National Research Council of Italy

Institute of Geosciences and Earth Resources

Unconventional geothermal systems

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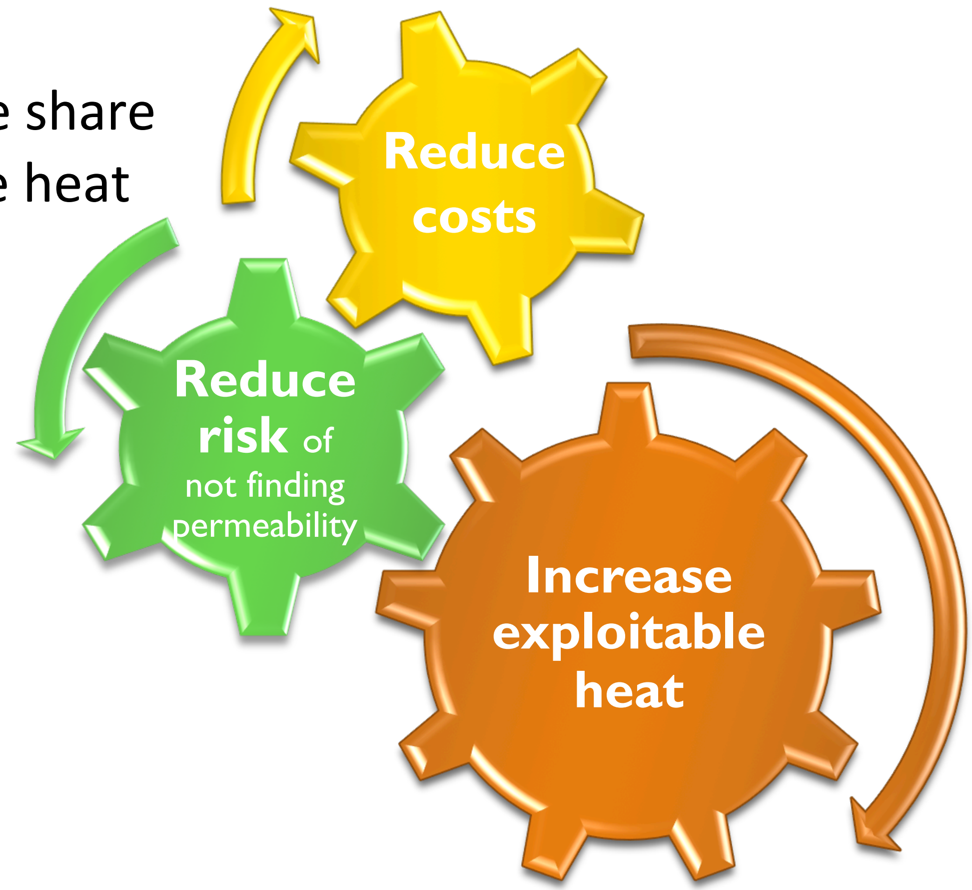
The Abdus Salam International Centre for Theoretical Physics

International School on Geothermal Development
Trieste, 7-12 December 2015

Research in Geothermal Energy

Ultimate goal: Increase the share by increasing the exploitable heat



Research in Geothermal Energy

Unconventional Geothermal Systems (UGR) technology: emerging activities to harness energy from nowadays non-economic reservoir would make significant progress with qualified input from research.

This includes, beside peculiar power conversion and reservoir technology, also Operation & Maintenance techniques in aggressive geothermal environments, since UGS require specific solutions for corrosion and scaling problems. It will lead to an ***overall increase in energy production***

