On the utilisation of Super-critical Carbon Dioxide (ScCO2) in the geothermal power generation

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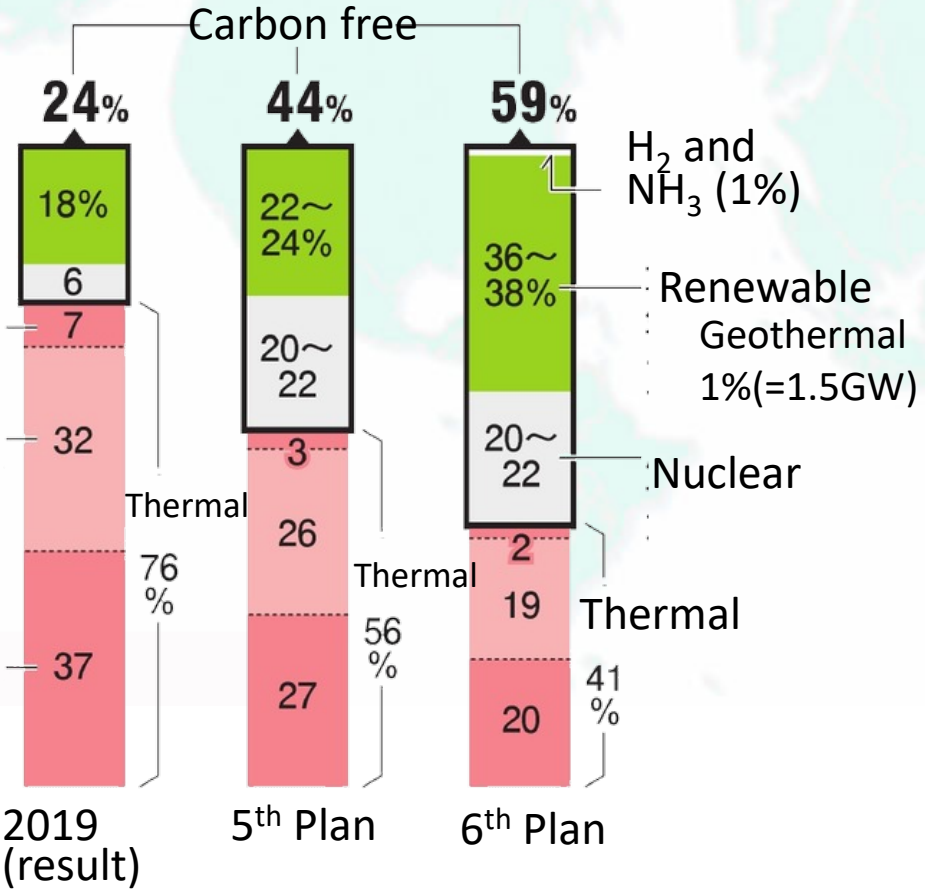
Background for the technology

Geothermal energy demand

The 6th energy supply plan in 2030 by the Japanese government



Basic figure https://www.asahi.com/articles/ASP7P4V2QP7NULFA01D.html

Problems for the geothermal development in Japan

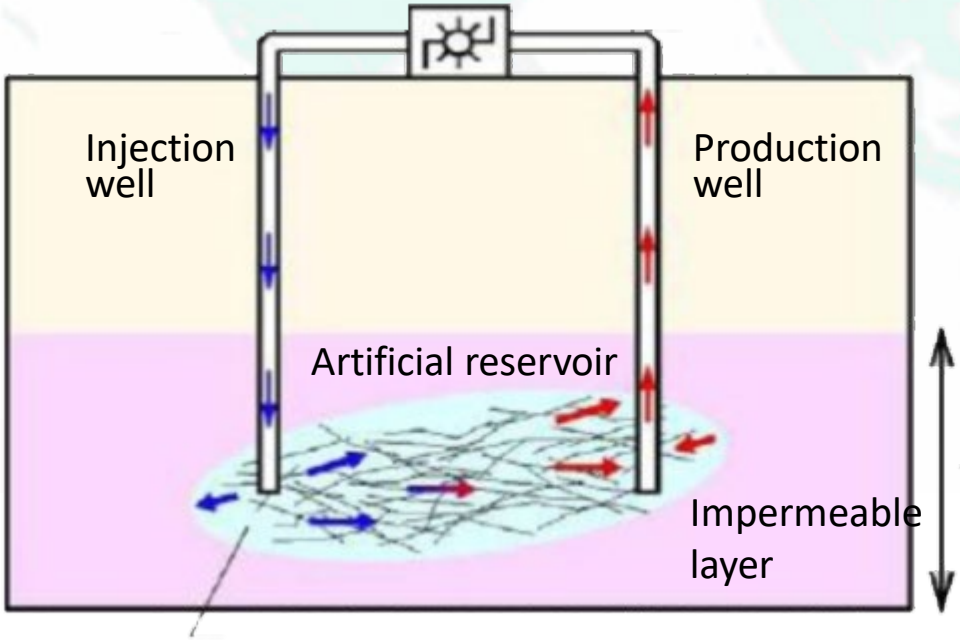
1. Agreement for the development by Onsen (Spring) owners
   Understanding of the geothermal fluid in the hot spring and geothermall reservoirs is necessary

