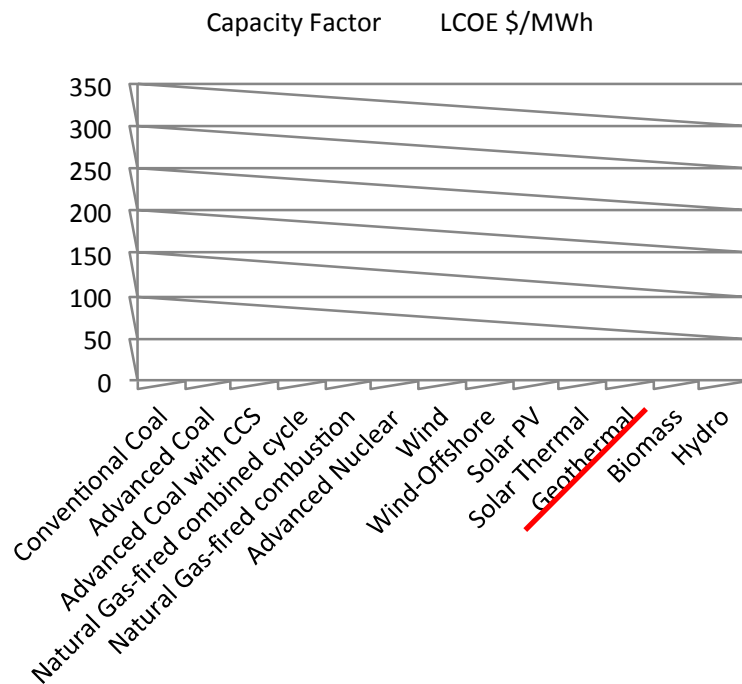
It is most economical for geothermal power stations to serve as **base load** throughout the year.



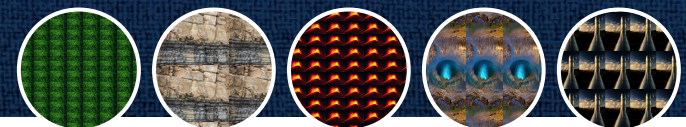
Geothermal Energy pros



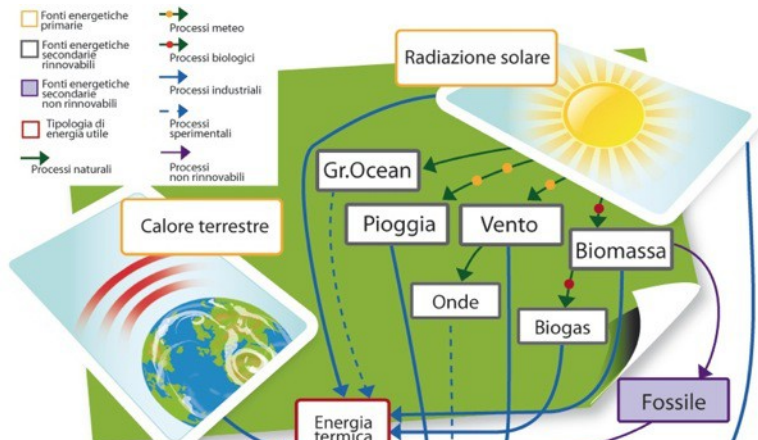
The **total cost (LCOE)** of geothermal power production is **cheap** if compared to those of others renewables



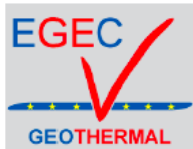
Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011, EIA



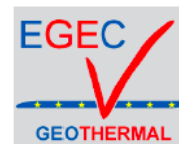
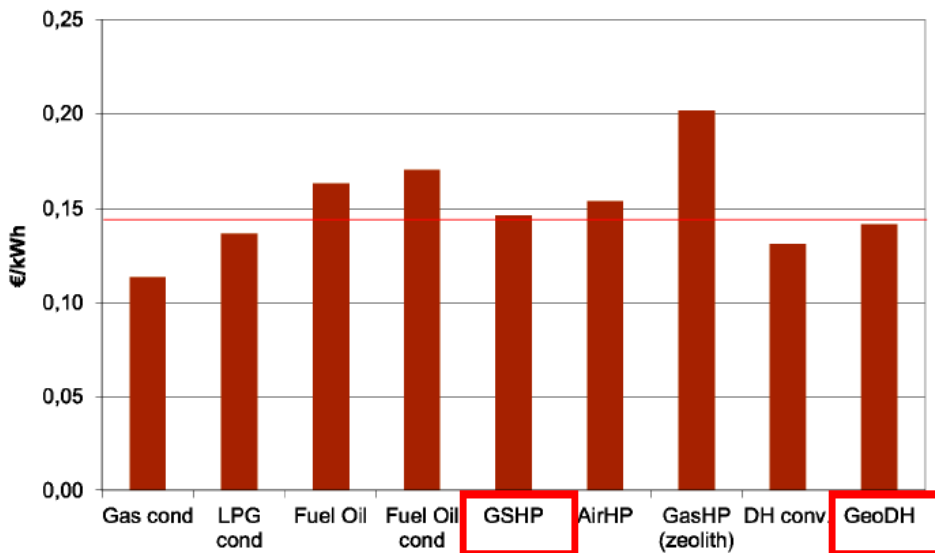
Geothermal Energy pros



