Electricity Generation using Enhanced Geothermal Systems with CO_2 as Heat Transmission Fluid

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INTRODUCTION

Harnessing clean geothermal energy from Hot Rocks or Enhanced Geothermal Systems (EGS) using water /superheated steam for electricity generation is progressing well in Australia and worldwide.

This paper investigates the feasibility of using carbon dioxide (CO_2) instead of water as EGS heat transmission fluid which has the potential additional benefit of CO_2 geosequestration of significant scale.

Background

Hot rocks /EGS are defined as subsurface reservoirs that have been enhanced to extract geothermal energy. The thermal energy is recovered by creating or accessing a system of open, connected subsurface reservoirs through which water can be circulated down injection wells, heated by contact with the subsurface hot rocks, and returned to the surface in production wells as superheated water/steam used to drive a turbine to generate electricity (Figures 1 and 2).

Given the need to reduce carbon dioxide emissions, the use of CO_2 as the heat transfer fluid has some distinct advantages (improved heat transfer efficiency/sequestration). If successful, this approach could establish a significant CO_2 geosequestration province with capacity to manage the majority of total CO_2 emissions from Eastern Australia.

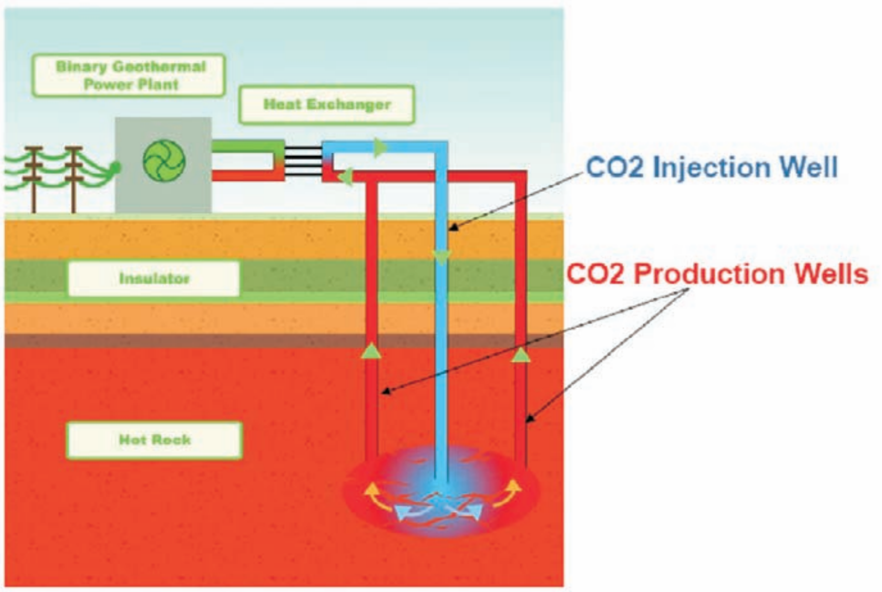

Figure 1. EGS geothermal power generation using CO_2.