2. Development in the national park
   Environmental friendly development such as height restrictions on power plants is required

3. Long time for the development
   Financial support such as subsidy is supported by JOGMEC

Concelt of Hot Dry Rock (HDR)

Geothermal power generation by the idea of HDR (Hot Dry Rock) has been technologically developed since the 1970s. This technology creates a hydrothermal system by artificial cracks where the natural hydrothermal system is underdeveloped, injects water from the injection well, and takes it out from the production well. For this reason, geothermal power generation is possible by excavating deep wells in any region of the world. It is, currently, developing as an EGS (Enhanced Geothermal System) technology.

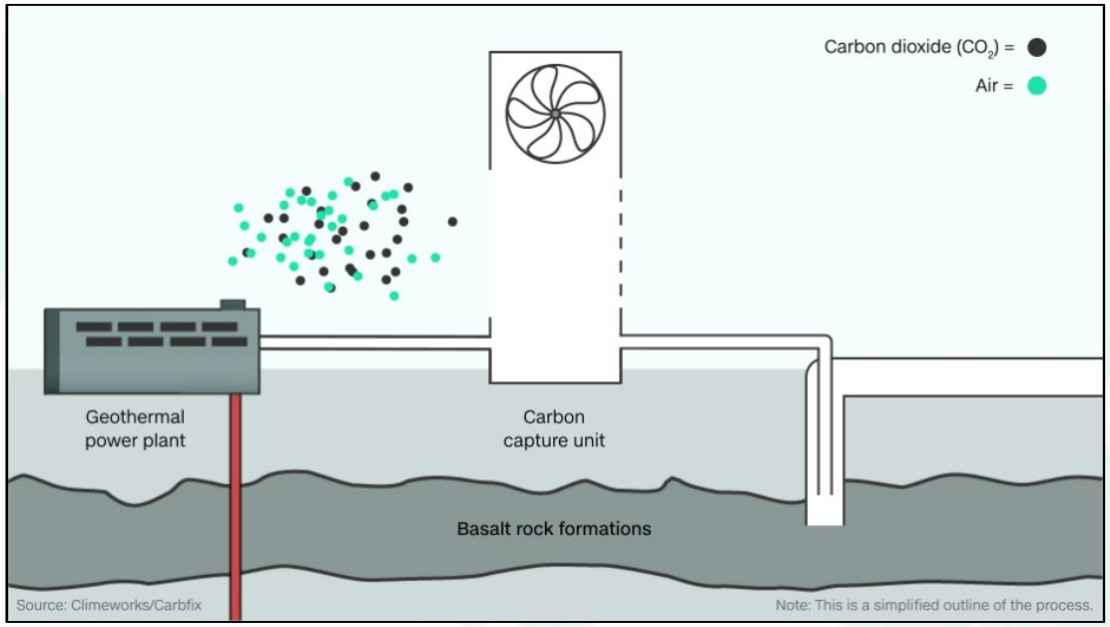


Inject water or CO_2 into the reservoir

- It is impossible to control 100% of artificial cracks (dominated cracks, induced seismicity).
- Recovery rate is less than half (the whereabouts of leaked water is unknown).
- The concept of crack-free rock body has change to various types of fracture structures.

