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Enhanced Geothermal Systems (EGS) Using CO_2 as Working Fluid

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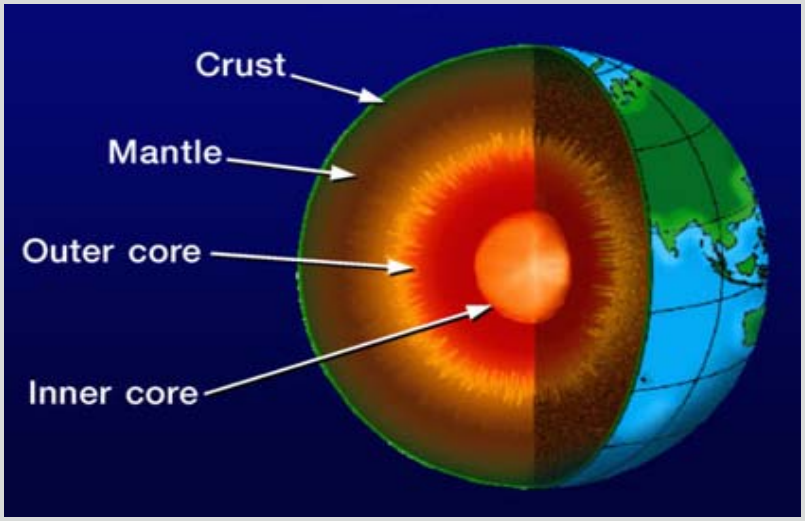
cags China Australia Geological Storage of CO_2 中澳二氧化碳地质封存

What is Geothermal Energy?

Geo: (*Greek*) - Earth

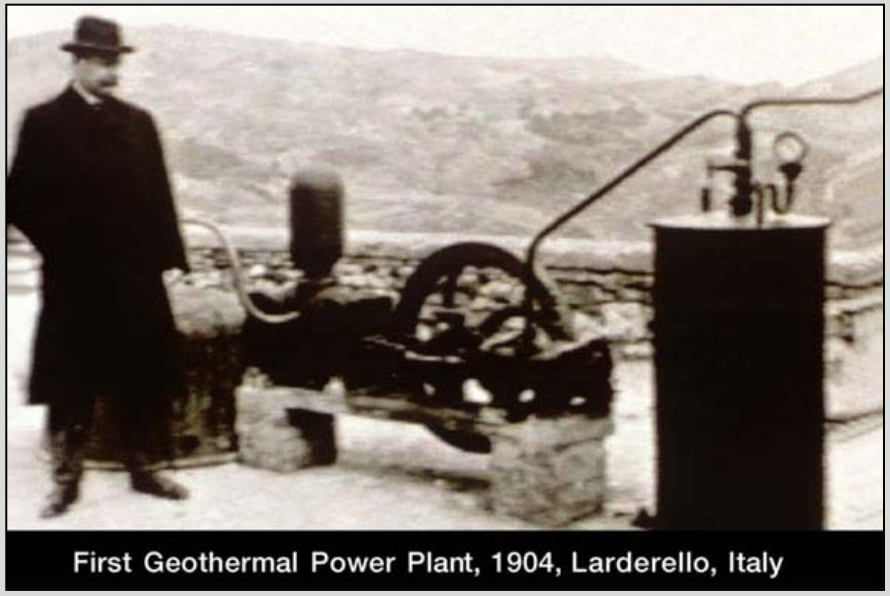
Thermal: Of, relating to, using, producing, or caused by heat.

The Earth



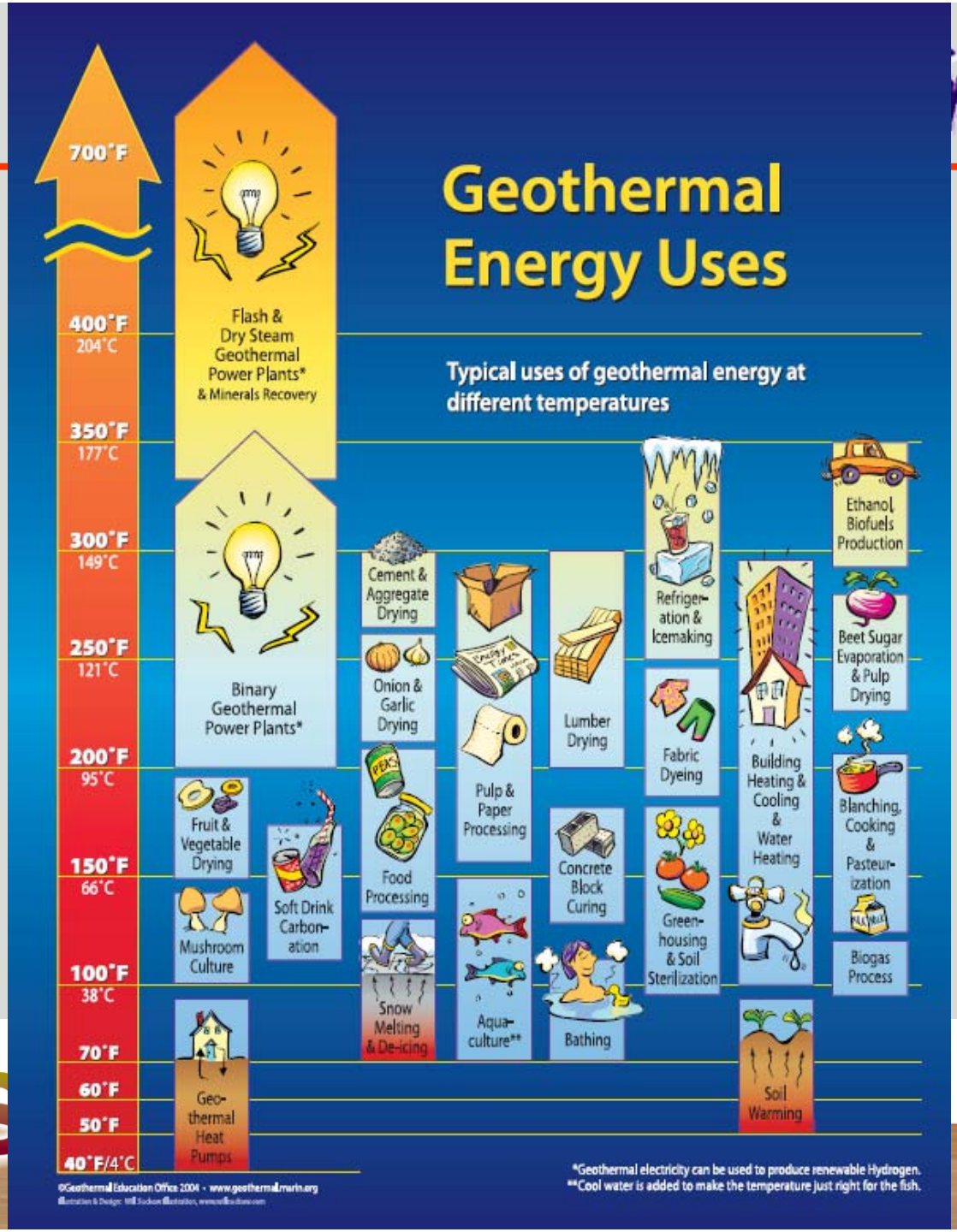
- Parts of the earth
- Flow of magma
- Below surface Temperatures
  - Gradient from hot to cold
- Heat can be ejected as steam or hot water.
  - Hydrothermal reservoirs, water and hot porous rock.
- Yellowstone National Park

What can we do with heat?



First Geothermal Power Plant, 1904, Larderello, Italy

conventional geothermal plants capture hot water from geysers or steam from vents to spin turbines

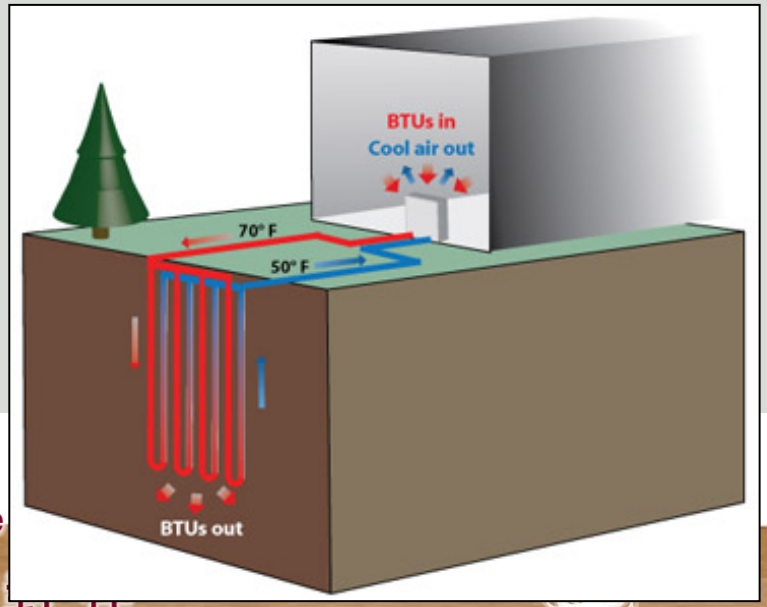

Geothermal Energy Uses
Typical uses of geothermal energy at different temperatures
700˚F
400˚F
204˚C
350˚F
177˚C
300˚F
149˚C
250˚F
121˚C
200˚F
95˚C
150˚F
66˚C
100˚F
38˚C
70˚F
60˚F
50˚F
40˚F/4˚C
Flash & Dry Steam Geothermal Power Plants* & Minerals Recovery
Binary Geothermal Power Plants*
Geo-thermal Heat Pumps
Fruit & Vegetable Drying
Mushroom Culture
Soft Drink Carbon-ation
Cement & Aggregate Drying
Onion & Garlic Drying
Food Processing
Snow Melting & De-icing
Pulp & Paper Processing
Aqua-culture**
Lumber Drying
Concrete Block Curing
Bathing
Refriger-ation & Icemaking
Fabric Dyeing
Green-housing & Soil Sterilization
Building Heating & Cooling & Water Heating
Soil Warming
Ethanol Biofuels Production
Beet Sugar Evaporation & Pulp Drying
Blanching, Cooking & Pasteur-ization
Biogas Process
©Geothermal Education Office 2004 • www.geothermal.marin.org
*Geothermal electricity can be used to produce renewable Hydrogen.
**Cool water is added to make the temperature just right for the fish.

