Feasibility of using supercritical CO_2 as heat transmission fluid in the EGS integrating the carbon storage constraints

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Outline

- > Storage capacities of different geological options
- > EGSCO2 concept and relevant works (papers)
- > Advantages of CO_2 as heat transmission fluid
- > Structure of the CO_2 injection well bore
- > Main physical chemical processes and water – rock interactions
- > Possible weak points: efficiency and security
- > Need to develop a hybrid concept combining advantageous of CO_2 as a heat transmission fluid with CO_2 geologic storage
- > Concluding remarks

CO_2 Storage potential for different geological options

> **Hydrocarbon reservoirs (declining oil and gas fields)**

- **675-900 Gt CO_2 ~45 % of emissions until 2050 (BAU*)**

> **Unminable coal seams**

- **15-200 Gt CO_2 ~2- 20% of emissions until 2050 (BAU)**

> **Deep Saline Aquifers**

- **100-10 000 Gt CO_2 20 to 500% of emissions until 2050 (BAU)**

⬇

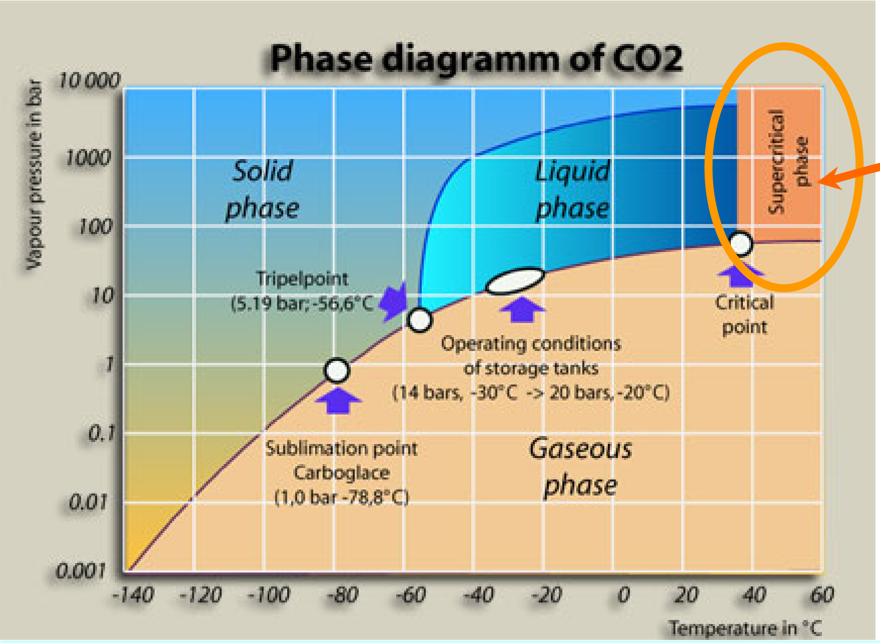
> **Combining geothermal heat recovery and permanent CO_2 storage looks extremely promising**

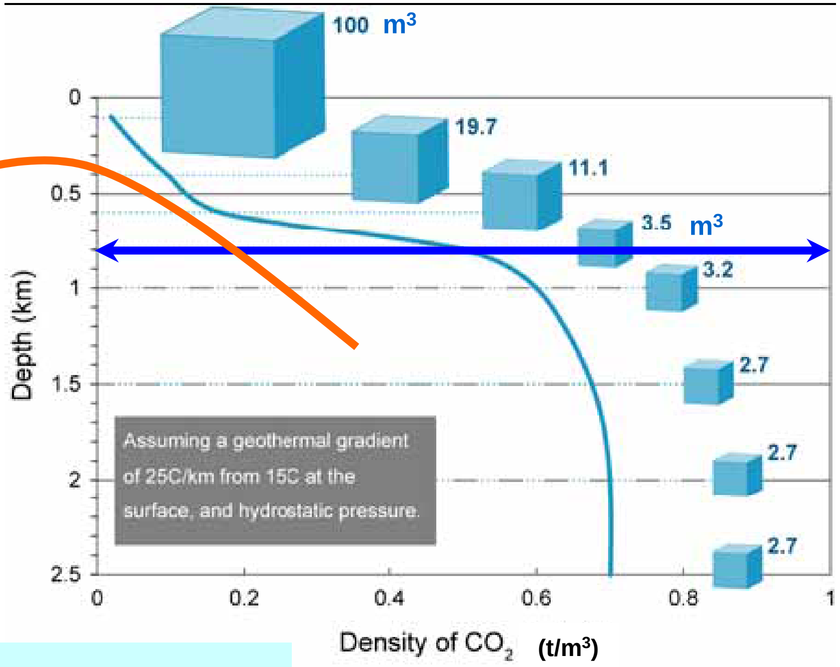
** Business-As-Usual*

EGSCO2 concept and relevant works (papers)