Unconventional Geothermal Systems

1. Hot brine systems
2. Geo-pressurized systems
3. Magmatic systems
4. Super-critical systems
5. EGS

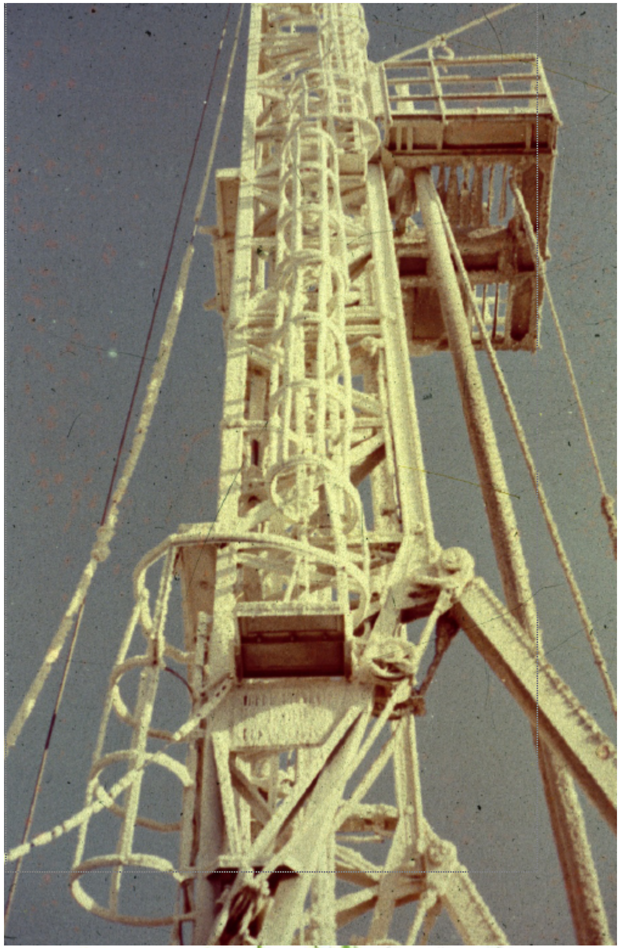
Technologies in development

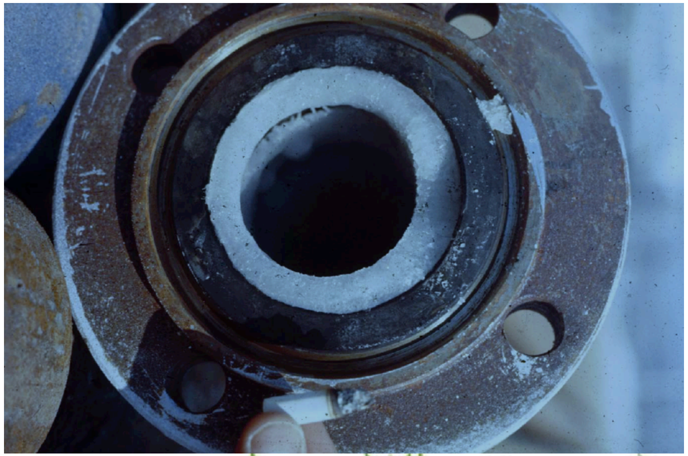
1 Hot brine Systems

Hot brine Systems

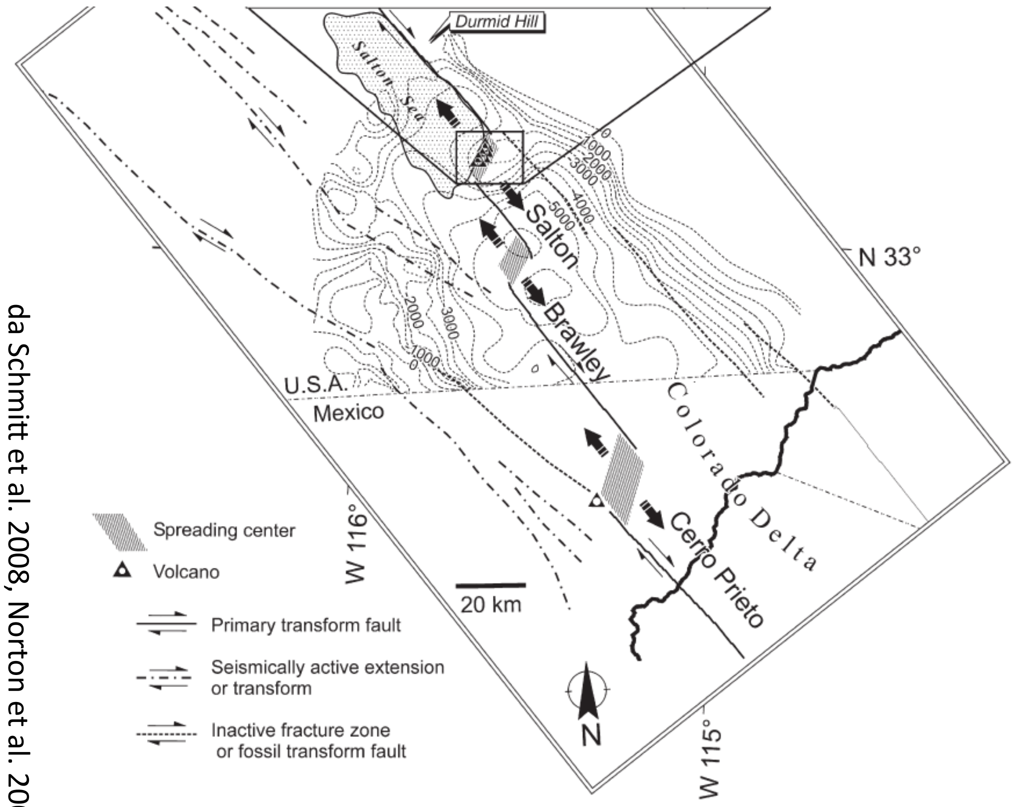
- Special **hydrothermal systems** where fluids undercome a high saline concentration becoming **saline brine** (TDS >> 35 g/l).
- The origin is due to many factors (fluid origin, lythology during the water-rock interaction, temperature of interaction, fluid chemistry, self-sealing and prolonged convective circulation in insulated volume and high temperature)
- The peculiar fluid chemistry require costly treatments and customized plants.
- Co-production of chemicals and metals may increase economics (SiO_2, Li, Zn etc…)

Hot brine Systems





Case study Salton Sea, Imperial Valley, California, USA



da Schmitt et al. 2008, Norton et al. 2006

Geodynamics: Pull-apart basin, Pleistocenic and Olocenic intrusions, possibly still cooling

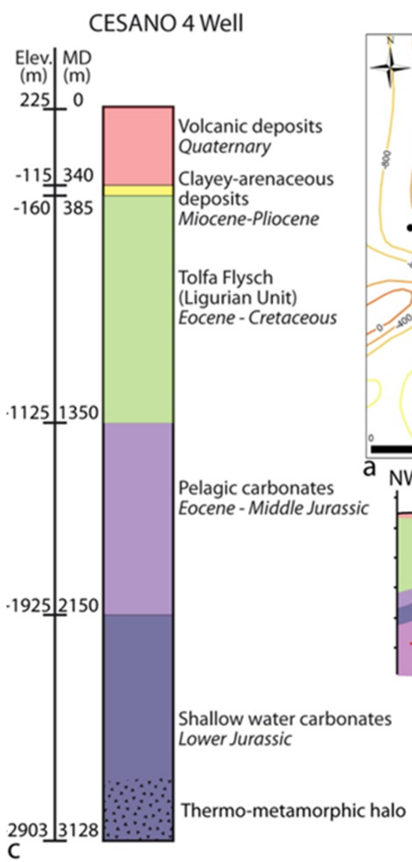
Geotermal Reservoir: Silicoclastic sedimentary rocks

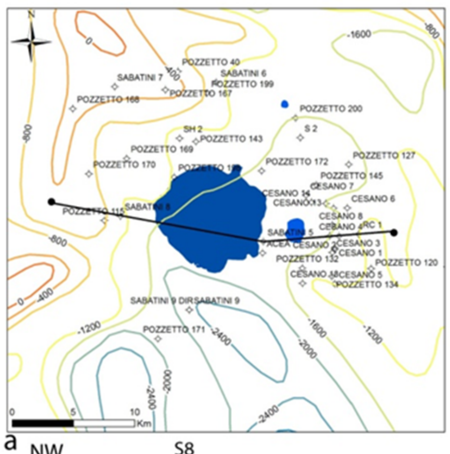
Temperature: up to 390°C (2000 meters b.g.l.)

Fluid geochemistry: brine(up to 26 wt.%) rich of metals (Fe, Zn, Pb, Cu etc…)

Co-Production: Power from geothermal fluids (437 MW) and metal (Zn)

Case study Cesano, Monti Sabatini, Italy

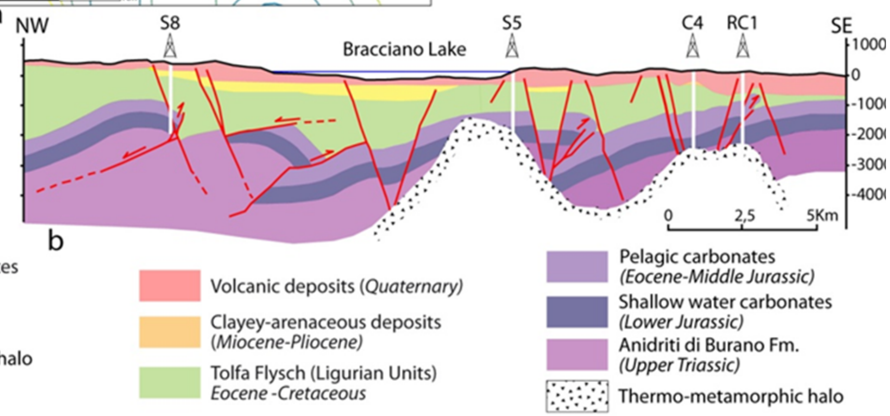




Serbatoio: rocce carbonatiche fratturate

Fluido: «Salamoia» con salinità sino a 350 mg/l; temperatura variabile tra 145°C (pozzo C5 a 1800m) e 300°C (pozzo C4 a 3080m); pressioni sino a 150 bar

Note: 12 pozzi perforati nel periodo 1975-1982 (profondità massima 3219 m, pozzo C6) con produttività molto variabile



- Brine up to 350 g/l TDS)
- Self-sealing processes from a hydrothermal circulation
- Power generatin plant producing 235 t/h of brine and strong scaling issues.
- Proposed use of dissolved salts Since the '80
- Thermometamorphic phenomena, high pressure fluids and temperature up to 368°C (at 2175 m b.g.l.) have been met during the production
- The plant was closed due to the economics

2 Geopressurized Systems

Geopressurized Systems

Clastic complexes, usually sand, too young (<10 Ma) to be diagenetized very permeable (primary porosity), hosting **confined aquifers** at depth > 2 km