CCS project in Iceland using geothermal heat

【Orca Project】

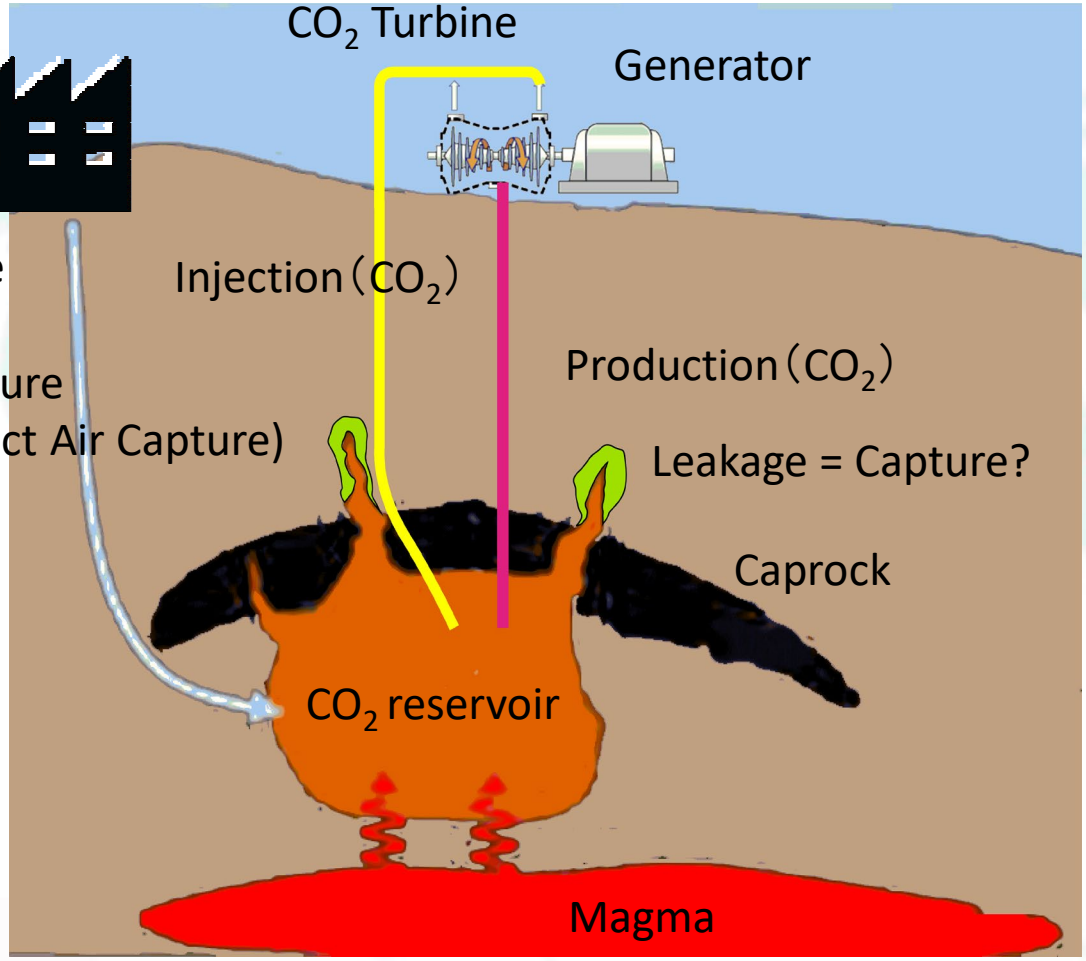


(https://edition.cnn.com/2021/10/20/world/carbon-capture-storage-climate-iceland-intl-cmd/index.html)

- CO_2 capture by DAC using heat from the geothermal power plant
- CO_2 injection to a depth of about 2,000 m
- CO_2 reacts with basalt and is converted to the carbonate over several years
- Geological storage of about 4,000 tons of CO_2 in every year

Audi press release (2020)

Conceptual image of the geothermal system using CO_2



CO_2 Source
- Factory
- CO_2 Capture
- DAC(Direct Air Capture)

Characteristics of Super-critical Carbon Dioxide ($ScCO_2$)

- Density is close to liquid
- Viscosity / diffusion coefficient is close to gas

- Injection of $ScCO_2$ into a geothermal reservoir and production of heated $ScCO_2$ generate electricity by a CO_2 turbine which would be smaller than that of using vapour.
- Siphon effect by the high compressivity of $ScCO_2$ causes the circulation without power.
- Mineral trapping would be happened by the escaped CO_2.