- **Brown (2000)** A Hot Dry Rock geothermal energy concept utilizing supercritical CO_2 instead of water. 25th Workshop on Geothermal Reservoir Engineering, Stanford, California (January 24-26, 2000)
- **Fouillac et al. (2004)** Could sequestration CO_2 as be combined with the development of EGS? 3rd Annual Conference on CCS, Alexndria, (Via, May 3-6, 2004).
- **Ueda et al. (2005)** Experimental Studies of CO2-Rock Interaction at Elevated Temperatures under Hydrothermal Conditions, *Geochemical Journal,* Vol. 39, No. 5, pp. 417–425.
- **Merkel et al. (2005)** Compilation of contributions on $scCO_2$ & Hot Dry Rock (in German language).
- **Pruess and Azaroual (2006)** On the feasibility of using $scCO_2$ as heat transmission fluid in an engineered HDR geothermal system. 31st Workshop on Geothermal Reservoir Engineering, Stanford, California (Jan. 30 – Feb. 1, 2006)
- **Pruess (2006a)** EGS using CO_2 as working fluid—A novel approach for generating renewable energy with simultaneous sequestration of carbon. *Geothermics*, Vol. 35, p. 351-367.
- **Pruess (2006b)** EGS with CO2 as the heat transmission fluid—A game-changing alternative for producing renewable energy with simultaneous storage of carbon. Philadelphia GSA Annual Meeting (22-25 October 2006).
- **Kühn et al. (2007)** Mineral trapping of CO_2 in operated hydrogeothermal reservoirs. EGU 2007, Vol. 9, A-09207.

Advantages: properties of supercritical CO_2



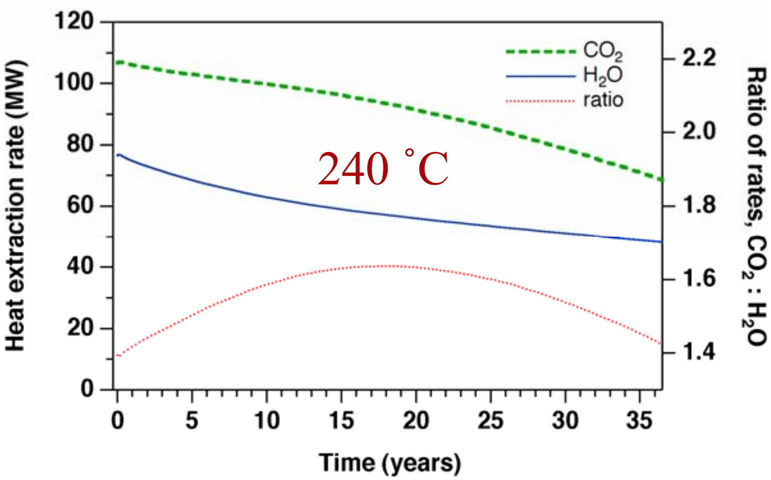


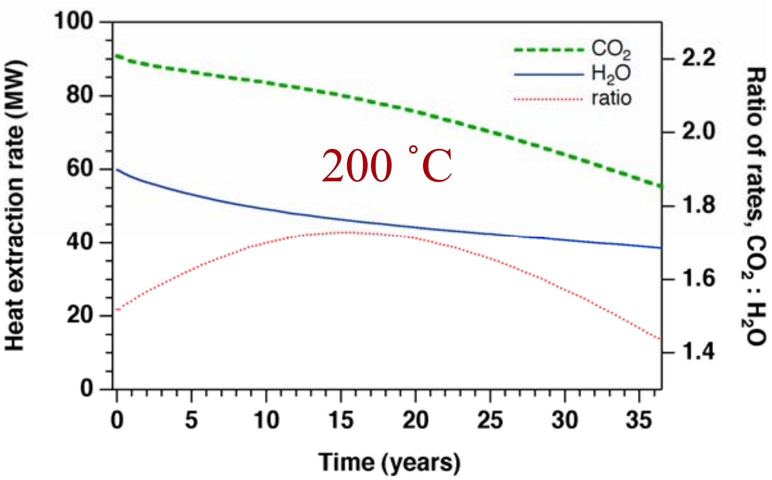
Assuming a geothermal gradient of 25C/km from 15C at the surface, and hydrostatic pressure.

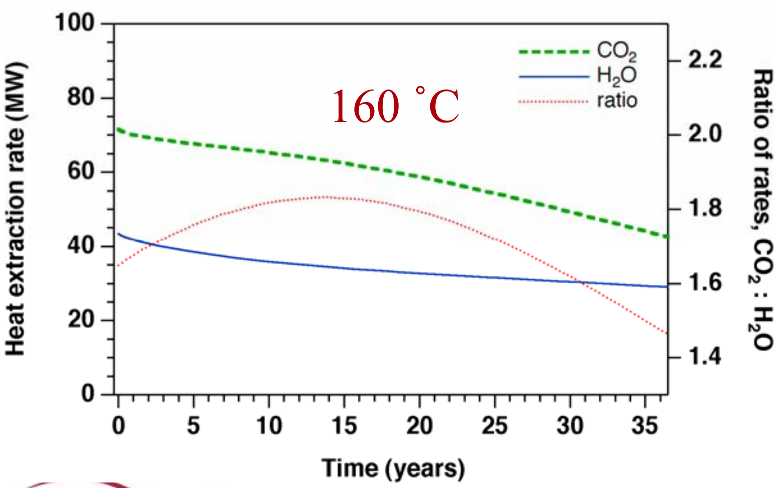
Critical temperature: 31 °C
Critical pressure: 73.83 bar
Geothermal gradient: 25°C / km
Hydrostatic pressure gradient: 100 bar / km
Mean depth below which the CO_2 is supercritical: ~ 800 m

