# Enhanced Geothermal Systems (EGS): Comparing Water and $CO_2$ as Heat Transmission Fluids

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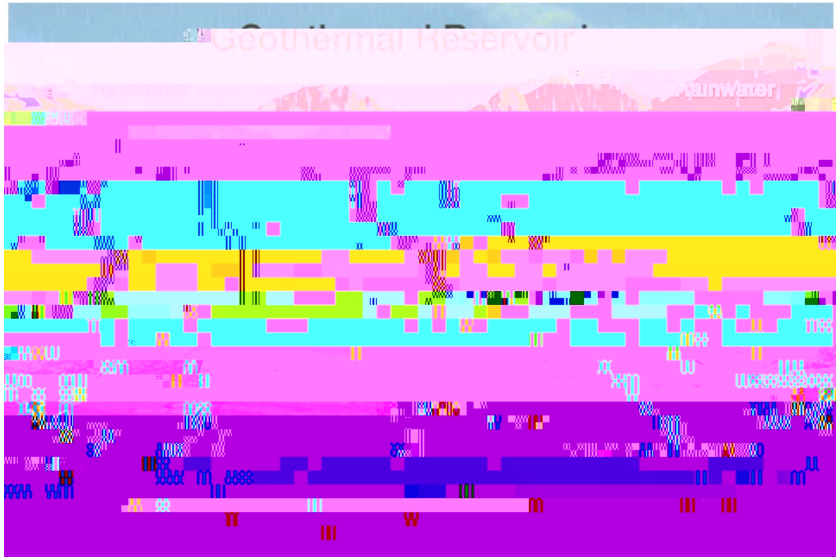
# U.S. Geothermal Resources are Huge

Heat content in subsurface rocks to 6 km depth, relative to ambient temperature
(Dave Blackwell, SMU)

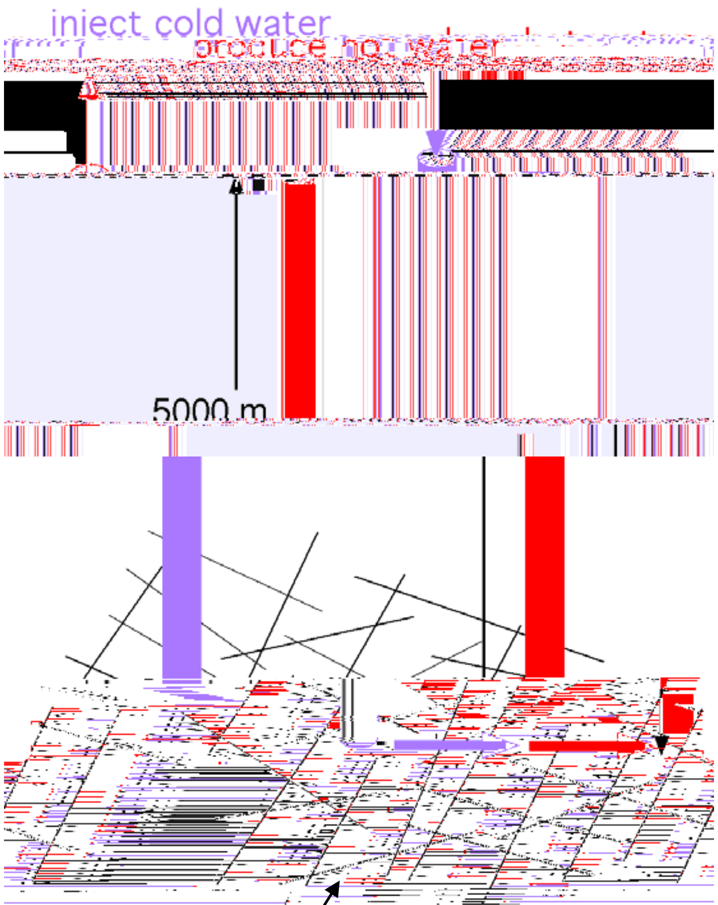
# Why is Geothermal Energy Contribution so Small?

