DOE's EGS Program Review

Using CO_2 as Working Fluid in EGS to Combine Energy Extraction with Sequestration of Carbon

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Project Objective

Evaluate the feasibility of using CO_2 as heat transmission fluid for EGS, and compare with “conventional” water-based systems. Assess the potential for combining energy extraction with sequestration of CO_2.

Change: CO_2-based EGS represents a new initiative in our project on “Geothermal Reservoir Dynamics.” This has grown to a major priority in our FY06 work that had not been anticipated in earlier planning.

Challenges and Opportunities for EGS

- Water is a powerful solvent for many rock minerals, making it very difficult to achieve long-term stable operation of water-based EGS systems.
- Inevitable water losses may seriously impede the viability of EGS in water-short regions, such as the Western U.S.
- Using CO_2 as heat transmission fluid may avoid the chemistry problems of water-based systems, may offer competitive or superior performance as a working fluid for heat extraction, and may allow to achieve CO_2 sequestration as an ancillary benefit.
- Operating EGS with CO_2 offers a game-changing alternative, with large potential for superior performance and improved economics.

Background/Approach

- The concept of using CO_2 as working fluid for EGS was originally proposed by Donald Brown (2000), but has received little attention in the technical community.
- Our modeling capabilities have matured to the point where we could begin a serious quantitative evaluation of the relative merits of water and CO_2 as heat transmission fluids for EGS.
- LBNL staff active in geothermal research has leveraged their strong engagement in studies of CO_2 storage in geologic formations.
- Initial studies showed such enormous promise for CO_2 that much of our EGS effort planned for FY06 was redirected towards EGS-CO_2.

Results/Accomplishments

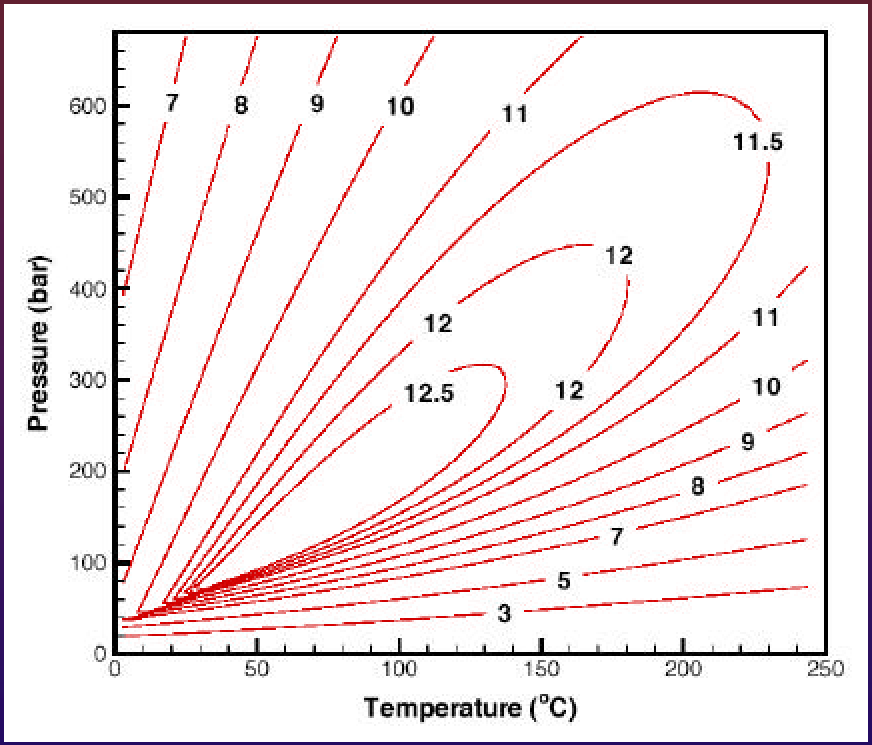
- Presented a first paper on our findings at the Stanford 2006 geothermal workshop.
- Assisted DOE in developing a White Paper to support the case for an EGS-CO_2 R&D programme.
- Submitted a paper with detailed reservoir engineering analyses of CO_2-based EGS to *Geothermics*.
- Submitted an abstract on EGS-CO_2 to the GSA Annual Meeting (Philadelphia, October 2006).