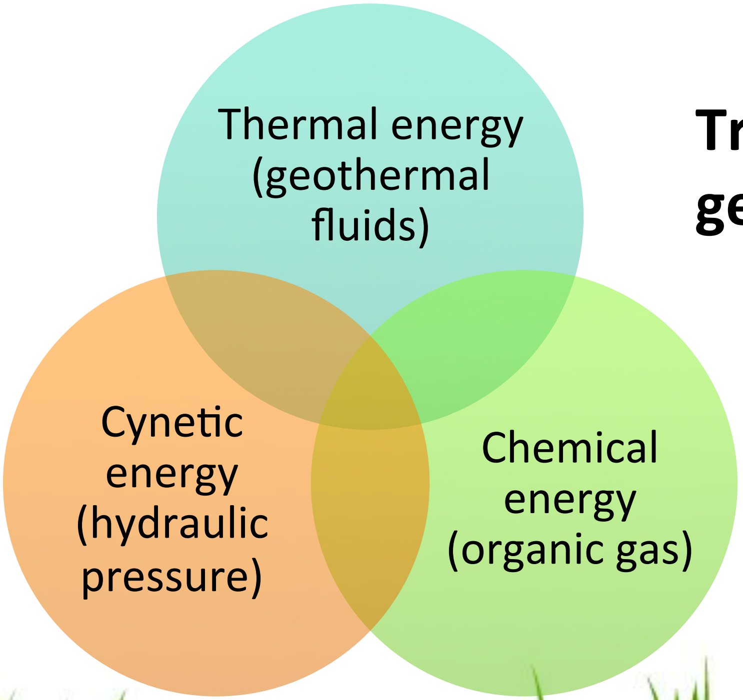
Fluid pressure in the reservoir is not hydrostic but lithostatic, reaching hundreds of atms.

Normal geothermal gradient, usually no or light thermal anomalies.

Organic gases are present, increasing commercial viability

Geopressurized Systems

- Reservoir pressure > Hydrostatic pressure
- High fluid temperature
- Dissolved hydrocarbons

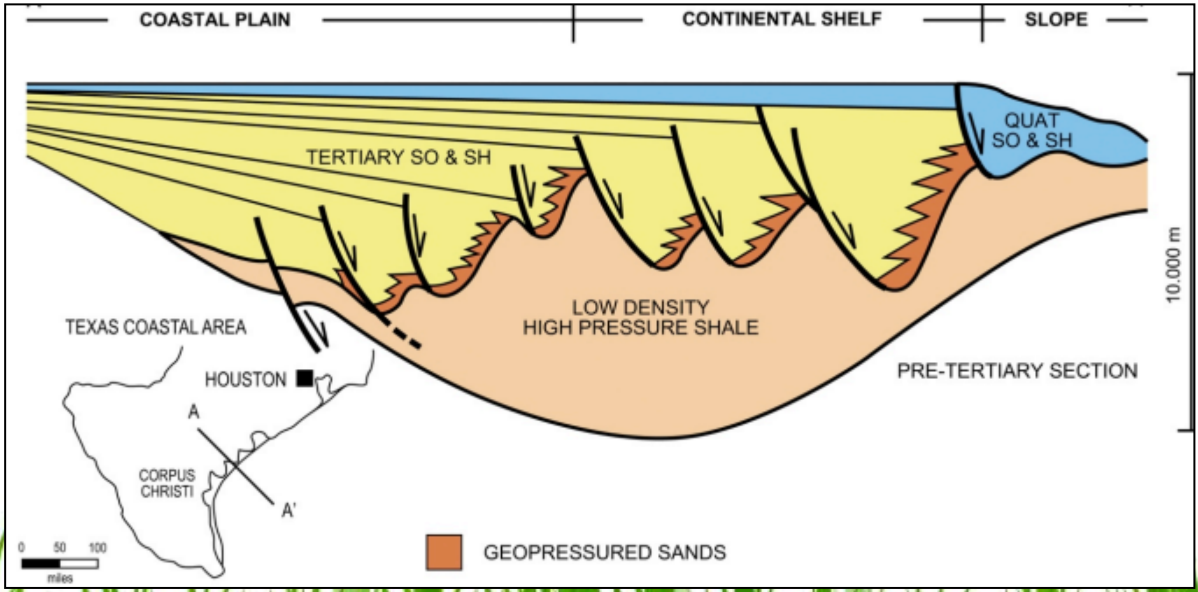


Triple energy generation

Geopressurized Systems

- USA (DOE) invested 200 M$, on ’70-’90, for two research projects “Wells of Opportunity” e “Design Well”.
- The most important is the “Pleasant Bayou” well, which demostrated power production (hybrid plant using binary to produce 1MW from 1988 to 1990). The Louisiana Geothermal LLC is developing a project (economically feasible)

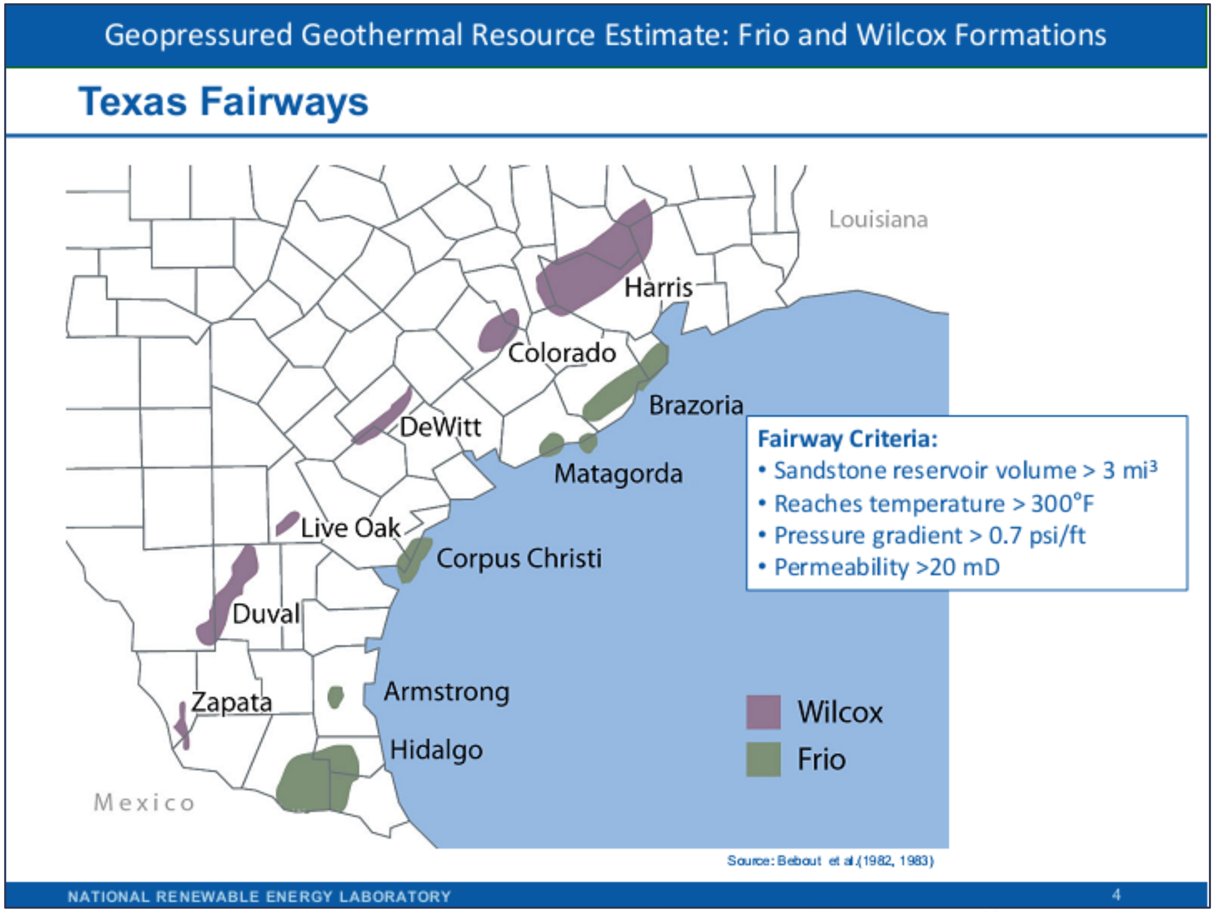
- The most important and known systems are in USA, along Gulf of Mexico,Texas and Louisiana located in deltaic fluvial silico-clastic deposits.