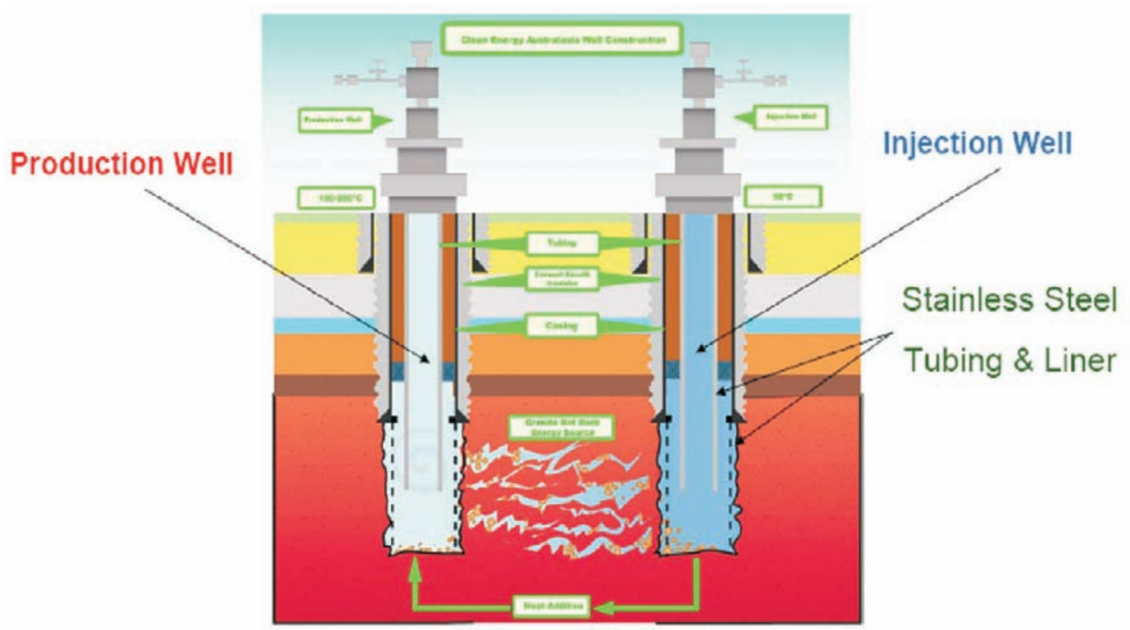

Figure 2. EGS geothermal wells construction using CO_2 as the heat transmission fluid.

Benefits

Previous work has indicated that CO_2 may be technically superior to water or steam in transferring natural heat from hot rocks due to:

- Lower viscosity therefore greater subsurface mobility (Figures 3a & b) [3];
- Heat extraction rate is greater than water at lower temperatures and pressures (Figure 4);
- Increase in efficiency due to lower parasitic power consumption through improved wellbore hydraulics due to greater compressibility and expansivity (Figure 3c);
- Sequestration of CO_2 resulting in negative emission of greenhouse gas (Figure 5); and
- Geothermal energy produce zero emissions.

Technical and Commercial Challenges

However there are a number of challenges, including:

- The infrastructure required to capture and to transport CO_2 over long distance pipelines (Figure 6 Santos MCS);
- The potentially corrosive nature of CO_2 with associated water;
- Compression requirements to transport and store CO_2;
- Capital Requirements to enable the infrastructure; and
- Emissions Trading Scheme (structure of scheme yet to be finalised/announced).

Hot Rocks/ EGS Locations

Australia is estimated to have 22,000 EJ or 5,000 times its annual energy consumption stored in EGS resources [1]. 'Over 80% of the resource was found to be concentrated in central Australia, extending over the north-eastern corner of South Australia and the south-western corner of Queensland. Much of this region is essentially coincident with the Cooper Basin, an infrabasin below the Great Artesian Basin (GAB)' [1].

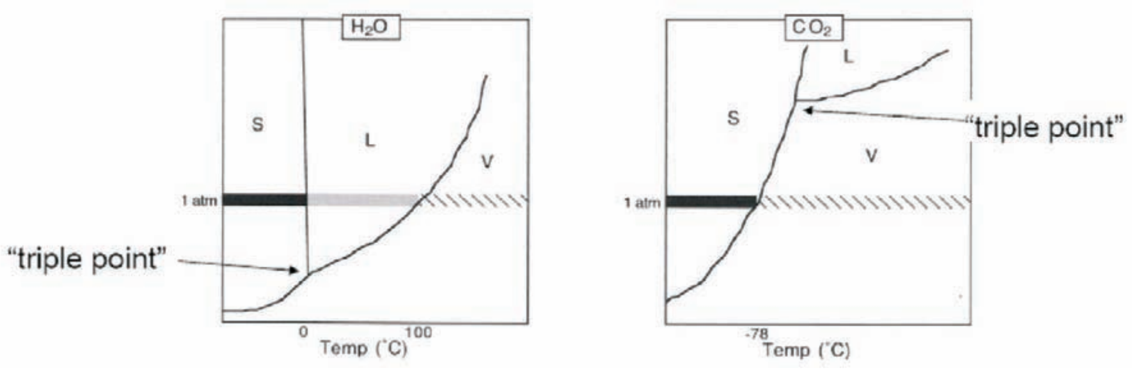

Figure 3(a). Water and Carbon Dioxide properties: phase diagrams.