CO_2 and Water Compared as Heat Transmission Fluids for EGS

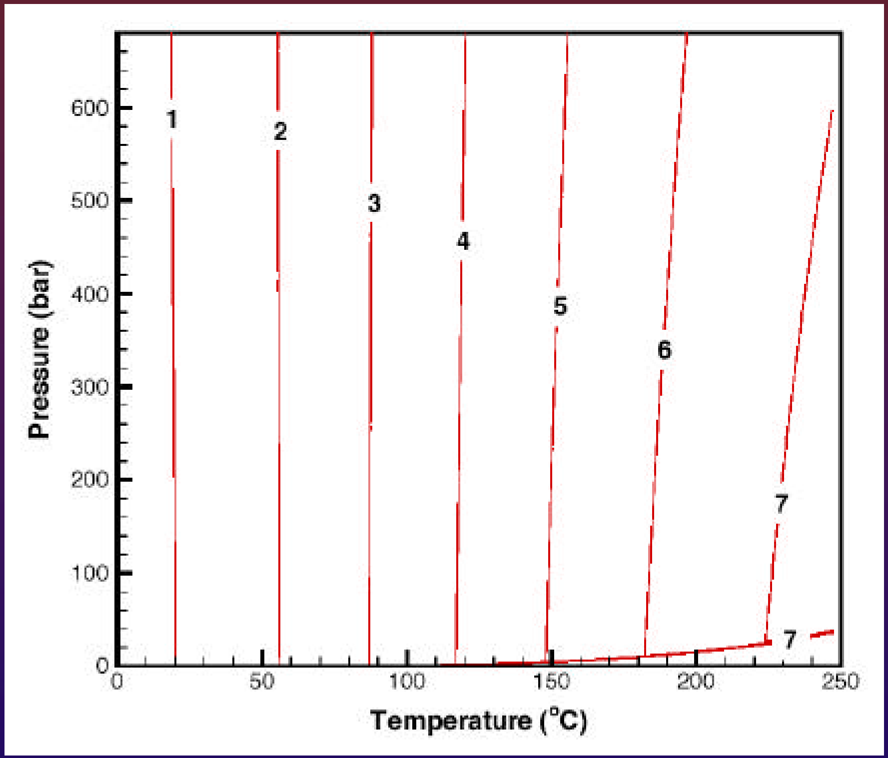
property	CO_2	water
ease of flow	**lower viscosity**, lower density	higher viscosity, **higher density**
heat transmission	smaller specific heat	**larger specific heat**
fluid circulation in wellbores	**highly compressible and larger expansivity** **==> more buoyancy**	low compressibility, modest expansivity ==> 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

Ratio of Fluid Density to Viscosity

(10^6 sm^{-2})

