

# Enhanced Geothermal Systems (EGS): Comparing Water and CO<sub>2</sub> as Heat Transmission Fluids

*Karsten Pruess*

Earth Sciences Division  
Lawrence Berkeley National Laboratory

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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)

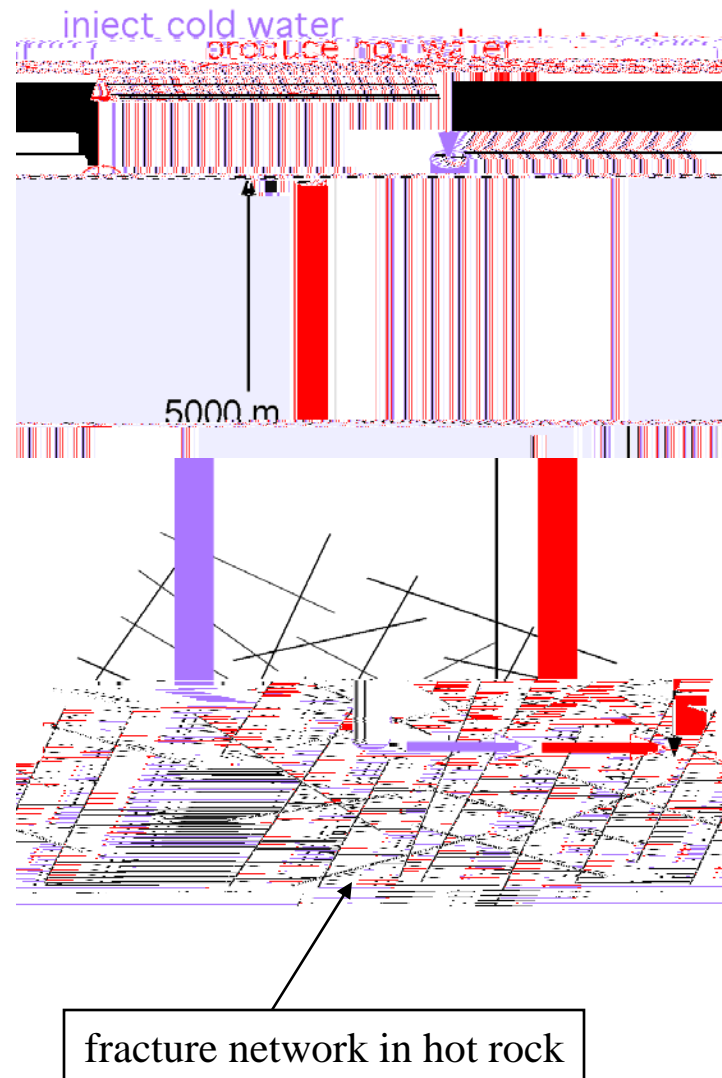
# Why is Geothermal Energy Contribution so Small?

- 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)



- 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:
  - ∅ dissolution and precipitation of rock minerals, that may cause anything from short-circuiting flows to formation plugging
  - ∅ large “parasitic” power requirements for keeping water circulating
  - ∅ water losses from the circulation system
  - ∅ inadequate reservoir size - heat transfer limitations
  - ∅ high cost of deep boreholes ( 5 km)

# How about using CO<sub>2</sub> as Heat Transmission Fluid?

property	CO <sub>2</sub>	water
chemistry	<b>poor solvent for rock minerals</b>	powerful solvent for rock minerals: lots of potential for dissolution and precipitation
fluid circulation in wellbores	<b>highly compressible and larger expansivity</b> ==> <b>more buoyancy, lower parasitic power consumption</b>	low compressibility, modest expansivity ==> less buoyancy
ease of flow in reservoir	<b>lower viscosity</b> , lower density	higher viscosity, <b>higher density</b>
heat transmission	smaller specific heat	<b>larger specific heat</b>

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

# EGS-CO<sub>2</sub> Issues

- Effectiveness of CO<sub>2</sub> as a heat transfer medium.
- Other processes induced by CO<sub>2</sub>, that may affect feasibility and sustainability of EGS with CO<sub>2</sub> (chemical reactions, corrosion).
- Can we make an EGS-CO<sub>2</sub> reservoir? (Circulate CO<sub>2</sub> to remove the water.)
- Energy conversion system (binary plant w/ heat exchanger; directly using CO<sub>2</sub> on the turbines)
- Economics.
- Fluid lost = fluid stored?