- Geothermal energy extraction is currently limited to hydrothermal systems (the “low-hanging fruit”).
- There is a vast store of geothermal heat that is difficult to recover (hot rocks lacking fluid and permeability).
- How can the essentially inexhaustible heat in deep geologic formations be tapped and transferred to the land surface for human use?



Source: Geothermal Education Office (GEO)
http://www.geothermal.marin.org/

# Enhanced Geothermal Systems (EGS)




fracture network in hot rock

- Artificially create permeability through hydraulic and chemical stimulation.
- Transfer heat to the land surface by circulating water through a system of injection and production boreholes.
- Experimental projects in U.S., U.K., France, Japan, Australia, Sweden, Switzerland, Germany.
- EGS is currently not economically viable; the chief obstacles are:
  - ü dissolution and precipitation of rock minerals, that may cause anything from short-circuiting flows to formation plugging
  - ü large “parasitic” power requirements for keeping water circulating
  - ü water losses from the circulation system
  - ü inadequate reservoir size - heat transfer limitations
  - ü high cost of deep boreholes (≈ 5 km)

# How about using $CO_2$ as Heat Transmission Fluid?

| property | $CO_2$ | water |
| --- | --- | --- |
| chemistry | **poor solvent for rock minerals** | powerful solvent for rock minerals: lots of potential for dissolution and precipitation |
| fluid circulation in wellbores | **highly compressible and larger expansivity**<br>**==> more buoyancy, lower parasitic power consumption** | low compressibility, modest expansivity<br>==> less buoyancy |
| ease of flow in reservoir | **lower viscosity**, lower density | higher viscosity, **higher density** |
| heat transmission | smaller specific heat | **larger specific heat** |

Favorable properties are shown **bold-faced**.

# EGS-$CO_2$ Issues

- Effectiveness of $CO_2$ as a heat transfer medium.
- Other processes induced by $CO_2$, that may affect feasibility and sustainability of EGS with $CO_2$ (chemical reactions, corrosion).
- Can we make an EGS-$CO_2$ reservoir? (Circulate $CO_2$ to remove the water.)
- Energy conversion system (binary plant w/ heat exchanger; directly using $CO_2$ on the turbines)
- Economics.
- Fluid lost = fluid stored?

# General Makeup of a $CO_2$-Based EGS Reservoir

<u>Zone 1</u>

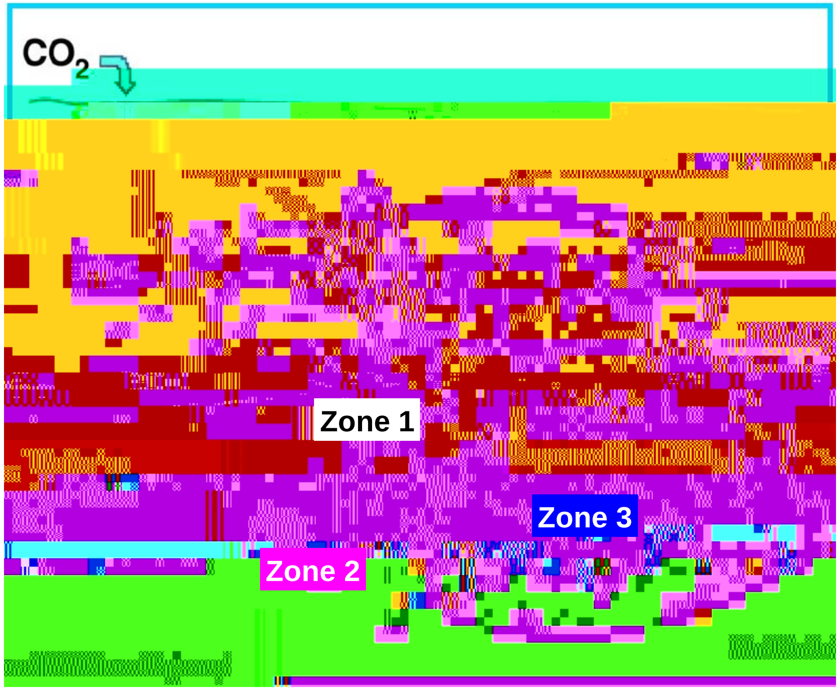
Central zone and core of EGS system, where most of the fluid circulation and heat extraction is taking place. This zone contains supercritical $CO_2$; all water has been removed by dissolution into the flowing $CO_2$.