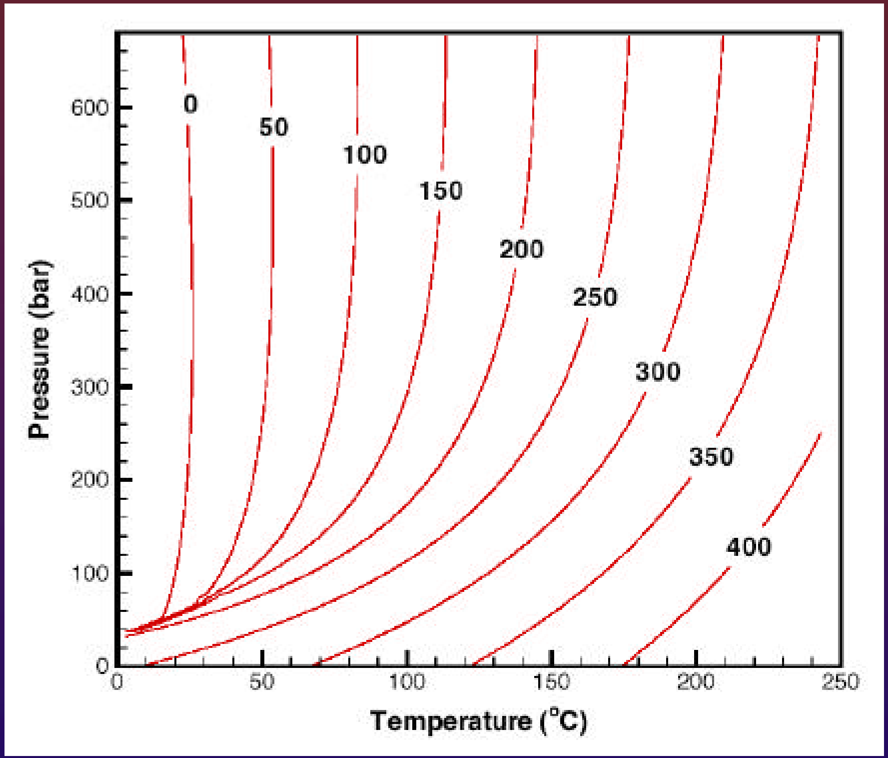


CO_2

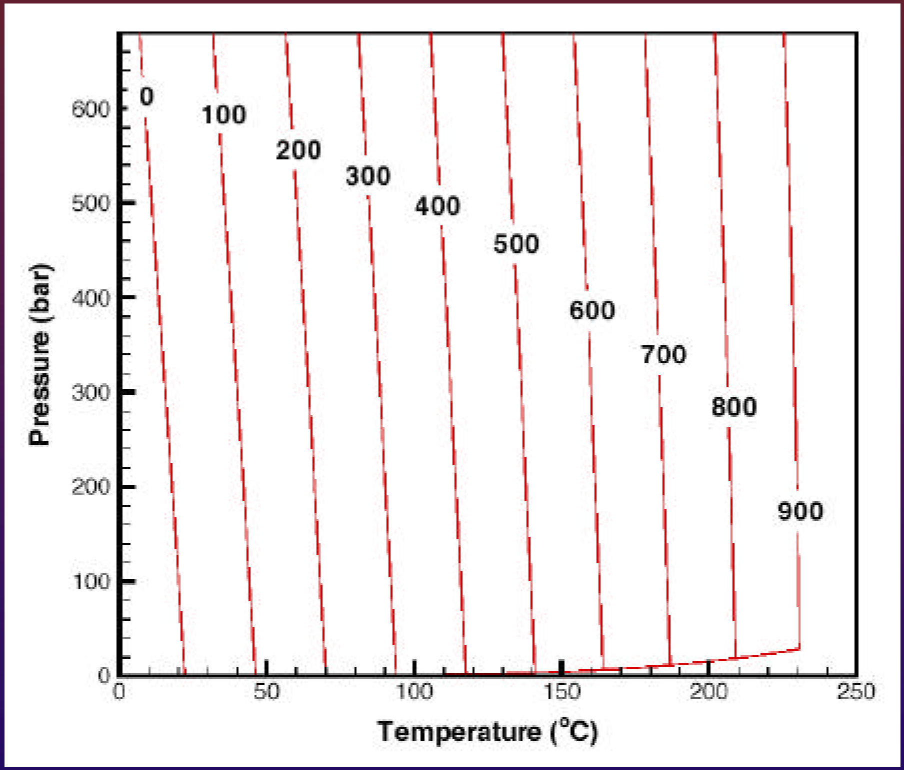


water

Specific Enthalpy (kJ/kg)

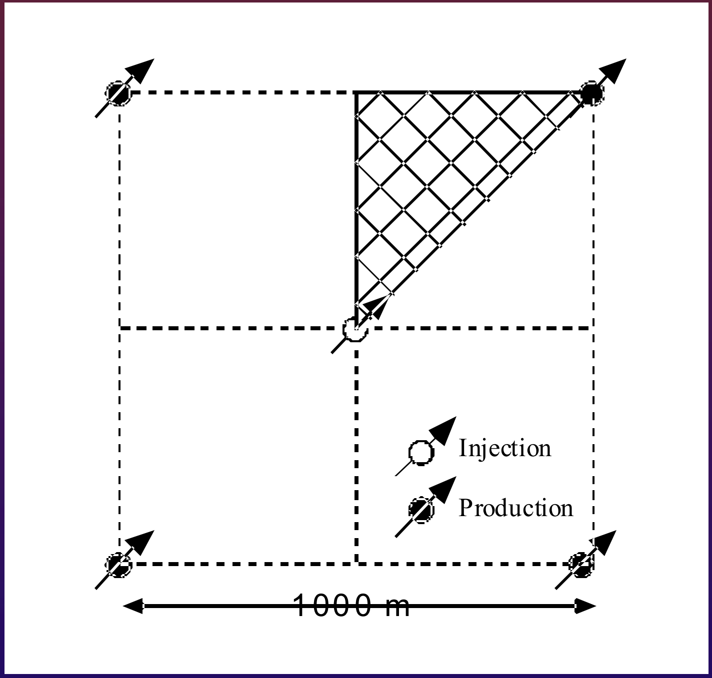


CO_2



water

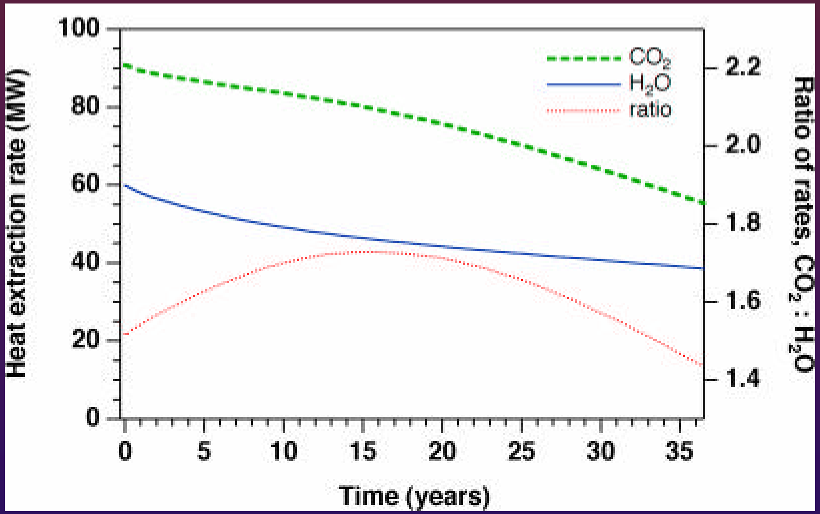
Five-Spot Well Pattern for Heat Extraction Studies



