

Moonie Oil Field CO₂ EOR Project

Initial Injection Plan 2021

Chapter 8: Groundwater Geochemistry

Commercial in Confidence



The Moonie Oil Well 27 (M27)

Contents

8.0 Executive Summary..... 3

 8.1 Background 7

 8.1.1 Water Quality..... 7

 8.1.2 No connection with surface Waters. 8

8.2 Existing Groundwater Chemistry Characteristics..... 8

 8.2.1 Upper Precipice Seals..... 9

 8.2.2 The Main Precipice Water Leg 10

8.3 The Associated CO₂ Chemical Reactions..... 11

8.4 CO₂ containment..... 12

8.5 Migration of CO₂ and Related Ions 12

8.6 Chemical Reactions of Hydrogen Sulphide with Water and Air..... 13

 8.6.1 Production of Sulphuric Acid from H₂S & H₂O 13

8.7 Fate of Oxygen, Iron, Manganese and Heavy Metals 14

8.8 The fate of NO_x & SO_x. 14

8.9 Geochemical Trapping Mechanisms 15

 8.9.1 Solubility Trapping 15

 8.9.2 Ionic Trapping 15

 8.9.3 Mineral Trapping..... 15

8.10 Supercritical scCO₂ and Oil Miscibility 15

8.11 Rate of dissolution of CO₂ in Groundwater (Water/Oil mixture)..... 16

List of Figures

Figure 8-1 The Precipice “Oily water leg” (light green) situated in the Moonie Anticline 4

Figure 8-2 A plot of Moonie Oil versus Water production. 7

Figure 8-3 Cross section highlighting the basal shale separating the sealing Precipice SS..... 9

List of Tables

Table 8-1, Table of Chemical Reactions 11

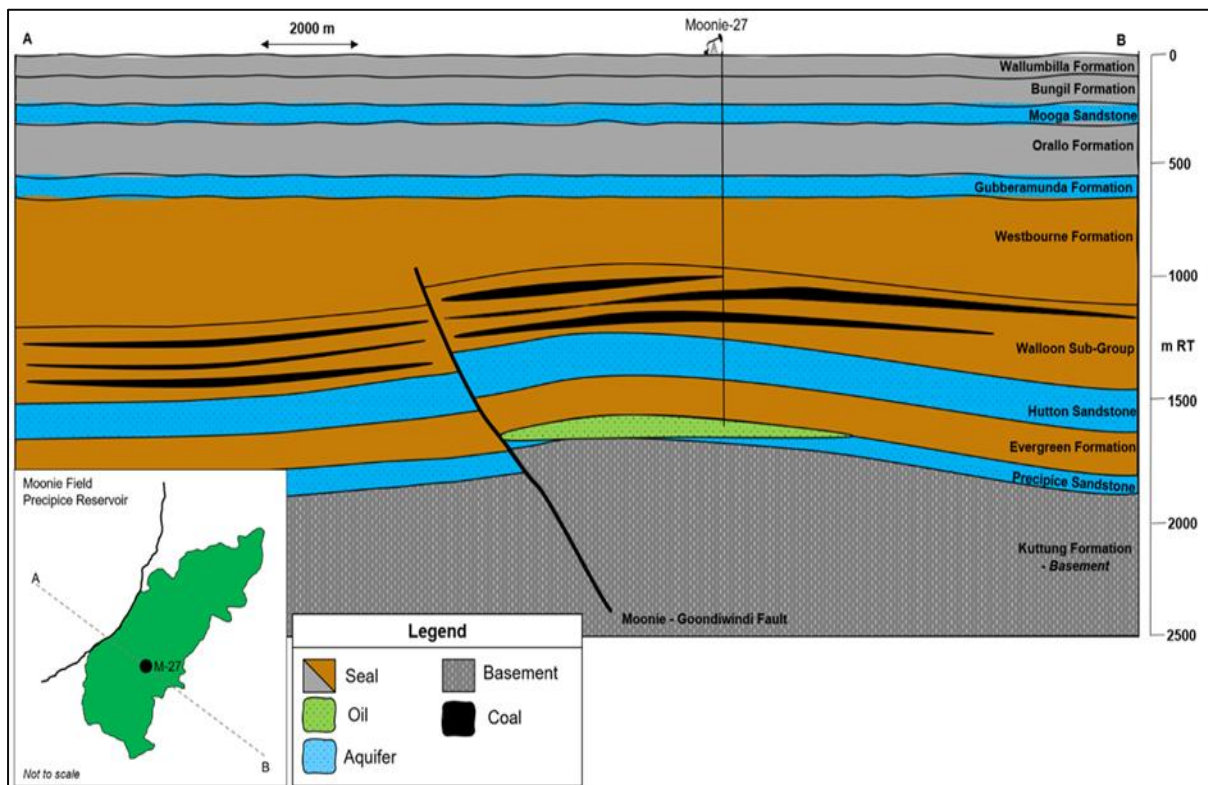
8.0 Executive Summary

This Chapter discusses the modelling of chemical reactions between the injected CO₂ and groundwater over time. It details the water of the target “Precipice oily water leg” found within the “Precipice Formation” and the surrounding water legs at an injection depth greater than 1.5km. The probable impact on groundwater quality has been modelled over time and risk assessed, as discussed in Chapter 12 Assessment of Impact Groundwater, and Chapter 13, Impact on the Receiving Environment.

The key points for this chapter are:

- There will be no significant deterioration or impact on the quality of the existing groundwater within the “Precipice oily water leg” as a result of CO₂ injection.
- An impermeable top seal separates the Precipice Sandstone from the overlying Evergreen Member. The seal has trapped gas, oil and water for approximately 90 Ma. It has also isolated the water of the Precipice Sandstone reservoirs from those of the overlying Evergreen Member with each having water of a distinct isotopic signature, i.e., each being unique.
- There are two distinct zones and water bodies within the Precipice Formation (see Figure 8-1, overpage),
 - the upper “Precipice oily water leg” – water once underlying the trapped Moonie oil reservoir in sands of the Precipice Sandstone. Small quantities of oil left in the Precipice sands post-production, has mixed with the water. This ‘Precipice oily water leg’ is retained within the Moonie structural trap (anticline) and is above and separate to the main “Precipice water leg”, (see Figure 8-1, overpage),
 - Overlying the Precipice Sandstone is the Evergreen water leg, separated from the “Precipice oily water leg” by a 20-80m thick impermeable layer of the Lower Evergreen Member (Figure 8-1).