Characteristics of $ScCO_2$

Critical point of carbon dioxide

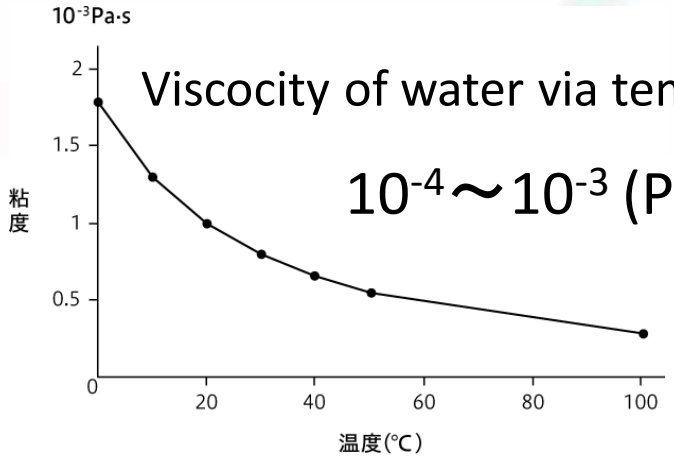
Temperature 31.1 ℃ & Pressure 7.38MPa

Physical property of $ScCO_2$

Property	Phase		
	Gas	Super-critical	Liquid
Density [kg/m³]	0.6～1	200～900	1000
Viscosity [Pa·s]	10^{-5}	10^{-5}～10^{-4}	10^{-3}
Diffusion costant[m²/s]	10^{-5}	10^{-7}～10^{-8}	＜10^{-9}

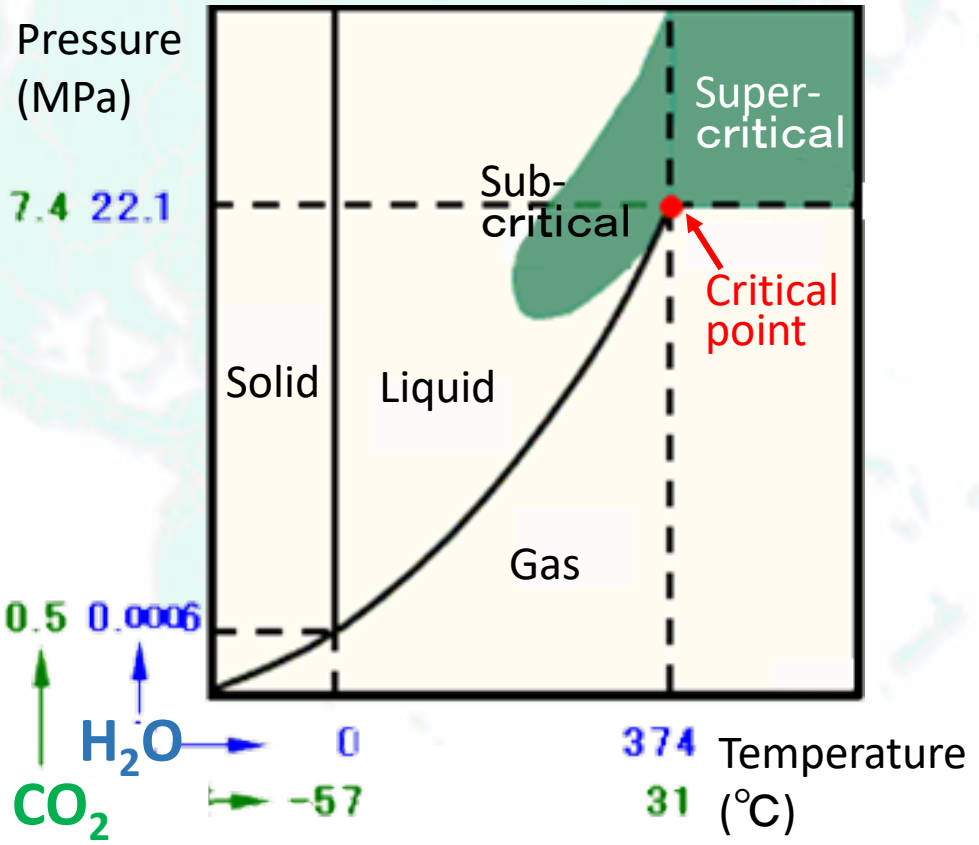
Dissolving power Gas ---------- ○ ------Liquid

Diffusivity Gas ------ ○ ------- -------Liquid



Viscocity of water via temp.