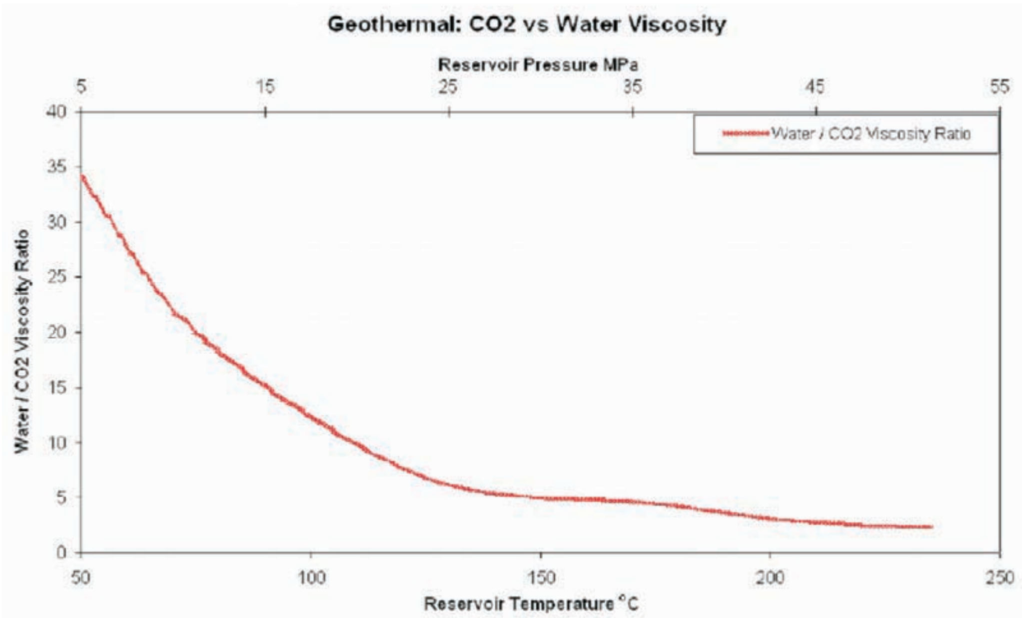

Figure 3(b). Water and Carbon Dioxide properties: viscosity ratio.

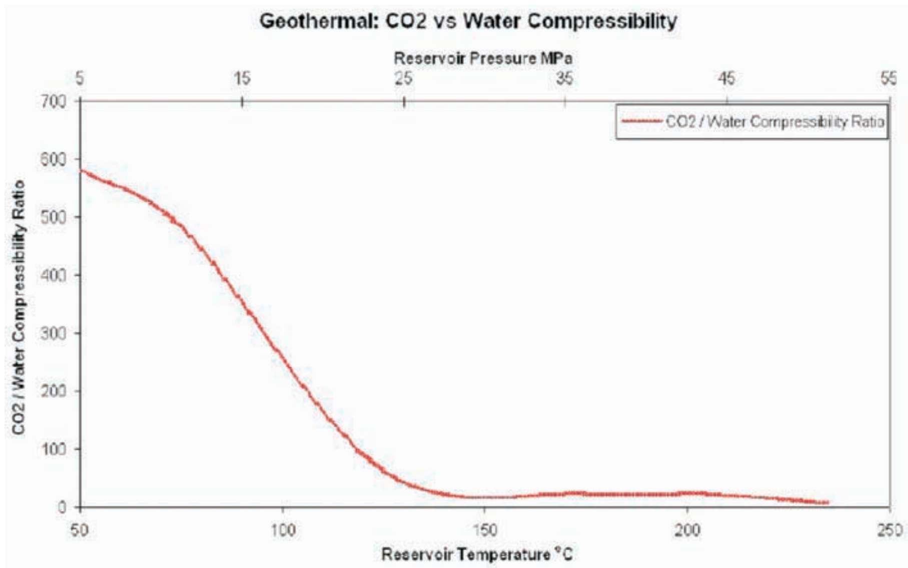

Figure 3(c). Water and Carbon Dioxide properties: compressibility ratio.