Da John et alii, 1998

Geopressurized Systems

Potential reservoirs investigated in the main sand formations (Frio e Wilcox) in Texas (from Esposito et alii, 2011)



Geopressurized Systems

The GTP (Geothermal Technologies Program), the Rocky Mountain Oilfield Testing Center (RMOTC) in Wyoming , the National Renewable Energy Lab (NREL) and the ORMAT NEVADA are testing the coproduction of heat and power.

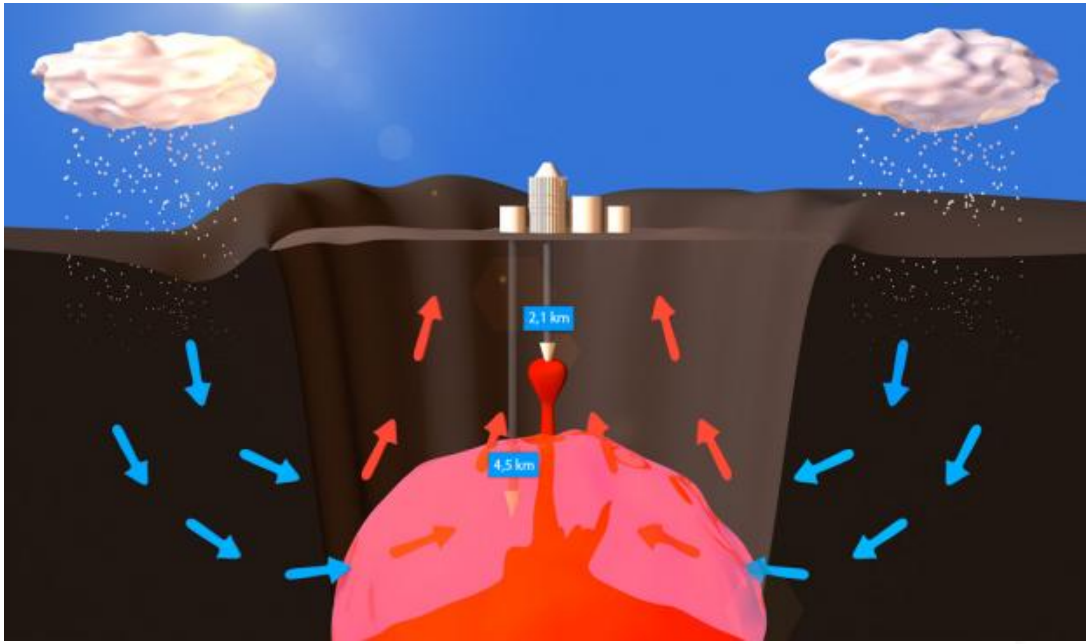
	Design	Operational Results	
		Phase 1	Phase 2
Flow rate, bpd	40,000	12,000 to 40,000	11,000 to 50,000
Total hot water used, bbl		3,047,192	9,077,323
Inlet water temperature, °F	170	195 to 198	196 to 198
Outlet water temperature, °F	152	80 to 170	47 to 150
Average ambient temp., °F	50	-7 to 85	-2 to 81
Generator gross power, kW	180	105 to 305	105 to300
Daily avg. net power output, kW	132	80 to 280	80 to 275
Overall avg. net power, kW		171	190
Total power produced, MWhr		586	1,595

Reinhardt et al_2011

3 Magmatic Systems

Magmatic Systems

Systems connected to active volcanoes having **shallow magma chambers** (< 5-6 km), where drilling may reach rocks at extremely high temperature and water can be circulated and heated. Aggressive fluids are abundant.



Magmatic Systems

Proposed since many years (e.g. Carson, 1985), but never implemented, various technologies for heat exchange and trasport:

- inverse fluid circulation in large diameter wells with bottom-hole close to magma chamber, equipped with inner tubing inside the production casing
- permeability enhancement of vetrified cap rock of magma chamber and closed loop fluid circulation obtained by a doublet (injection and production wells)

Magmatic Systems

Hot rocks close to magma chamber should be able to heat fluids for a log time.
In Kakkonda, Japan, on 1995 there was an experiment in a well that reached magma, which never produced power or heat.

In iceland (Krafla volcanic caldera) an exploration well drilled in 2008-2009 reached ryolitic magma while looking for supercritical fluids. It has been completed and engineered by injecting cold water, and produced for many months a superheated steam at high pressure and T=500°C) (IDDP, Special Issue 2014, Geothermics; http://iddp.is/).

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Supercritical fluid Systems

Supercritical fluid Systems

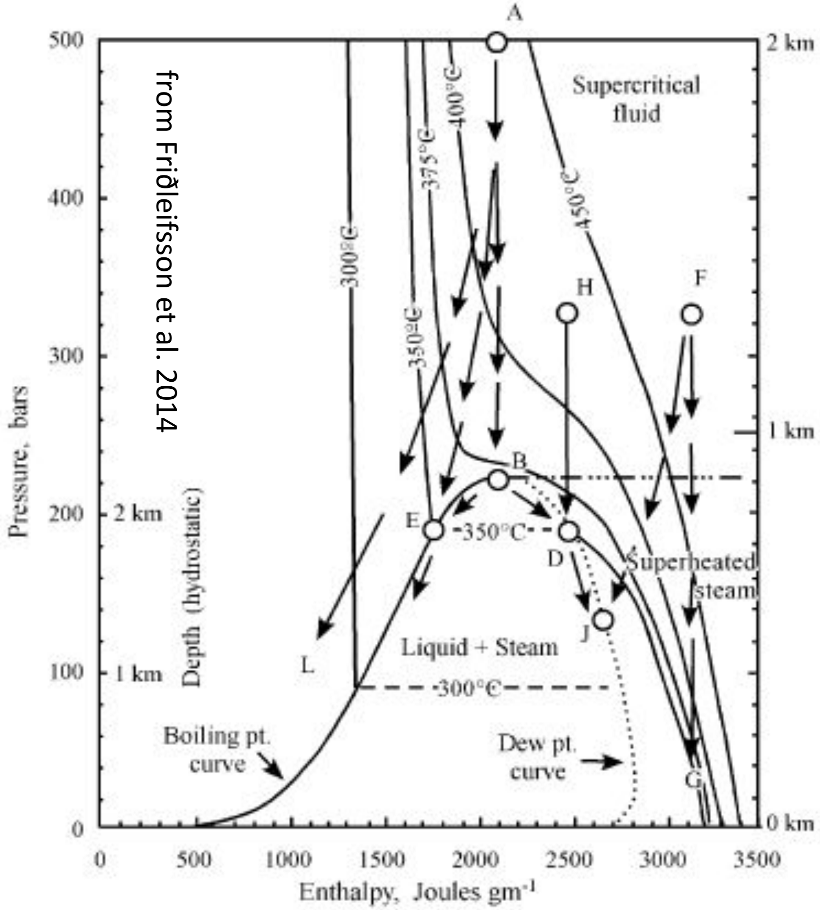
A fluid is called "super-critical" when temperatures and pressures are high enough (for pure water T>374°C and P>22 MPa) that there is **no longer any distinction between its liquid and vapour phases.**

Super-critical water occurs naturally in deep underground reservoirs close to magmatic intrusions, where minerals in aqueous solutions near or above the critical point have existed for millions of years.