Types of Geothermal Exploitation

1. Direct Use-

   A. Municipal/Agricultural Direct Heating

   B. Groundsource Heat Pumps: Basic Heat Exchange



Surface Geothermal Systems

There are three different types surface of Geothermal system designs

Flash / Steam Plants

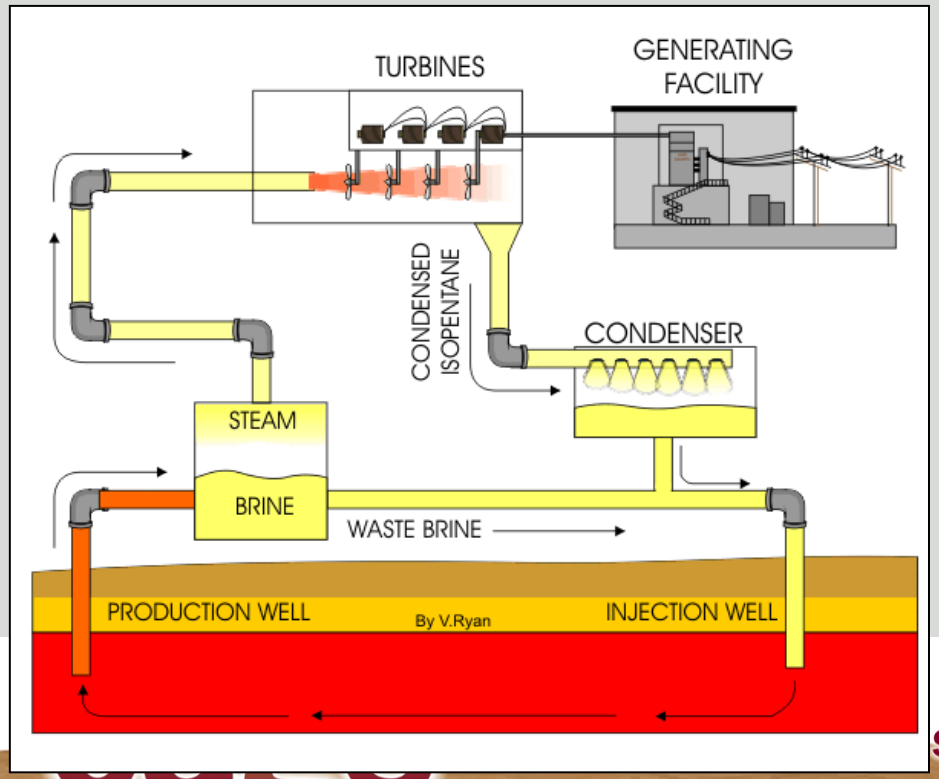
Dry Steam Power Plants

Binary cycle power plant

Geothermal Electricity Production

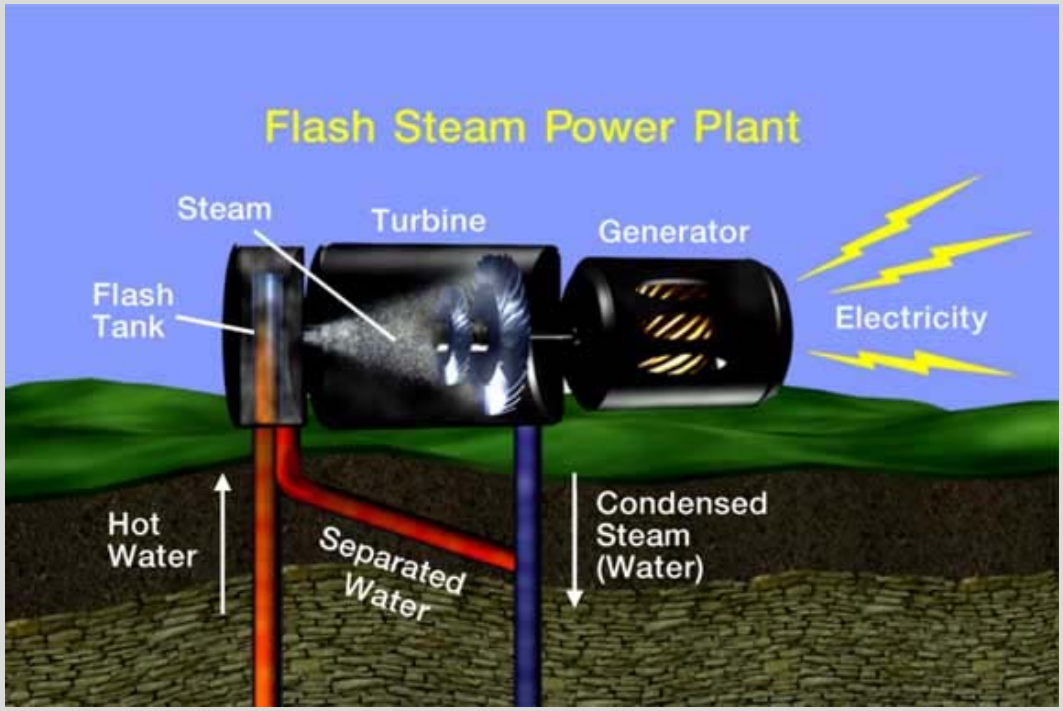
Traditional Production: (Four Basic Types)

A. Flash Steam Power: Water Injection, Steam Production, Vapor-Brine Separation, Turbine Generation, Vapor Condensation, Condensate Reinjection.



Applied to Geothermal Fields > 150°C

Flash or Steam plants

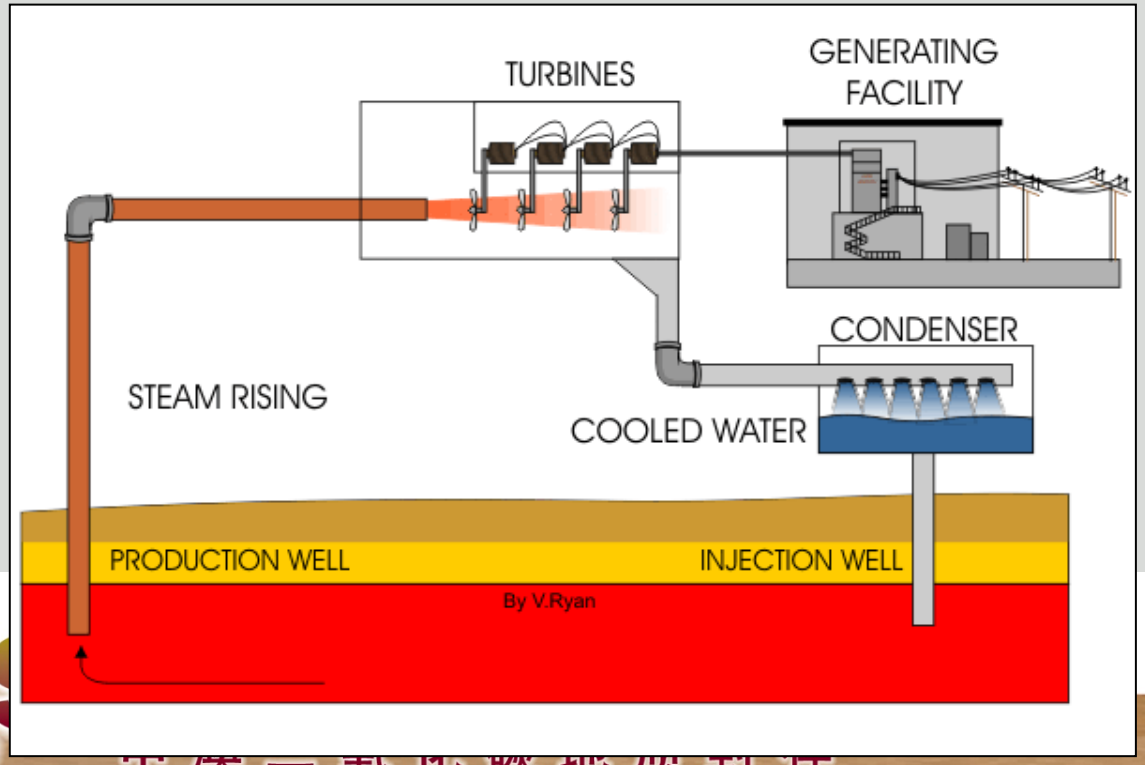


- Hot, High pressure water
- Turbines generate electricity
- Costs 4-6 cents per Kwh.