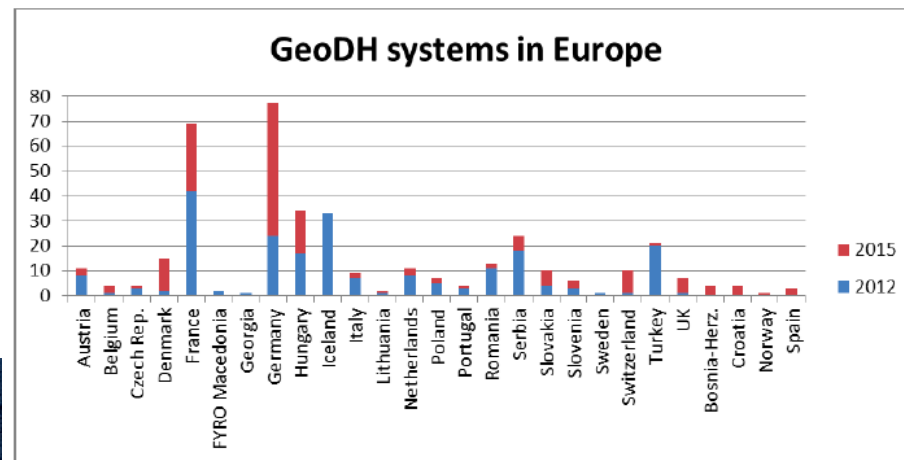
The **total cost (LCOE)** of geothermal power production is **cheap** if compared to those of others renewables and fuels



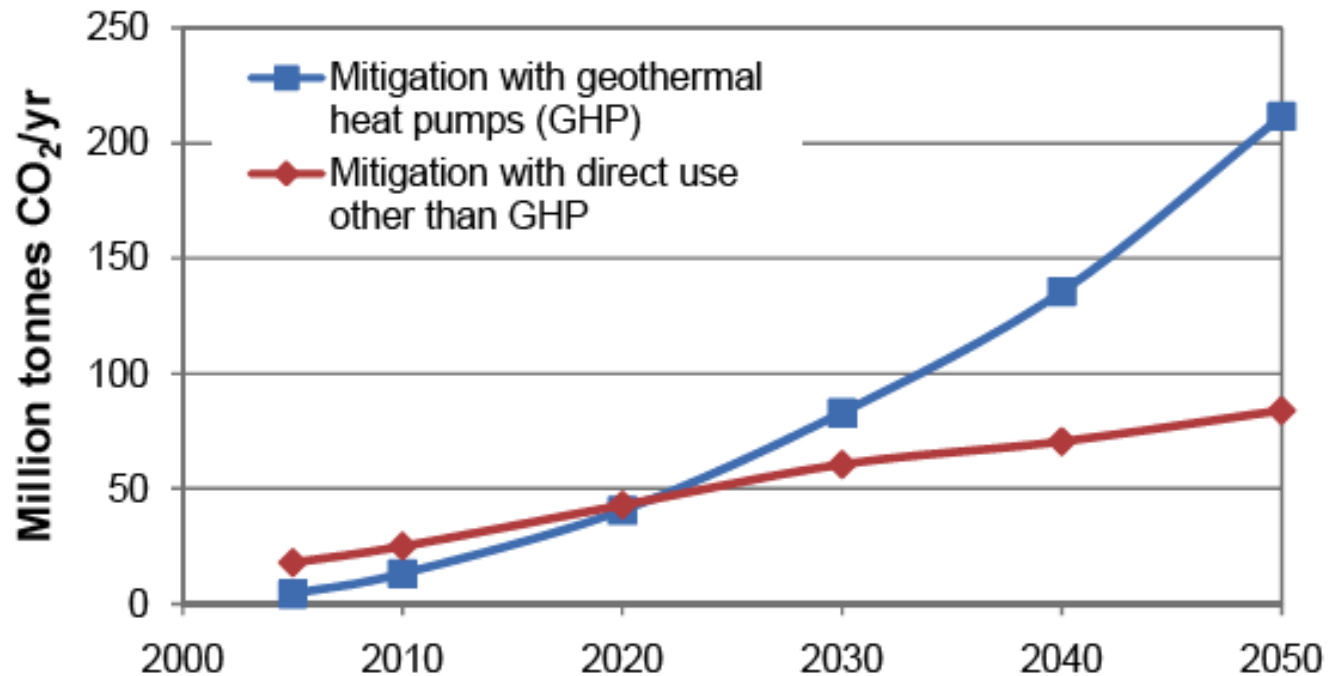
Full cost of Heat, calculated for small building or flat



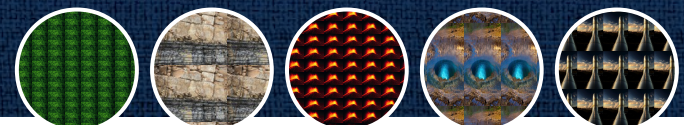
GeoDH Systems in Europe

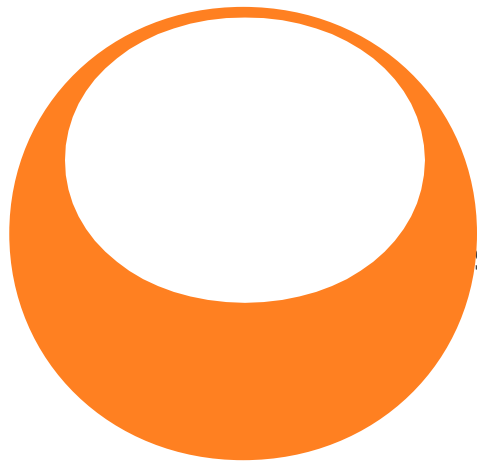


Geothermal Energy pros



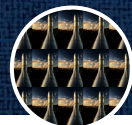
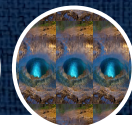
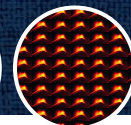
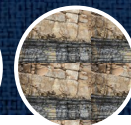
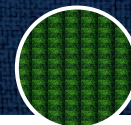
CO₂ emission mitigation of Geothermal Heat. For each Geothermal Heat Pump (blue) it assumes an emission of 50 tonnes CO₂-equivalent/TJ. For other sources of geothermal heating (red) it assumes an emission of 4 tonnes CO₂-equivalent/TJ. Both assume an emission of 100 tonnes CO₂ equivalent/TJ for fossil heat provision. Fridleifsson et al., 2008





isks? Environmental impact?