# General Makeup of a CO<sub>2</sub>-Based EGS Reservoir

## Zone 1

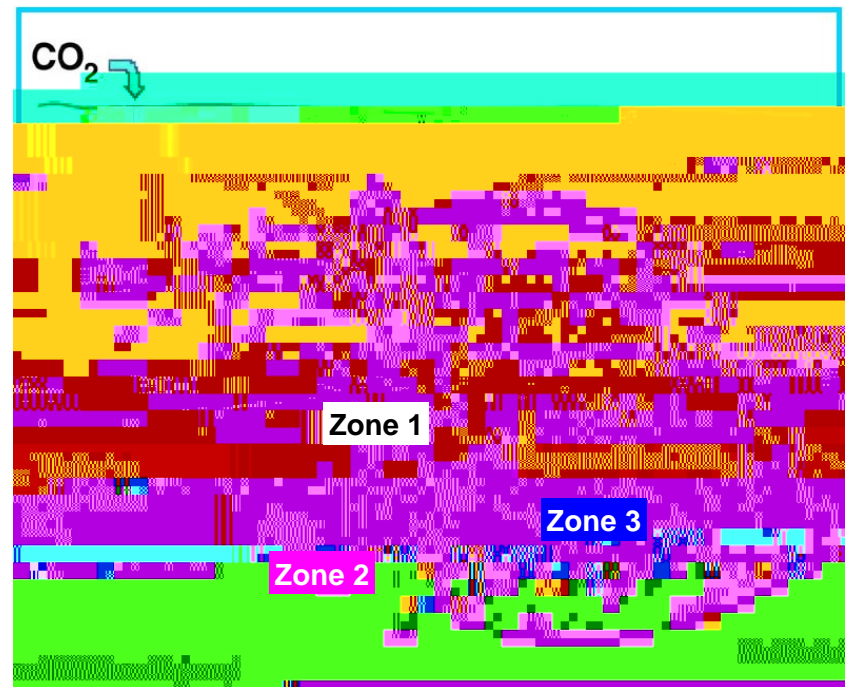
Central zone and core of EGS system, where most of the fluid circulation and heat extraction is taking place. This zone contains supercritical CO<sub>2</sub>; all water has been removed by dissolution into the flowing CO<sub>2</sub>.

## Zone 2

An intermediate region with weaker fluid circulation and heat extraction, which contains a two-phase mixture of CO<sub>2</sub> and water.