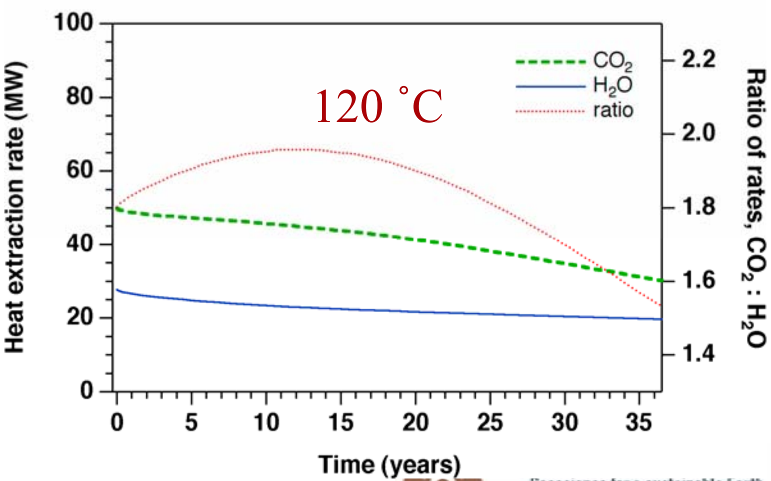
Supercritical CO_2 occupies a much smaller volume than under gaseous state, its upward migration tendency is less due to its density which is very similar to basin fluid densities ➡ **Increase in storage capacity and security**

Heat extraction from different reservoir temperatures (CO_2 *vs.* H_2O) at 500 bar (~ 5 km)