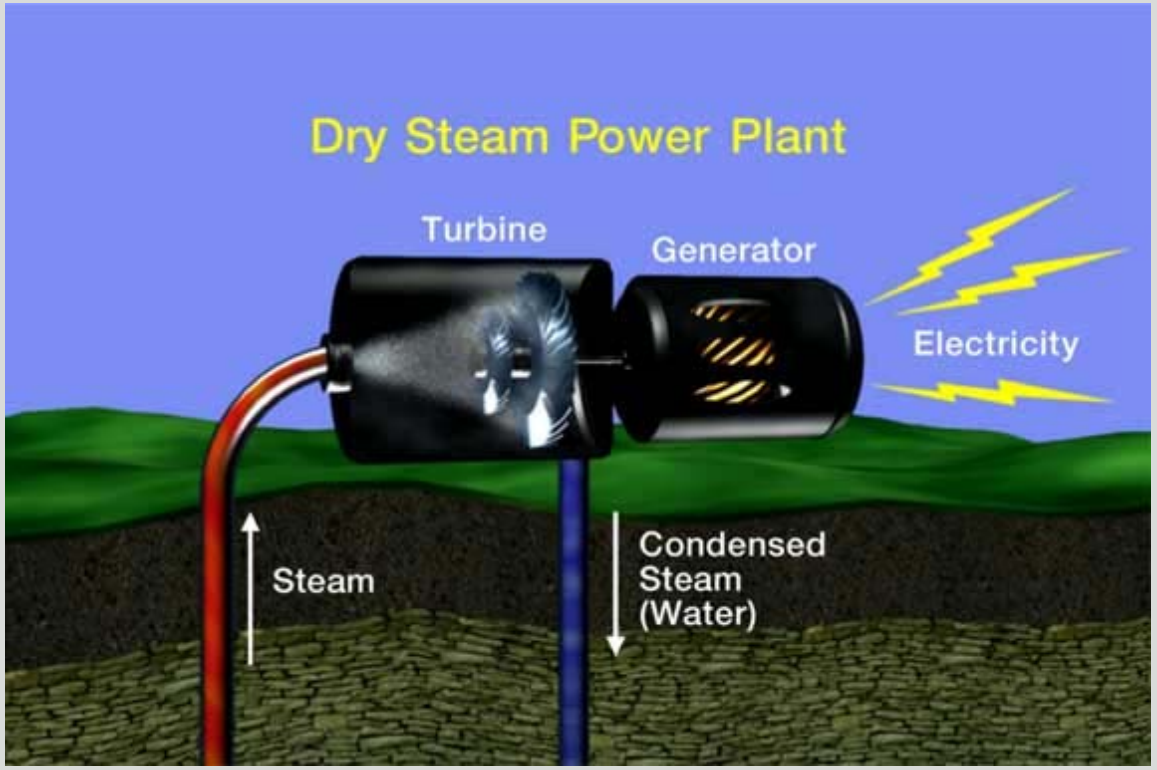
Geothermal Electricity Production

Traditional Production:

B. Dry Steam Power: Naturally Produced Vapor (No Separation Req.)



Dry Steam Plants

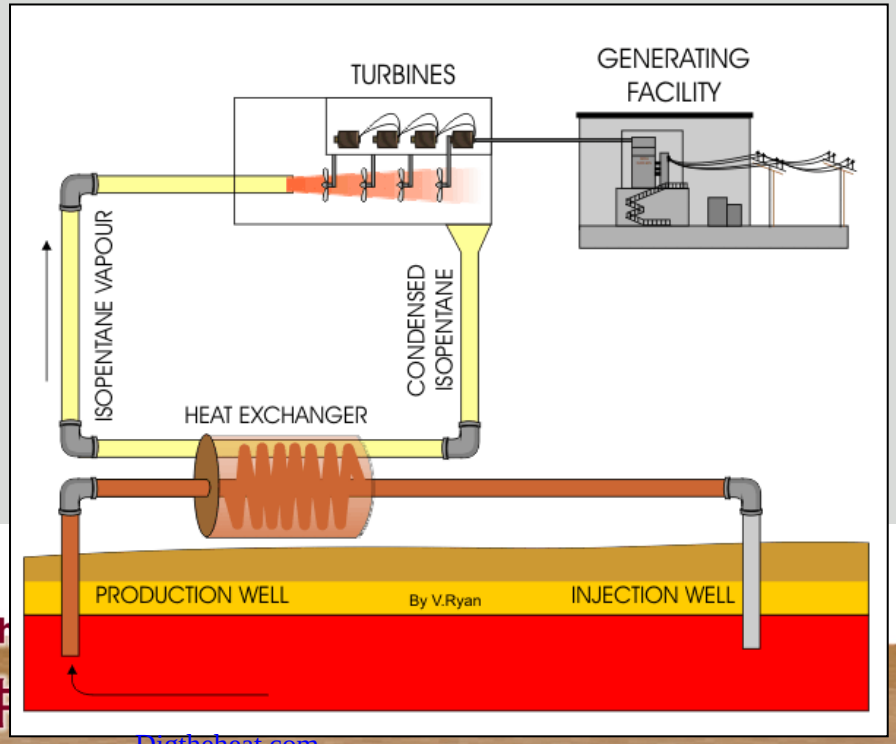


- Steam passes through turbine
- 1050 -1220 degrees F

Geothermal Electricity Production

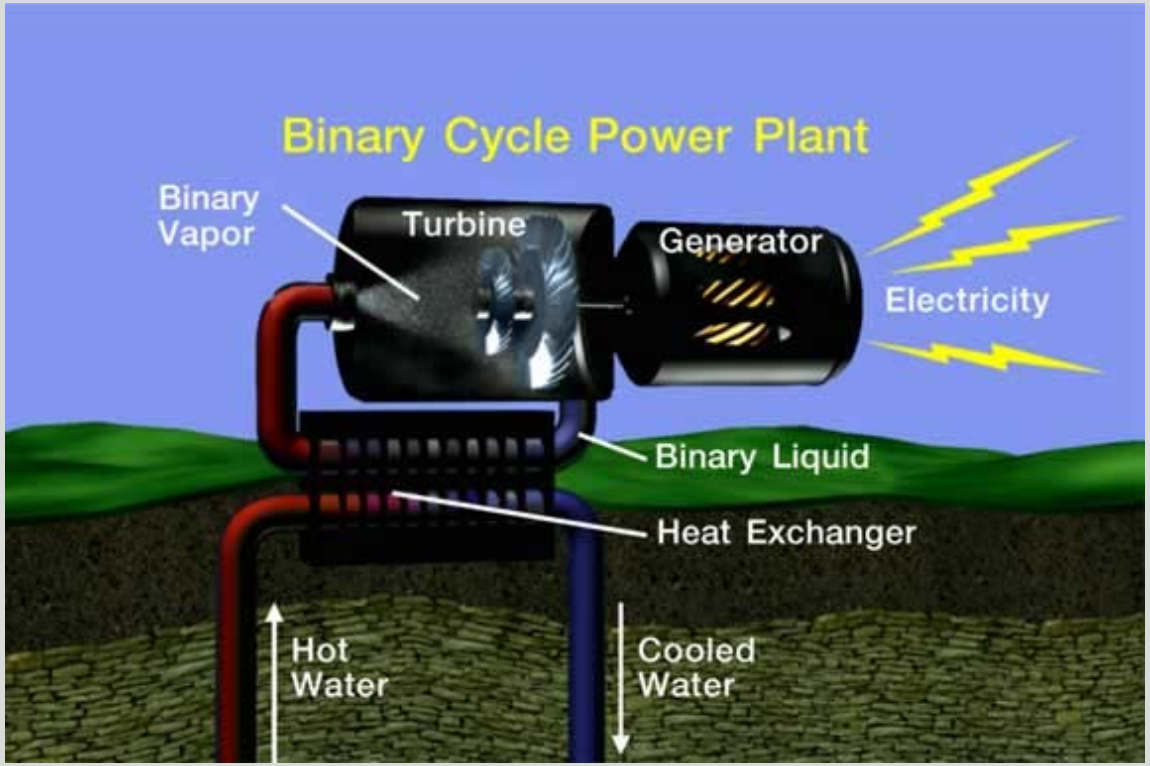
Traditional Production:

C. Binary Power: For resources < 150°C. Heat exchange system between geothermal brine and "working fluid". Working fluid has lower boiling point (i.e.pentaflouropropane). Binary has potential to reduce the geothermal emmission rate to zero. (Organic Rankine Power system)



Digtheheat.com

Binary Cycle Power Plant



- Hot water (100 – 300 deg F)
- Heat Exchanger
- Binary liquid lower specific heat (vaporizes)

Binary Power continued…

Examples of secondary fluids: butane, isobutane, freon, ammonia (Kalina Cycle), carbon dioxide

The choice of the secondary gas depends on the inlet temperature and the inlet pressure. Each gas has a different net power output depending on these parameters (Dai et al., 2009).

Geothermal Electricity Production

Traditional Production:

D. Flash-Binary Power: Combination System.

Two units: Vapor-Fluid separation for first plant. Lower temperature condensed fluid used in second binary plant.

Berlin Geothermal Field, El Salvador

http://www.enex.is/lisalib/getfile.aspx?itemid=2309

Efficiency

•Functions like a conventional coal power plant.

•Efficiencies vary by input heat.

$$TCE = \left(\frac{T_h - T_l}{T_h} \right) \times 100$$

TCE = Theoretical cycle efficiency
T_h = absolute temperature of the steam leaving the boiler °R
T_l = absolute temperature of the condenser °R

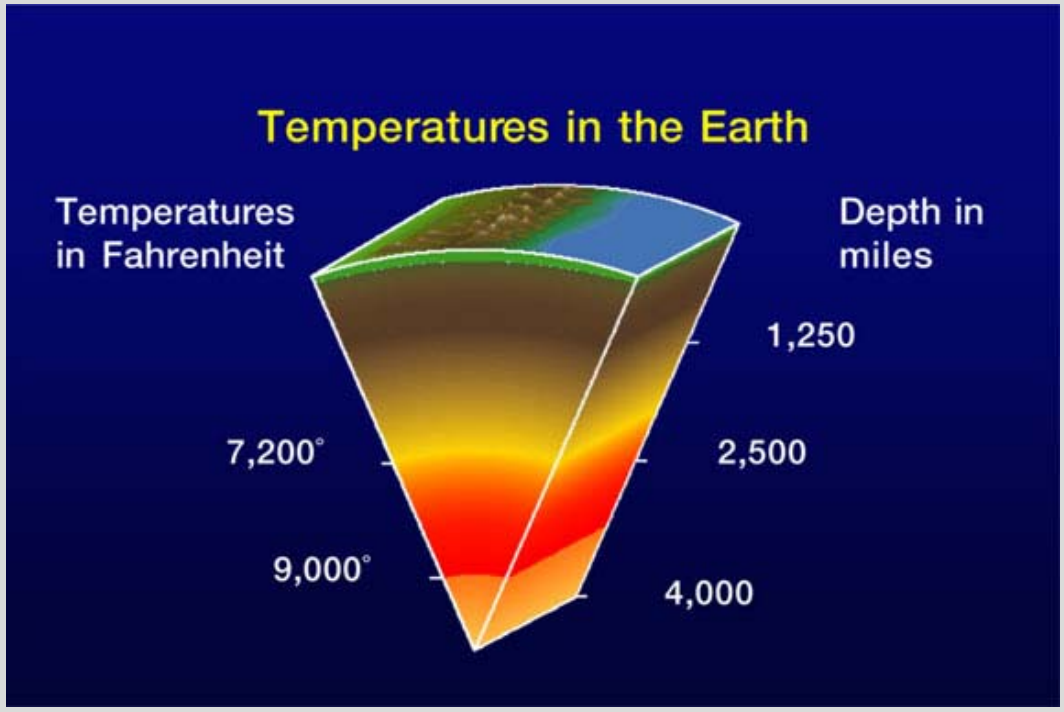
•At 400 deg. expect ~ 23%, not including parasitic load.