Figure 8-1 The Precipice “Oily water leg” (light green) situated in the Moonie Anticline



- The chemistry of the lower main “Precipice water leg” is distinctly different from the upper “Precipice oily water leg”. The “oily water leg” has a high carbonate content, gases (including CO₂), oil, oil derivatives (with a geothermic origin as against a biogenic origin) and water. The ‘Precipice water leg’ remains relatively pristine.
- The “oily water leg” has been produced for decades and what remains is classified as “disturbed” from its original condition, i.e., contaminated by oil and production/completion fluids,
 - The current untreated water has been assessed by DES applying S.41 of the EPA Act Regulations and is classified as a “waste”. It would be identified as polluted or contaminated by oil and related chemicals, and therefore excluded from protection by the EPA Act 2019.
- The extracted groundwater quality is poor to unusable without treatment. No public boreholes to access water at this depth or stratigraphic unit exist within the immediate area.

- While this assessment of water quality is normal for an oil field reservoir; it is not normal groundwater envisaged by the EPA Act 2019 for protection.
- This initial injection project will not significantly alter or adversely impact the oil reservoir baseline conditions.
- The CO₂ will react with water on contact forming carbolic acid, which in turn react with elements present in the reservoir (other than quartz and chert comprising the bulk of the formation). The resultant molecules or compounds are chemically trapped in the “oily water leg” through solubility, ionic and mineral entrapment reactions (Section 8.9). Of the molecules not trapped and remaining in solution, initially the drawn down pressure applied by the PM wells by the artificial pumping equipment will cause a flow of fluids in the oily water leg and any untrapped molecules (but those remaining in solution) will move to the production wells and then to the surface. When pumping ceases, the altered molecules remain entrapped in the anticline.
- The carbolic acid will not alter the target formation as it is comprised of Quartz and Chert which is unreactive to acid,
- Theoretically, some of the molecules of CO₂ mixing with water have a slightly higher density and will initially move downward under gravity. However, the movement is limited by permeability of the rock formation in the oily water leg, at a depth greater than 1.5km, and also by the fact that the CO₂ + H₂O reaction is a two-way reaction. As the heavier CO₂/water molecule meets more water and/ or the pressure reduces or temperature increases, the reaction reverses and the CO₂ dissociate from the water and returns to a gaseous form. It will then migrate to the top of the anticlinal trap
- SO_x and NO_x molecules (at a delivered concentration of 20ppm and 33ppm respectively from the Milmerran CO₂ delivery specification, in Chapter 10 Assessment of Impact Air) are also trapped in the anticline and the 3 chemical entrapment mechanisms are discussed below,

- Negligible amounts of hydrogen sulphide (H_2S at 15ppm) is present in the received CO_2 fluid stream and injected (see the delivered CO_2 specification in Chapter 10 Assessment of Impact Air). Downhole it reacts with water to form a weak sulphuric acid which in turn reacts with the carbonates in solution, including the carbonic acid. The sulphuric acid is neutralised and entrapped. Of the elements not entrapped in this process (if any), while the injection program is continuing, the remaining H_2S in solution will be produced at the surface separator unit. However, the amount of H_2S is estimated to be so minute as to be immeasurable. The gas from the Separator will be fed to and burnt in the generator. In this process, H_2S is burnt and changes to sulphur and water.

This chapter discusses:

- The stratigraphy potentially affected by the injection of CO_2 ,
- The chemical processes predicted in the injection zone at the perforations (validated by laboratory tests),
- The associated chemical reactions of various products in the reservoir (CO_2 and any associated gas products from the CTSCo plant),
- The nature and time scale of any change; and
- The stability of the CO_2 flood once injected.

8.1 Background

Currently the percentage of oily water being pumped to the surface is declining and water is increasing. A typical production profile of the latter years of a depleted oil field is illustrated in Figure 8-2 below. The economic life at current production of PL1 is predicted to be extended by 10-12 years through tertiary recovery using enhanced oil recovery, as discussed in Chapter 18.

Figure 8-2 A plot of Moonie Oil versus Water production.



8.1.1 Water Quality

The Moonie Oil Field “oily water leg” has been producing for decades. The remaining fluid in the “Precipice upper water leg” is classified as “disturbed” from its original condition. A mineralogy and groundwater quality profile has been developed, tracked, and reported to Government by field operators for over 50 years. Under the current EAct and Regulations and Schedules, the quality of the Moonie “oily water leg” without treatment would be classified under the legislation as being a waste and toxic. The water is assessed under the ANZACC water guidelines (2000) as being unfit for human or stock consumption. While this assessment of water quality is normal for an oil field reservoir, it is not normal groundwater envisaged for protection by the EAct 2019. Depending on its quality produced water at Moonie cannot be directly used at surface without treatment.

No public boreholes to the depth of the Moonie “oily water leg” exist in the immediate region. Local landholders prefer to access cleaner water found at shallower depths.

The initial injection project will not significantly alter or adversely impact the oil reservoir baseline conditions. Reservoir modelling by the University of Queensland (UQ) indicates that, as a result of CO₂ injection, the pH contained within the “oily water leg” contained within the Moonie anticline will move towards a neutral state and over the long term will revert to original reservoir conditions. This factor alone could be perceived as a positive impact of CO₂ injection.