Lab experiment (Hashida et al., 2001; Tsuchiya et al., 2001) proved that at about 25-50 Mpa and 400-600 °C, fluid circulation within unsealed fractures is possible in a granitic rock.

Supercritical fluid Systems

The basic idea of deep well development is to bring water-dominated super-critical fluid to the surface in such a way that it is directly transformed to superheated steam along an adiabatic decompression path.



from Friðleifsson et al. 2014

Supercritical fluid Systems

The enthalpy is one order of magnitude higher, per unit volume, than for a conventional hydrothermal fluid.

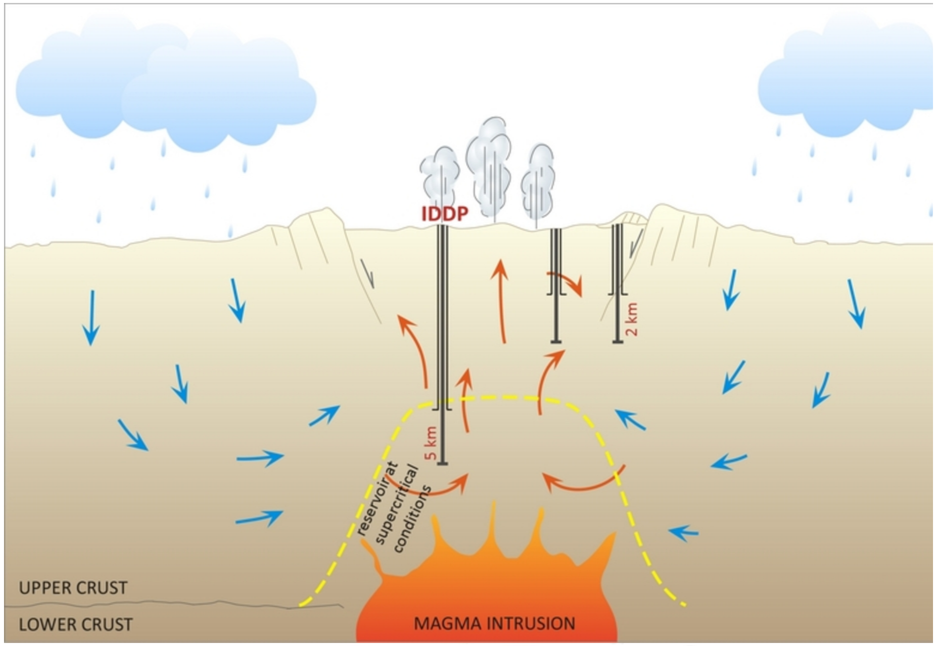
A deep well producing 2500 m^3/h of steam from a reservoir with a temperature significantly above 450° C **could yield enough high-enthalpy steam to generate 40-50 MW of electric power**.

This exceeds by a factor of ~10 the power typically obtained from conventional geothermal wells, implying that much more energy could be obtained from presently exploited high-temperature geothermal fields from a smaller number of wells.

Fluids are supposedly rich of F and Cl, and probably rich of other, possibly ecomically viable, materials and chemicals.

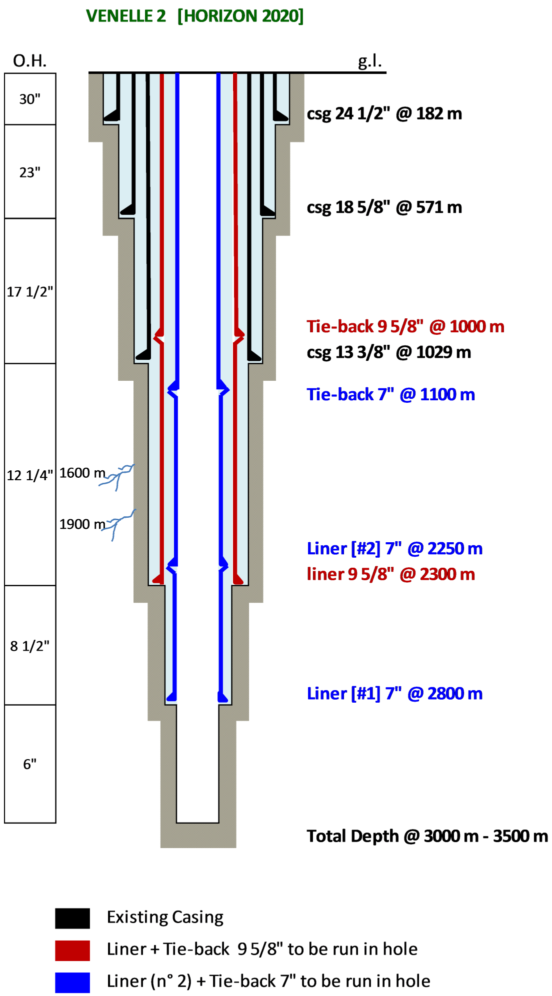
Supercritical fluid Systems **Case studies**

- Deep Seated Geothermal Resources Survey well in Japan was drilled in 1994-1995 to reach the deep-seated part of the Kakkonda geothermal field. At a depth of 3.7 km the operation stopped for safety concerns, principally due to a H_2S discharge and difficulty in controlling the drilling. The inferred temperature exceeded 500°C.
- In the IDDP-1 well in Krafla, Iceland, the drill bit hit 900°C hot rhyolitic magma at 2.1 km depth. They decided to produce from the contact zone of the intrusion, which in its first few months to operations has proved to be highly productive. A new well is under development.



Supercritical fluid Systems Case studies

- San Pompeo 2 well in Larderello, Italy, was drilled in 1979 produced a fluid at pressure above 24 MPa (five times higher than the standard) and extrapolated temperature exceeding 400°C. The well was closed after a hydrogen gas explosion, which severely damaged the drilling string. Samples of the deep fluids highlighted the important presence of gases, and a strongly corrosive environment.
- The DESCRAMBLE european project, recently started, will drill a new well in Larderello to prove drilling technology for very high temperature and pressure conditions