Disadvantages, needs and gaps of Geothermal Energy

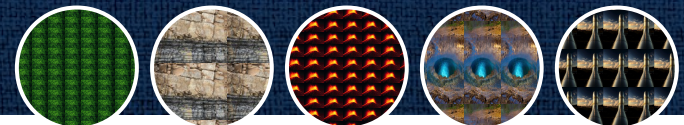


Geothermal Energy **cons**



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

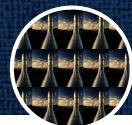
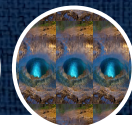
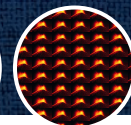
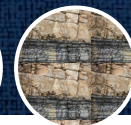
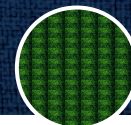
The average geothermal capacity on the entire 526 units in operation is 20.6 MW

BIG

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

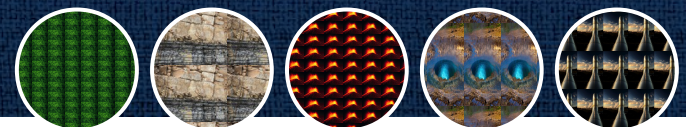
SMALL

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**

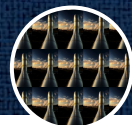
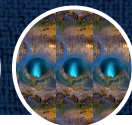
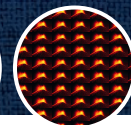
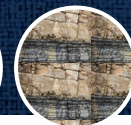
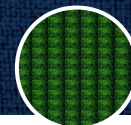
- The economics of electricity production is influenced by the drilling costs and resource development;
- The productivity of electricity per well is a function of reservoir fluid thermodynamic characteristics (phase and temperature);
- The higher the energy content of the reservoir fluid, the lesser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



Geothermal Energy **cons**

Environmental impact – main categories

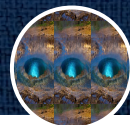
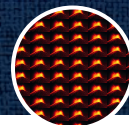
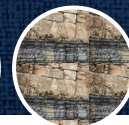
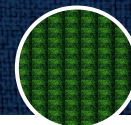
- Surface disturbances
 - Landscape, surface water
- Physical effects
 - Fluid withdrawal on natural manifestations, land subsidence, induced seismicity, visual effect (buildings, cooling towers, surface pipelines, power transmission lines etc.)
- Noise
- Thermal pollution
 - liquid and steam release 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

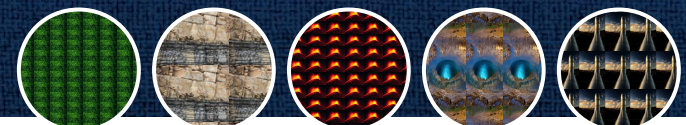
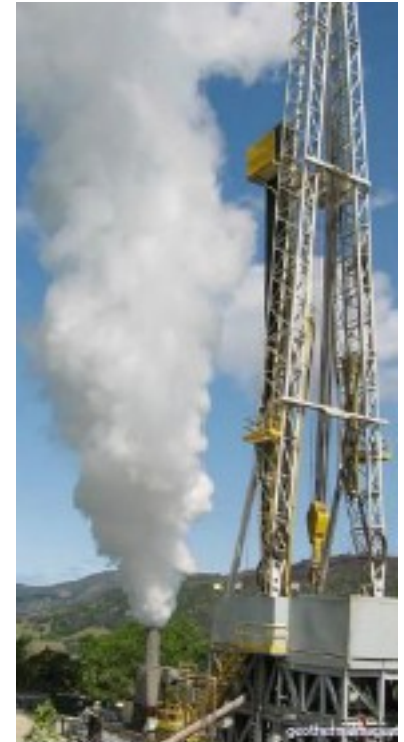
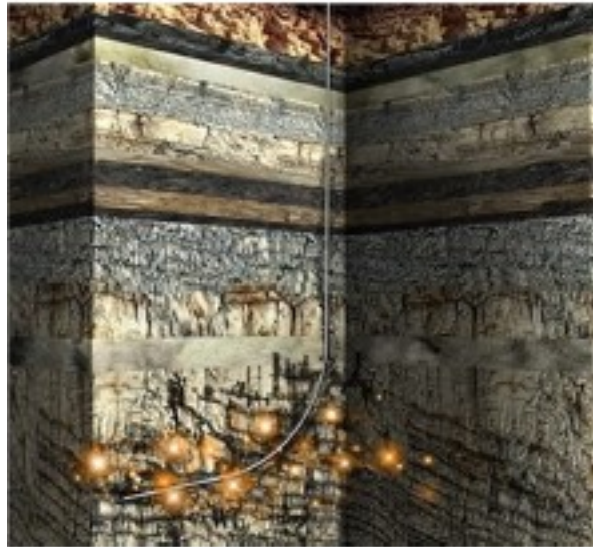
- Building of access roads and drilling pads



Geothermal Energy cons

Activities causing environmental impacts

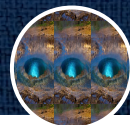
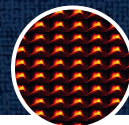
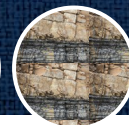
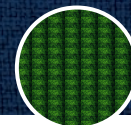
- Building of access roads and drilling pads
- **Well drilling, repairs, stimulation and testing phase**



Geothermal Energy cons

Activities causing environmental impacts

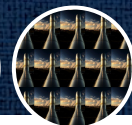
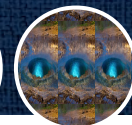
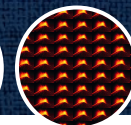
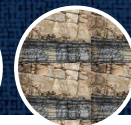
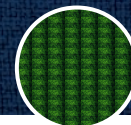
- Building of access roads and drilling pads
- **Well drilling, repairs, stimulation and testing phase**
- Laying of pipelines, electric power transformation and transmission lines