•In 2006 the US produced 2850 MW of geothermal electricity

Limitations of surface geothermal

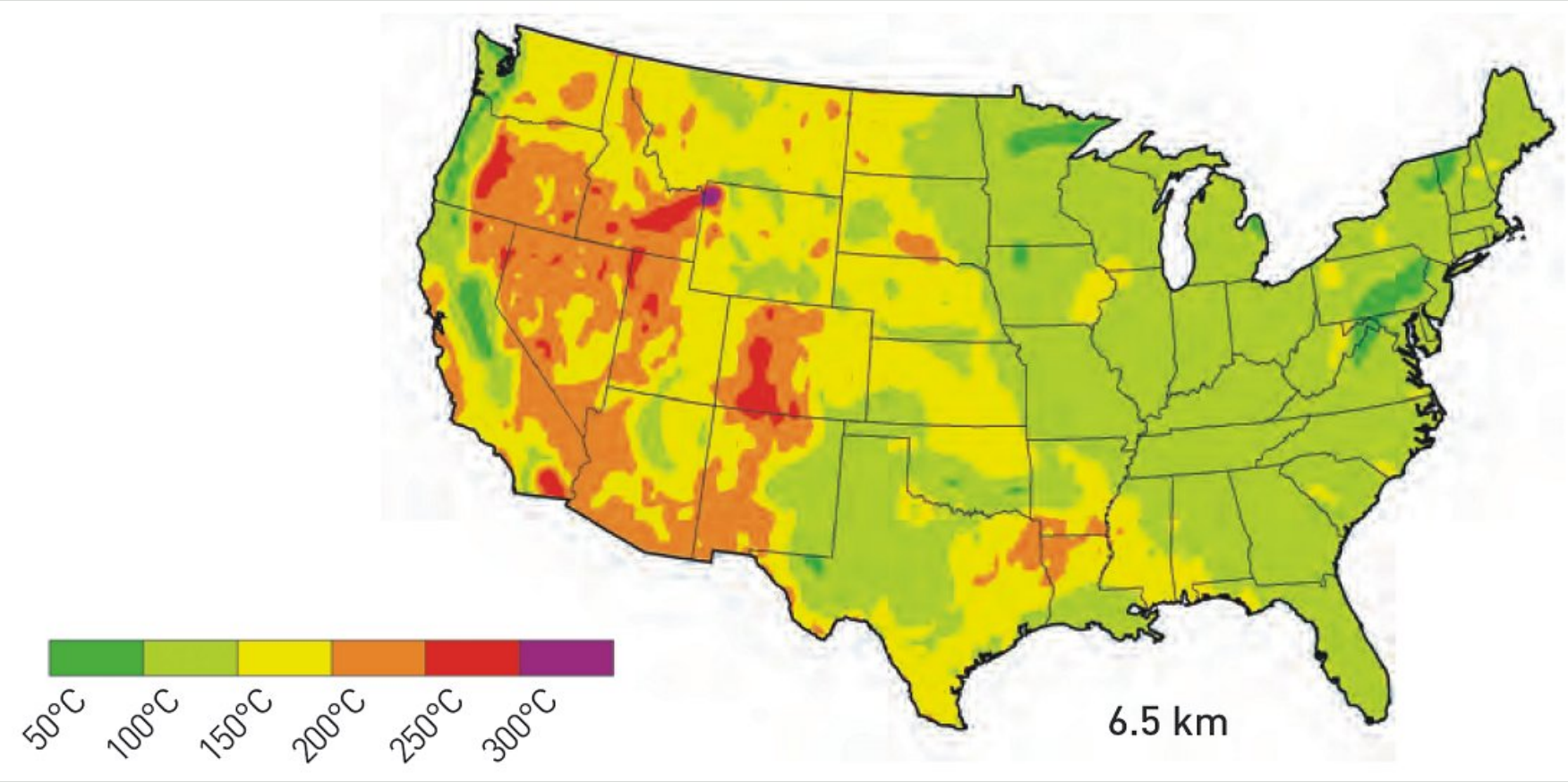
- These are surface based
- Represent "low hanging fruit"
- Most viable sites have been tapped
- Not as efficient as Coal, by the numbers

Enhanced Geothermal Systems An Idea



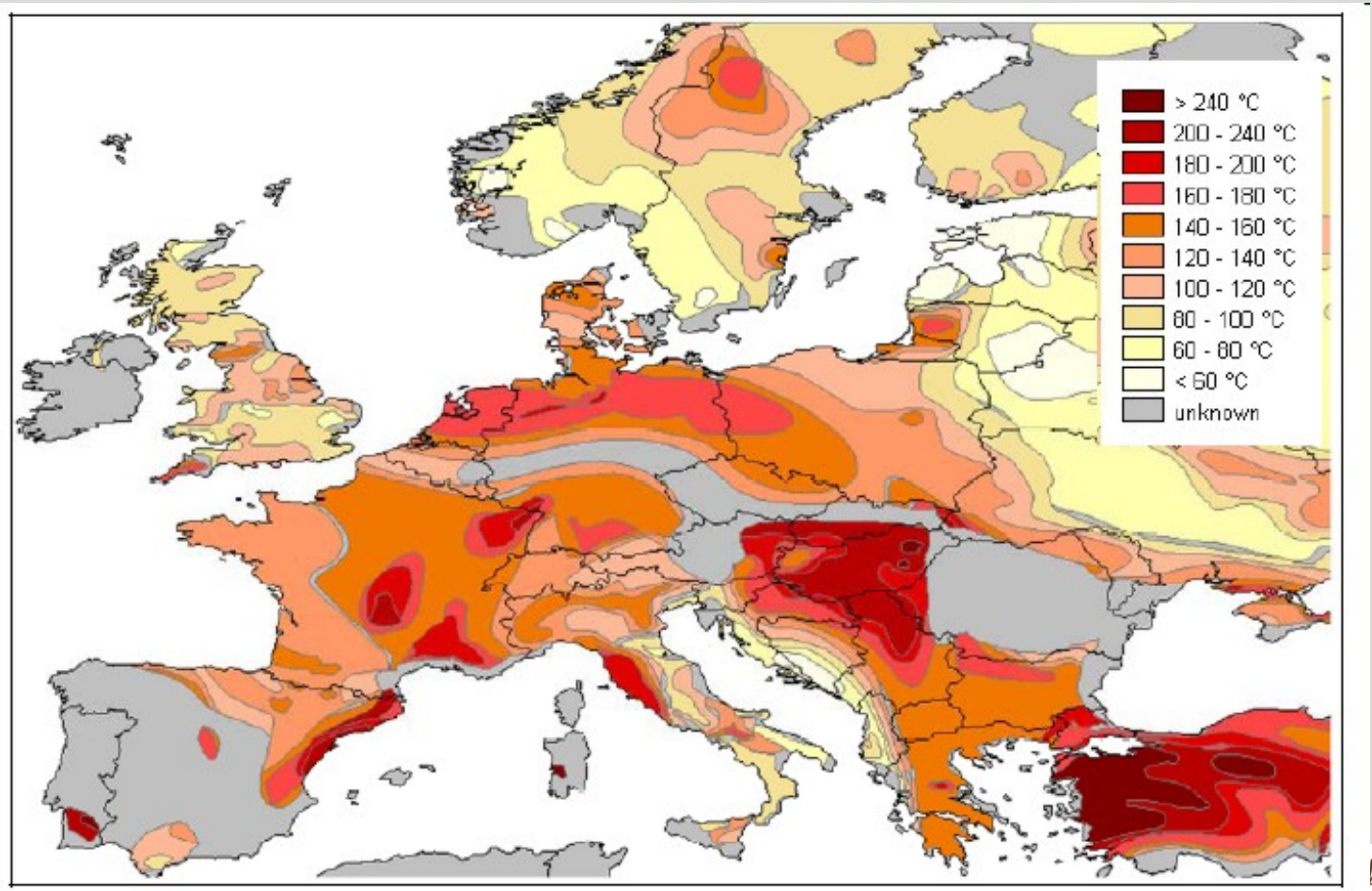
- Temperature profile
- Think about the energy stored in the earth.
- How would one take advantage of this?