8.1.2 No connection with surface Waters.

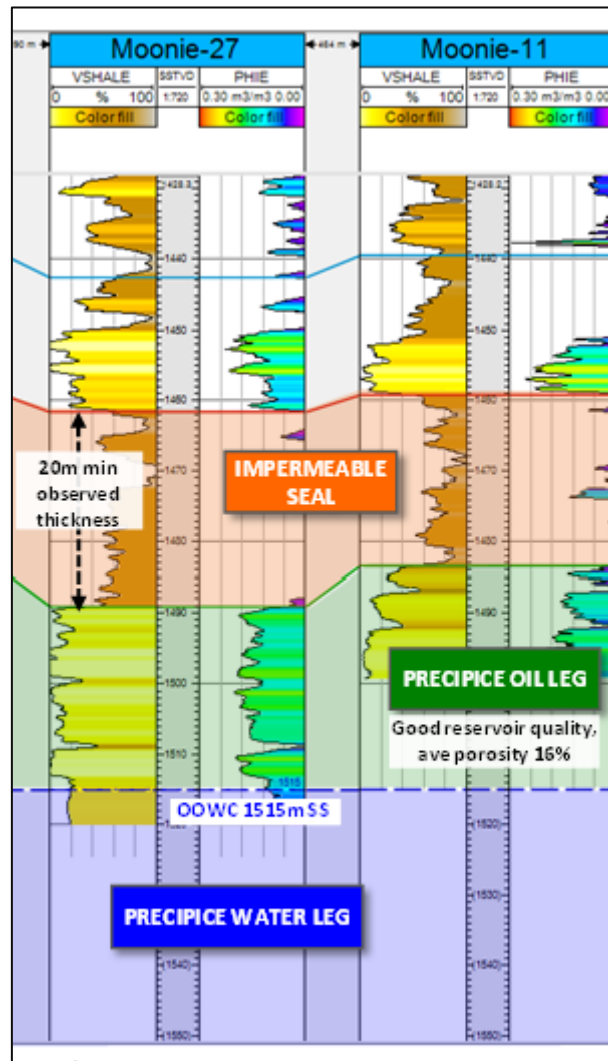
From the UQ study, there is no evidence of hydro-chemical connectivity between the Precipice Sandstone and surface water (river drainage).

8.2 Existing Groundwater Chemistry Characteristics

The formation water chemistry of the Moonie oil reservoir has a different chemical composition than the water in shallower aquifers at less than 300m accessed by the majority of Landholders and contains oil, long chained hydrocarbons and other linked organic chemicals (BTEX). It has also been “produced” for more than 5 decades and as such is classified as being “disturbed” from its original condition. This is unlike the upper and lower water bodies (the Evergreen and the lower Precipice Main Water Leg) which are still in ‘virgin condition’ Table 8-1).

The isotopic signature of the “Precipice main water leg” is completely distinct from the water in the overlying Evergreen aquifer, confirmed by isotopic water analysis completed by University of Queensland (UQ). This difference in water chemistry and the entrapment of oil in the Precipice Sandstone proves that there is an impermeable seal between the Precipice Sandstone units and the overlying Evergreen Member isolating the sands of the two members of the Evergreen Formation. (see Figure 8-3, a cross section highlighting basal Evergreen Member shale separating sealing Precipice SS.). Testifying to the strength of the impermeable Precipice topseal, which has trapped gas and oil for approximately 90 Ma years.

Figure 8-3 Cross section highlighting the basal shale separating the sealing Precipice SS



8.2.1 Upper Precipice Seals

The upper Precipice Sandstone seal is discussed in Chapter 5 Geology and Geomorphology. The seal is 20 -80m thick, depending on location. The contact between the Precipice Sandstone and the overlying Evergreen Member seal is transitional in nature.

The impermeable nature of the Precipice Sandstone seal means that injected supercritical scCO_2 (which is less dense than water or oil) will migrate upward within the Moonie structure until it reaches the base of the impermeable seal (Bachu, 2000). When the front face of the injected scCO_2 flood front contacts water it forms a mild carbonic acid as discussed below. As the front reaches the contact surface of the transition section before the impermeable seals, the mild carbonic acid will form

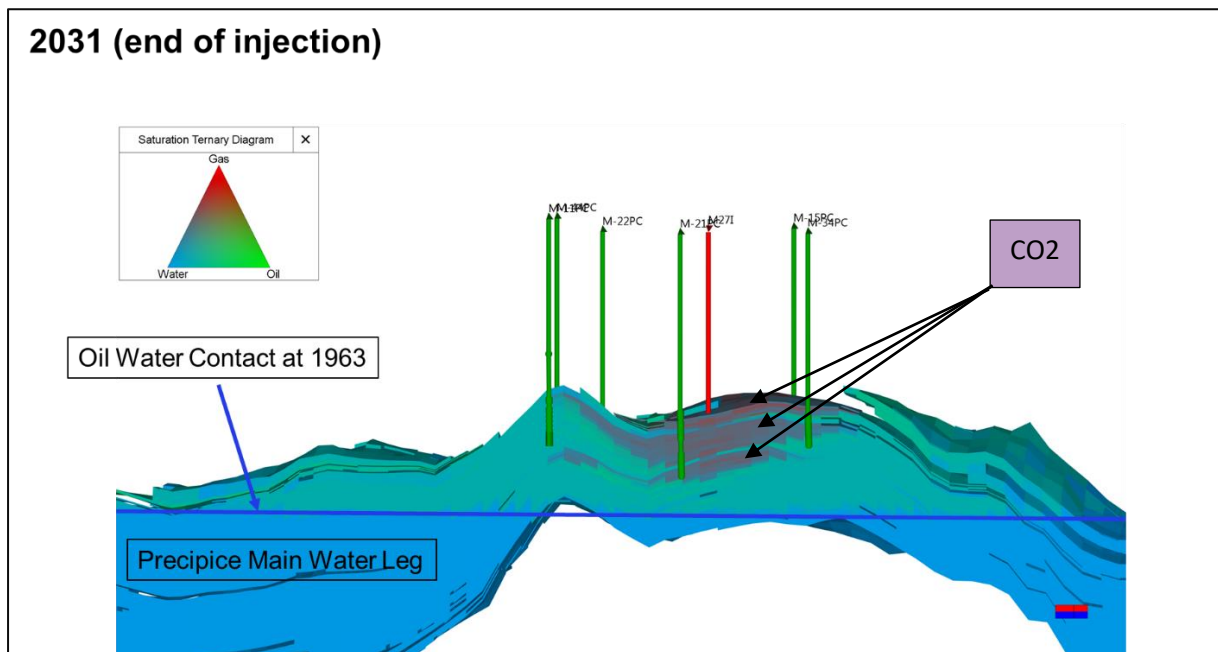
a self-sealing carbonate-based mineralisation, which prevents further penetration of the transition zone and the seals.