<u>Zone 2</u>

An intermediate region with weaker fluid circulation and heat extraction, which contains a two-phase mixture of $CO_2$ and water.

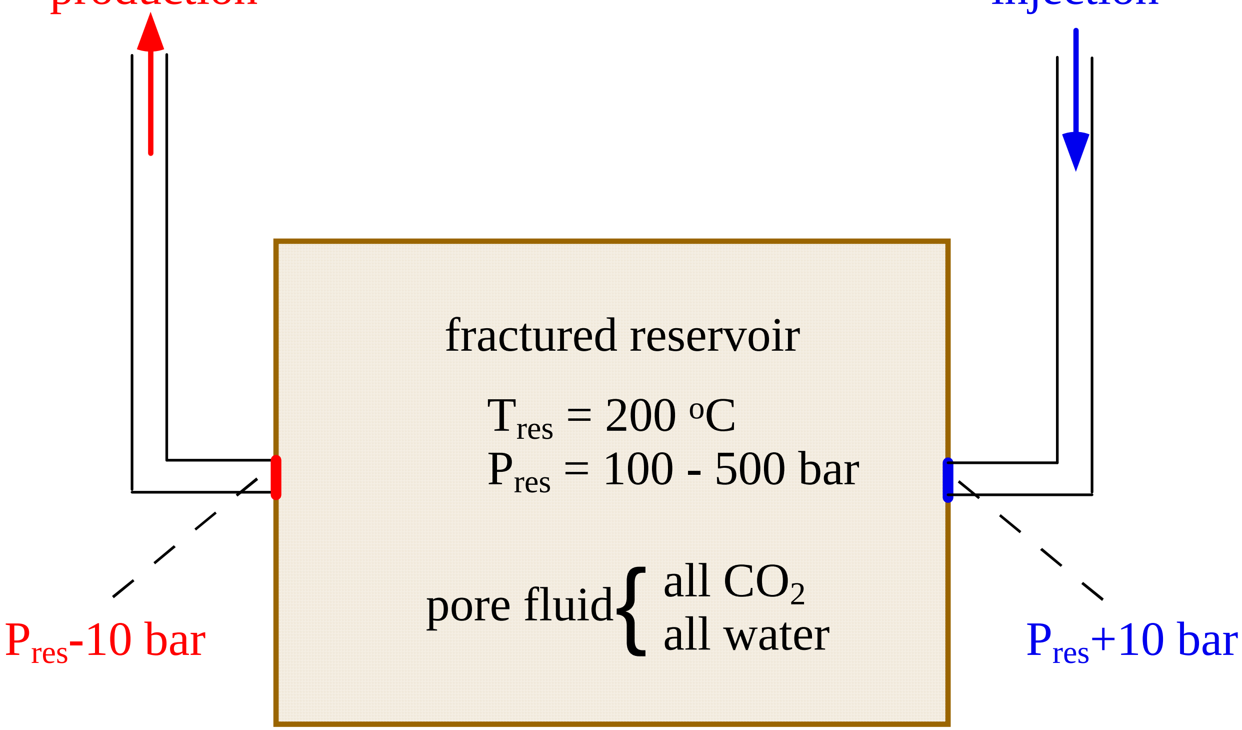
<u>Zone 3</u>

The outer region affected by EGS activities. The fluid is a single aqueous phase with dissolved $CO_2$.