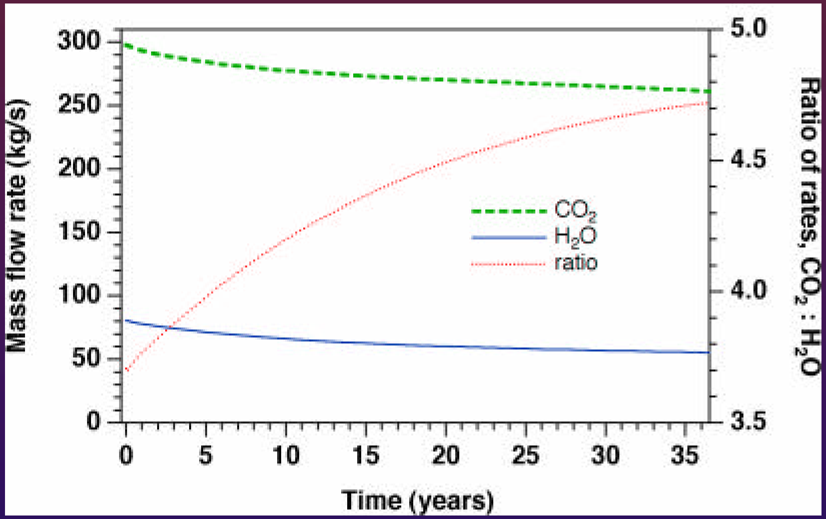
Formation	
thickness	305 m
fracture spacing	50 m
permeable volume fraction	2%
permeability	50.0×10^{-15} m^2
porosity in permeable domain*	50%
rock grain density	2650 kg/m^3
rock specific heat	1000 J/kg/ þC
rock thermal conductivity	2.1 W/m/ þC
Initial Conditions	
reservoir fluid	all CO_2, or all water
temperature	200 þC
pressure	500 bar
Production/Injection	
pattern area	1 km^2
injector-producer distance	707.1 m
injection temperature	20 þC
injection pressure (downhole)	510 bar
production pressure (downhole)	490 bar