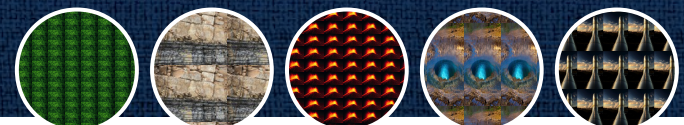
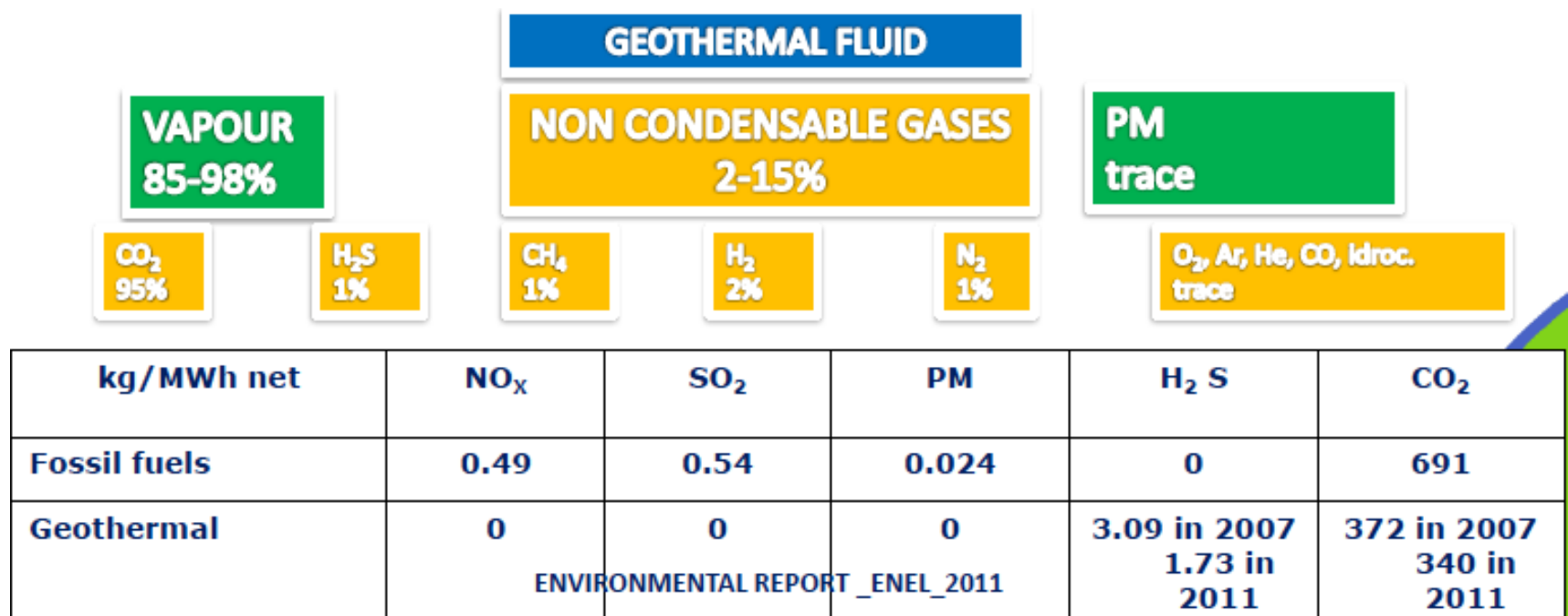
Geothermal Energy cons

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

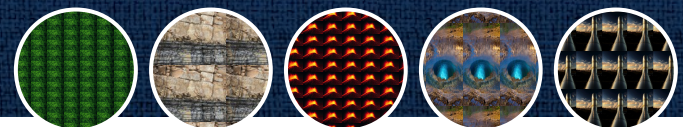


Geothermal Energy **cons**



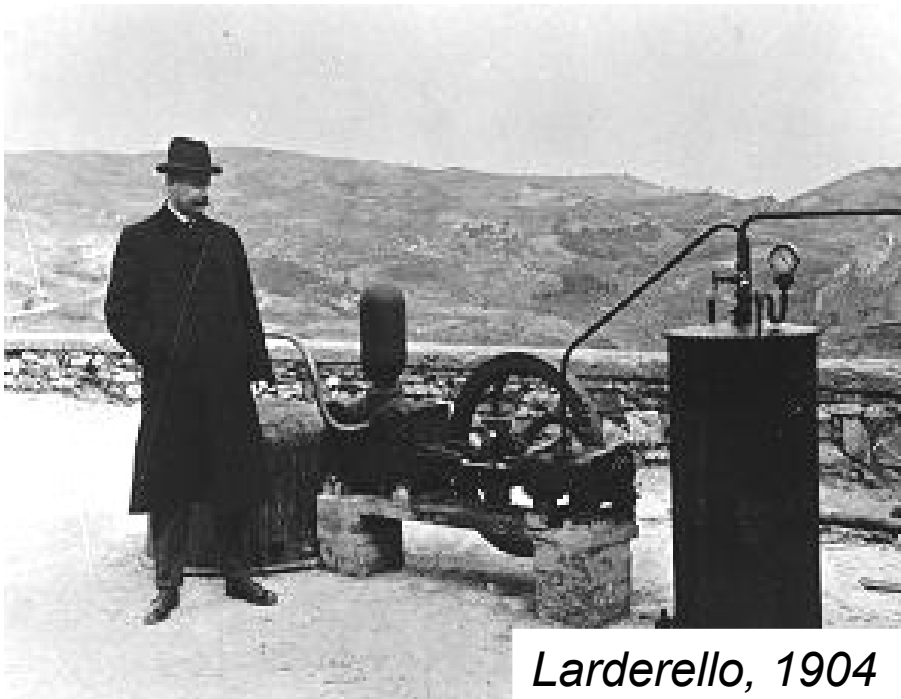
Enel, in order to mitigate the H_2S and Hg effluent to the environment with a specific treatment, uses a technology fully designed and developed by Enel: AMIS plant, reaching a very high efficiency in H_2S and Hg removal, lower capital and O&M costs in comparison with commercial process, no solid sulphur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

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



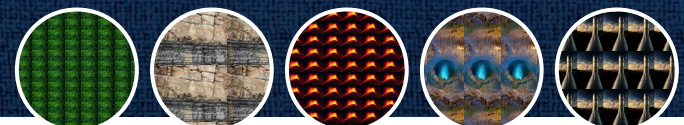
Geothermal Energy cons

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.