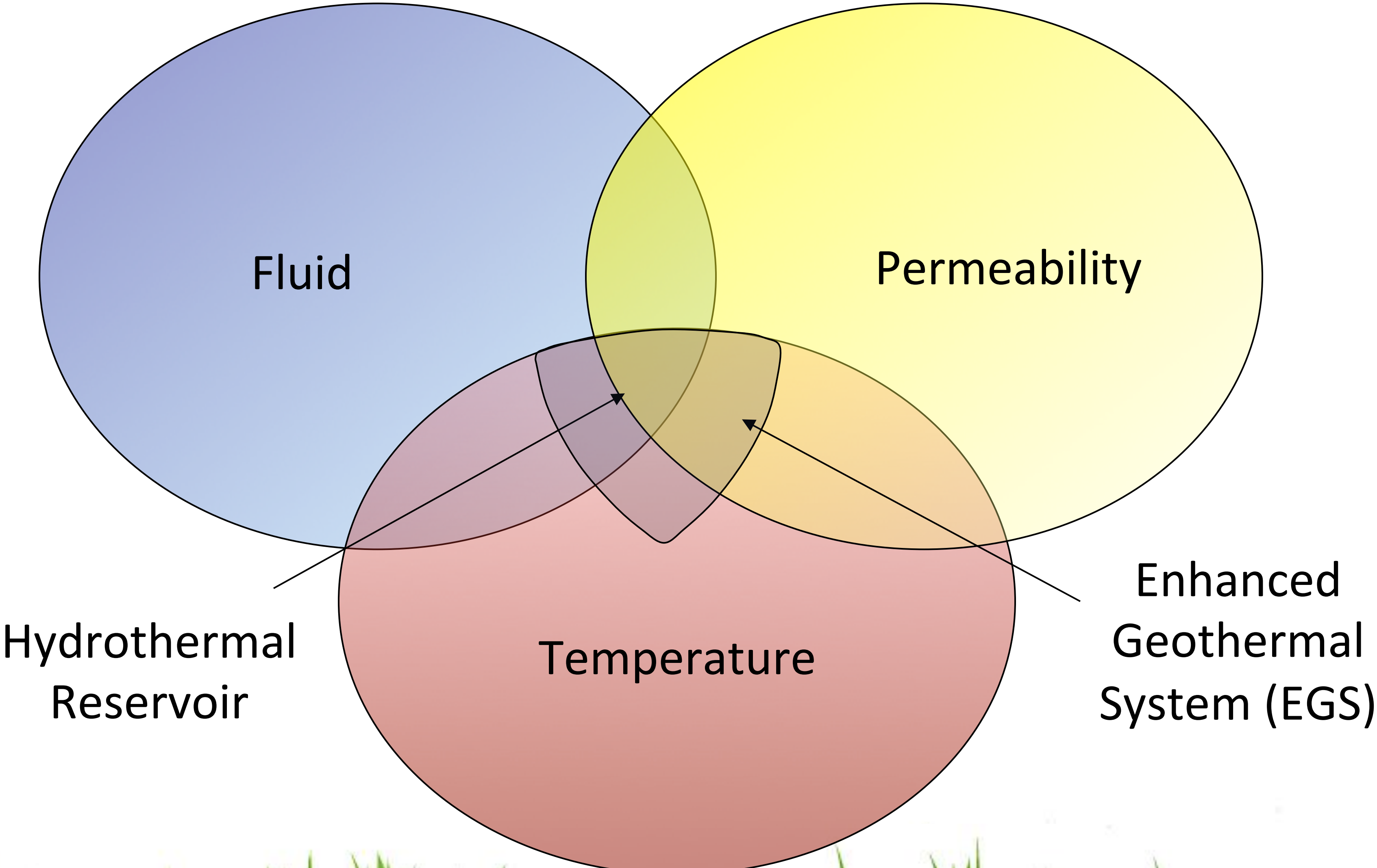
5 EGS Systems

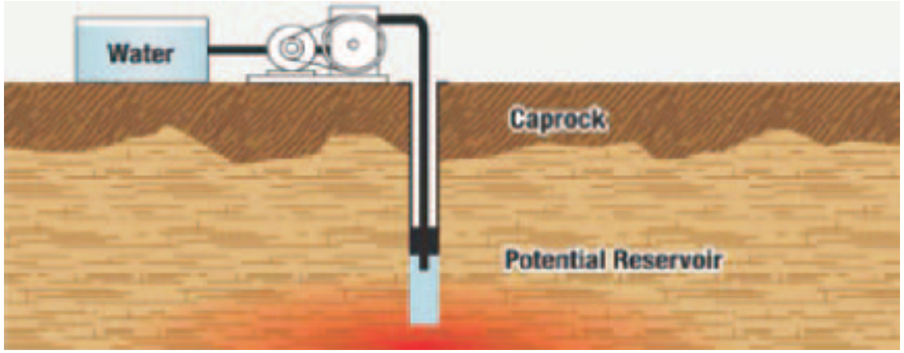
EGS Systems

Originally Hot Dry Rocks (HDR), then Hot Wet Rocks (HFR), nowadays **Enhanced or Engineered Geothermal Systems**, these systems comprehend the development of geothermal systems where the natural flow capacity of the system is not sufficient to support adequate power production but where artificial fracturing of the system by chemical and/or hydraulic stimulation can allow production at a commercial level. The reservoirs are created to produce energy from geothermal resources that are otherwise not economical due to lack of water and/or permeability.

The term is rather confused, and sometime EGS is referred to unconventional geothermal systems.

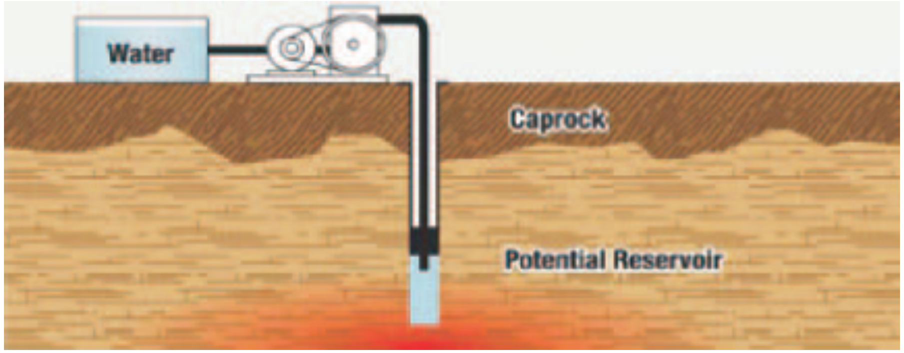
EGS Systems

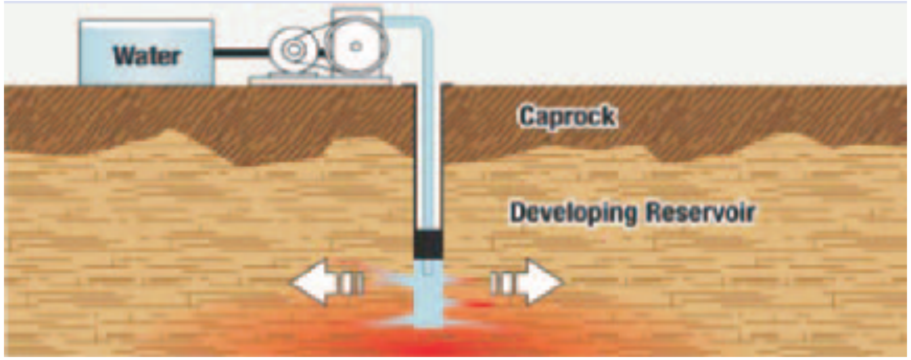

Fluid
Permeability
Temperature
Hydrothermal Reservoir
Enhanced Geothermal System (EGS)



How it works

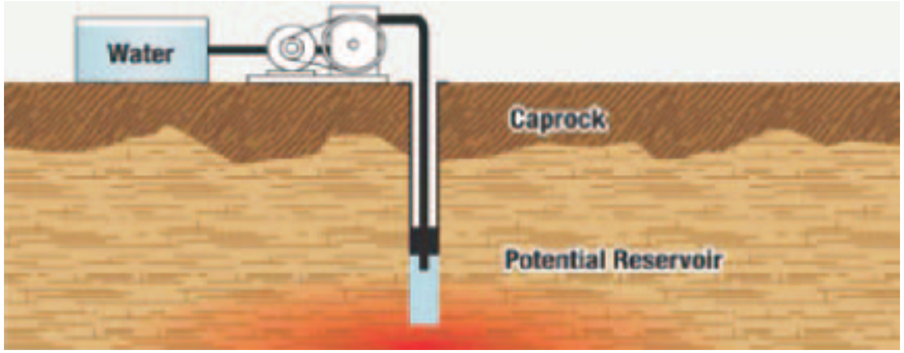
Injection well in low permebility rocks and useful T°