Results for Reference Case

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



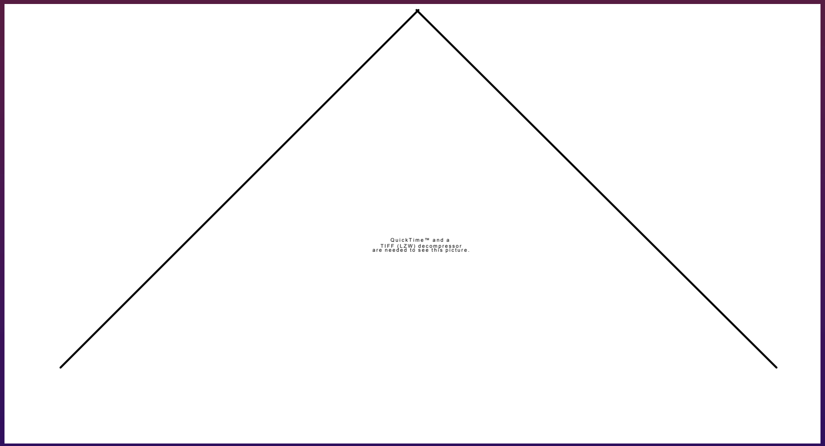
Heat extraction rate

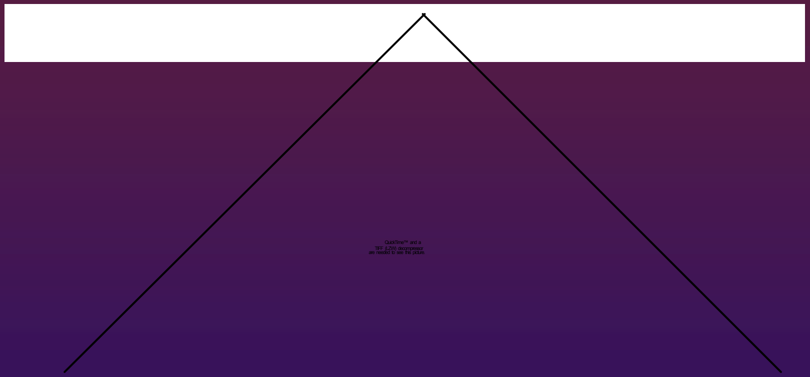


Mass flow rate

Reference Case - Temperatures after 25 Years

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