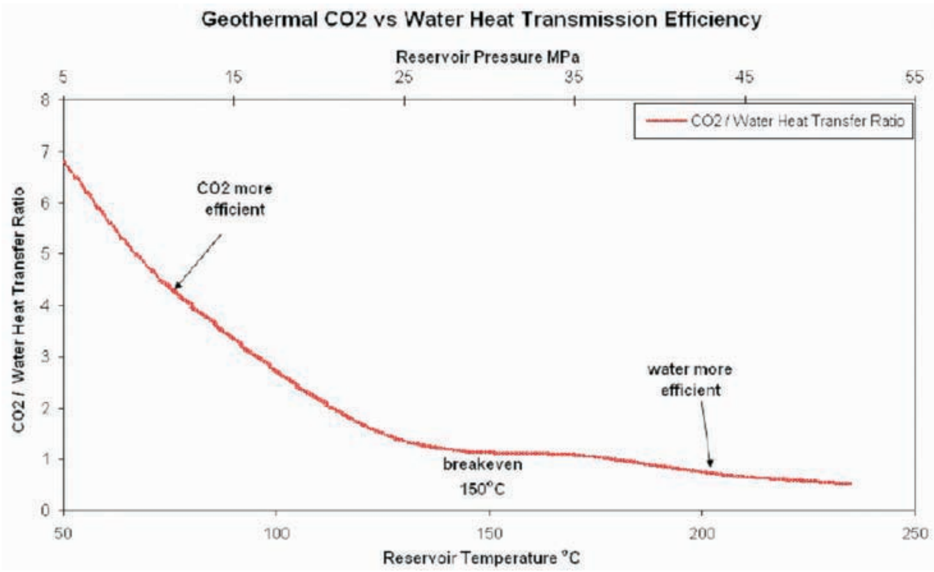

Figure 4. Carbon Dioxide vs water heat transfer efficieny.

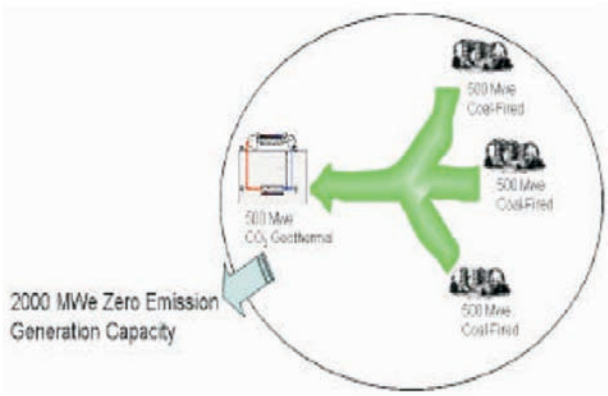

Figure 5. Geothermal power - CO_2 sequestration model (courtesy of UQ Geothermal School of Excellence).