8.2.2 The Main Precipice Water Leg

Approximately 60,000,000 tonnes of oily water have been produced from the Precipice Sandstone to date. This has been a by-product of decades of oil production from this interval (since 1963). The Bridgeport Energy dynamic model predicts with an initial injection volume of 120,000 tonnes/year over 8 years into the Precipice 'oily water leg', the CO₂ flood front will not reach the oil-water contact of 1963 (Figure 8-2). A total of 960,000 tonnes of CO₂ will be injected over the modelled 8 years, 20% of the injection volume is discharged at surface leaving 768,000 tonnes sequestered. The 768,000 tonnes is significantly less than the 60 M tonnes extracted being only 1.3% of the extracted volume.

Figure 8-4 illustrates the predicted position of the oily water interface and the injected volume of CO₂ at the cessation of pumping in 2031.

Figure 8-4, a 3D cross-section model of the Moonie Oil Field Injection zone at completion of injection in 2031



The remaining CO₂ gas (coloured purple above in Figure 8-2) is illustrated as residing at the top of the structure. This volume is small enough that there is no potential for the buoyant scCO₂ to

penetrate the main Precipice main water leg during the injection program, as the injected fluids will only occupy a small percentage of the potential extracted volume within the oil field.

8.3 The Associated CO₂ Chemical Reactions

The addition of liquid CO₂ and minute amounts of SO_x and NO_x entrained in the CO₂ stream can partially dissolve in water to form the hydronium ion (H₃O⁺). The latter has a moderate affect in lowering the pH where the scCO₂ flood front reacts with formation water.

The various entrapment reactions are illustrated in Table 8-1 below.

Table 8-1, Table of Chemical Reactions

Carbonate Reactions - dissolution and dissociation of CO ₂ in water	1. $\text{CO}_2 \leftrightarrow \text{CO}_2 (\text{aq})$ 2. $\text{CO}_2 (\text{aq}) + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3$ 3. $\text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-$
SO _x Reactions	4. $\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3$ 5. $\text{H}_2\text{SO}_3 + \text{H}_2\text{O} \rightarrow 2\text{H}^+ + \text{SO}_4^{2-}$
NO _x Reactions	6. $3\text{NO}_2 + \text{H}_2\text{O} \rightarrow 2\text{HNO}_3 + \text{NO}(\text{g})$ 7. $\text{HNO}_3 \rightarrow \text{H}^+ + \text{NO}_3^-$

Modelling predicts that, over time, the existing slightly alkaline pH within the “oily water leg” will change to a pH range of 5.0 to 5.5. The model predicts that the altered pH will return to the original reservoir pH level over time. In contact with minerals, carbonates and clay, the CO₂⁻ ions react and that reaction buffers the pH, precipitating self-sealing minerals in the immediate area. The reaction only occurs on exposure to the minerals and proceeds to completion until spent.

At cessation of pumping there will be no fluid movement within the anticline.

The primary mineral of the Precipice Sandstone at Moonie Field is quartz at approximately 80% (Pearce et al, 2019), followed by feldspar and chert. These primary components are all inert and not

reactive to acid. The rock integrity/structure is therefore not predicted to be degraded by changes in the pH of the formation water. Otto (2998) made conclusions based on entirely different geological formations, not at depth (1.5km to 2.2km) and modelled on an entirely different volume of injected CO₂.

However, due to the geological anticline formation, carbonates in solution have accumulated in the Moonie Anticline for 90 Ma, as distinct from the main Precipice water leg. Because of the relatively strong water drive in the main “Precipice water leg”, there is a distinct difference to the minerology of the upper “Precipice oily water leg” which has less flow and is trapped in the anticline.

At the local exposure front with surrounding carbonates and other minerals in solution, the carbonic ions react with the carbonate, clay, and minerals (see discussion in Chapter 6) to precipitate self-sealing carbonates and minerals. The reaction only occurs on exposure to the minerals and continues as long as liquid CO₂ is in contact with the minerals.

When injection ceases and the production monitoring wells are shut in, all the fluids in the reservoir become static and there will be no fluid movement within the anticline.

8.4 CO₂ containment

The geochemical reactions are controlled by several factors and combinations of scCO₂, water, rock characteristics, temperature, pressure, pH, and minerology of the receiving environment. UQ has modelled this chemistry over time (up to 1,000 years). The modelling indicates the injected CO₂ does not stay in the scCO₂ phase but converts to the normal CO₂ phase and remains trapped within the anticline in the Precipice “oily water leg”.

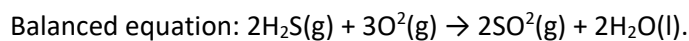
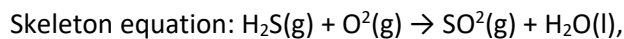
8.5 Migration of CO₂ and Related Ions

At reservoir conditions, the scCO₂ is less dense than both water and oil, despite the relative molecular weight and will naturally migrate to the top of the Moonie anticline. The injected CO₂ in this initial project will only fill <15% of the volume available in the uppermost part of the structure. Once pumping stops the artificial fluid drive stops and so does the movement of the CO₂ within the unit. At this stage the scCO₂ remains trapped in the upper sandstone of the anticline.

During migration, the CO₂ will react with minerals and fluids. Certain reactions will create “heavier” molecules that under normal circumstances, will migrate slowly downwards until they come into contact with formation water and disassociate. If some heavier molecules are not trapped once they come into contact with water, they are disassociated and return upwards in the anticline. The sheer volume of water and the water drive in the lower main Precipice water leg would move to dilute and dissipate any further effect.