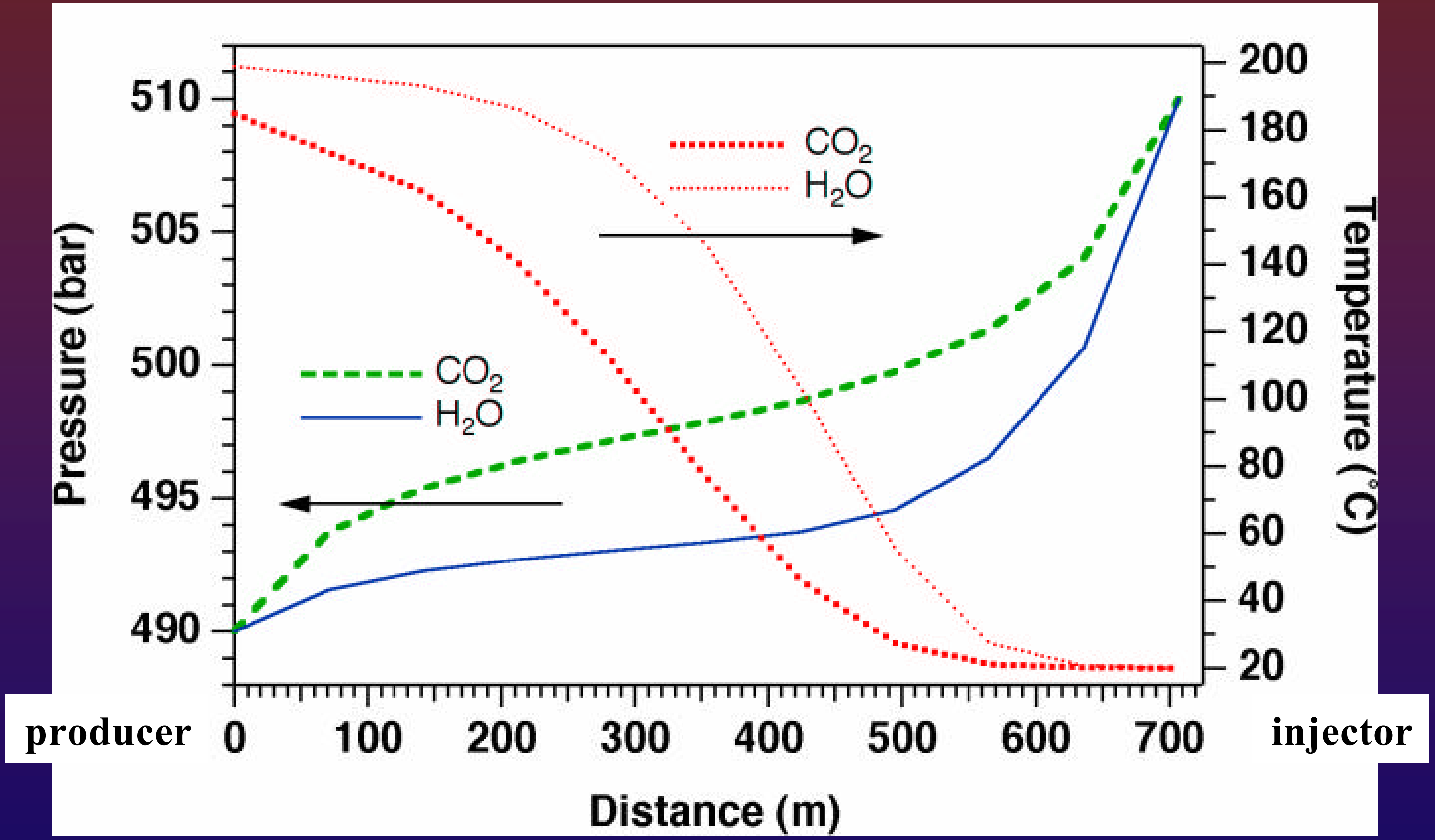


CO_2

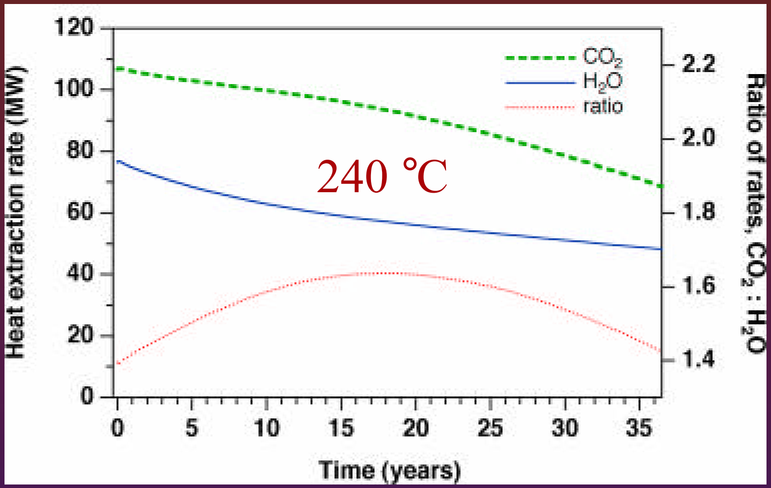
water

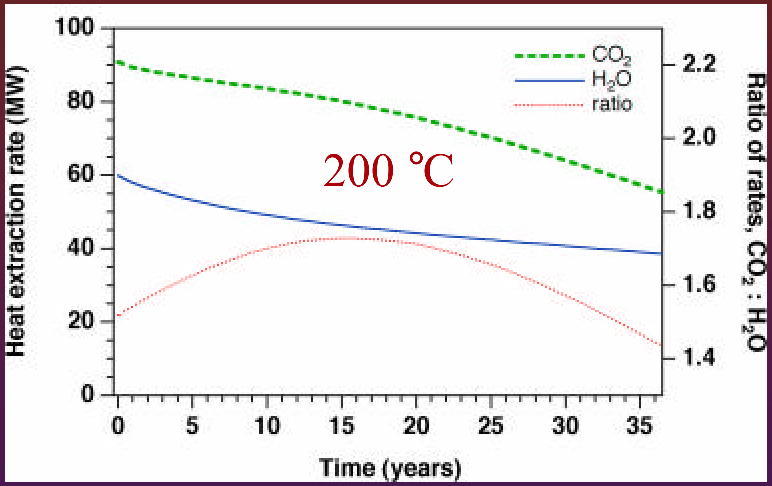
Reference Case after 25 Years

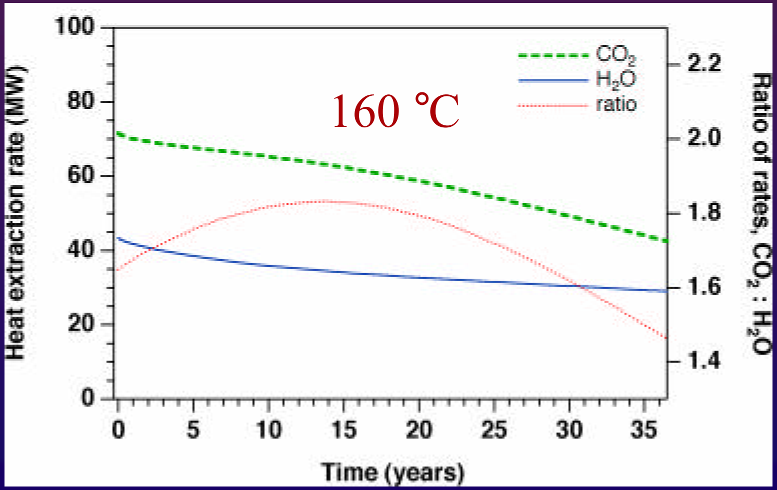
Profiles along a Line from Producer to Injector