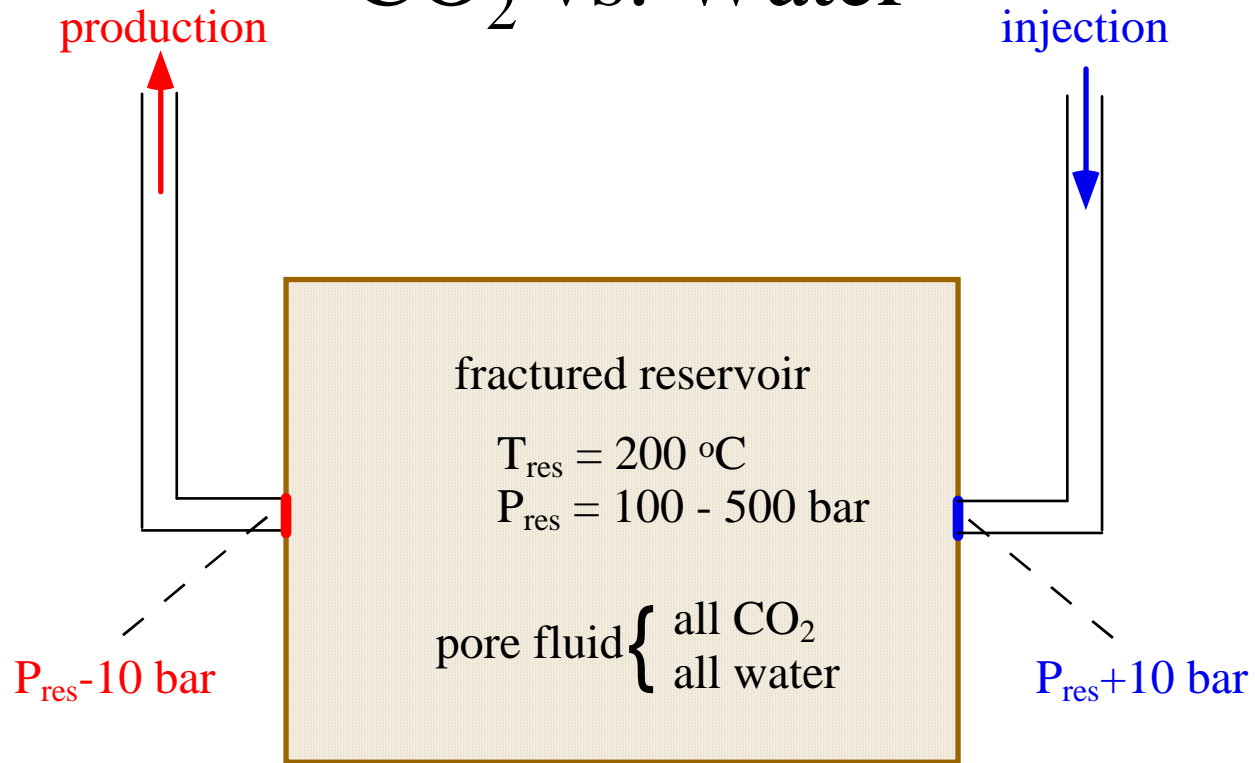
## Zone 3

The outer region affected by EGS activities. The fluid is a single aqueous phase with dissolved CO<sub>2</sub>.



(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<sub>2</sub> vs. Water

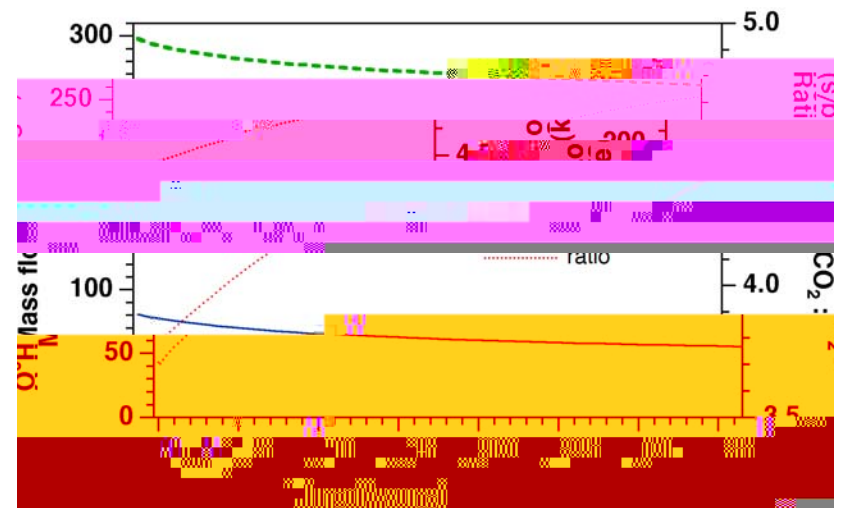
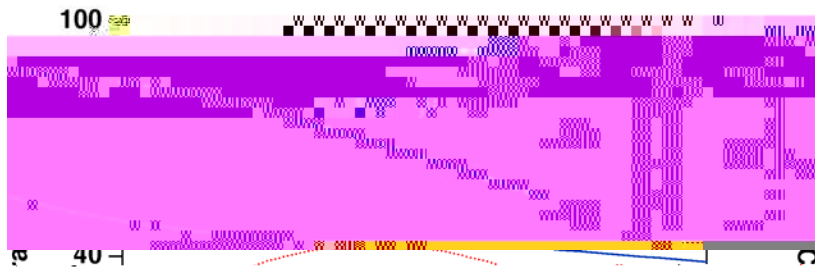