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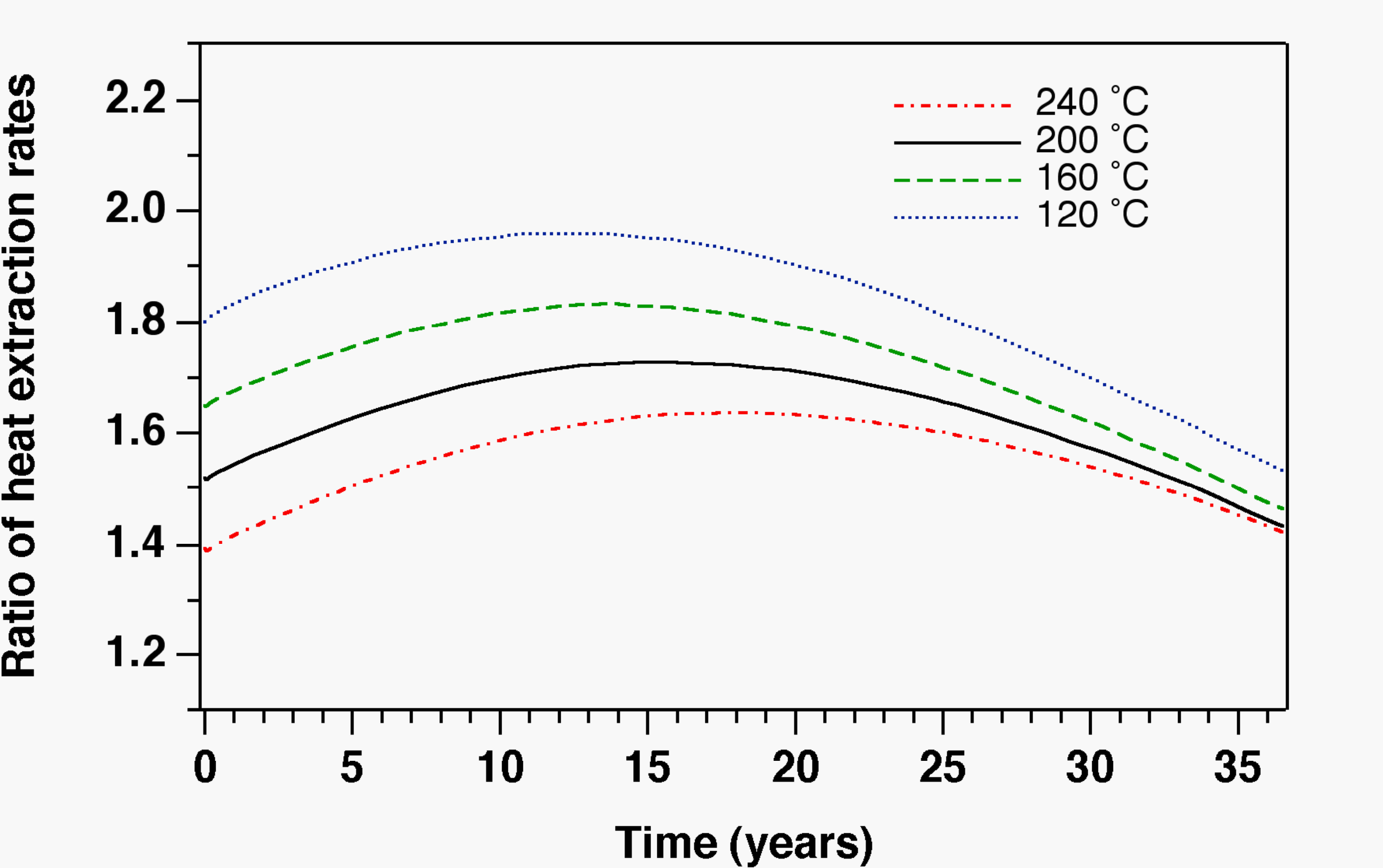
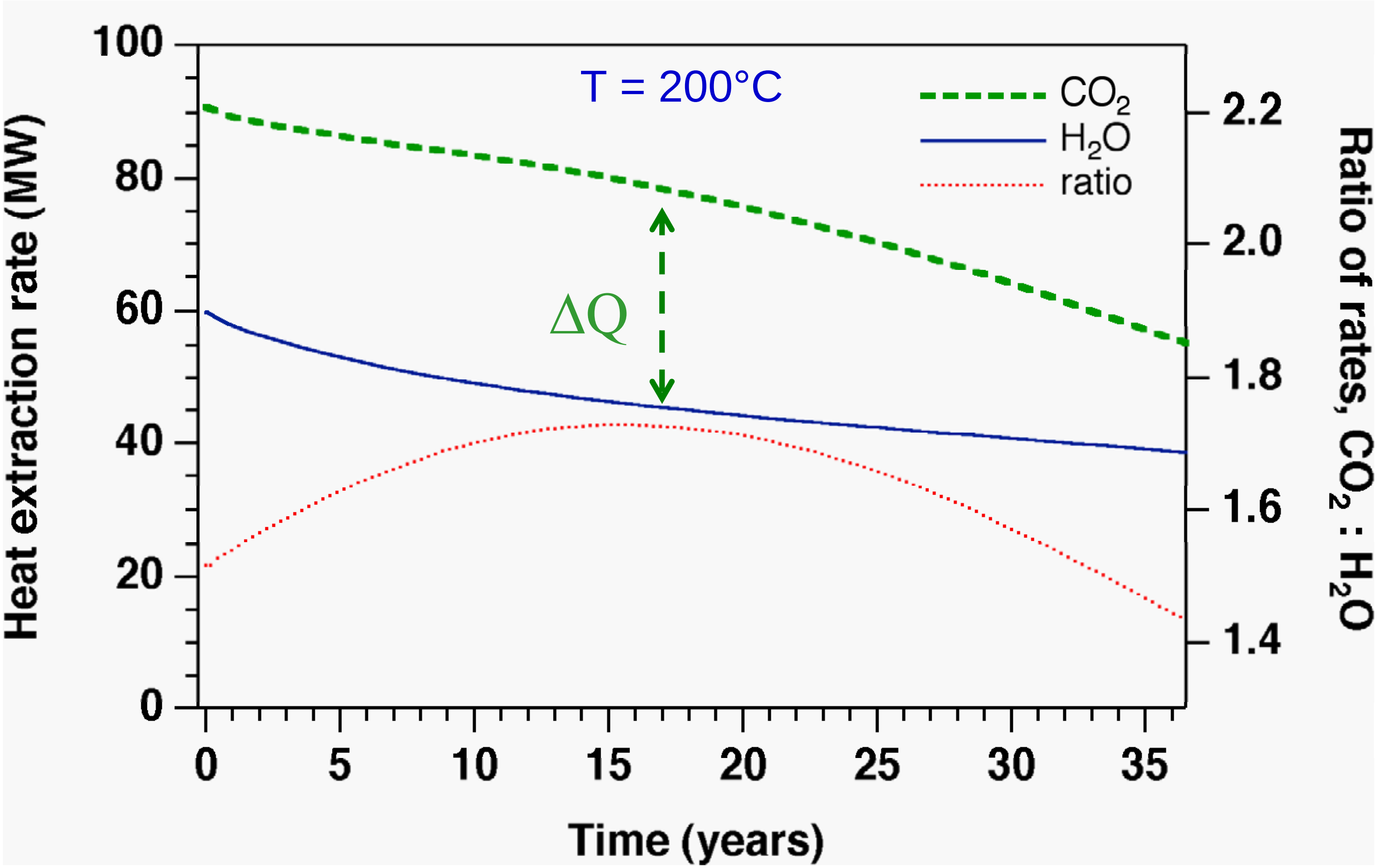
Ratios of net heat extraction rates (CO_2 *vs.* H_2O) for different initial reservoir temperatures



Pruess K. (2006) Geothermics, 35(4) 351-367.

Comparing Heat Transmission Fluids (CO_2 *vs.* H_2O)



Heat extraction rates when using CO_2 are approximately 50 % larger than for water.