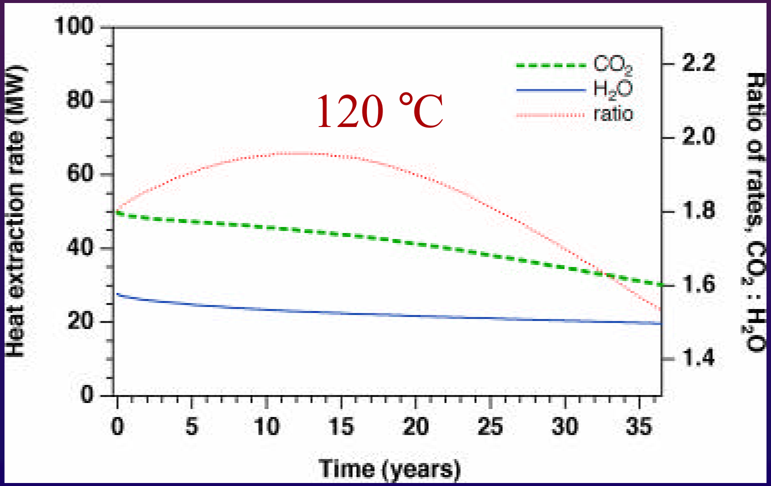


Different Reservoir Temperatures



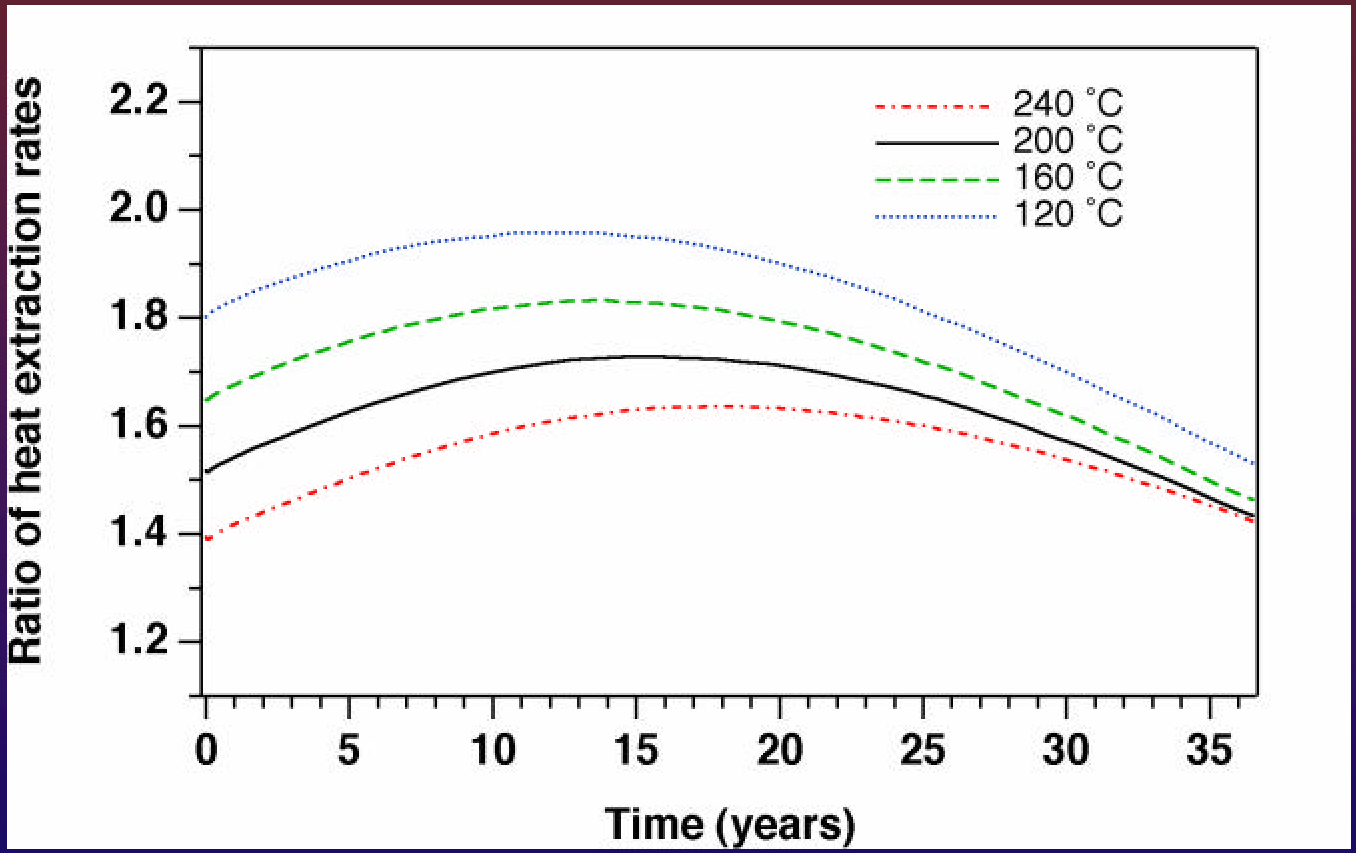






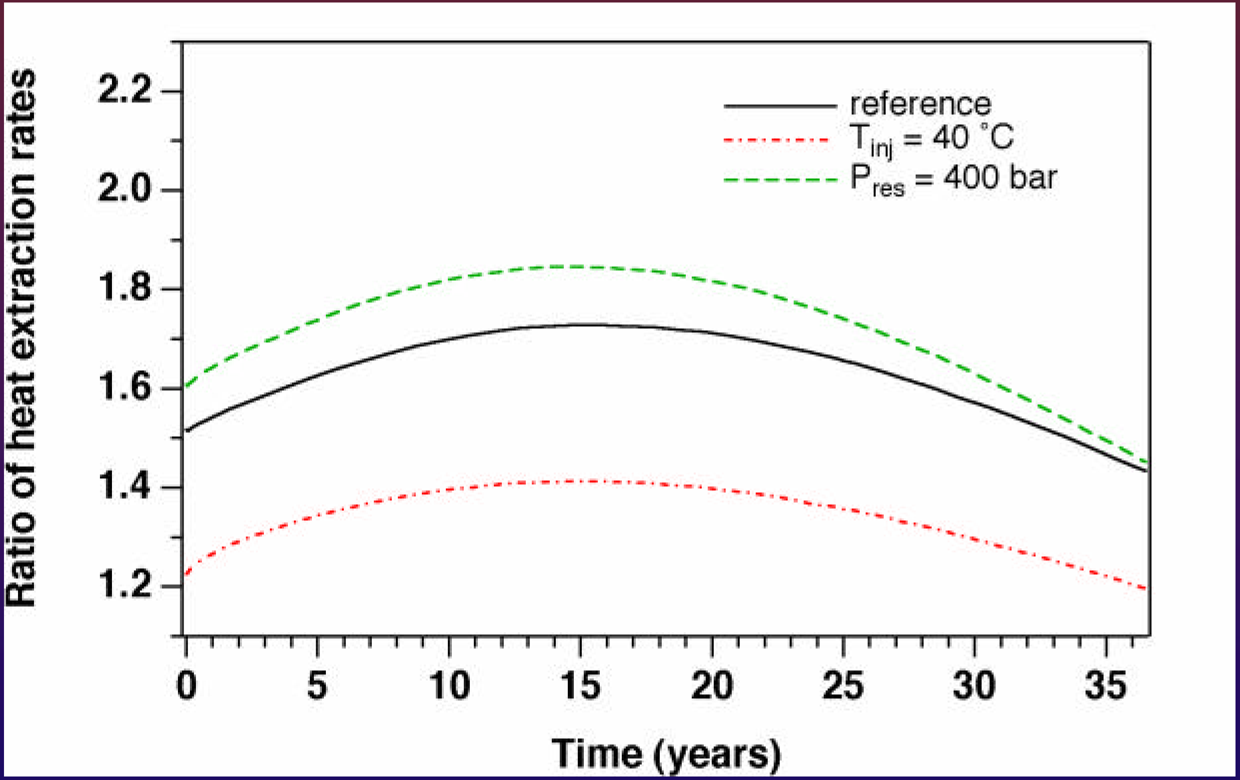
CO_2 vs. Water Heat Extraction Rates

Different Reservoir Temperatures

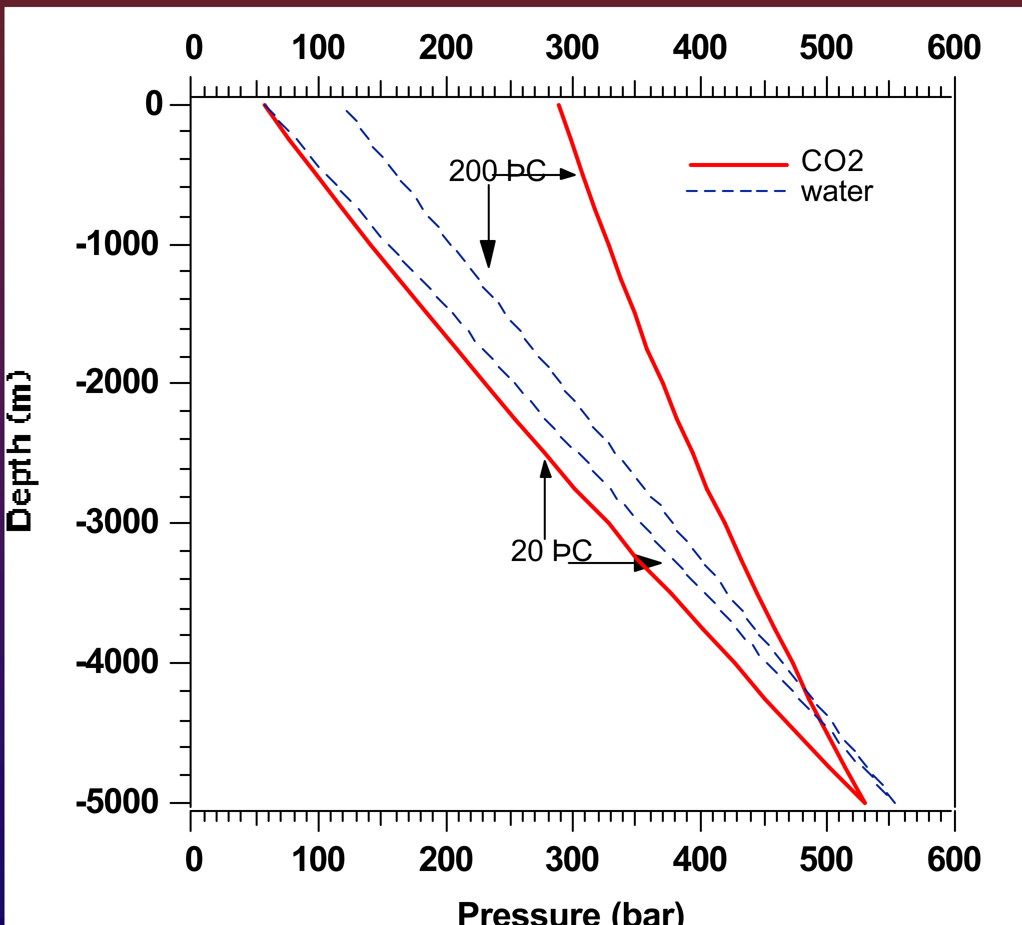


CO_2 vs. Water Heat Extraction Rates

Dependence on Injection Temperature and Reservoir Pressure



Wellbore Flow: CO_2 vs. Water



? $P = P_{prod} - P_{inj}$

CO_2: 288.1 - 57.4 = 230.7 bar

Water: 118.6 - 57.4 = 61.2 bar

CO_2 Storage Capacity

- Mathematical modeling suggests that a CO_2 mass flow of approximately 20 kg/s is required per MW electric power capacity.
- From experience with long-term circulation tests with water-based systems, expect a fluid loss rate of order 5%, or 1 kg/s of CO_2 per MW electric power.
- For 1,000 MWe of installed EGS capacity, the amount of fluid lost in circulation and stored underground is estimated as 1 tonne of CO_2 per second.
- This rate of fluid storage is equivalent to CO_2 emissions from 3,000 MWe of coal-fired power generation.
- CO_2 inventory in 1,000 MWe of installed EGS capacity is estimated as 137 Mt.

Summary of Results

- Thermophysical properties make CO_2 an attractive fluid for heat extraction.
- Heat extraction rates when using CO_2 are estimated to be approximately 50 % larger than for water.
- Larger buoyancy forces compared to water mean reduced power requirements for the fluid circulation system.
- Chemical interactions between rocks and fluids would be weaker and are likely to be more favorable for CO_2 than for water.
- Unavoidable fluid losses are costly for water, but could earn greenhouse gas storage credits when using CO_2. The sequestration potential for EGS-CO_2 is large.
- It may be possible to feed CO_2 directly to the turbines, obviating the need for a heat exchanger and secondary fluid circulation.

Conclusion

- Will the project objective be achieved by the project completion date?
  - Yes –initial demonstration of attractive properties of CO_2 as heat transmission fluid has already been achieved.
  - No – project is just getting started, no completion date has been set.