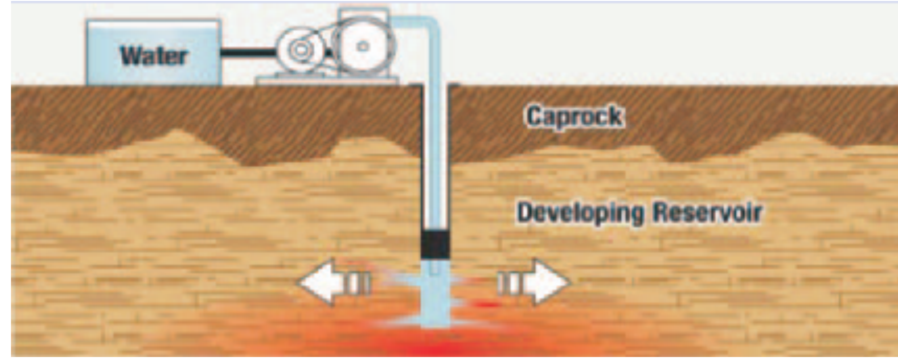




How it works

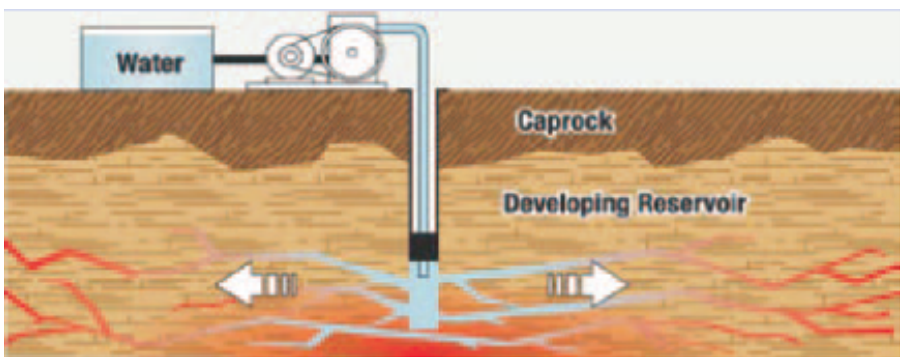
Water is injected at P able to fracture or expand existing fractures