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

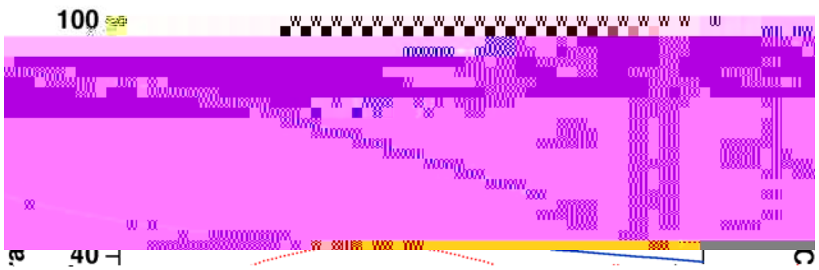
# Comparing Operating Fluids for EGS: $CO_2$ vs. Water

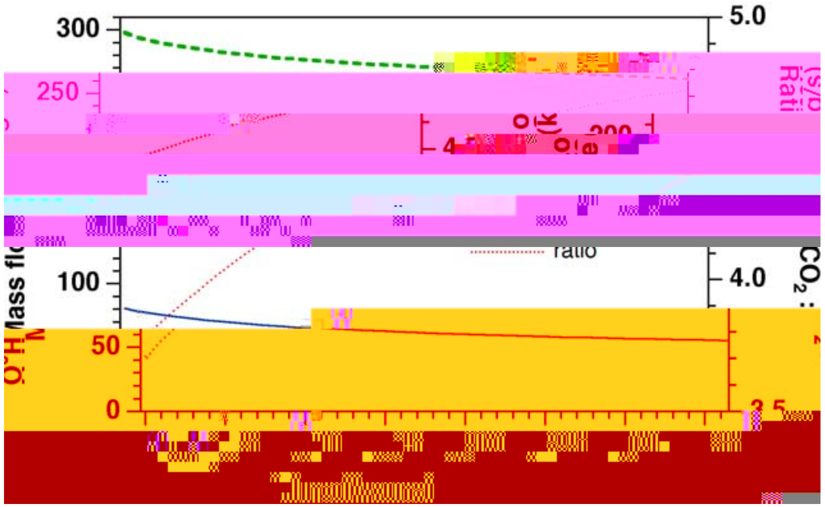



ü monitor mass flow, heat extraction rates