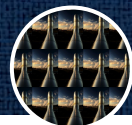
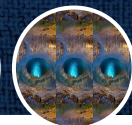
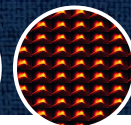
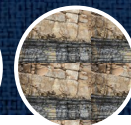
The real geothermal potential is scarcely known, it is seldom defined in detail by the countries and is not properly introduced in the Energy Plans



Geothermal Energy **cons**



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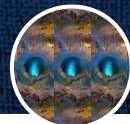
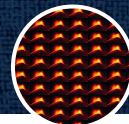
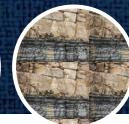
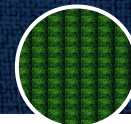


while increasing pros: how?

Research frontiers of Geothermal Energy



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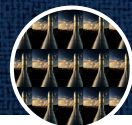
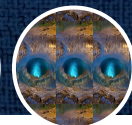
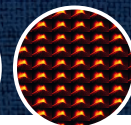
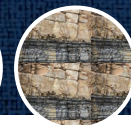


Research in Geothermal Energy

Ultimate goal: Increase the share
by increasing the exploitable volumes



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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.

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.

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

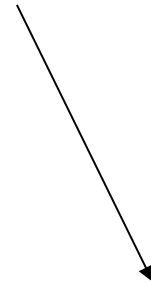
Goal: increase production



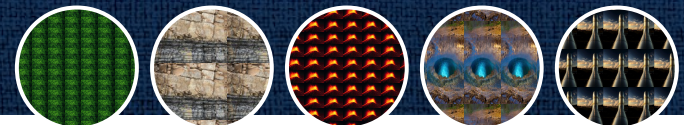
Increase the heated mass of fluid

Target1: > permeability (EGS)

Target2: > number of sites

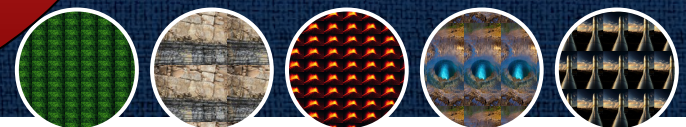
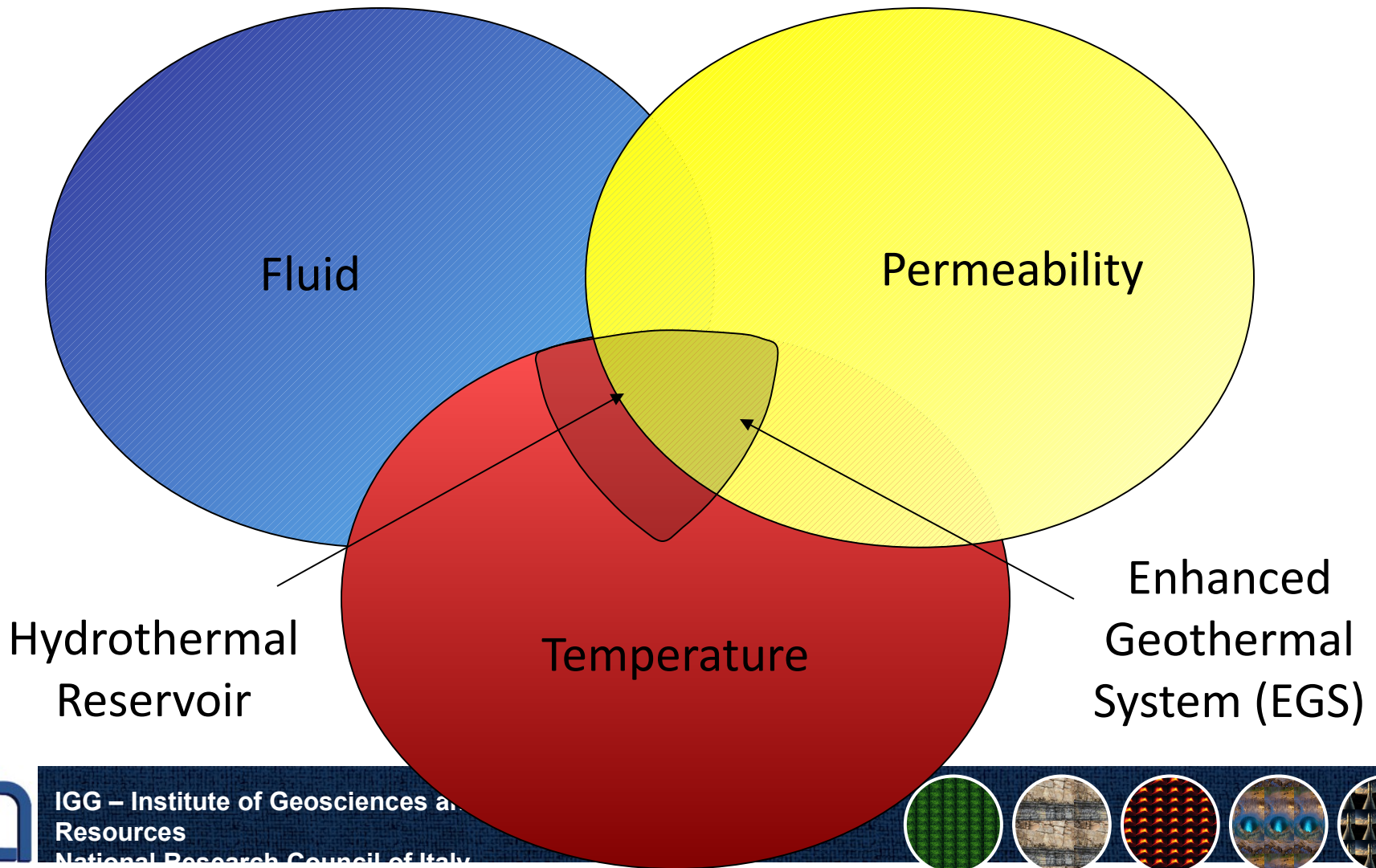