8.6 Chemical Reactions of Hydrogen Sulphide with Water and Air

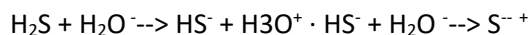
Hydrogen sulphide is present in the delivered CO₂ at a concentration of 15 ppm. Hydrogen sulphide gas reacts with oxygen gas to yield sulphur dioxide gas and water. This could occur on uplift and at the separator, however the expected volume is expected to be negligible. For completeness, the chemical reaction with Air is:



8.6.1 Production of Sulphuric Acid from H₂S & H₂O

Hydrogen sulphide (H₂S), which is slightly soluble in water, reacts with water to form a weak sulphuric acid. As a weak acid, it dissociates initially into the hydrosulphide ion, HS⁻ (pKa=6.9), and then the Sulphide ion, S²⁻ (pKa=11.96). The presence of the hydronium ion, H₃O⁺ is also present.

The reaction is detailed below and can cause corrosion with metal in high concentrations,



However, H₂S is neutralised by the presence of sodium, calcium bicarbonate and other carbonates (e.g., magnesium bicarbonate), all of which are present in the “Oily Water Leg”. Further, the H₂S will be trapped via the two chemical entrapment mechanisms discussed below in Sections 8.7.3 (Ionic Trapping) and 8.7.4 (Mineral Trapping). The H₂S which is not trapped chemically (if any) will be part of the fluid stream being brought to the surface by pumping. The H₂S present in the surface separator will be directed to the generators where the residual H₂S will be burned. In this burning process, the H₂S is converted to water and sulphur.

OSHA established an atmospheric eight-hour H₂S permissible exposure limit-time weighted average (PEL-TWA) of 10 ppm and a 15-minute short-term exposure limit (PEL-STEL) of 15 ppm for exposed workers. NIOSH sets the recommended exposure limit to 10 ppm. As the hydrogen sulphide will be contained within the liquid phase, there is no direct risk to workers. If the H₂S in the liquid phase were to change phase to a gas, then the liberation of the H₂S would be in the atmosphere. The above workplace safety threshold will be adopted. The presence of H₂S as a gas is already routinely assessed in the Moonie Oil Field and monitoring apparatus are on hand. Notwithstanding, this assessment will be extended to the separator and generator and become a routine monitoring program at the facility.

8.7 Fate of Oxygen, Iron, Manganese and Heavy Metals

Given the small amount of CO₂ being injected, modelling predicts that the pH level will change from slightly alkaline to neutral where contact with minerals, carbonates and clay is made. In this process, the suite of ions associated with iron, manganese and heavy metals are held in solution, instead of precipitating out of increasingly acidic solutions. Furthermore, Otto (1998) correctly identifies that oxygen is usually depleted in the oily water leg, as is the case at Moonie.

8.8 The fate of NO_x & SO_x.

A relatively small concentration of NO₂ and SO₂ compounds will be present in the predominantly liquid CO₂ delivered to the field. The scCO₂ flood front is controlled by migration towards the crest of the structure and the ongoing removal of the “oily water leg” fluids by pressure reduction at the five PM wells. In this initial injection project, eighty percent of the delivered scCO₂ is sequestered in the depleted formation by a combination of chemical entrapment and physical forces (density - buoyancy). Similarly, minor SO₂, and NO₂ fractions are also entrapped via the same reactions discussed above. (Table 8.2)

8.9 Geochemical Trapping Mechanisms

The chemical containment of CO₂ in the reservoir occurs in three distinct ways (Krische et al., 2004):

1. Solubility trapping, where CO₂ dissolves or partly dissolves into the receiving environment (water),
2. Ionic Trapping, where the ionic species HCO₃⁻ and CO₃²⁻ are formed from dissolving CO₂; and
3. Mineral Trapping, where the dissolving CO₂ forms sealing carbonate and precipitates as it reacts with minerals, colloidal clays and carbonates particularly at the Precipice seal interface.

8.9.1 Solubility Trapping

The scCO₂ partially dissolves on contact with water and is held within the aqueous phase. During this process there is a phase change from scCO₂ to CO₂.

8.9.2 Ionic Trapping

The scCO₂ partially dissolves in water, producing carbolic ions (Table 8-1). These ions then react with the carbonated solution, in essence trapping the ions within the new carbonate products formed.

8.9.3 Mineral Trapping

As the scCO₂ comes into contact with clay-based or carbonate minerals, the resulting reaction produces carbonate-based elements which entrap the CO₂ and related ions.

8.10 Supercritical scCO₂ and Oil Miscibility

Based on fluid density, the fluid column within the anticline has segregated into gas, oil and water zones. The miscibility of scCO₂ in water produces ions and changes the miscibility of the oil with water, tending to disassociate some of the oil from the oil layer. The rate at which the oil increases its miscibility is dependent on the concentration of oil and related oil fractions, the immediate hydraulic pressure, the temperature, the purity of the immediate elements and the maintenance of the CO₂ in the supercritical state. The rate of change in oil miscibility will be subject to experimentation. Some of the previously held oil fraction becomes more miscible and can flow together with formation water towards the production wells. Some miscible CO₂/water is caught up in this flow with the remainder of the CO₂ being sequestered. For this initial project the model predicts a split of 80% sequestered, to 20% presenting at the production separator. This percentage

may increase to 100% sequestered if surface capture and compression is justified on economical/environmental assessment.

8.11 Rate of dissolution of CO₂ in Groundwater (Water/Oil mixture)

Change in rate of CO₂ dissolution in water will vary according to a combination of factors including the purity of the CO₂, the maintenance of the supercritical phase, the presence of oil and related products, the presence and state of minerals and elements, temperature, pressure, and water salinity. The final rate of dissolution will be determined by experimentation.