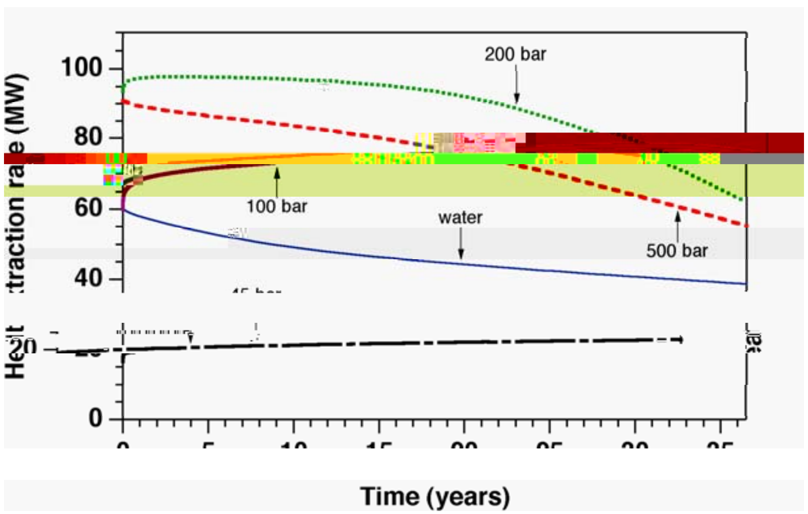
# Reference Case

$T_{res}$ = 200 ˚C, $P_{res}$ = 500 bar, $T_{inj}$ = 20 ˚C



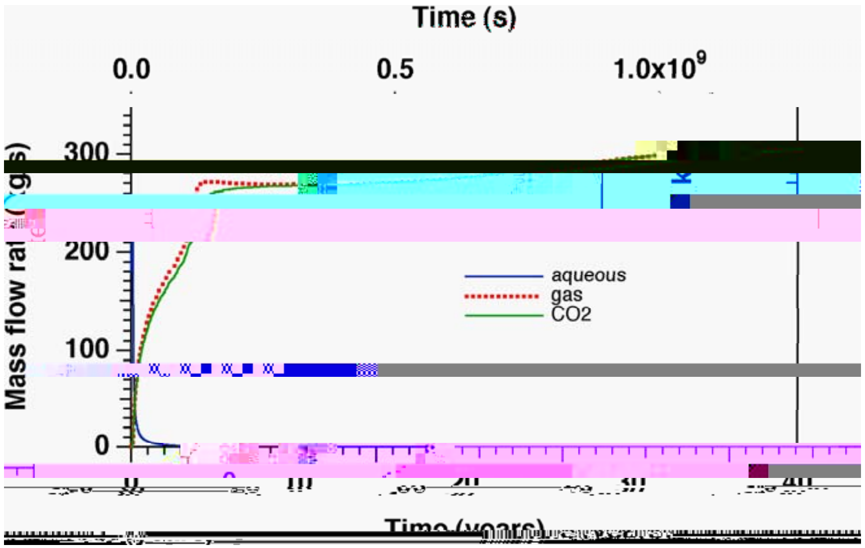



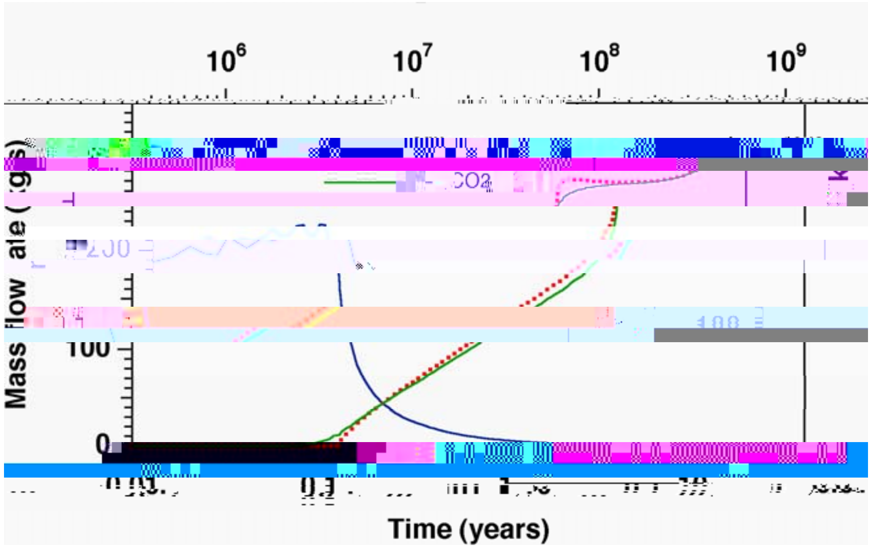
# Simulation Results for Different Reservoir Pressures at T = 200 $^oC$