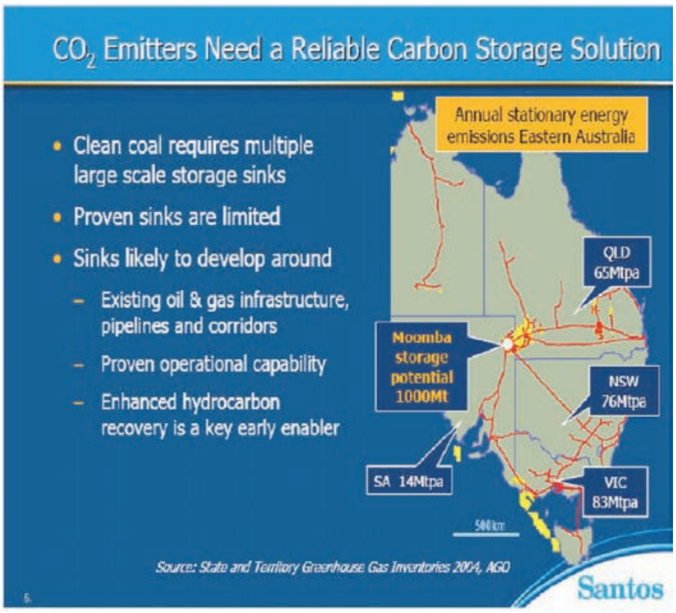

Figure 6. Santos Moomba carbon storage (courtesy Santos Ltd).

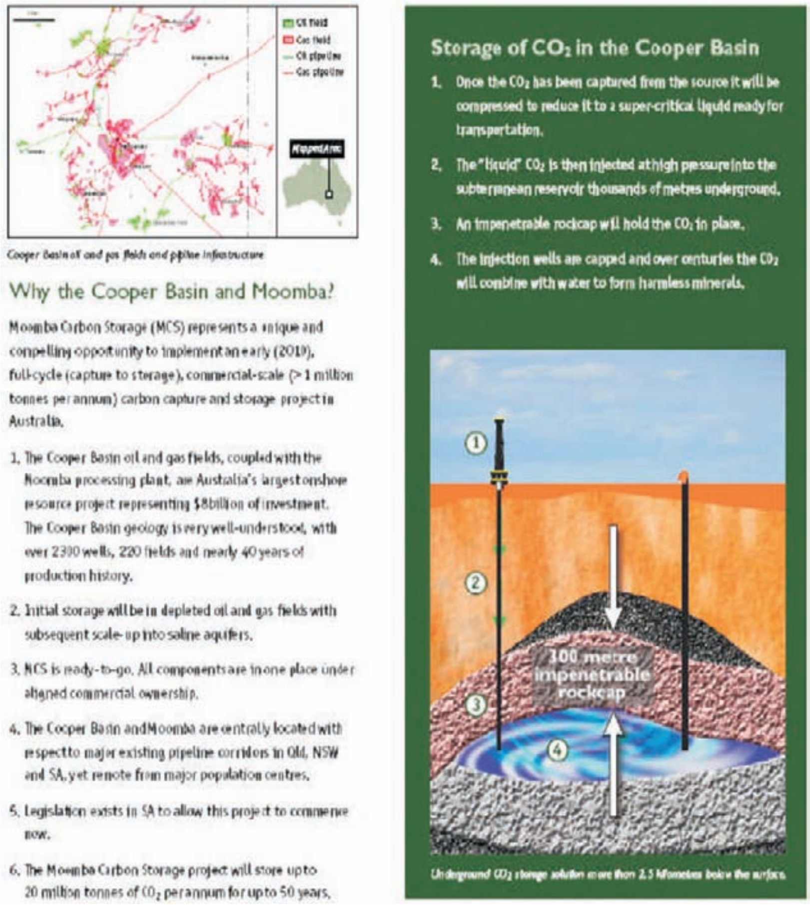

Figure 7. Santos Moomba carbon storage (courtesy Santos Ltd).