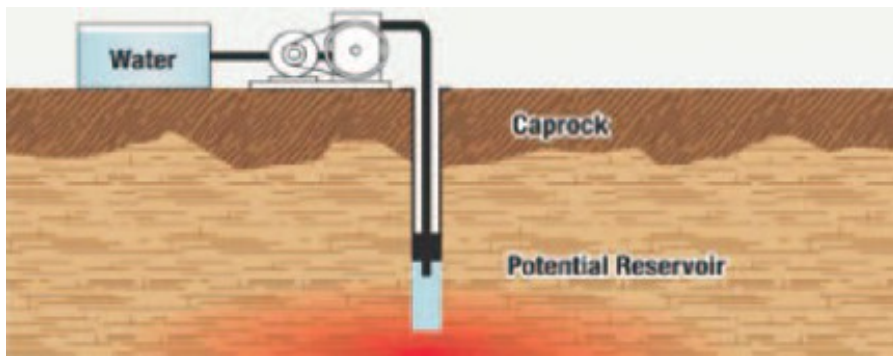
Target3: Increase efficiency of power and heating&cooling production per unit mass of fluid



Research in Geothermal Energy

Target1: > fluid mass, > permeability



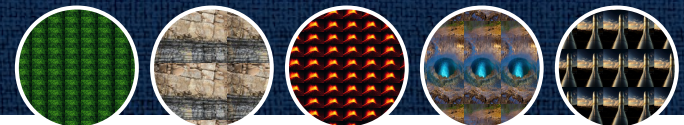


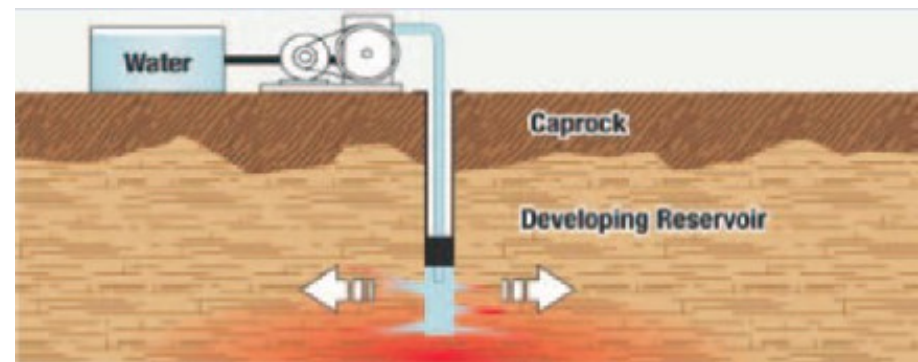
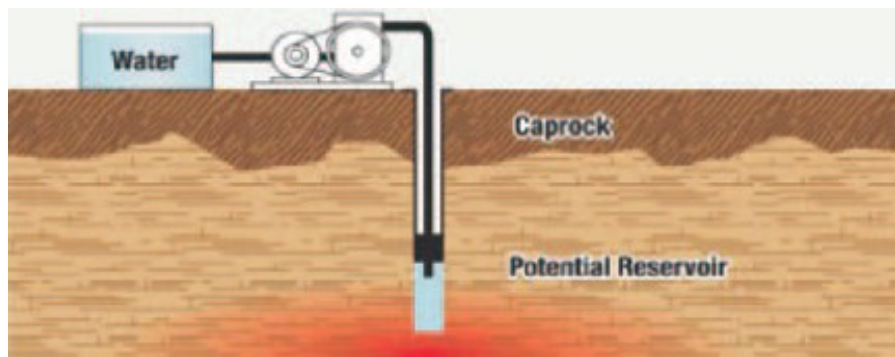
How it works

Injection well in low permeability rocks and useful T°



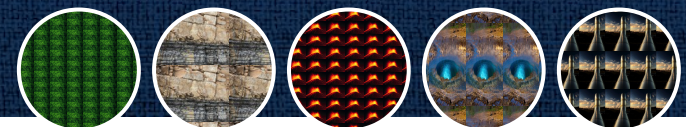
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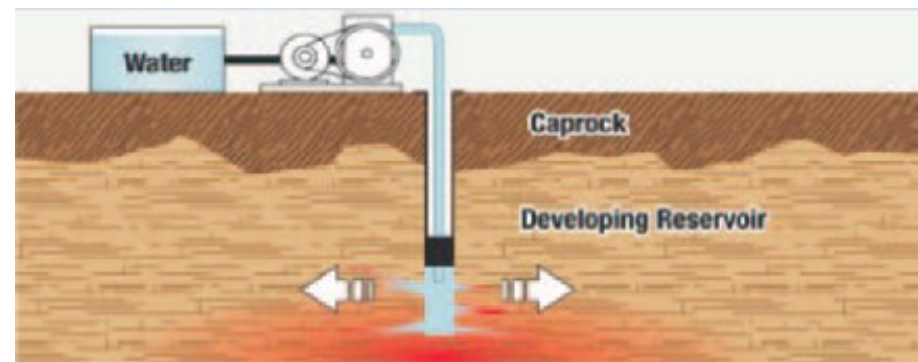
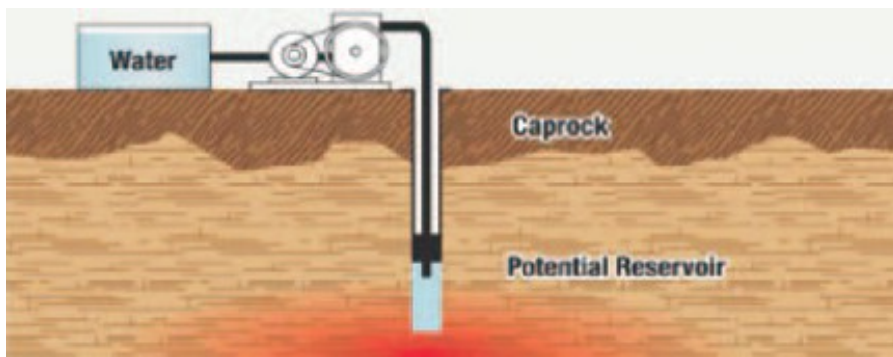