Moonie Oil Field CO₂ EOR Project

Initial Injection Plan 2021

Chapter 9: Predictive Reservoir Models & Petrophysics

Commercial in Confidence



The Moonie Oil Well 27 (M27)

Contents

9.0 Executive Summary..... 3

 9.1 Introduction 5

 9.2 Thermally adjusted Reservoir Seal Fracture Pressure 5

 9.3 Moonie Model Trap Volumes - Original Oil in Place Calculations 6

 9.4 CO₂ Injected Radius from the M27 injection well..... 8

 9.5 The Flow Vector Simulation Model..... 8

 9.6 scCO₂ Phase Behaviour 13

 9.7 Relative densities of scCO₂, oil and water 14

List of Figures

Figure 9-1, The Plot of the predicted Reservoir oily water leg Pressure over time..... 6

Figure 9-2, The Hydrocarbon Pore Volume Map for the Precipice Reservoir 7

Figure 9-3, Moonie Oil Field trap volume illustrated in light green..... 8

Figure 9-4, the extent of the scCO₂ trap at end of year three. 9

Figure 9-5, the volumetric CO₂ trap with the oil reservoir at end of injection in year 8 9

Figure 9-6, the modelled volumetric extent of CO₂ in 2050 10

Figure 9-7, 3D simulation of the extent of CO₂ saturation in the Precipice Oily Water Leg 10

Figure 9.8, 3D illustration of the modelled CO₂ saturation in the Precipice oily water leg at end of injection 11

Figure 9.9, 3D illustration of the modelled CO₂ saturation in the Precipice oily water at end of production 2050..... 11

Figure 9-10, from the model 2D illustration of CO₂ saturation at the end of 3 years of injection. 12

Figure 9-11, from the model 2D illustration of CO₂ saturation at the end of injection at 8 years 12

Figure 9-12, from the model 2D illustration of CO₂ saturation at the end of field production 2050 ... 13

Figure 9-13, The Carbon Dioxide Phase Change Diagram..... 14

List of Tables

Table 9-1, The Static Model Case..... 6

Table 9-2, Relative Densities of CO₂ Oil and Water 14

9.0 Executive Summary

The purpose of this amendment is to validate the initial injection project and demonstrate the potential and the ideal geological trap for long term storage of CO₂. Petrophysical and structural modelling analysis forms the basis to create a reservoir model that predicts the behaviour of injected CO₂, other gases, oil, oil fractions and groundwater within the Moonie anticline Precipice “oily water leg”. While the Bridgeport model extends out 50 years the UQ models extend over a period of 1,000 years and indicate the pH returning to the main reservoir conditions along with temperature, pressure, and entrapment of the CO₂ within the Moonie oil field anticline.

Petrophysical analysis is used to calibrate and populate the static geological model cells with geologically realistic porosity, permeability, water and oil saturations in the formation, shale contents and other values linked to downhole analysis, using such data as the Moonie Oil Field core plug analysis, well wireline logs and test data. This information is used to analyse trends in the effective porosity and relative permeabilities linked to each stratigraphic zone. This data is then used to produce a dynamic model simulation. Both UQ SDAAP and Bridgeport have created and run different scale models to predict potential behaviour of the CO₂ flood front and pressure changes in response to various injected CO₂ volumes and injection pressures of the modelling has shown the potential impacts over time.

Numerous vintages of geological analysis and dynamic reservoir modelling by various operators including Bridgeport and by UQ studies indicate the Moonie Oil Field is a low containment risk and an ideal trap to receive and store CO₂.due to the following factors:

- CO₂ remains in the oil column trap that has been stable for the last 90Ma,
- The target Precipice formation, the “oily water leg” contained within the anticline (the target zone) has sufficient porosity and permeability to allow CO₂ to be injected at the initial intended rate of 120,000 tonnes p.a.,
- The target injection zone has sufficient volume to receive the intended injection volume, the model predicting that only 15% of the available anticline volume will be utilised over the entire injection period of eight years,
- Thermogenic sourced CO₂ and other gases are already evident in the Precipice “oily water leg” in a geological trap that has been stable for the last 90 Ma.
- CO₂ will not be able to migrate upward or downward out of the Precipice anticline due to the intra-formation baffles (low permeability units) and the principal reservoir seal at the top of

the formation or into any regional aquifers without human intervention. The reservoir seal has extremely low permeability (Harfoush et al. 2019a, 2019b, 2019c and Honari et al. 2019a) with core plug measurements of horizontal maximum corrected water permeability ranging from 0.003 to 0.086 mD (arithmetic average of 0.037 mD).

- The operational injected CO₂ pressure does not approach the critical reservoir field pressure limits.
- The regional aquifer or surface systems will be unaffected by the injection of CO₂ into Moonie oil field.
- The injection pressure will never exceed 90% of the fracture pressure and will be controlled by a surface pump governor.
- Injected CO₂ will be at super critical conditions, expanding and compressing like a gas but with the density and acting like a fluid within the geological trap.
- The total volume of CO₂ injected over the proposed 8-year project is 1 million tonnes, being <15% of the existing total available reservoir storage capacity.
- The drawdown pressure created by the PM wells generated by artificial lift cause the oil reservoir fluids to flow towards the producing wells, trapping 80 % of the residual CO₂ within the structure.
- The result is that pressure is transmitted horizontally within the Precipice anticline and dissipates with distance and in the Moonie model, predicts a preferred pathway uptake at the five-surrounding production PMwells.
- Critically, the models validate that pressure is not transmitted vertically through the substantial impermeable ultimate seal.

9.1 Introduction

The digital models from UQ and Bridgeport cannot be included in this amendment due to the size of the models. However, the following discussion is based on the outcomes from running the various models.

Within the Moonie anticline the original reservoir pressure was 17,440 kPa (2,530 psi.). Due to water and oil extraction the average reservoir pressure is currently lower at 16,065 kPa (2,330 psi.). The projected reservoir pressure on injection will be above 16,550 kPa (2,400 psi) and below the reservoir seal fracture pressure and designed to maintain the CO₂ in the supercritical phase within the formation.

9.2 Thermally adjusted Reservoir Seal Fracture Pressure

Based on core tests sampling, the reservoir seal fracture pressure has been calculated by University of Queensland (UQ) at 52,170kPa (>7,566 psi.). Rodger's et al 2019) recommends a safety injection pressure of 90% of the above reservoir seal fracture pressure being 46,953 kPa (6,809 psi). Due to downhole receiving thermal environmental conditions the reservoir fracture pressure is further reduced by 14.5% to 39,388 kPa (5,712 psi).