10^{-4}～10^{-3} (Pa/s)



Phase Diagram of CO_2

(https://shinko-airtech.com/supercritical/critical.html)

Subjects for the technology development

Ⅰ. Overall System Design

- Basic design for the system including the CO_2 turbine
- Pumping system to inject the CO_2 into the reservoir
- Selection for the suitable field and the estimation of the potential for this CO_2 geothermal system

Ⅱ. Reservoir creation using $ScCO_2$ as fracturing fluid

- Fracture experiments in the laboratory
- Comparison of water and CO_2 in the fracture creation
- Modelling of the experiments by a simulation
- Prediction of the reservoir creation in a field

Ⅲ. CO_2 flow and geochemical reaction in a geothermal reservior

- Interaction between rocks and CO_2 in a laboratory scale
- Simulation to explain the geochemical reactions in the laboratory.
- Simulation to explain the flow and geochemical reaction in the field scale
- Monitoring methods to detect the flow in the reservoir and trapped minerals.

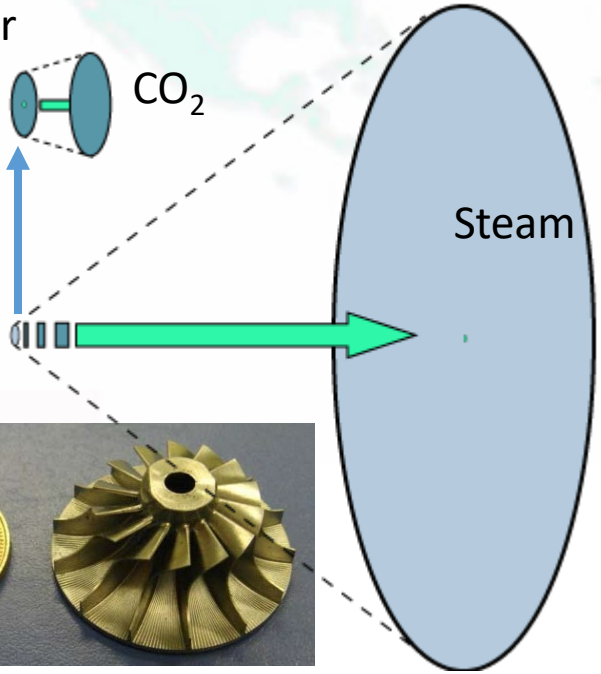
Ⅰ. Overall System Design

- Design for the CO_2 turbine in the geothermal system

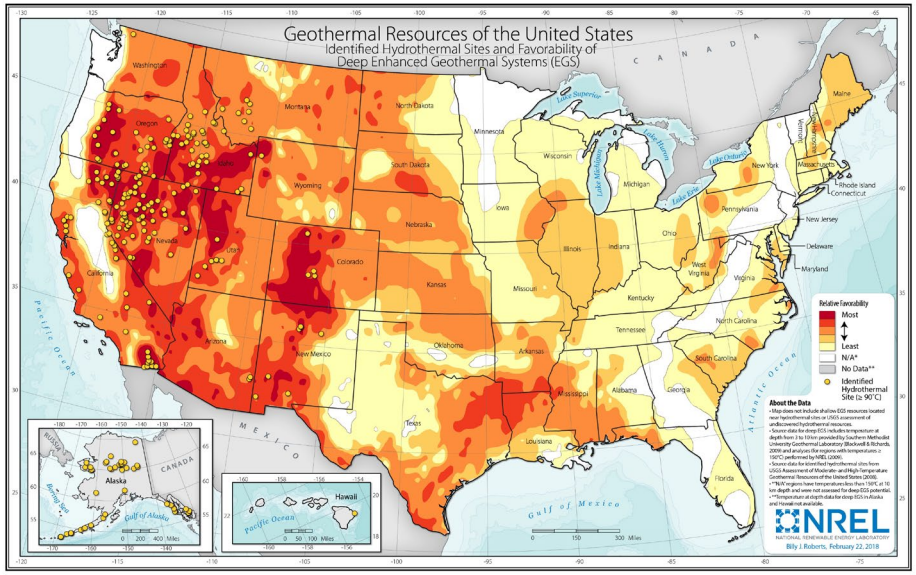
Comparison of the same output

CO_2 Turbine		Steam Turbine
10 times the volume at the turbine inlet	but	1/60 volume at turbine output

The size of the turbine is expected to be smaller



- Map of the geothermal energy for EGS technology (non-hydrothermal system)



EGS Map

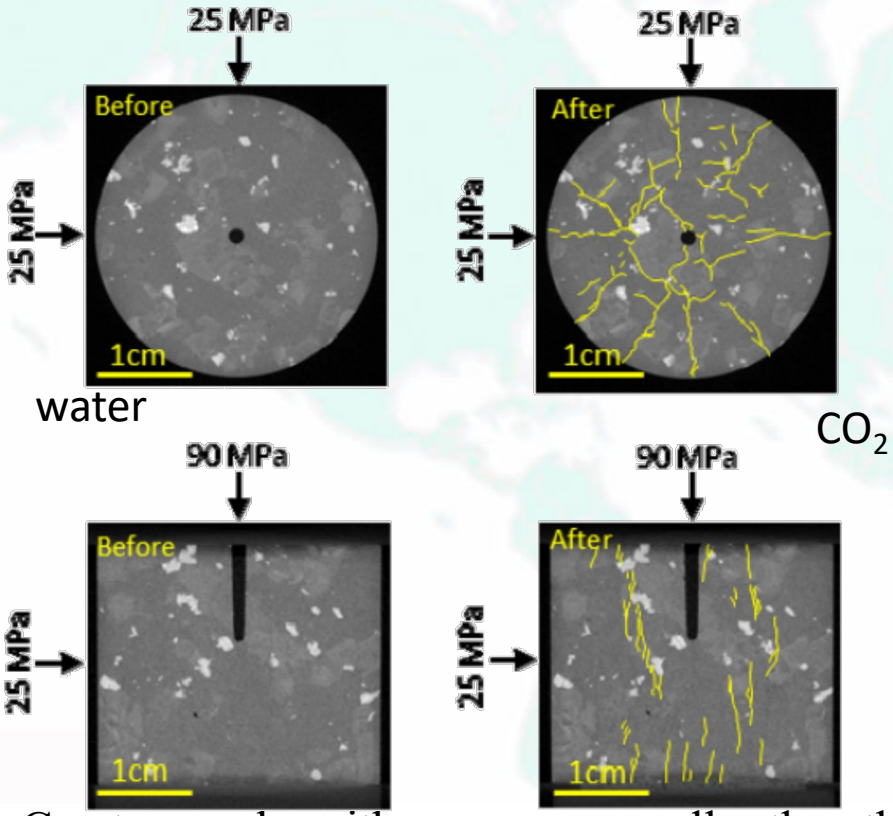
https://www.americangeosciences.org/critical-issues/maps/geothermal-energy-resource-US

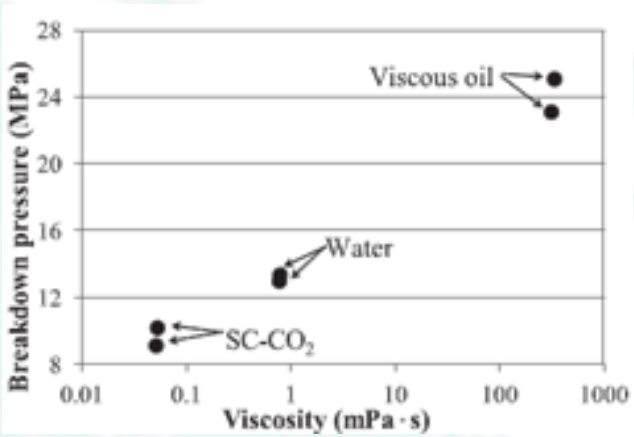
1. Geomagnetic survey data by aircraft
2. Curie temperature profile
3. Estimation of the heat source