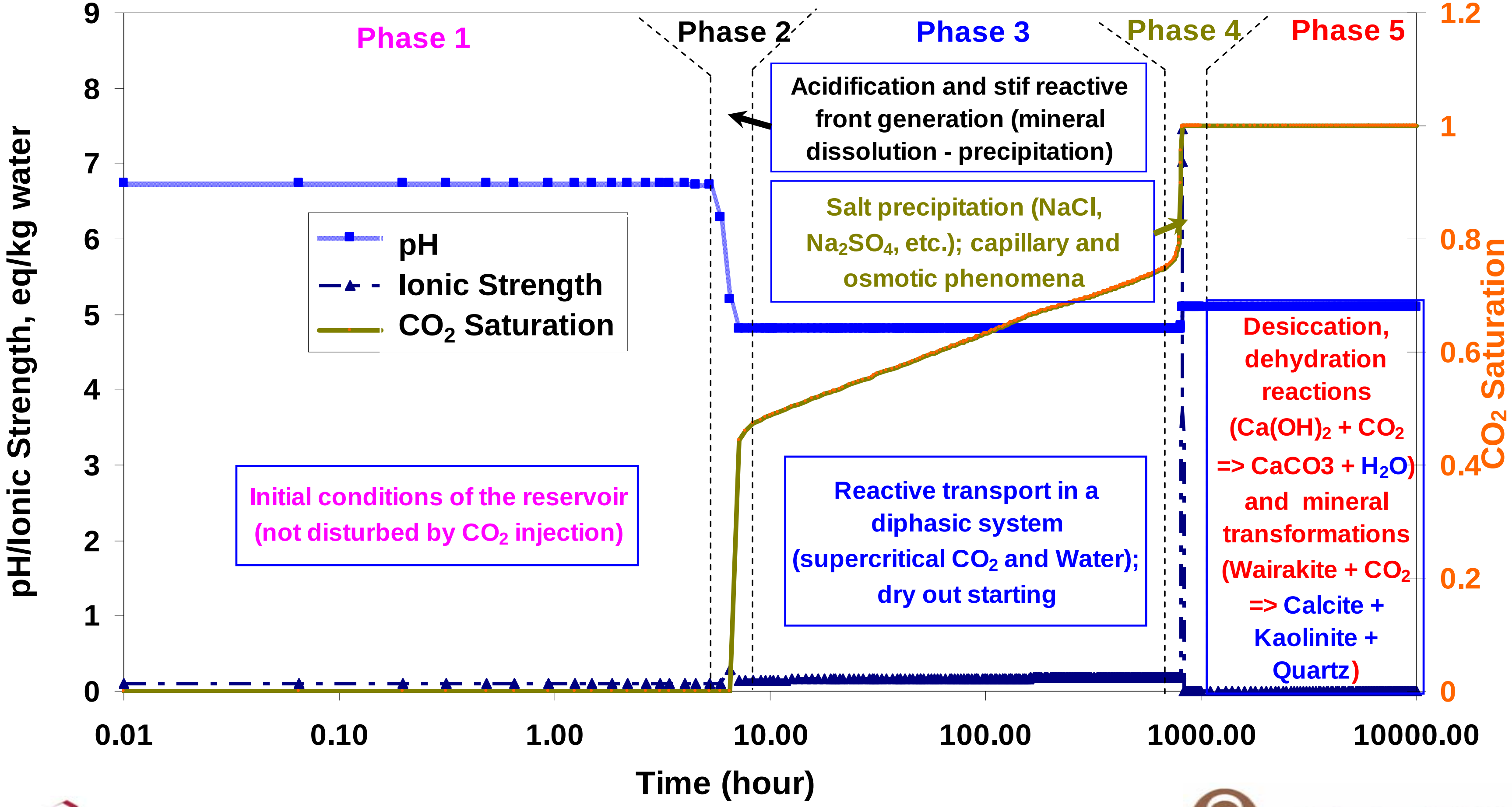
Pruess K. (2006) Geothermics, 35(4) 351-367.

EGS: Comparing Heat Transmission Fluids (CO_2 *vs.* H_2O)

property	CO_2	water
ease of flow	**lower viscosity**, lower density	higher viscosity, **higher density**
heat transmission	smaller specific heat	**larger specific heat**
fluid circulation in wellbores	**highly compressible and larger expansivity** **==> more buoyancy**	low compressibility, modest expansivity ==> less buoyancy
fluid losses	**earn credits for storing greenhouse gases**	costly
chemistry	**poor solvent; significant upside potential for porosity enhancement and reservoir growth**	powerful solvent for rock minerals: lots of potential for dissolution and precipitation

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

Temporal evolution of reactive fronts captured at 10 m from CO_2 injection well



Initial conditions of the reservoir (not disturbed by CO_2 injection)

Acidification and stif reactive front generation (mineral dissolution - precipitation)