US subsurface temperature at a depth of 6.5 km



Source: MIT (2006, *The Future of Geothermal Energy: Impact of Enhanced Geothermal systems (EGS) on the United States in the 21st Century*)

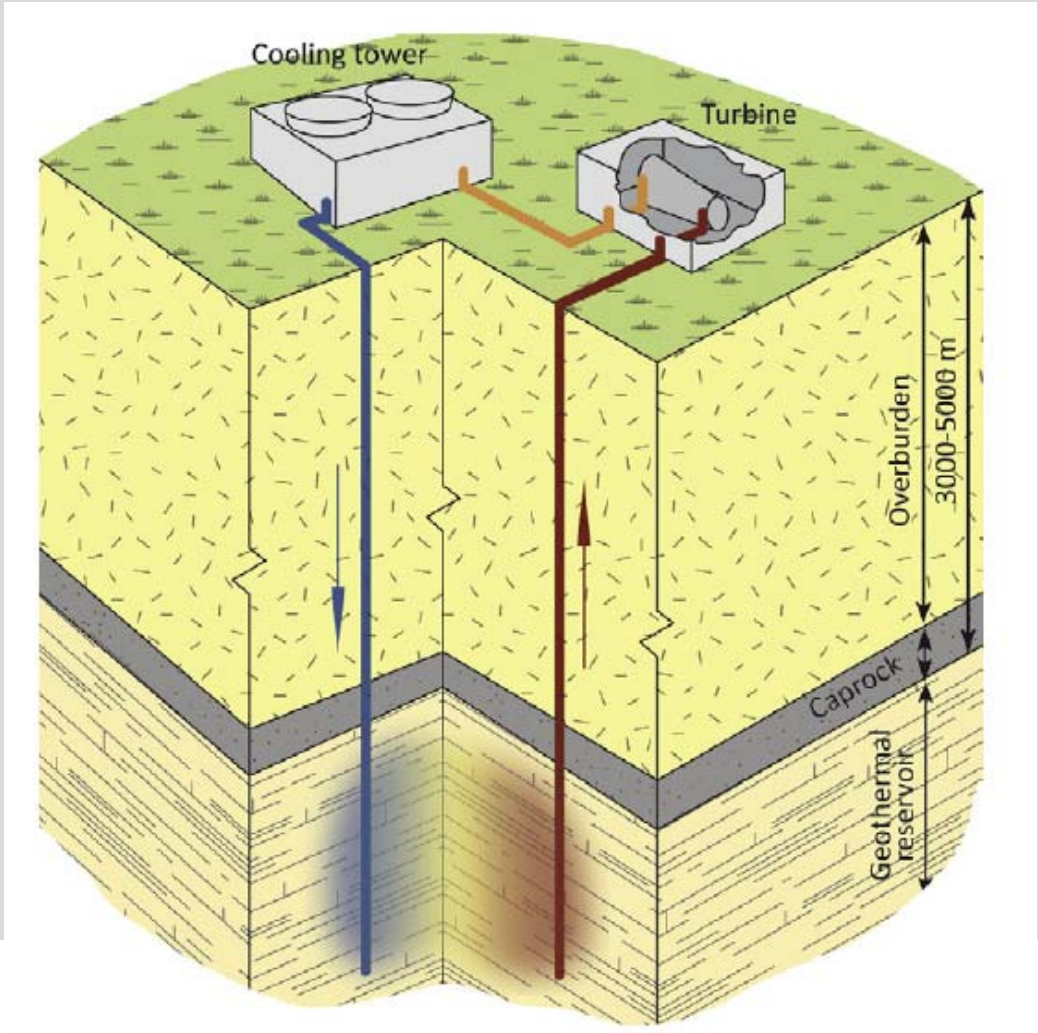
Temperatures encountered as a depth of 5 km in Europe



Source: GAC (2006, *Trans-Mediterranean Interconnection for Concentrating Solar Power, Final Report*, GAC)

Enhance Geothermal System

Working Fluid Underground: Water/CO_2



Enhanced Geothermal Systems in practice

- Basically the same technology as surface geothermal for electricity production
- Some different nuances
- Take advantage of heat ANYWHERE

Nuances

- Use drilling technology to access heat of the earth.
- Create fractures in rock under ground.
  - Allows for the flow of water.
  - Creates an artificial well through which water or fluid can be pumped.

Drilling

Depending on depth different solutions are available.

Fracturing

- Looking for hot, tectonically stressed, and fractured rock.
  - over time fractures seal due to secondary mineralization. Low permeability.

- Reopen fractures with hydraulic, thermal, and chemical processes.

Enhanced Geothermal Systems in practice

The Enhanced Geothermal System designs for the actual electricity generation are similar to surface geothermal.