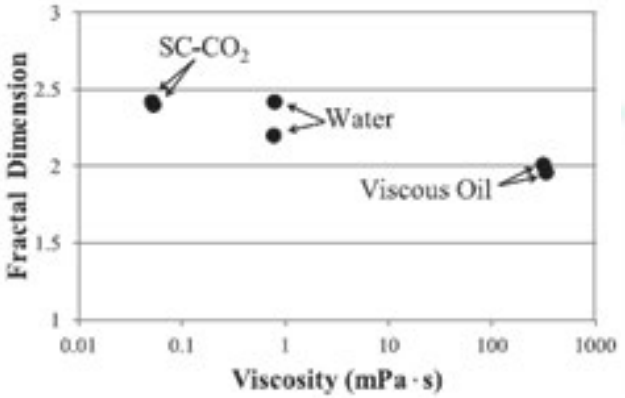
4. Estimation of the electricity output

II. Reservoir creation using $ScCO_2$ as fracturing fluid

⇒ What kind of cracks will occur by the injection of $ScCO_2$?
How is the risk of an earthquake?





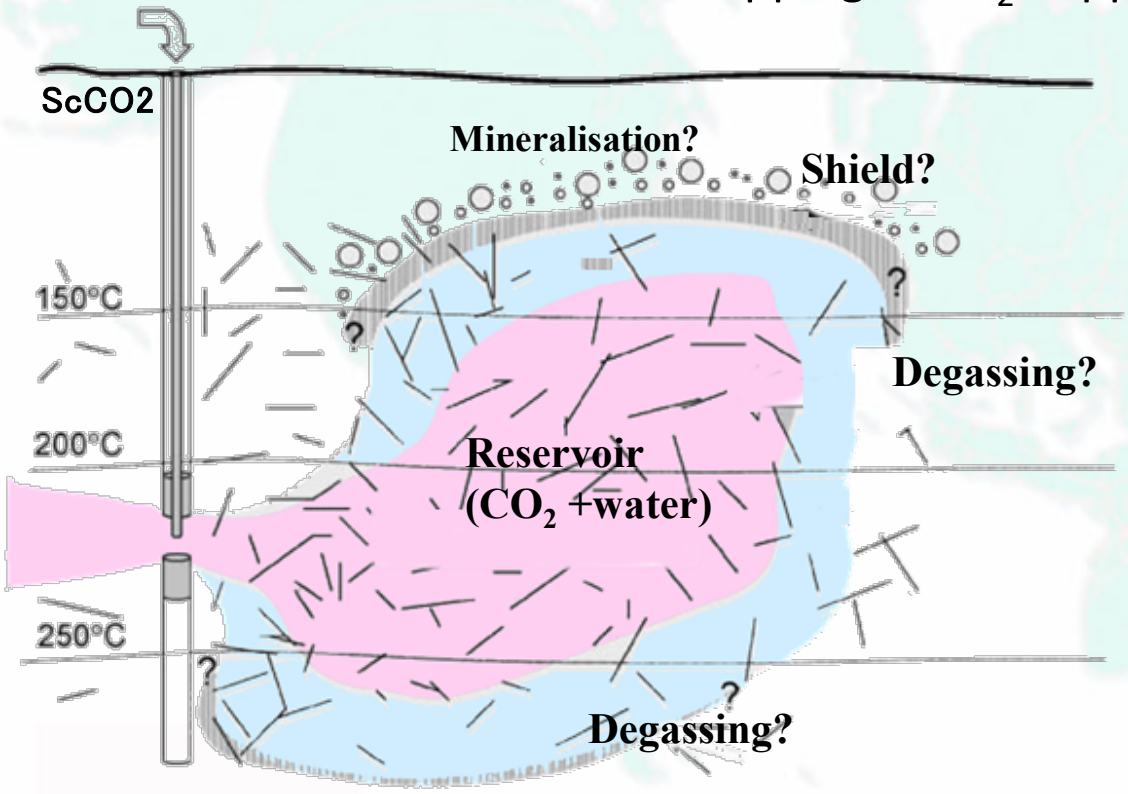


- Creates cracks with a pressure smaller than that of water.
- Cracks develop more three-dimensionally than those caused by water.
- The cracks created by ScCO2 have a largersurface area and form flow paths that is more suitable for the heat exchange in HDR than those created by water.（Ishida et al., 2015）

Ⅲ. CO_2 flow and geochemical reaction in a geothermal reservior

⇒ How does $ScCO_2$ behave at the geothermal reservoir with the high temperature and pressure?