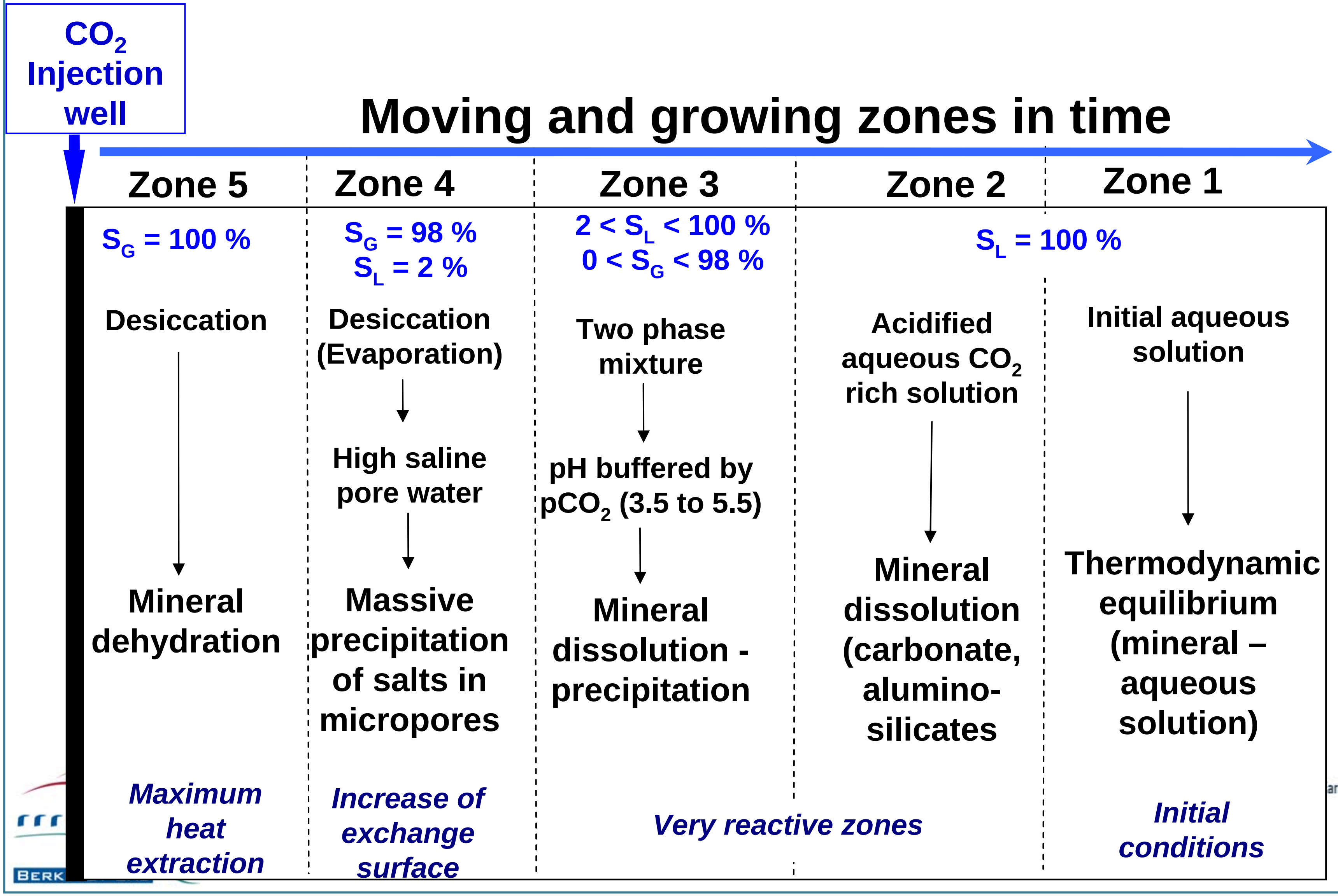
Salt precipitation (NaCl, Na_2SO_4, etc.); capillary and osmotic phenomena

Reactive transport in a diphasic system (supercritical CO_2 and Water); dry out starting

Desiccation, dehydration reactions ($Ca(OH)_2 + CO_2$ => $CaCO3 + H_2O$) and mineral transformations (Wairakite + CO_2 => Calcite + Kaolinite + Quartz)

Modified from André et al. (2007) Energy Conversion & Management (under press)

Reactive zones around the CO_2 injection well bore after certain period of injection (geochemical processes)