Flash or Steam Plants

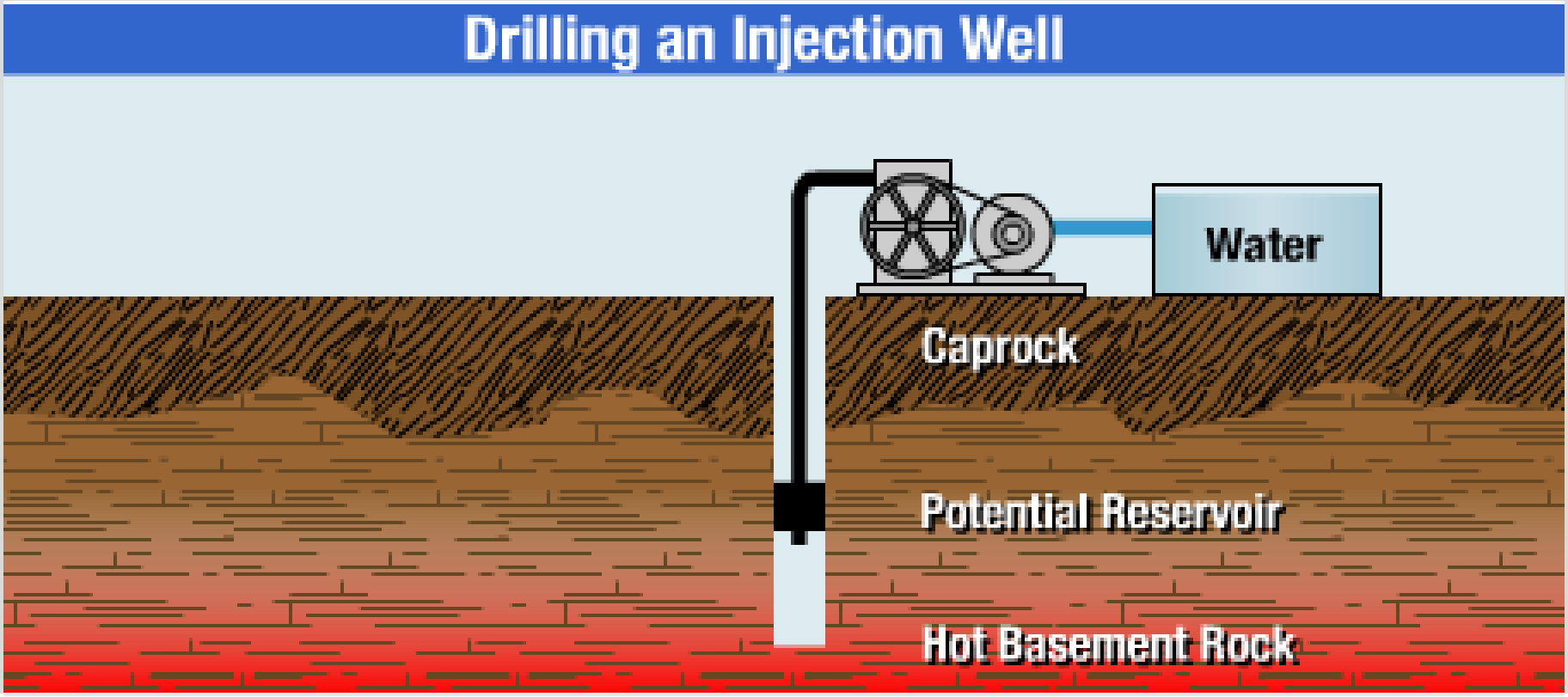
Dry Steam Power Plants

Binary cycle power plant

Type of plant depends on conditions

清華大學

Drilling an Injection Well



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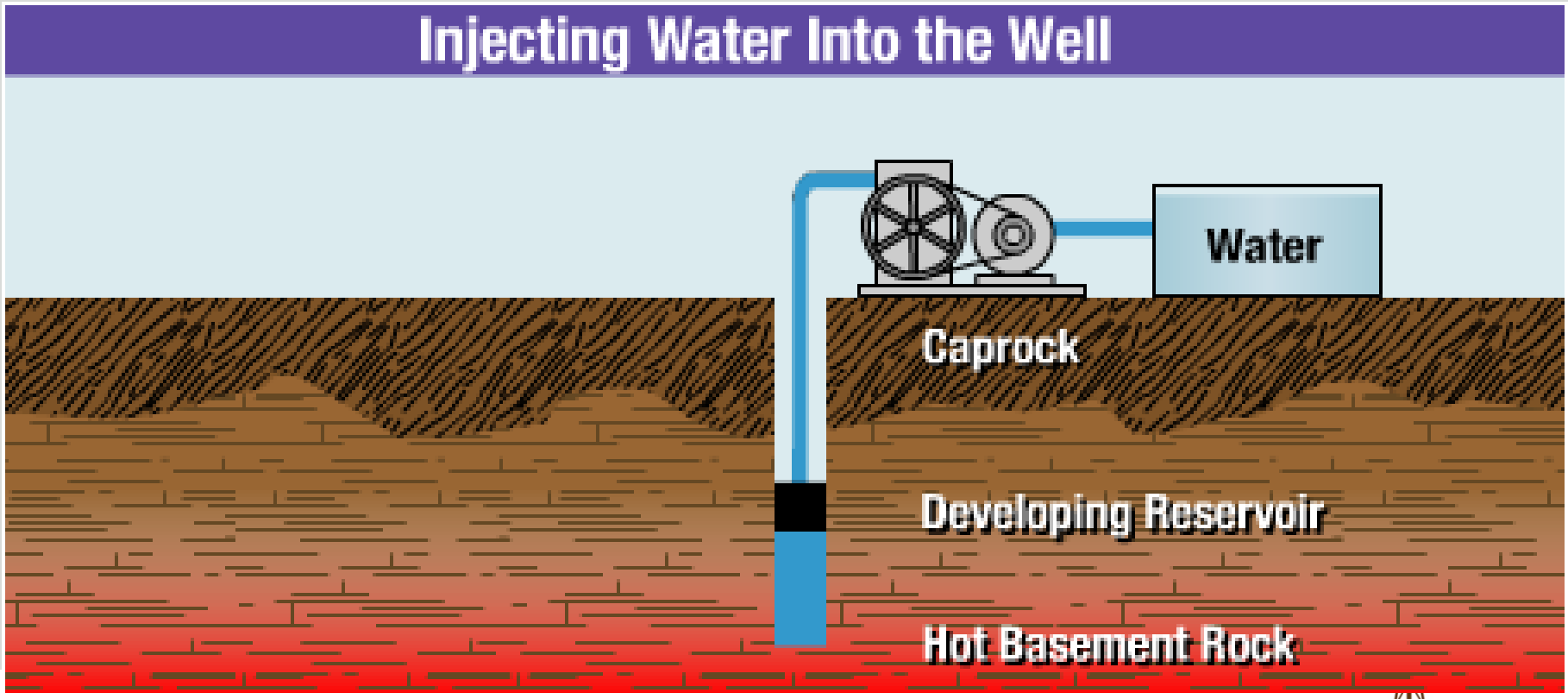
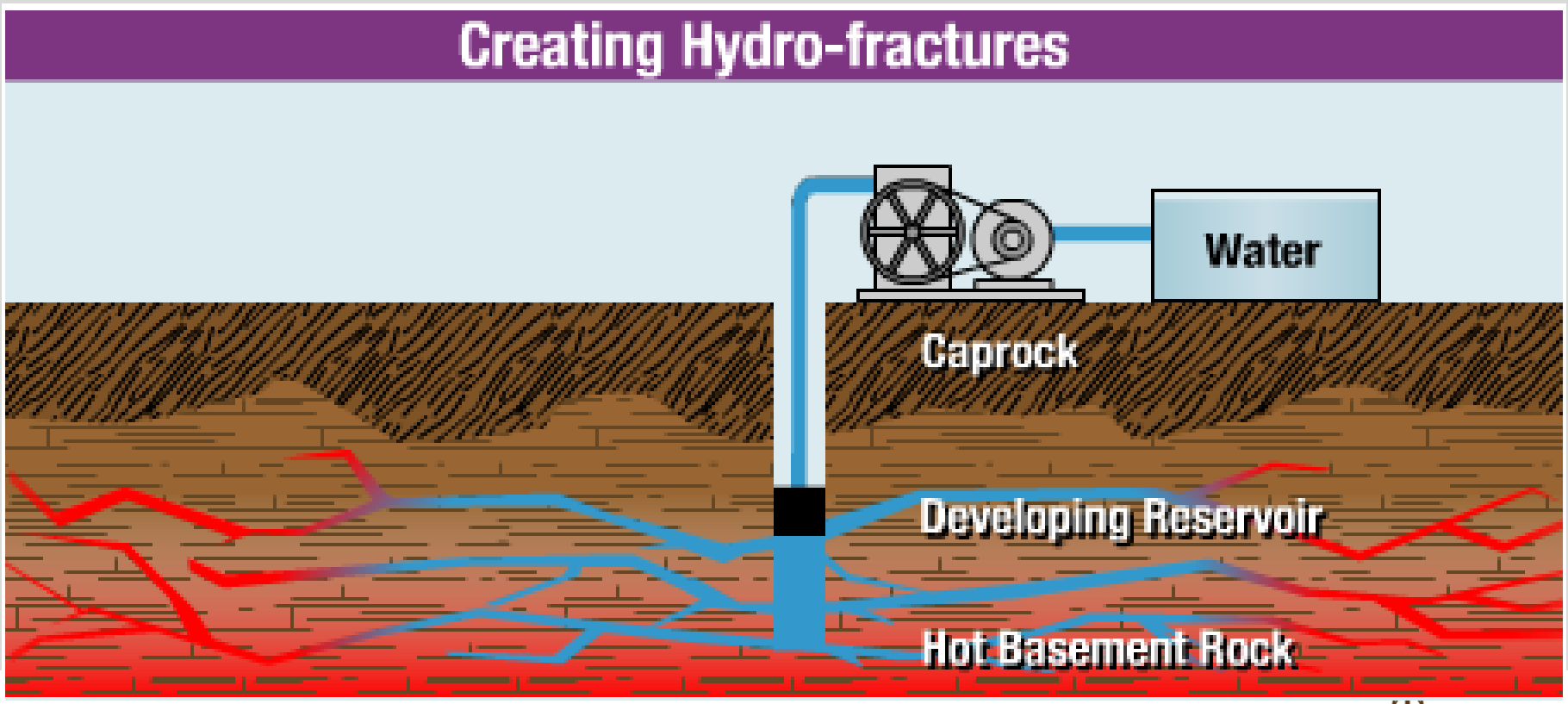
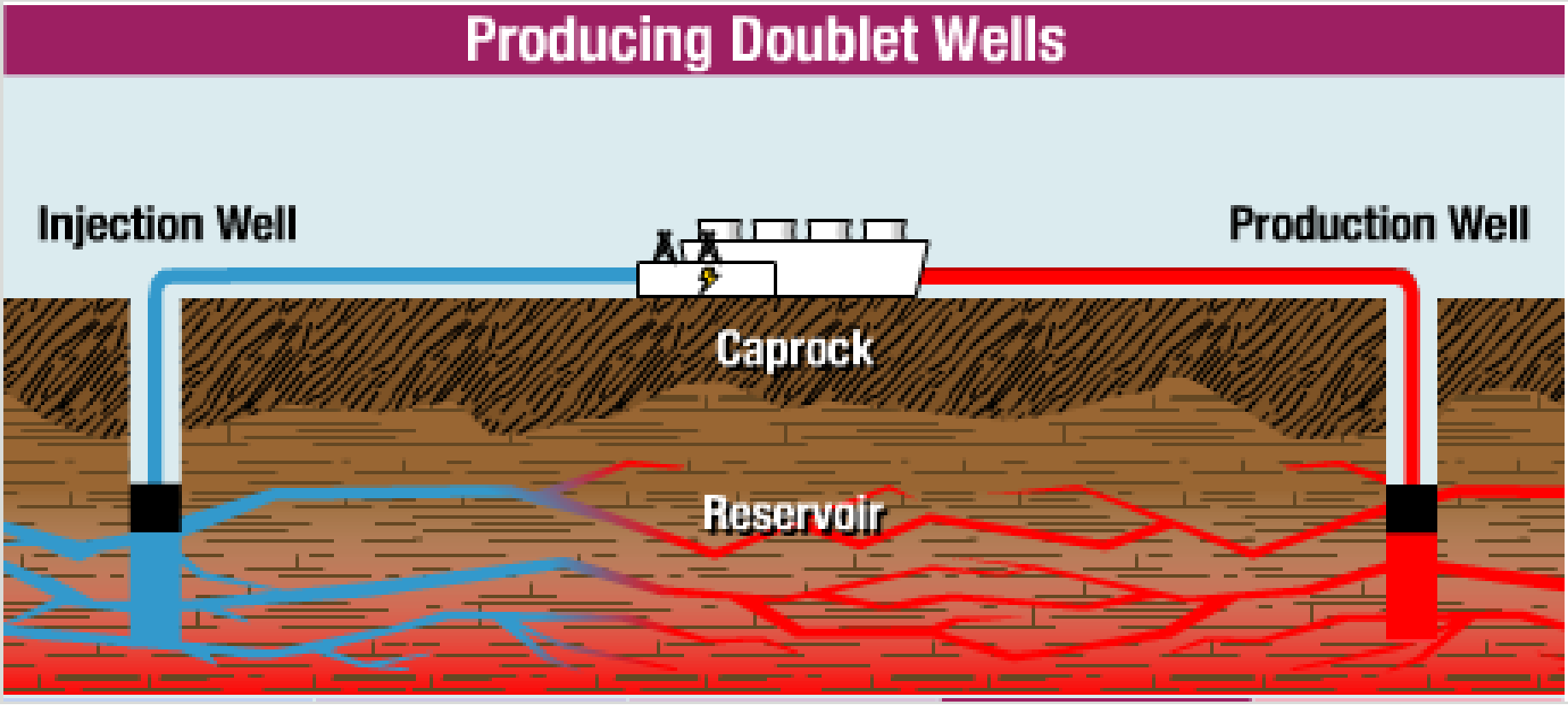
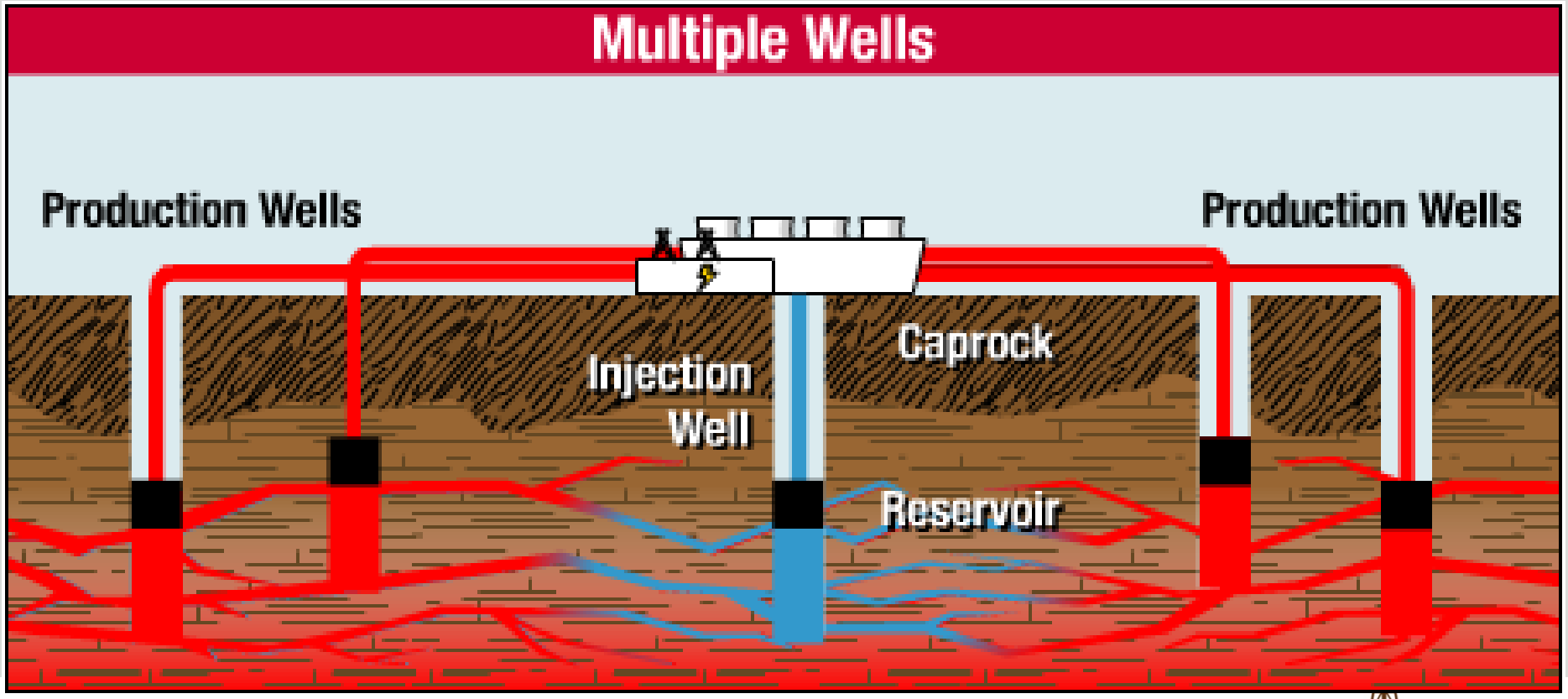
China Australia Geological Storage of CO_2