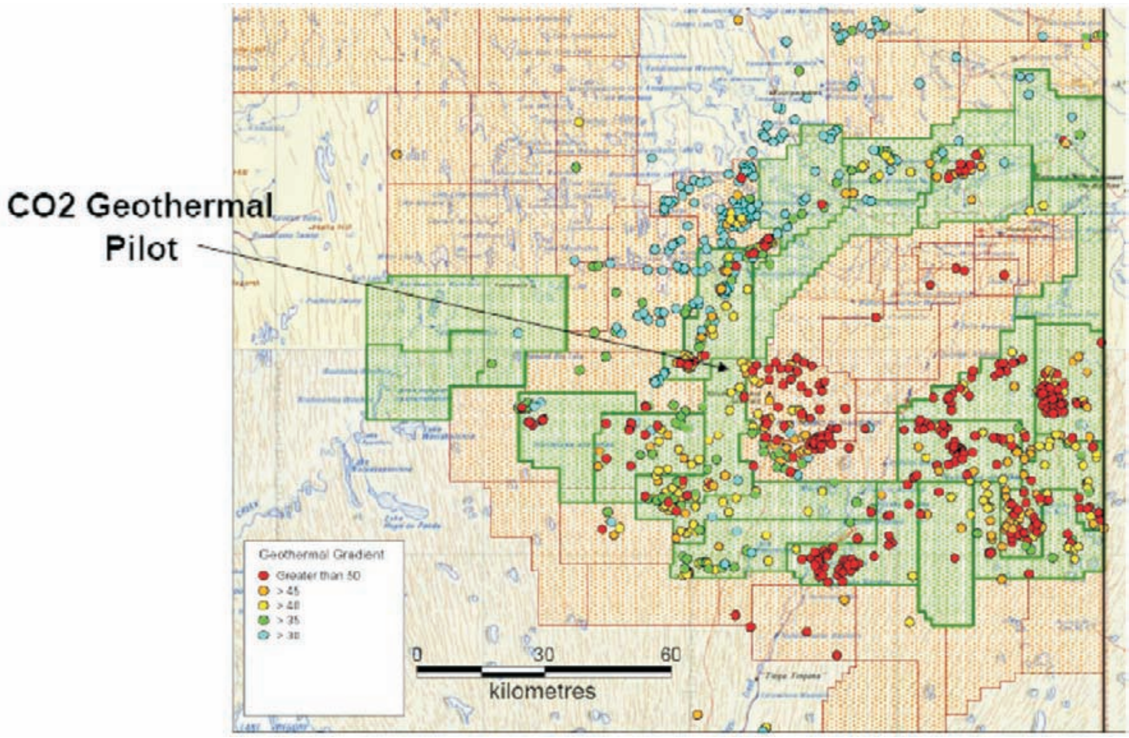

Figure 8. CEA geothermal tenements - Cooper Basin.

CO_2 Source Locations

Coal fired power stations on Australia's eastern seaboard are considered to be the most likely source of CO_2 for potential capture and geosequestration ('clean coal' technology), as well as potential use in EGS projects in the Cooper Basin. Relatively small volumes of CO_2 are extracted from Cooper Basin natural gas processing plant at Moomba, which could be captured and utilised *in-situ* for a small scale EGS / CO_2 pilot.

Project potential

In June 2007 Santos Ltd announced the Moomba Carbon Storage (MCS) project [2] concept to store CO_2 in depleted petroleum reservoirs in the Cooper Basin with the potential to become the world's largest CO_2 storage facility (Figure 7). Initial injection using CO_2 captured from the Moomba plant will commence at approximately 1 million tonnes per annum. Subject to the success of the demonstration phase, MCS would then be scaled up to serve as a regional, multi-user carbon storage hub serving eastern Queensland and NSW's Hunter Valley coal fired power stations. It is projected that these volumes could exceed 20 million tonnes per annum of CO_2 for over 50 years.

Coal fired power plants currently emit nearly 200 million tonnes per annum, approximately 30 % of Australia's total greenhouse gas emissions [3]. The Australian Greenhouse office has forecast that under 'business as usual' , by 2020, Australia will be emitting 837 million tones of which stationary emissions will account for over half (423 million tonnes).

It is estimated that EGS using CO_2 as heat transmission fluid, assuming losses of 5 % or more of the CO_2 circulation, has the potential to sequester the majority if not all of the projected CO_2 emissions from coal fired power stations, on an on-going basis.

In addition, the electricity generation from EGS geothermal would be estimated to add 1 MW of geothermal zero emission electricity generation per 3 MW of 'clean coal' sequestered electricity [3].