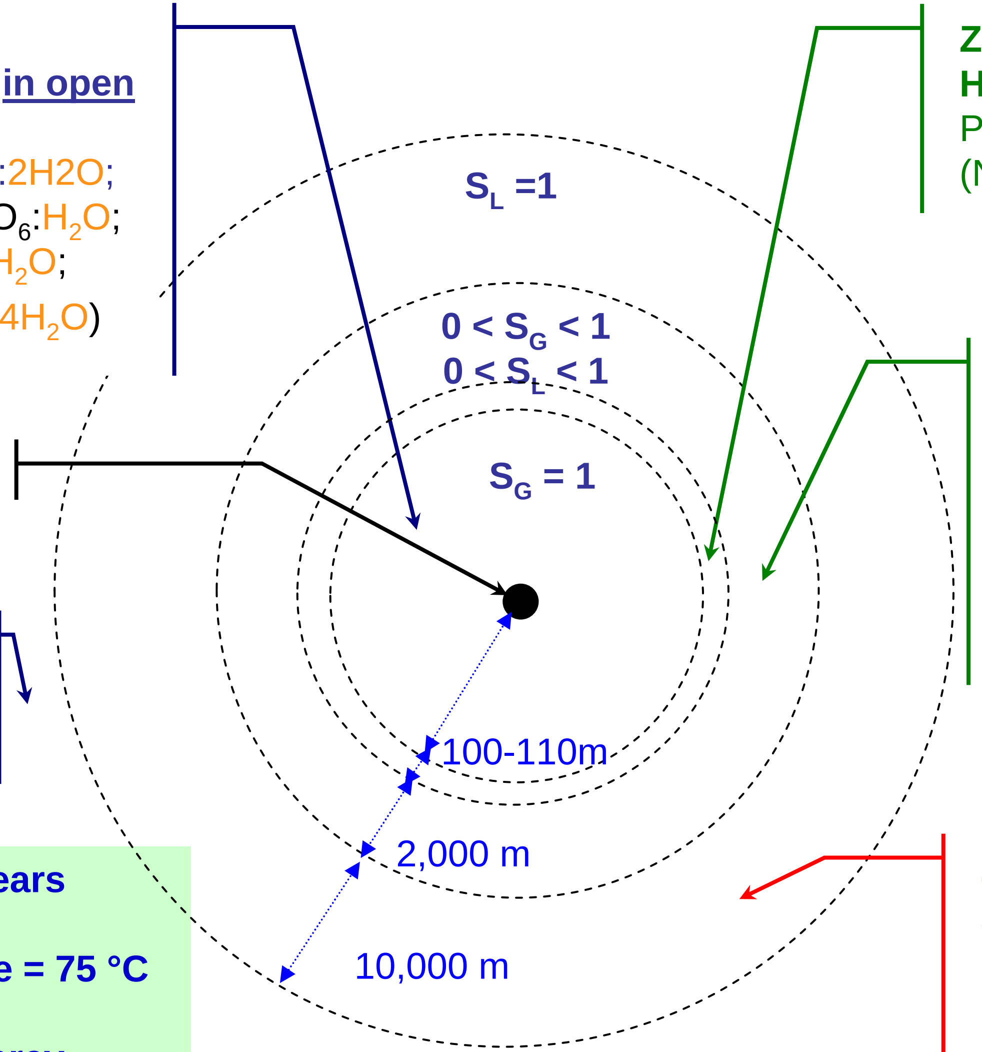


CO_2 Injection well

Moving and growing zones in time

Zone 5	Zone 4	Zone 3	Zone 2	Zone 1
$S_G = 100\ \%$	$S_G = 98\ \%$ $S_L = 2\ \%$	$2 < S_L < 100\ \%$ $0 < S_G < 98\ \%$	$S_L = 100\ \%$	
Desiccation	Desiccation (Evaporation)	Two phase mixture	Acidified aqueous CO_2 rich solution	Initial aqueous solution
	High saline pore water	pH buffered by pCO_2 (3.5 to 5.5)		
Mineral dehydration	Massive precipitation of salts in micropores	Mineral dissolution - precipitation	Mineral dissolution (carbonate, alumino-silicates	Thermodynamic equilibrium (mineral – aqueous solution)
Maximum heat extraction	*Increase of exchange surface*	*Very reactive zones*		*Initial conditions*

Schematic thermo-hydro-chemical simulation results (Injection of CO_2 in saline aquifer)



Zone 5:
-Dehydration reactions __in open systems__
(Wairakite: $Ca(Al_2Si_4O_{12})$:2H2O;
Analcime: $Na_{.96}Al_{.96}Si_{2.04}O_6$:$H_2O$;
Natrolite: $Na_2Al_2Si_3O_{10}$:$2H_2O$;
Laumontite: $CaAl_2Si_4O_{12}$:$4H_2O$)

INJECTION WELL

Zone 1:
-Non affected zone
(Initial conditions)

Injection time = 30 years
Flow rate = 10 kg.s^{-1}
Injection temperature = 75 °C
Porosity = 20%
Permeability = 0.1 Darcy

Zone 4:
Highly saline water
Precipitation of salts
(NaCl, Na_2SO_4, …)

Zone 3:
Dissolution – Precipitation of minerals
(Calcite, Dolomite, Anhydrite, etc.),
highly buffered pH

Zone 2:
Acidified domain
Non (Dissolution – Precipitation of minerals)

Carbon storage capacity of the EGSCO2 & energy efficiency

- Simulations using reference case (Trej = 20°C; Tpro = 200°C; Efficiency ~ 0.45) of long-term $EGSCO_2$ circulation showed:
  - **One needs CO_2 circulation at a rate of 20 ton/s for 1,000 MW of electric power,**
  - **For 1 year, the fluid loss (sequestered) rates decrease from 12 to 7%,**
  - **For long-term, the reasonable loss is about 5% of injection rate (1 ton/s per 1,000 MW of electric power),**
  - **This corresponds to CO_2 emissions of about 3,000 MW of coal fired generation,**
- 1,000 MW (electric) of EGSCO2 could store all the CO_2 generated by 3,000 MW of coal-fired power plants.