# Fluid Mobility

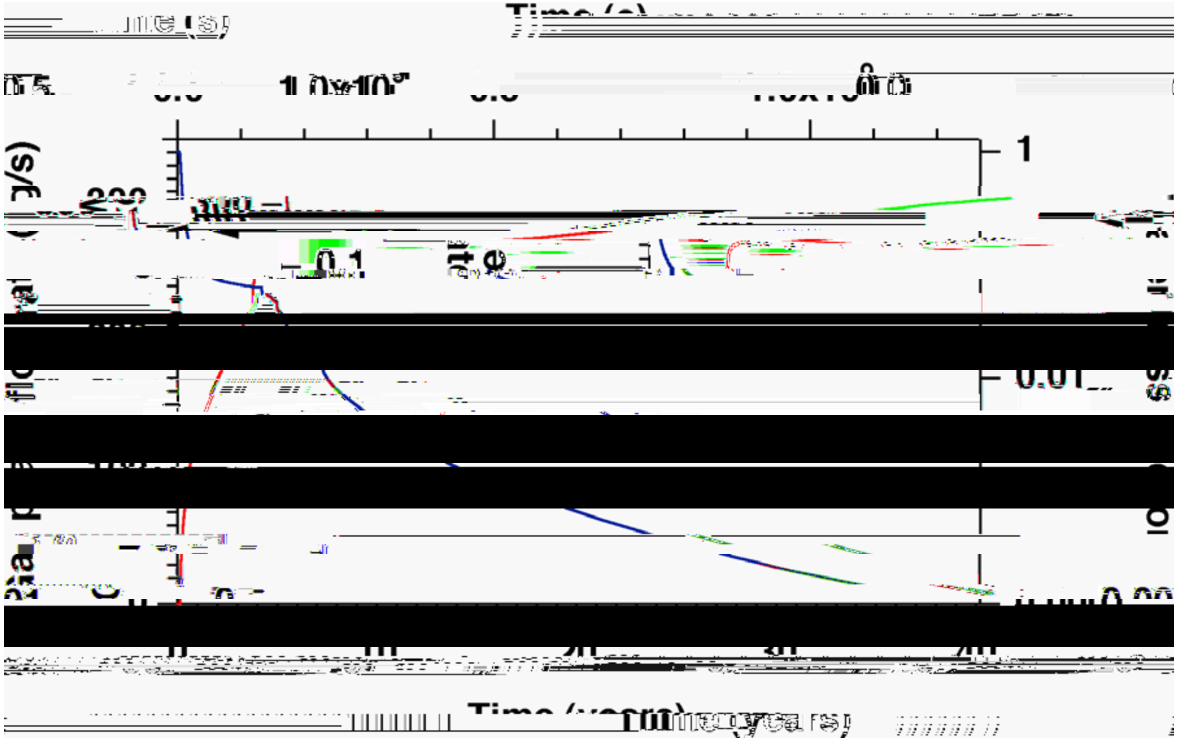
# Injecting $CO_2$ into an Aqueous System