中澳二氧化碳地质封存


Injecting Water Into the Well
Water
Caprock
Developing Reservoir
Hot Basement Rock


Creating Hydro-fractures
Water
Caprock
Developing Reservoir
Hot Basement Rock


Producing Doublet Wells
Injection Well
Production Well
Caprock
Reservoir


Multiple Wells
Production Wells
Production Wells
Caprock
Injection Well
Reservoir

Videos

- Enhanced Geothermal Systems (EGS)
- SketchUp Model - Enhanced Geothermal Systems (EGS)
- A Conversation on Enhanced Geothermal

CO_2-EGS

General Makeup of a CO2-Based EGS Reservoir

Zone 1

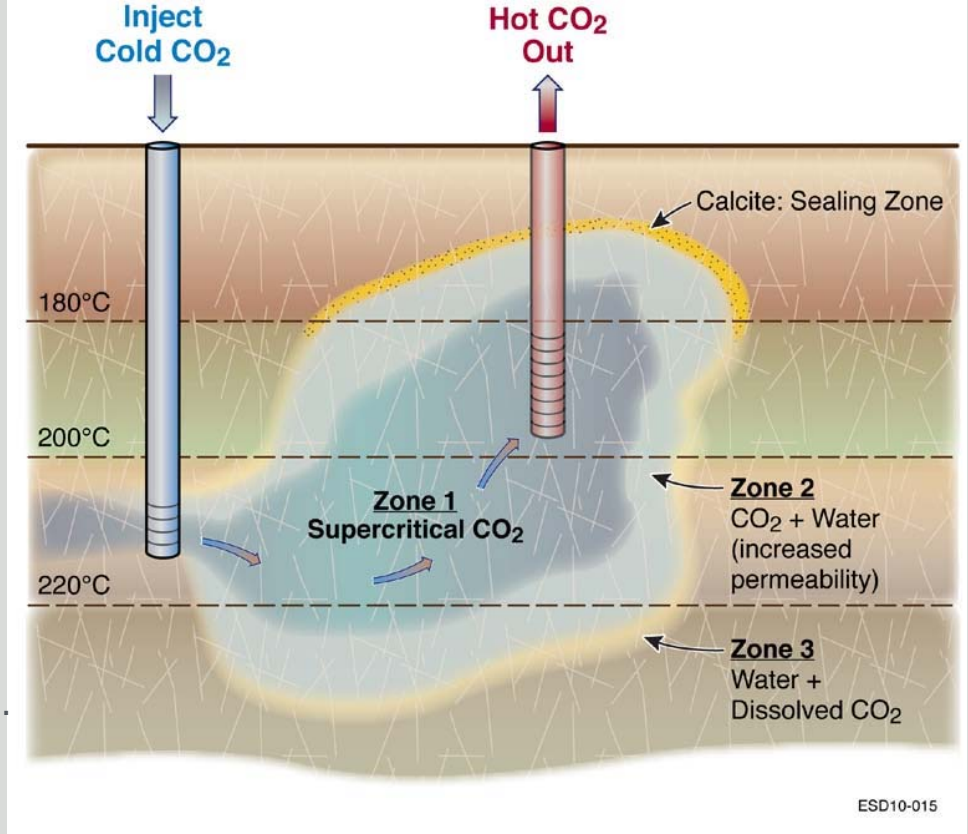
Central zone and core of EGS system, where most of the fluid circulation and heat extraction is taking place. This zone contains **supercritical CO_2**; all water has been removed by dissolution into the flowing CO_2 (rock-fluid interactions weak).

Zone 2

An **intermediate region** with weaker fluid circulation and heat extraction, which contains a **two-phase mixture** of CO_2 and water (expect dominant dissolution).

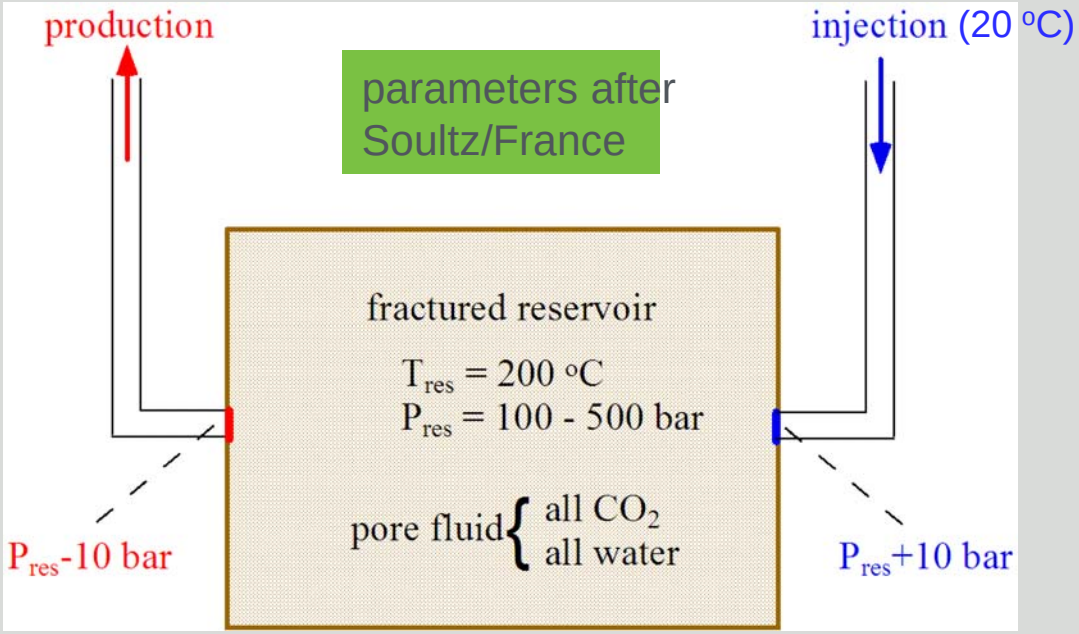
Zone 3

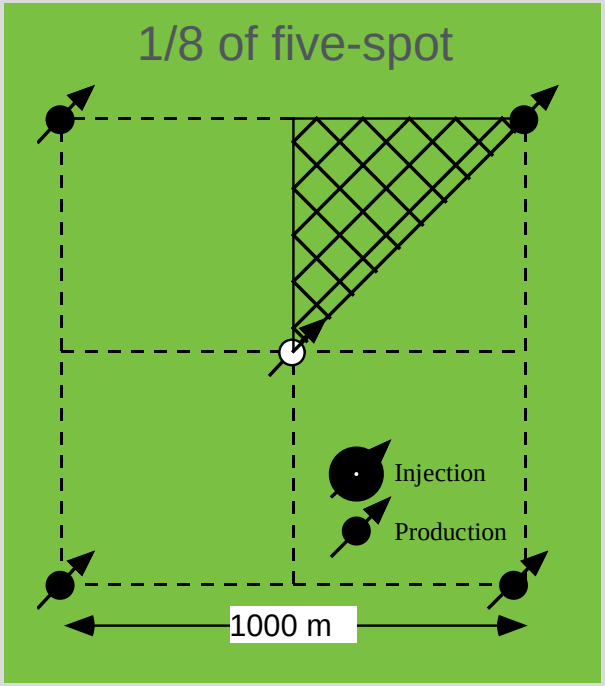
The **outer region** affected by EGS activities. The fluid is a **single aqueous phase** with dissolved CO_2 (expect dominant precipitation).



(after Christian Fouillac et al., *Third Annual Conference on Carbon Capture and Sequestration*, Alexandria, VA, May 3-6, 2004)

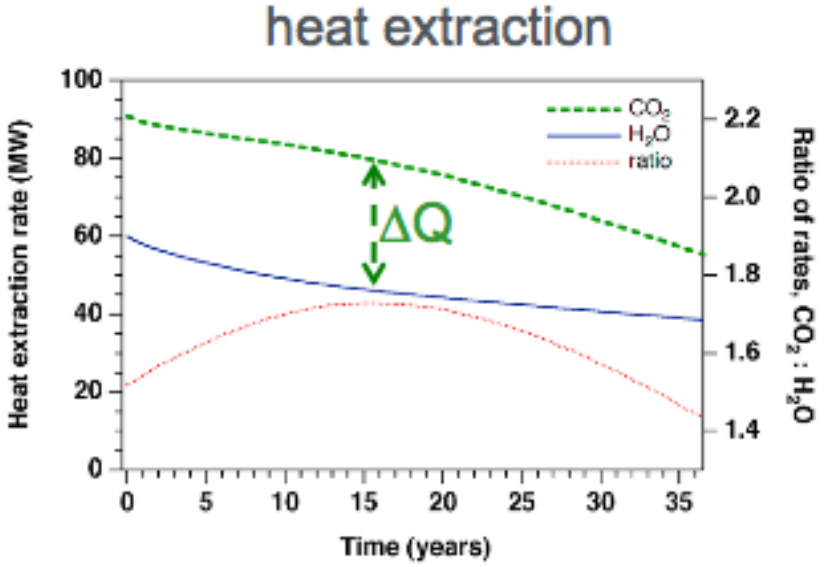
Comparing Operating Fluid for EGS: CO2 vs. Water