Project delivery

Clean Energy Australasia Pty Ltd (CEA) holds geothermal tenements in the SA Cooper Basin (10,950 km^2) and in the GAB in Queensland (3,600 km^2), suitable for large scale EGS electricity generation (Figure 8).

In the Cooper Basin, synergy exists between the MCS and EGS using CO_2 as heat transmission fluid, in sharing the capacity to support potentially large scale 'clean coal' projects in Eastern Australia, in addition to potentially large scale zero emission geothermal electricity generation.

As a first step, the feasibility of a Cooper Basin EGS / CO_2 pilot using CO_2 captured by the Moomba plant is being considered by CEA (Figure 9).

Pilot Project

The proposed Cooper Basin pilot would be a small scale demonstration plant, initially to match local CO_2 availability. Future major expansion is feasible once large quantities of CO_2 from coal fired power stations are transported to the MCS project (Figure 6)

Located near the Moomba plant, the pilot would consist of one injection well and one or more production wells. The wells would be drilled through sedimentary rocks to granitic basement, and then drilled a further 500 metres through basement. The temperature at total depth is estimated at 150-200 °C, based on temperature gradient is ~50 °C/km. The project parameters are estimated as follows;

Resource properties		
Thickness to 5km	1000 - 2000	metres
Thickness - wellbore	500	metres
Fracture height	100	metres
Porosity	2-5	%
Permeability	10-100	md
Well Depth	3000-4000	metres
Initial Conditions		
Water Saturation	100	%
Temperature	150-200	°C
Pressure	300-450	bar
Residual Saturation	5-30%	%
Temperature - 5km	200-250	°C
Temperature Average	~200	°C
Production/Injection		
Area	1	km^2
Injector-Producer Distance	0.7	km
Injection Temperature	25-50	°C
Rock grain density	2650	kg/m^3
Rock specific heat	1000	J/kg/ °C
Rock thermal conductivity	2.1	W/m/°C
Resource thickness	1-3	km

The expectation is that the basement rock will be water saturated. Initially the producing wells would produce of 100% water. Gradually over time increasing amounts of CO_2 would be produced (Figure 10). While theoretically 100% CO_2 production is possible, this is unlikely to occur for several years, if at all, due to migration of CO_2 to surrounding areas, reservoir rock heterogeneities,

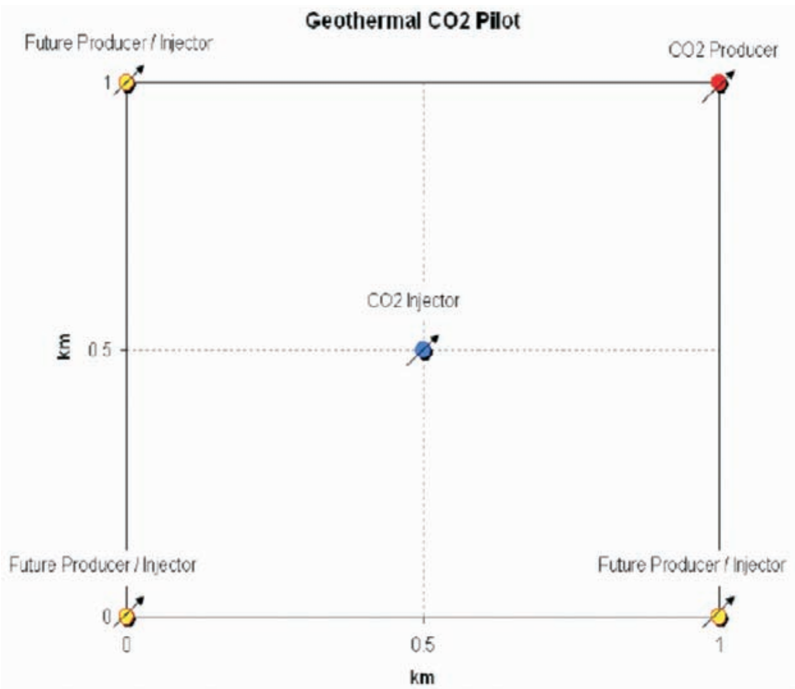

Figure 9. Geothermal using CO_2 pilot.