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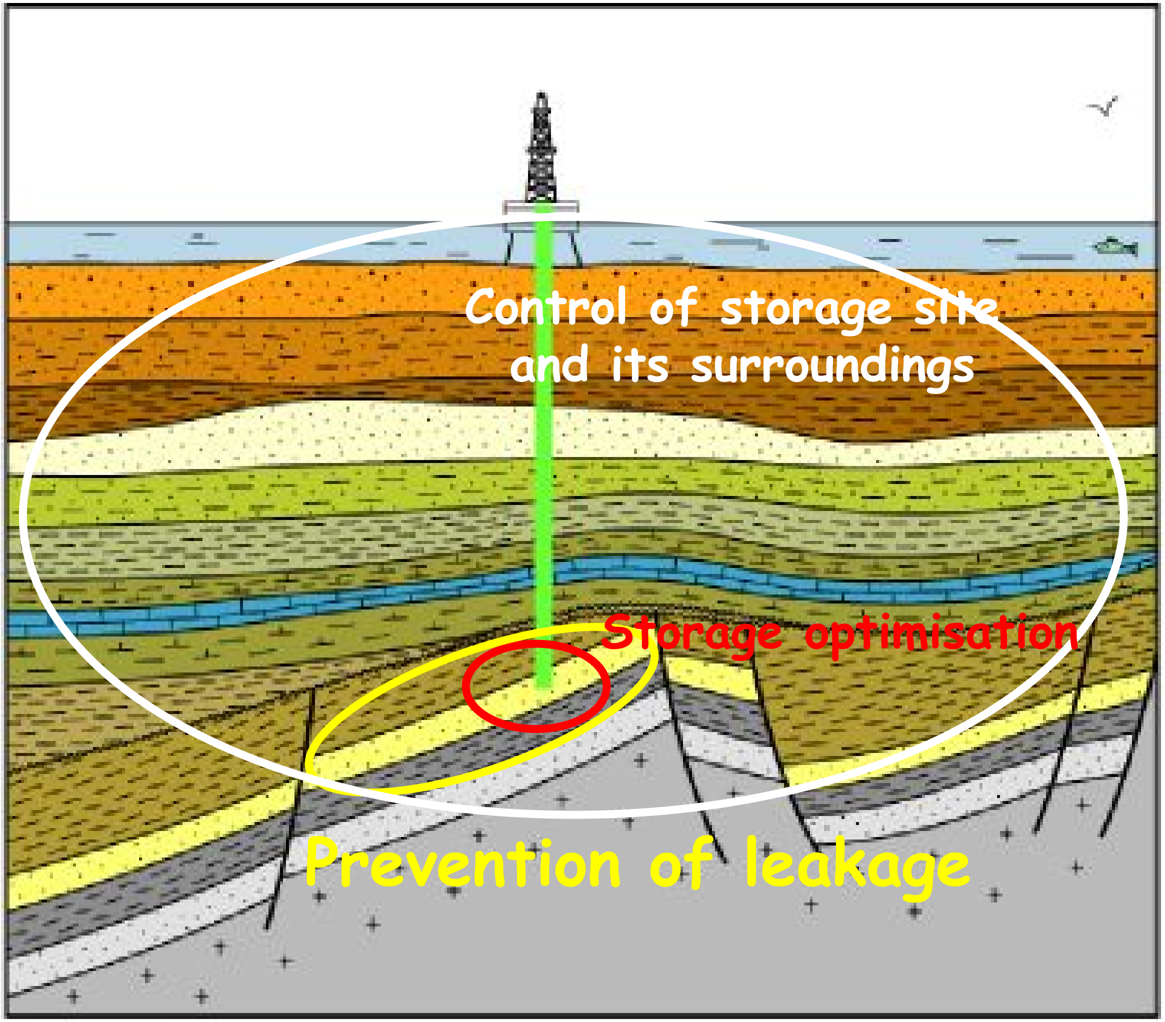
Possible weak points: efficiency and security of geological storage of CO_2 for several centuries



- Understanding all phenomena
- Site selection
- Predictive modelling
- Monitoring methodology for security and trading
- Risk assessment, mitigation & remediation

Specific characteristics of geological storage of CO_2 in geothermal reservoirs

- Leakage prevention is a prerequisite for the concept of Geological Storage of CO_2
- Fractured reservoirs may present preferential flow paths for CO_2 movement with proven cap rock relevant for the CO_2 storage
- The integrity of geothermal fractured reservoir will be of paramount importance for the robustness of the combined geothermal and CO_2 storage hybrid concept
- Water-Rock Interaction kinetics and mass transfer between phases are very fast for HT/HP & high CO_2 concentrations

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Some criteria for security

> **Security will be optimal**

- Storage sites are selected after a thorough and careful geological study, they must present certain structural properties and be in zone with low seismic risk
- Long term predictive modelling of the reservoir property changes by CO_2 injection must be performed
- Well completion (steel casing, cement) must be specially designed
- Pre-existing wells in the storage area must be known and their conditions assessed
- A strategy for Monitoring - Mitigation - Verification must be established and implemented before starting CO_2 injection

Estimating, Verifying and Emissions from CO_2 storage sites

- Geology of storage site needs to be precisely evaluated and local and regional hydrogeology and leakage pathways identified
- Potential leakage will be evaluated based on site characterization and realistic modelling that predicts reactive movement of CO_2 over time
- Establish an adequate monitoring plan which should identify potential leakage pathways, measure leakages and validate/update models

Conclusions & Remarks (1/2)

- Based on its thermophysical properties supercritical CO_2 presents some advantages for heat extraction
- Even if the study of geochemical processes and reactive transport in diphasic systems (CO_2 + water) is still in its infancy, results from CO_2 storage studies suggest favorable properties compared to water
- Reactions of CO_2 with reservoir minerals, in an open system, may lead to continuous reservoir growth, with increases in heat exchange area, porosity, and permeability
- Use of CO_2 as heat transmission fluid for EGS looks promising and deserves more studies.

Conclusions & Remarks (2/2)

> **It is necessary to develop R&D projects because:**

- Many thermophysical and physical-chemical properties suggest advantages from using CO_2 as heat transmission fluid,
- Current conditions are favorable for exploring $EGSCO_2$, due to a multitude of CO_2 storage research and industrial projects (demonstration pilots, industrial sites, fundamental and engineering research to conceptualize well bore aspects of CO_2 injection, such as casing, completion, cement, etc.),
- CO_2 would be circulated after the (hydraulic) EGS stimulation phase to transform the system from an initial water-based to a CO_2 reservoir (in the core).
  - Prior to dry-out, CO_2 enriched water which at geothermal temperatures would be highly reactive, and may prevent adequate reservoir growth if carbonates are formed with higher molar volume than the primary minerals.
  - This kind of problem could be avoided by injecting a non-reactive gas during the initial reservoir development phase, such as nitrogen, and gradually changing injected gas composition towards CO_2 after sufficient dry-out has been achieved.
  - ….

Acknowledgements

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