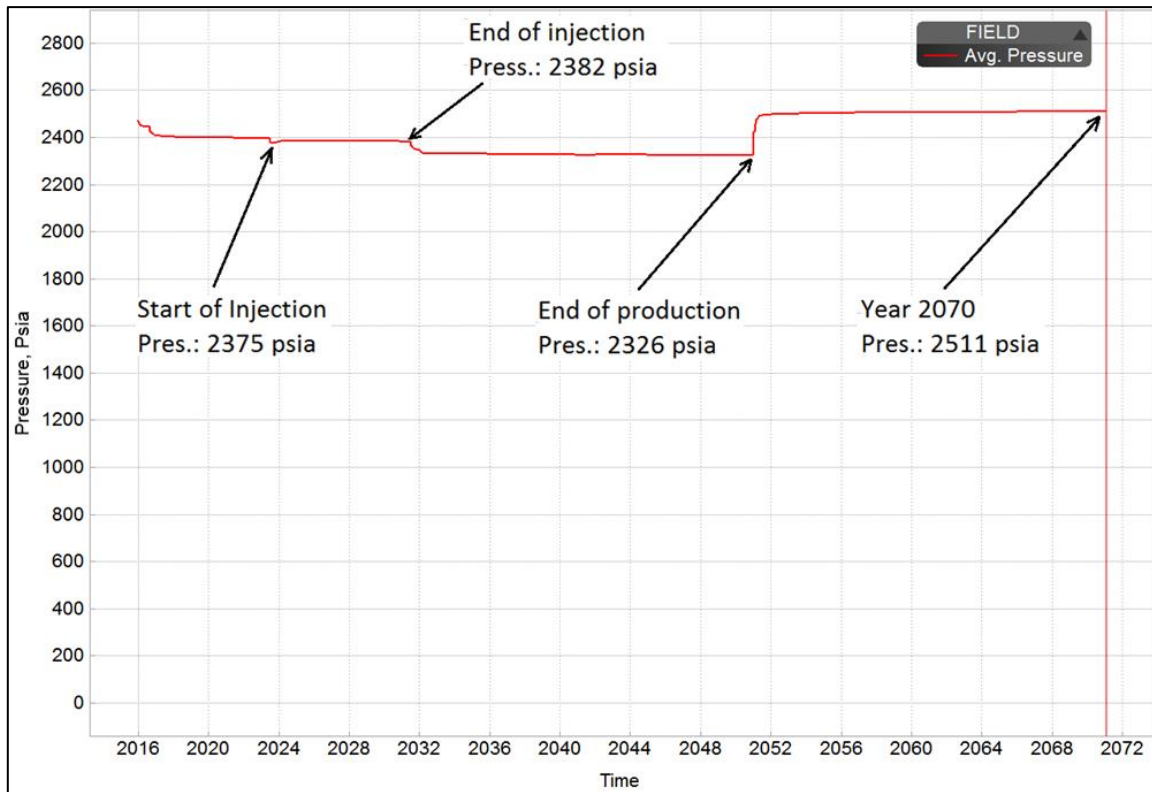
There is a significant safety margin between the planned reservoir injection pressure of >16,550 kPag (2,400 psi) and the thermally adjusted fracture pressure 39,388 kPa (5,712 psi.). Injection pressures at surface will be adjusted between 2,400 psi and 5,712 psi to balance the injection rate of liquid CO₂ with the delivery rate of the CO₂ by road tanker (due to storage limitations).

The greater Precipice main "water leg" sits under the Precipice "oily water leg". The model predicts that the injection process will not change the greater Precipice main "water leg" aquifer pressure.

The following graph Figure 9-1 shows the change in the local pressure of the Precipice oily water leg within the Moonie Anticline out to year 2070. Note the model results demonstrates that original reservoir pressure is not reached by the injection rate of CO₂ during the initial 8-year project and would only be reached in the main sequestration phase after oil production ceases and sequestration commences.

Figure 9-1: Modelled local changes in reservoir pressure during the CO₂ EOR operations is illustrated below.

Figure 9-1, The Plot of the predicted Reservoir oily water leg Pressure over time



9.3 Moonie Model Trap Volumes - Original Oil in Place Calculations

The volumes calculated below are taken from the same reservoir model in the original EA amendment supporting documentation. The model assumes a total 1.0 MMmt of injected CO₂ over 8 years. The results of the Static Model case are detailed in Table 9-1 below,