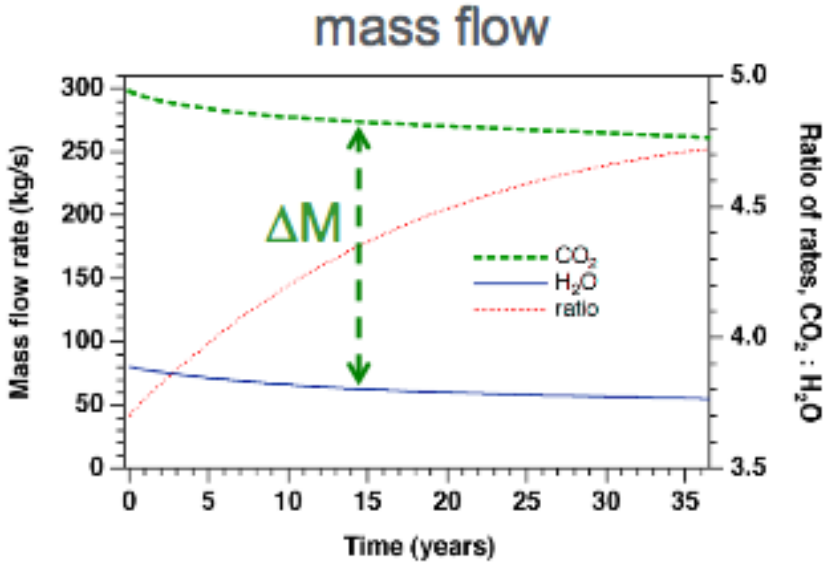




- monitor mass flow, heat extraction rates

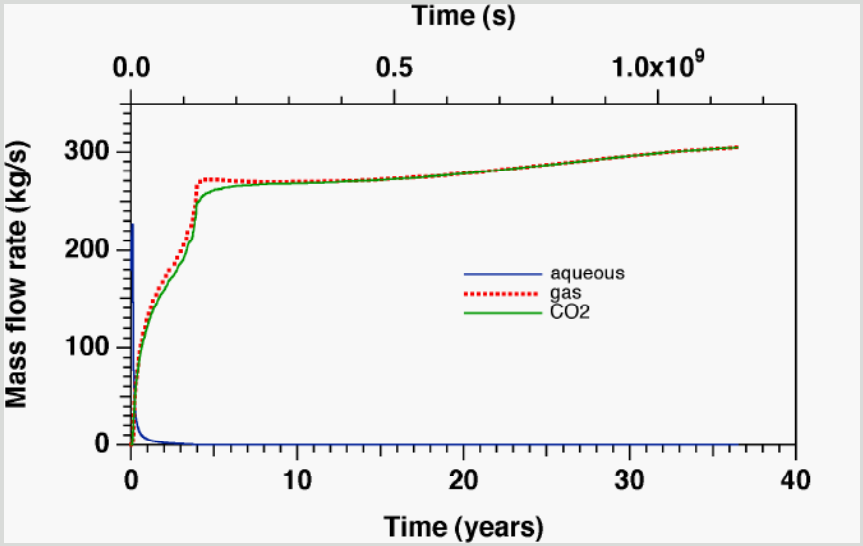
Heat Extraction and Mass Flow Rate

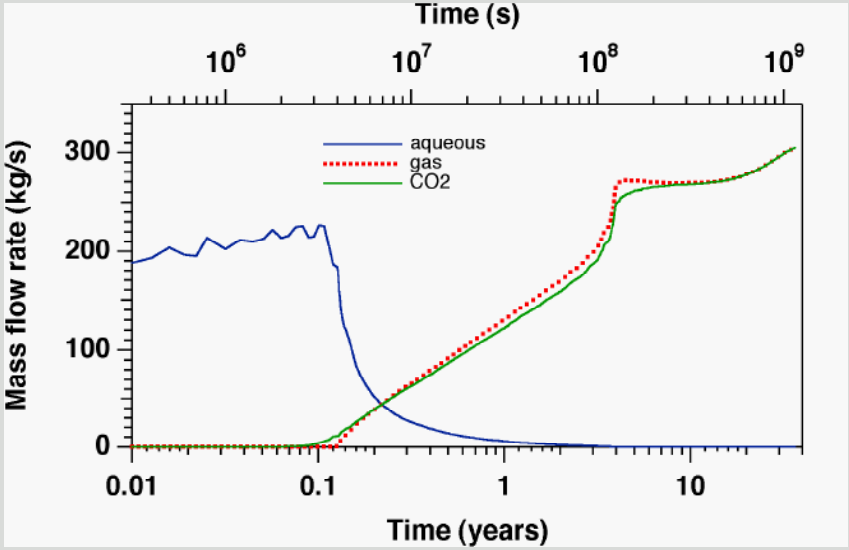




- Energy extraction rate with CO_2 is approximately 50 % larger than with water (average of 75 MW(th) = 13 MWe)
- Relative advantage of CO_2 becomes larger for lower reservoir temperatures
- CO_2 inventory: 1.8 Megatonnes
- For 1,000 MWe, would require 138.5 Megatonnes of CO_2

CO2-EGS Reservoir Development





- At early time (≤ 0.1 year), produce single-phase water
- This is followed by a two-phase water-CO_2 mixture (0.1 - 2.5 yr)
- Total production rate during two-phase period is low due to phase interference
- Subsequently produce a single supercritical CO_2-rich phase with dissolved water (Pruess and Spycher, WGC 2010)

EGS Frequently Asked Questions ---From google

- **What is EGS technology?**
  Enhanced Geothermal Systems (EGS) expands the potential of geothermal energy by orders of magnitude. The traditional geothermal approach relies on finding naturally occurring pockets of steam and hot water. The EGS process, by comparison, replicates these conditions by fracturing hot rock, circulating water through the system, and using the resulting steam to produce electricity in a conventional turbine. The water is then re-injected back into the rock, where the cycle begins again in a closed loop.
- EGS technologies go by many names including: Engineered Geothermal Systems (EGS), Hot Dry Rock (HDR), Hot Fractured Rock (HFR), Deep Earth Geothermal, and Deep Geothermal.

- **Why EGS?**
  EGS is a utility-scale, base-load, and renewable energy source that could produce electricity cheaper than coal. Since EGS builds the geothermal reservoir by design, EGS projects can be made large enough to produce as much power as a typical natural gas or coal power plant (500 - 1,000 MW). Everywhere on earth, the deeper you go, the hotter it gets, meaning EGS can be developed in many areas across the world. EGS is a base-load resource, meaning it can run 24 hours a day regardless of weather. A recent report by MIT on EGS estimated 2% of the heat below the continental United States could provide 2,500 times the country's total annual energy use.

- **Where can we do EGS?**
  EGS can theoretically be developed anywhere there is sufficiently hot rock (above 150 degrees centigrade). Because drilling deep is costly today, EGS is currently most economical in shallow, high temperature zones. All 50 US states have EGS resources at varying depths. As drilling technology improves, it will become more economical to develop deeper resources, unlocking the ubiquitous heat of the earth.

- **Is geothermal energy being used today? How much?**
  Yes. Geothermal energy has been used for heat and electricity for over a hundred years in volcanic regions such as California, Italy, Iceland, Mexico, the Philippines and Indonesia. Currently, approximately 9,000 MW of traditional geothermal, also known as hydrothermal, generating capacity is installed in 24 countries around the world. The United States is the world's largest producer of geothermal energy, with roughly 2,800 MW installed. Geothermal currently generates enough electricity to power roughly 2.8 million homes in the United States.

- **How is EGS different from traditional geothermal?**
  In traditional geothermal energy, also known as hydrothermal energy, pockets of hot water and steam are drilled into to produce power. The amount of power that can be produced from a hydrothermal system is dependent on the temperature and size of these pockets. Hydrothermal systems – while reliable and effective – are limited in nature, vary in size, and are geographically dispersed.
- The EGS process, by comparison, replicates natural conditions by fracturing hot rock, circulating water through the system, and using the resulting steam to produce electricity in a conventional turbine. The water is then re-injected back into the rock, where the cycle begins again in a closed loop. Since EGS' only prerequisite is heat, it can theoretically be deployed anywhere there is rock hot enough to produce power. Additionally, since permeability is created by design, EGS systems can be developed in a modular fashion.

- **What is the resource potential for EGS?**
  The crust of the earth contains an enormous amount of heat. The 2007 MIT Report on *The Future of Geothermal Energy* estimates that only 2% of the heat 3 - 10 km below the continental United States could meet 2,500 times the United States' current total energy use. The MIT Report also found that with today's EGS technology, the United States could produce 1 - 12 million MWs of electricity. For comparison, the entire current US electrical system is about 1 million MW. All 50 US states have substantial thermal resources at varying depths. In Australia, it is estimated that 1% of that nations' thermal resource could meet 26,000 times Australia's current total energy use. To learn more about how much power could be produced by EGS, see this Google Earth Layer, U.S. Geothermal Resource (3-10km depth).

- **Does EGS have any major technological hurdles?**
  A recent MIT report found, "there are no anticipated 'showstoppers' or fundamental constraints that will require new technologies to be discovered and implemented to achieve success. For more information, please see the full report, *The Future of Geothermal Energy*.

- **Where is EGS being developed today?**
  EGS projects are producing power in France and Germany. In Australia, there are over 30 companies exploring or developing EGS resources. The first US demonstration project, run jointly by the Department of Energy, Ormat Technologies, and GeothermEx Inc., is in Desert Peak, Nevada.

- **How many megawatts are EGS projects generating?**
  The European Union's EGS project near Soultz-sous-Forets, France, recently connected their first 1.5 MW demonstration plant to the local grid. The Landau project in Germany, connected their 2.5 MW system to the grid in 2007. The leading EGS projects in Australia present thousands of MW of opportunity for renewable baseload power. The Desert Peak project in Nevada, will use EGS techniques to expand the production capacities of the existing 11 MW hydrothermal system to 50 MW.

- **What about the cost of EGS? Can it really be made cheaper than coal?**
  Yes. While EGS technology has advanced rapidly in recent years, significant opportunities for innovation remain. Advances in drilling, reservoir, and heat-to-power technologies could all significantly reduce the cost of EGS. Energy technologies generally start at higher cost but become cheaper as technology progresses and scale increases. The RE<C initiative is working to advance EGS technology and lower the cost of energy produced from it.

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