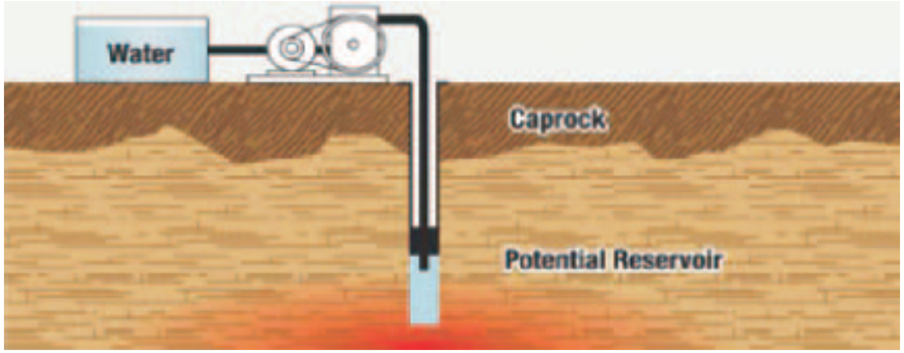


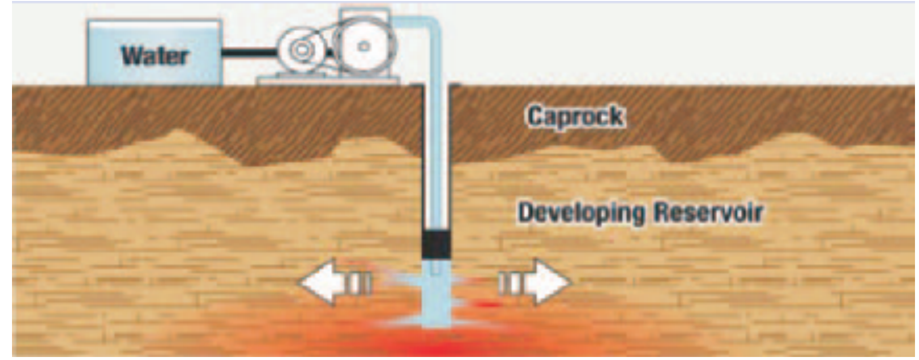
How it works

Hydrofracturing expand fractures



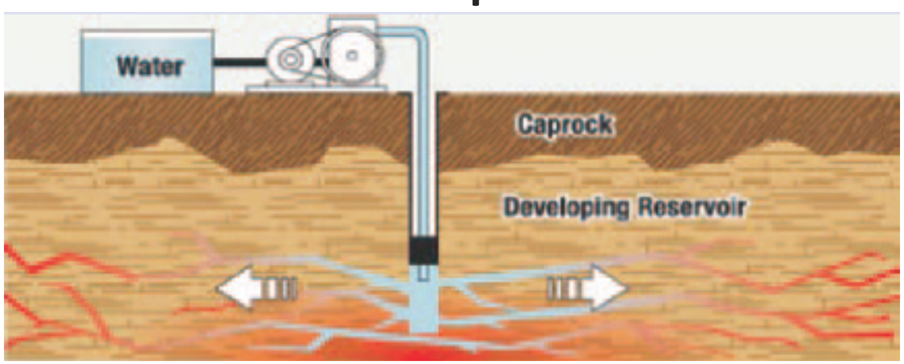
iea International Energy Agency

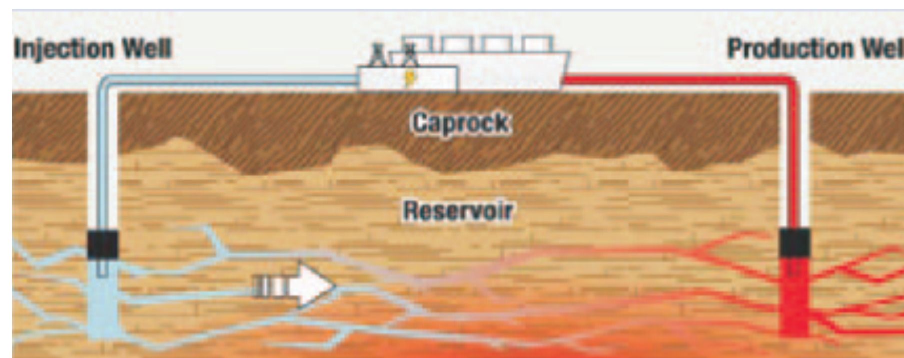


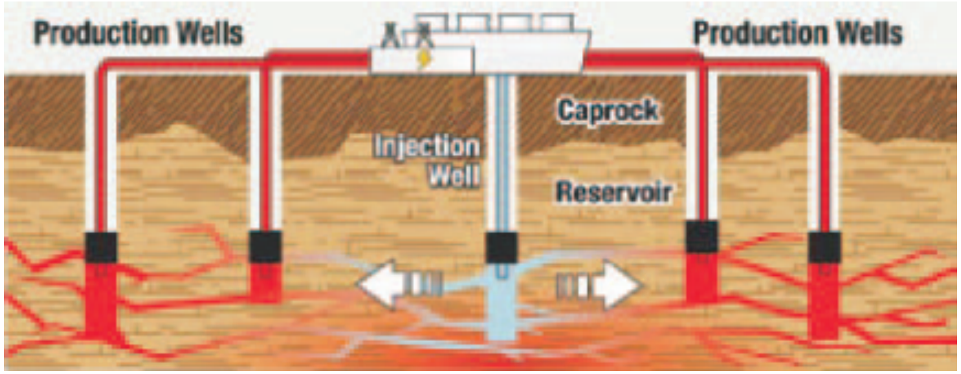


How it works

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





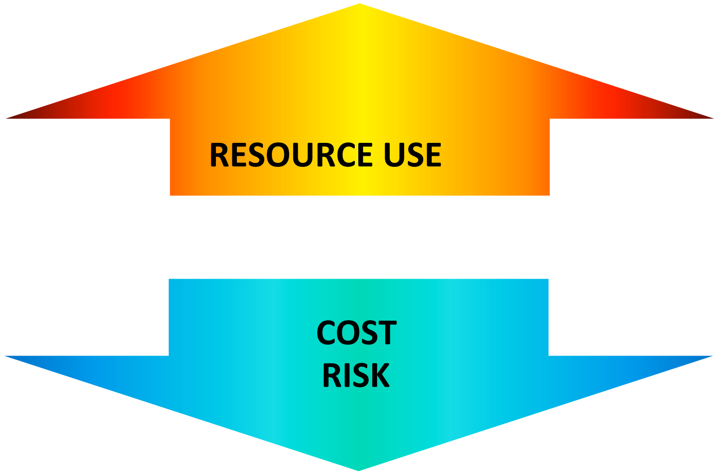


Production by new wells and enhanced fracturation/circulation

EGS Systems

The final objective:

development of a technology to produce electricity and/or heat from a basically ubiquitous resource - the internal heat of the Earth - in an economically viable manner relatively independent of site conditions.



Extending the resources far beyond a conventional use of geothermal resources requires the use of non-conventional methods for exploring, developing and exploiting geothermal resources that are not economically viable by conventional methods.

EGS Systems

EGS potential is huge

- After internationally organized EGS research over about 25 years the first EGS power plant is now producing electricity with 1.5 MW_e capacity at Soultz-sous-Forets/France, and projects developed in the same area are now in production
- Boom in Australia, followed by Germany and USA

EGS Systems

Numerous problems must be solved to reach the numerical goals and many unknowns need to be clarified:

- irregularities of the temperature field at depth
- favourable stress field conditions
- long-term effects, rock-water interaction
- possible short circuiting
- **EGS induced seismicity** (during stimulation but also due to production) becomes a real issue;
- uniform connectivity throughout a planned reservoir cannot yet be engineered.
- scalability

EGS Systems

Research topic Areas

- Techniques and tools for fracture mapping and analysis
- Techniques and tools of monitoring fracture propagation, fluid flow, and heat transfer (including real-time monitoring)
- Techniques to create, characterize, stimulate and evaluate fracture(s) and fracture networks
- Subsurface processes affecting fluid flow

EGS Systems

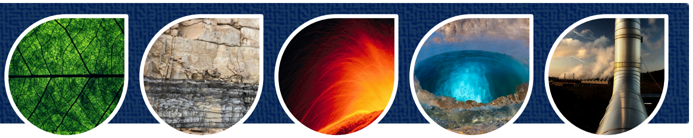
Research topic Areas

- Reservoir Characterization & Management
- Remote Sensing and Imaging Tools
- Exploration Models
- Resource Analysis
- Thermoelastic Hydraulic Fracture Design
- Production and Injection Strategies
- Permeability
- Tracers
- Gas Analysis of Geothermal Fluid Inclusions

Research in Geothermal Energy

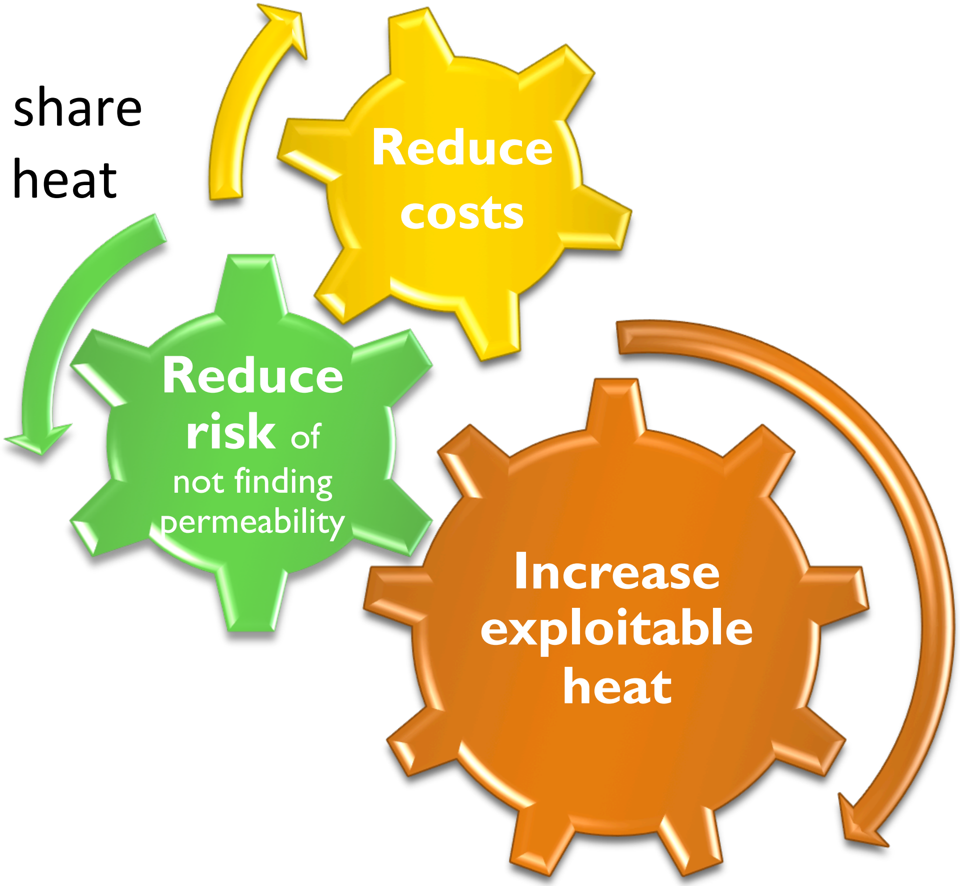
Water presence (as carrier medium)

	Wet	Dry
Shallow reservoirs 5: 500 m	**Conventional hydrothermal systems or heat exchange** • **Description: Hot shallow** reservoirs are used for generation of electricity in a conventional geothermal system • **Cold shallow** reservoirs are used for heat exchange, cooling buildings in summer and heating in winter • **Uses:** Electricity generation and heat	**Heat exchange** • **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
Deep reservoirs 500: 5000 m	**Conventional Hydrothermal systems** • **Description:** Super heated ground water is released through geothermal wells and is transformed into steam to generate electricity as it travels toward the surface • **Uses:** Electricity generation	**Enhanced geothermal systems** • **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



Research in Geothermal Energy

Ultimate goal: Increase the share by increasing the exploitable heat



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.

Jigokudani Hot Springs – Japan