∅ monitor mass flow, heat extraction rates

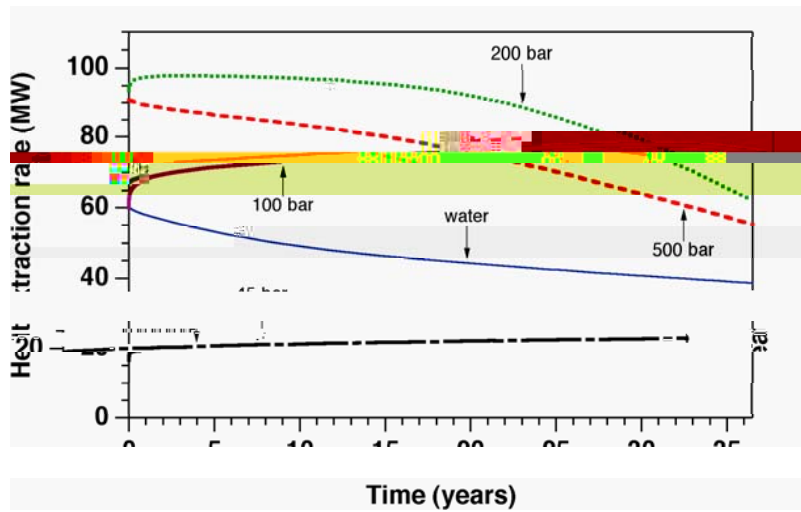


# Reference Case

$$T_{\text{res}} = 200 \text{ }^\circ\text{C}, P_{\text{res}} = 500 \text{ bar}, T_{\text{inj}} = 20 \text{ }^\circ\text{C}$$

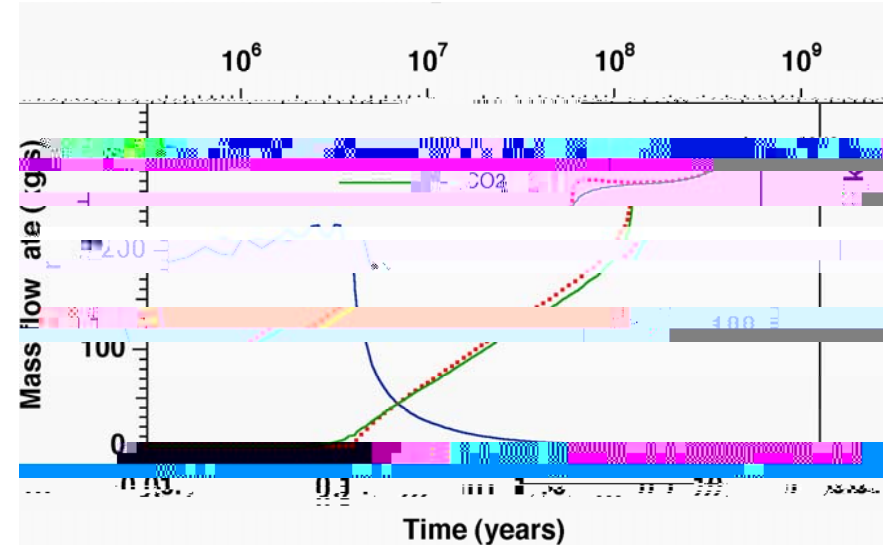
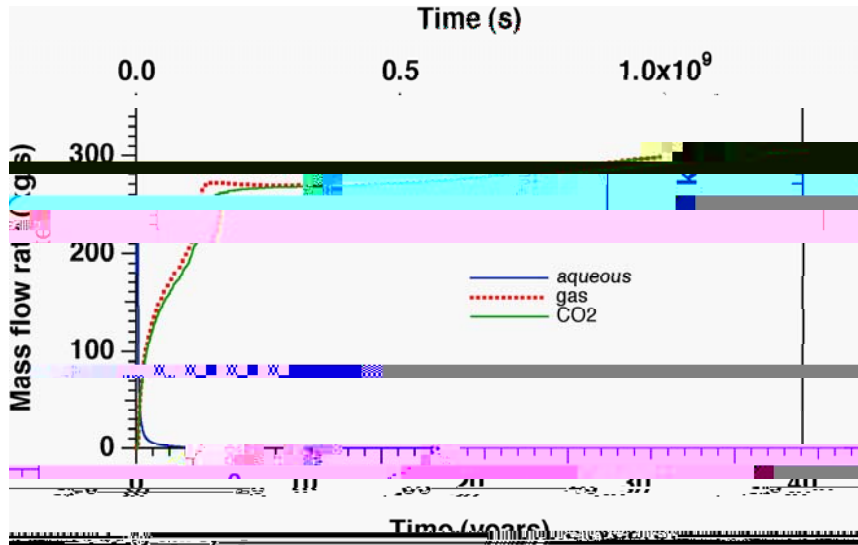