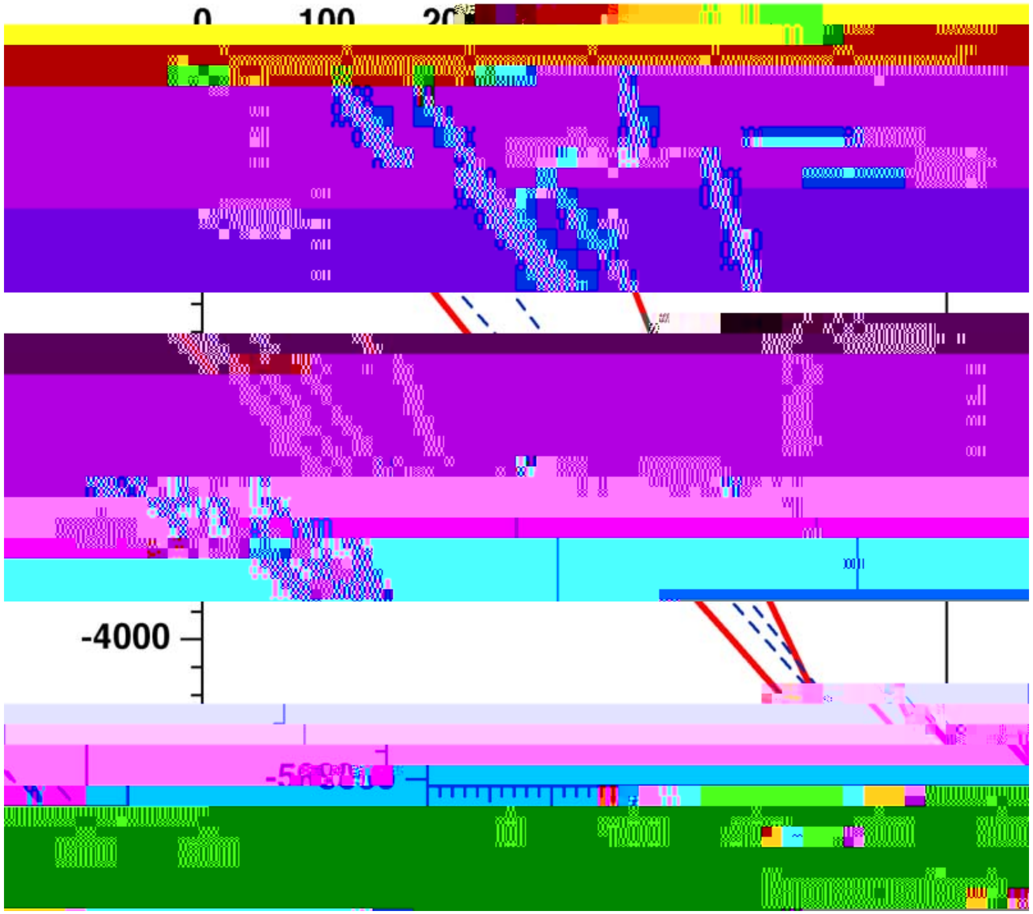

- At early time (≤ 0.1 year), produce single-phase water
- This is followed by a two-phase water-$CO_2$ mixture (0.1 - 2.5 yr)
- Total production rate during two-phase period is low due to phase interference
- Subsequently produce a single supercritical $CO_2$-rich phase with dissolved water

# Rate and Composition of Produced $CO_2$



# Wellbore Flow: $CO_2$ vs. Water

ΔP




Pressure difference between production and injection well

$CO_2$: 288.1 - 57.4 = 230.7 bar

water: 118.6 - 57.4 = 61.2 bar

$CO_2$ generates much larger pressures in production well, facilitating fluid circulation.

# $CO_2$ Storage Capacity

- Need a mass flow of approximately 20 tons of $CO_2$ per second, per GW electric power capacity.
- Expect a fluid loss rate of order 5%, or **1 ton per second of $CO_2$ per GW** of installed EGS capacity.
- This is equivalent to **$CO_2$ emissions from 3 GW** of coal-fired power generation.
- The MIT report (2006) projects 100 GW of EGS electric power by 2050.
- 100 GW of EGS with $CO_2$ would **store 3.2 Gt/yr** of $CO_2$, approximately

# Power Generation from $CO_2$-Based EGS

- One option is **binary conversion** technology, using similar equipment as water-based systems.
- Alternatively, it may be possible to **directly feed the produced $CO_2$** to the turbines. This may be possible because supercritical $CO_2$ without admixed liquid water is not corrosive to metals.
- Direct expansion of $CO_2$ in the turbines would avoid otherwise inevitable and irreversible heat losses in a heat exchanger.
- However, the produced

# Path Forward*

- Fluid-rock reaction experiments with supercritical $CO_2$
- Laboratory flow experiments for water-$CO_2$ mixtures and pure anhydrous $CO_2$
- Modeling of fluid flow, heat transfer and rock-fluid interactions (chemical/mechanical)
- Design studies for a field pilot test of EGS with $CO_2$

*cooperation with BRGM - French geological survey

# Concluding Remarks

- Water-based enhanced geothermal systems (EGS) face difficult hurdles to (1) achieve adequate heat extraction rates, and (2) maintain injectivity and heat extraction performance in the face of strong rock-fluid interactions.
- $CO_2$ has attractive properties as a heat transmission fluid for EGS.

- The fluid produced from an EGS operated with $CO_2$ will change from initially water (≈ 1 month), to a two-phase aqueous-$CO_2$ mixture (a few years), to sc$CO_2$ with dissolved water of order 0.1 wt.-%.
- Use of $CO_2$ as heat transmission fluid for EGS looks promising and

# Reactivity of Rocks for $scCO_2$

| Rock type | Characteristics |
|---|---|
| granite | ü generally high in $SiO_2$, low in carbonates<br>ü limited surface area and reactivity of mineral grains |
| sandstone | ü may have carbonate cements |