How it works

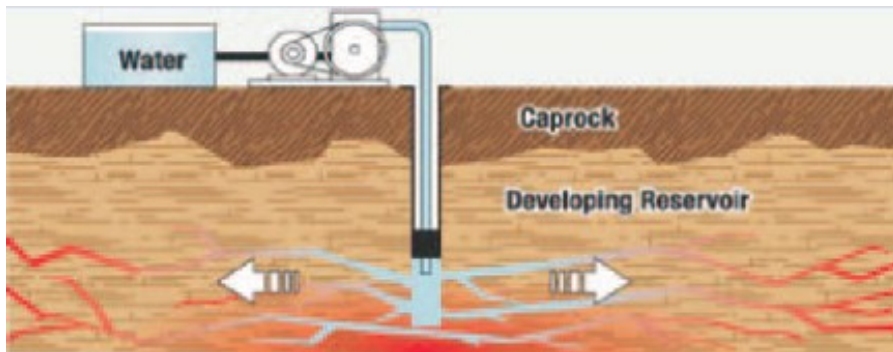
Water is injected at P able to fracture or expand existing fractures



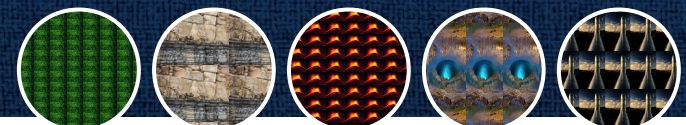


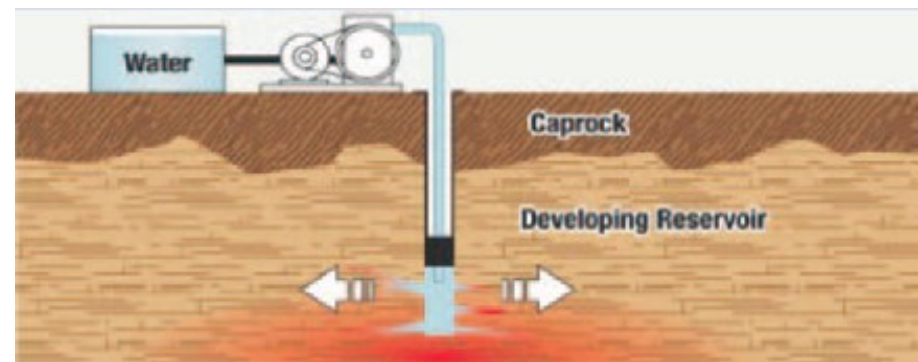
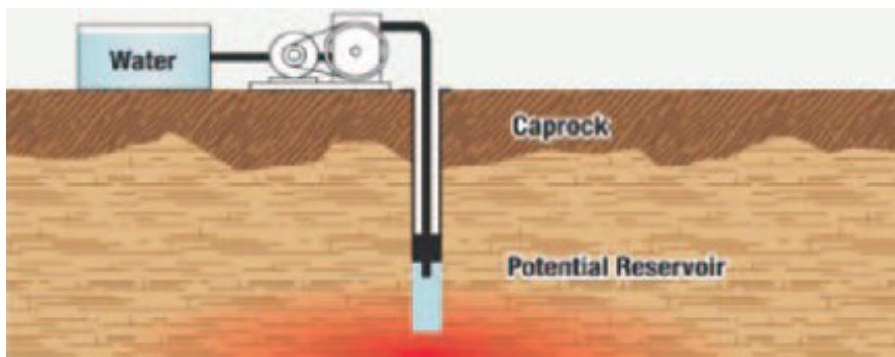
How it works

Hydrofracturing expand fractures

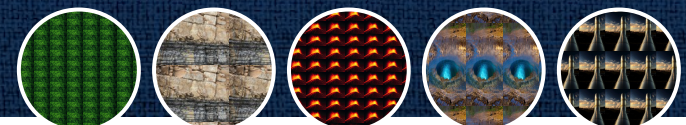
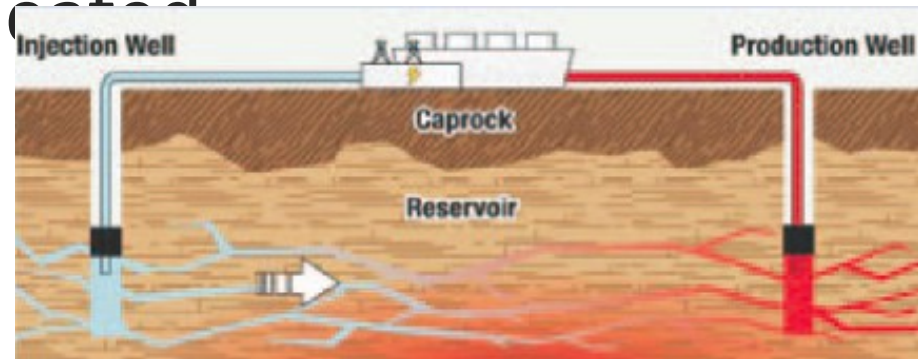
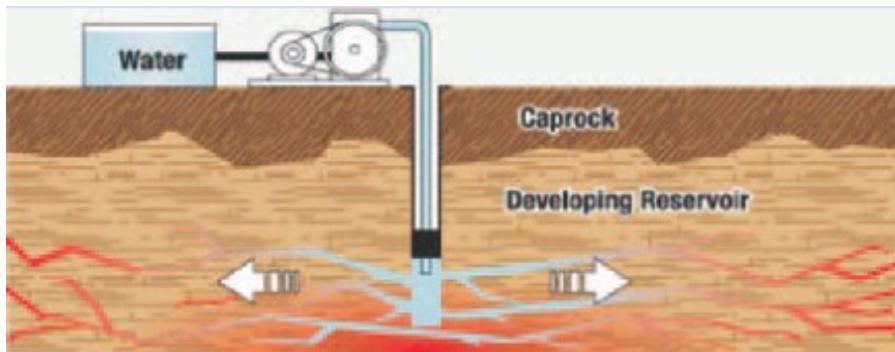