# Simulation Results for Different Reservoir Pressures at $T = 200\text{ }^{\circ}\text{C}$



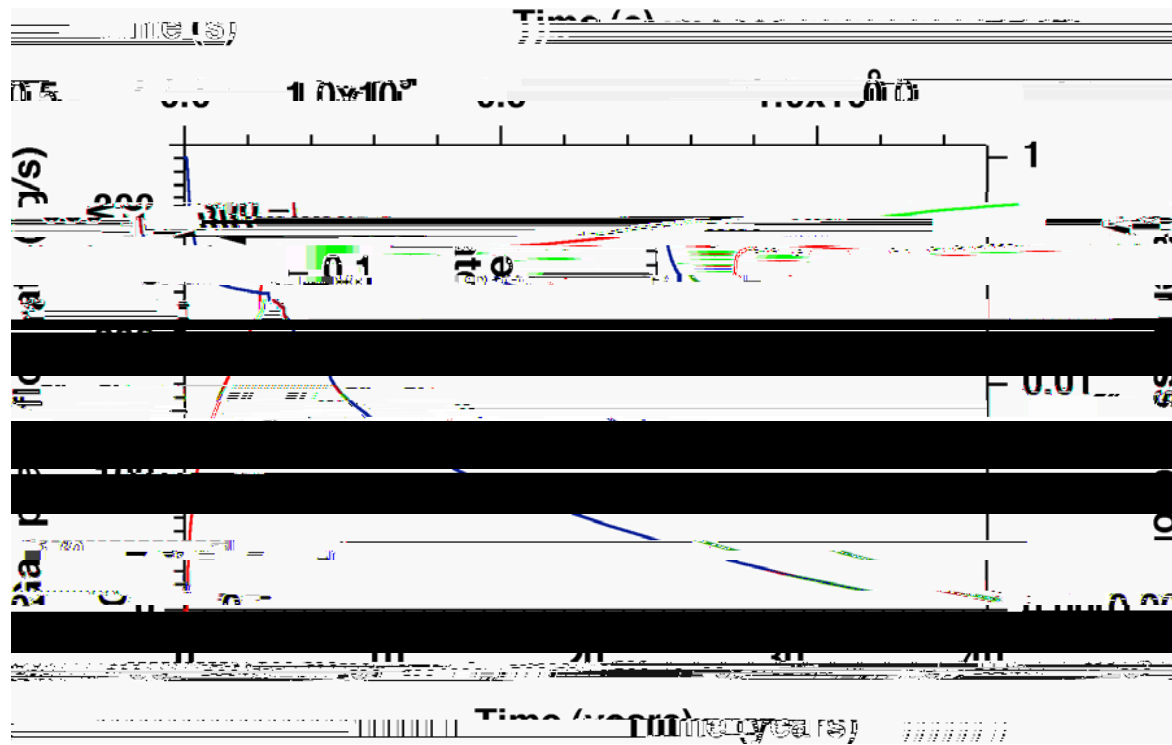
# Fluid Mobility

# Injecting CO<sub>2</sub> into an Aqueous System



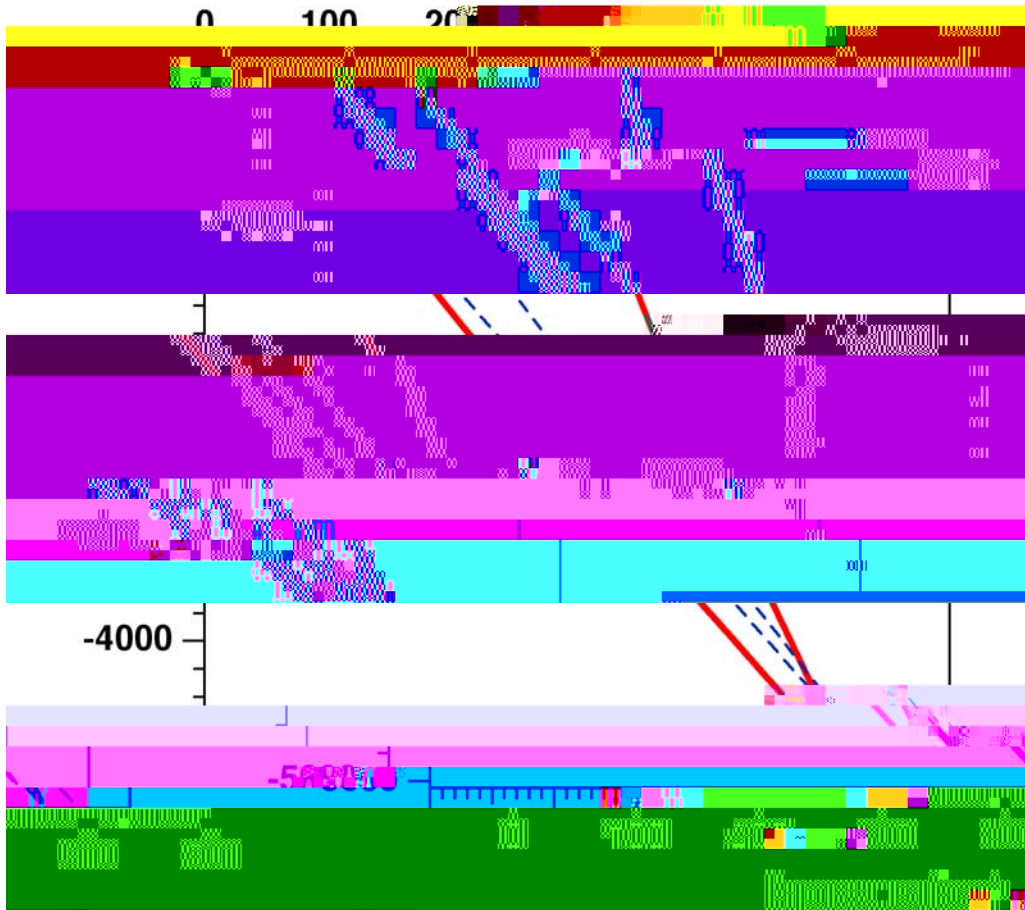
- At early time (  $\approx 0.1$  year), produce single-phase water
- This is followed by a two-phase water-CO<sub>2</sub> mixture (0.1 - 2.5 yr)
- Total production rate during two-phase period is low due to phase interference
- Subsequently produce a single supercritical CO<sub>2</sub>-rich phase with dissolved water

# Rate and Composition of Produced CO<sub>2</sub>



# Wellbore Flow: CO<sub>2</sub> vs. Water

P



Pressure difference between  
production and injection well

CO<sub>2</sub>:  $288.1 - 57.4 = 230.7$  bar

water:  $118.6 - 57.4 = 61.2$  bar

CO<sub>2</sub> generates much larger pressures  
in production well, facilitating fluid  
circulation.

# CO<sub>2</sub> Storage Capacity

- Need a mass flow of approximately 20 tons of CO<sub>2</sub> per second, per GW electric power capacity.
- Expect a fluid loss rate of order 5%, or **1 ton per second of CO<sub>2</sub> per GW** of installed EGS capacity.
- This is equivalent to **CO<sub>2</sub> 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<sub>2</sub> would **store 3.2 Gt/yr** of CO<sub>2</sub>, approximately

# Power Generation from CO<sub>2</sub>-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<sub>2</sub>** to the turbines. This may be possible because supercritical CO<sub>2</sub> without admixed liquid water is not corrosive to metals.
- Direct expansion of CO<sub>2</sub> 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<sub>2</sub>
- Laboratory flow experiments for water-CO<sub>2</sub> mixtures and pure anhydrous CO<sub>2</sub>
- Modeling of fluid flow, heat transfer and rock-fluid interactions (chemical/mechanical)
- Design studies for a field pilot test of EGS with CO<sub>2</sub>

\*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<sub>2</sub> has attractive properties as a heat transmission fluid for EGS.
  
- The fluid produced from an EGS operated with CO<sub>2</sub> will change from initially water ( ~ 1 month), to a two-phase aqueous-CO<sub>2</sub> mixture (a few years), to scCO<sub>2</sub> with dissolved water of order 0.1 wt.-%.
- Use of CO<sub>2</sub> as heat transmission fluid for EGS looks promising and

# Reactivity of Rocks for scCO<sub>2</sub>

## Rock type

## Characteristics

granite

- ∅ generally high in SiO<sub>2</sub>, low in carbonates
- ∅ limited surface area and reactivity of mineral grains

sandstone

- ∅ may have carbonate cements