Where does the mineral trapping of CO_2 happen?



- When CO_2 is injected into the ground, CO_2 dissolves in water and reacts with rocks, causing Ca and Mg to leached from the rocks.
- Eluted metal ions react with CO_2 dissolved in water to precipitate calcite and other carbonate minerals.

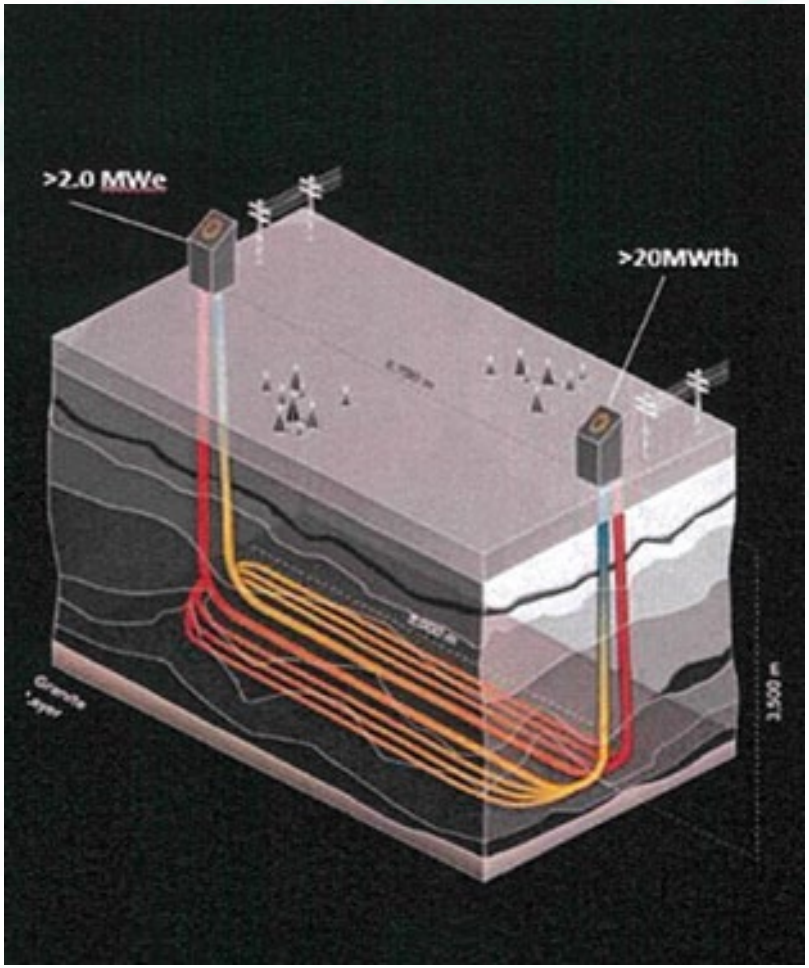
Ueda（2009）

$$CaAl_2Si_2O_8 + H^+ + HCO_3^- + H_2O \Rightarrow CaCO_3 + Al_2Si_2O_5(OH)_4$$

Plagioclase　　Calcite　　Kaolinite

Another EGS project in JOGMEC

Closed circuit heat exchange technology



Eavor Technologies Inc. https://eavor.com/

HDR technique problems

- Reservoir creation by fracturing (controlled by the existing cracks)
- Control of water flow in cracks (short circuit and regression)
- Induced seismicity

One of the closed circuit heat exchanges is developed by Eavor Technology Inc. in Canada and has also been created in Canada and Germany.

Technology to be developed

- Drilling technology (horizontal drilling and directional drilling)
- How to join a well
- Heat flow control (heat imbalance between wells and improvement of heat recovery rate)

Acknowledgememts

Any Questions or Comments?

For the better global environments

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