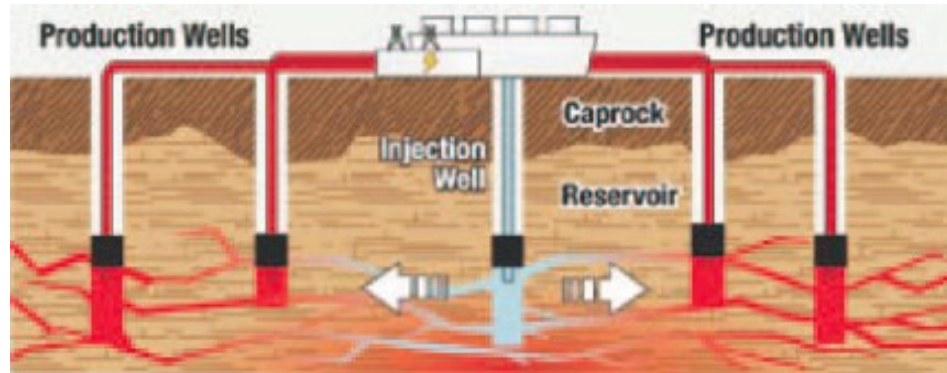
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How it works
Through a **production well** fractures are intercepted and water is circulated and heated

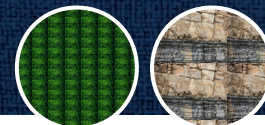




Production by new wells and enhanced
fracturation/circulation



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International
Energy Agency

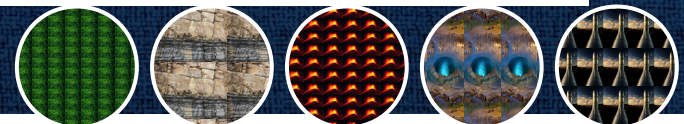
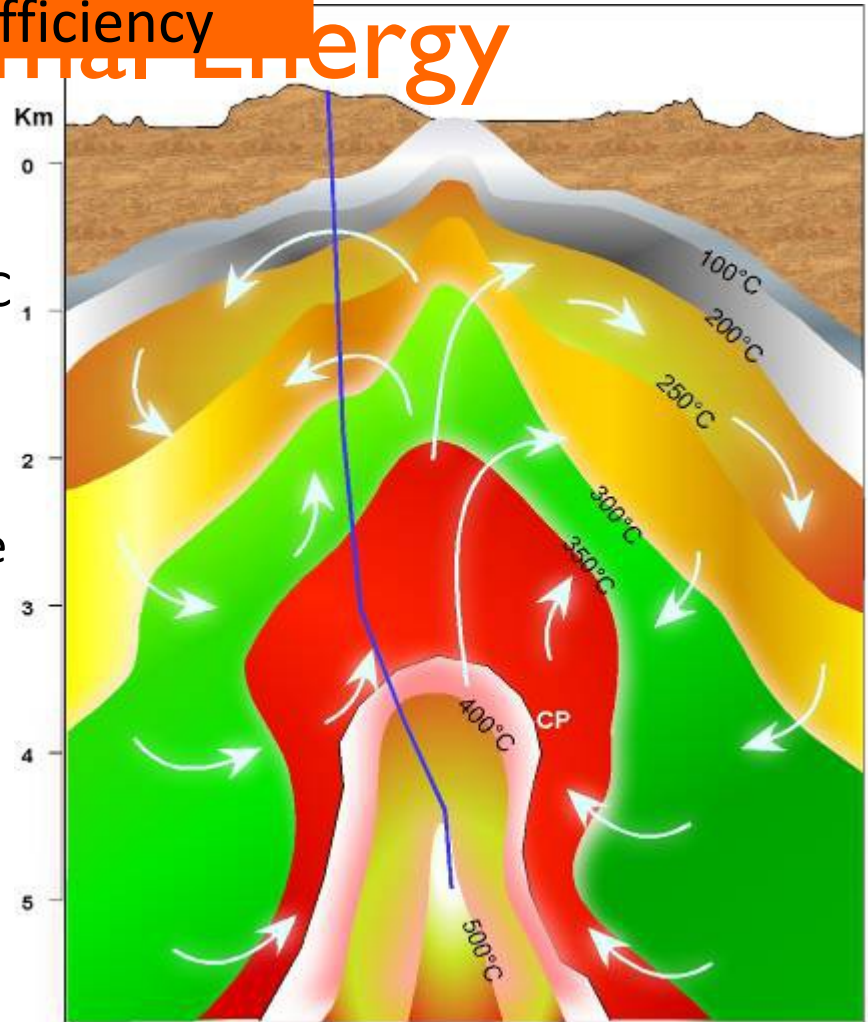
Research frontiers of

Target2: > sites, Target 3 > efficiency

Supercritical fluid resources.

A deep well producing 2500 m³/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

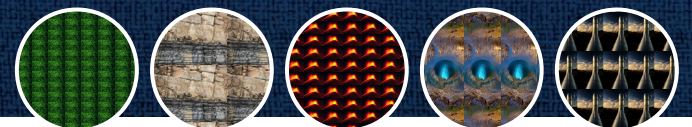
Geothermal is a “cheap”, sustainable, clean, flexible and base load energy when we are lucky enough to produce it economically (T and fluid)

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!!!!





Thank you for your attention

Jigokudani Hot Springs – Giappone



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