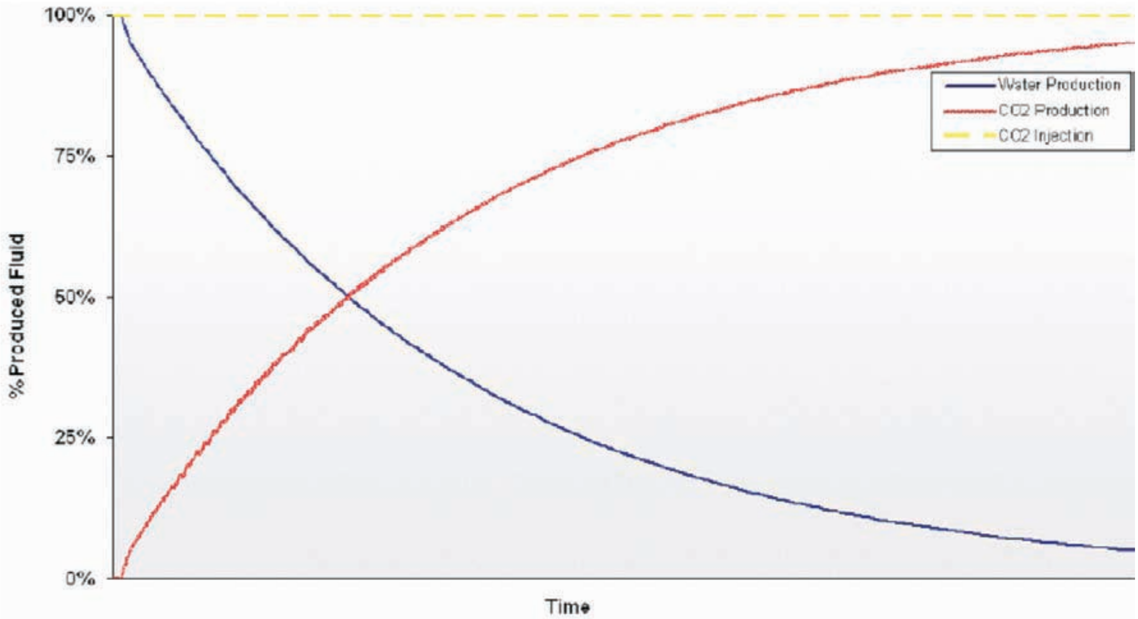

Figure 10. Geothermal CO_2 production / injection expected profiles using CO_2 as heat transmission fluid.

build up of residual CO_2 saturation, etc. Gradually, as the reservoir becomes saturated with CO_2, losses/sequestration are expected reduce to and remain at 5-10%, in line with experience with water based EGS systems.

Given the corrosive nature of CO_2 – water mix, the wellbore tubulars, as well the surface facilities in contact with reservoir fluids, would need to be constructed of corrosion resistant materials (Figure 2).

Project Expansion

The power generation could be readily expanded by adding more wells and increasing CO_2 injection volumes. CEAs 22 Cooper Basin geothermal tenements, covering an area of some 10,950 km^2 have the potential to sequester a significant proportion of Australia's greenhouse gas emissions in the medium to longer term. A single tenement of 500 km^2 could potentially generate 1000 MW using CO_2 as a heat transmission fluid and sequester 50 million tonnes of CO_2 per annum – approximately 25% of current CO_2 emissions from east coast coal fired power stations.

CONCLUSIONS

- CO_2 offers benefits as a geothermal heat transfer fluid to generate zero emission electricity.
- Significant CO_2 sequestration as part of this process results in negative emissions.
- CEA is actively pursuing a proof of concept pilot using CO_2 for geothermal.
- CO_2 geothermal could enhance the viability of 'clean coal' technology.

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