Table 9-1, The Static Model Case

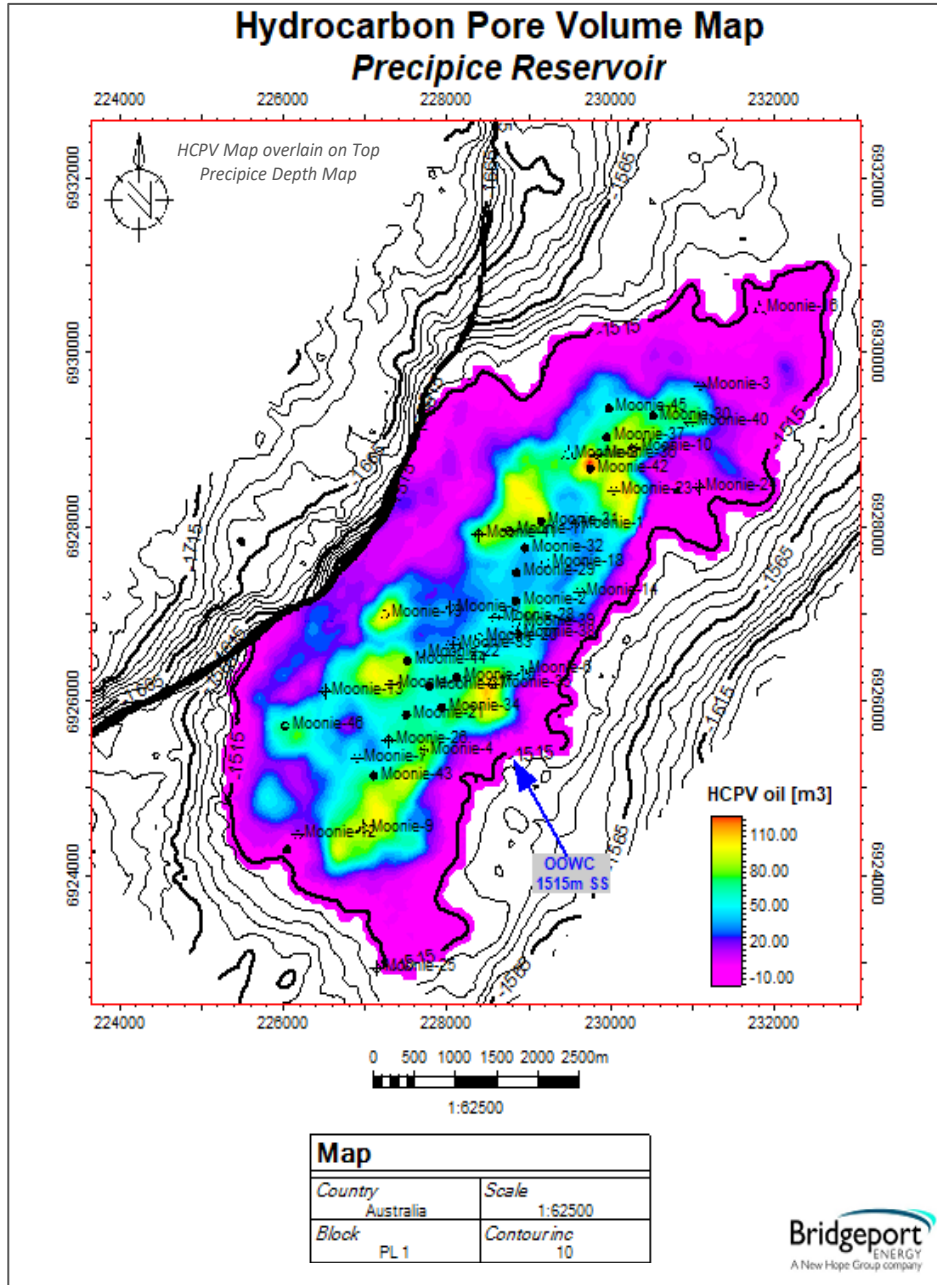
STATIC MODEL CASE (Base_Case_Moonie_Vols_SGS)	Bulk volume [MMm ³]	Pore volume [MMm ³]	HCPV oil [MMm ³]
PRECIPICE	545.35	32	11.92

From the model the CO₂ storage potential within the Precipice “oily water leg” reservoir overlying the Precipice “main water leg” is 11.9 MMm³ (HC pore volume) or 6.6 MMmt.

For this initial project, the maximum volume of CO₂ injected p.a. will be 120,000 tonnes p.a., or 216,200 m³ at reservoir conditions. In three years, this represents 0.65 MMm³ or 5.4% of capacity

and at 8 years represent 1.73 MMm³ or 14.5% of the capacity. Figure 9.2 below illustrates the Hydrocarbon Pore Volume Map for the Precipice Reservoir.

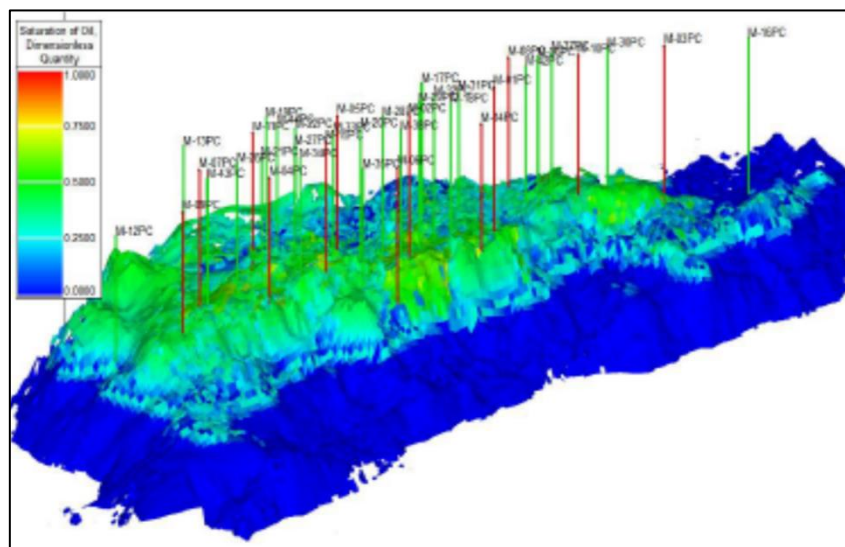
Figure 9-2, The Hydrocarbon Pore Volume Map for the Precipice Reservoir



9.4 CO₂ Injected Radius from the M27 injection well.

The overall Moonie Oil Field surface footprint is 4km by 16km. The injection well M27 is centrally located, and over 4 km from the sealed Goondiwindi Fault. Simulation of the oil, water and supercritical CO₂ (scCO₂) vector flows show the injected volume expansion around M27 will be approximately ~1200m X 400m. The injected scCO₂ does not approach the field limits. Figure 9-3 below illustrates this volume (light green) within the Moonie Oil Field.

Figure 9-3, Moonie Oil Field trap volume illustrated in light green



From the simulation model the injected scCO₂ cannot migrate outside of the initial project area as natural physical barriers prevent convection within the anticlinal restricted oil reservoir. Physically the scCO₂ is less dense than oil and water and does not migrate downwards in the pure state.

9.5 The Flow Vector Simulation Model

The flow vector simulation model predicts the injected volume remaining within the contained anticlinal reservoir (the Precipice “oily water leg”) and within the area of the initial project producing and monitoring wells over a period of eight years. The vectors calculated by the model are illustrated in the following Figures 9-4, 9-5 and 9-6. Note that the individual flow vectors represent modelled fluid movement. The size and number of lines are modelled representations of the volume and direction of movement resulting from local pressure gradients. All vectors flow towards the receiving production wells.

Figure 9-4 below, Illustrating the extent of CO₂ trapped at year three (2026).

Figure 9-4, the extent of the scCO₂ trap at end of year three.

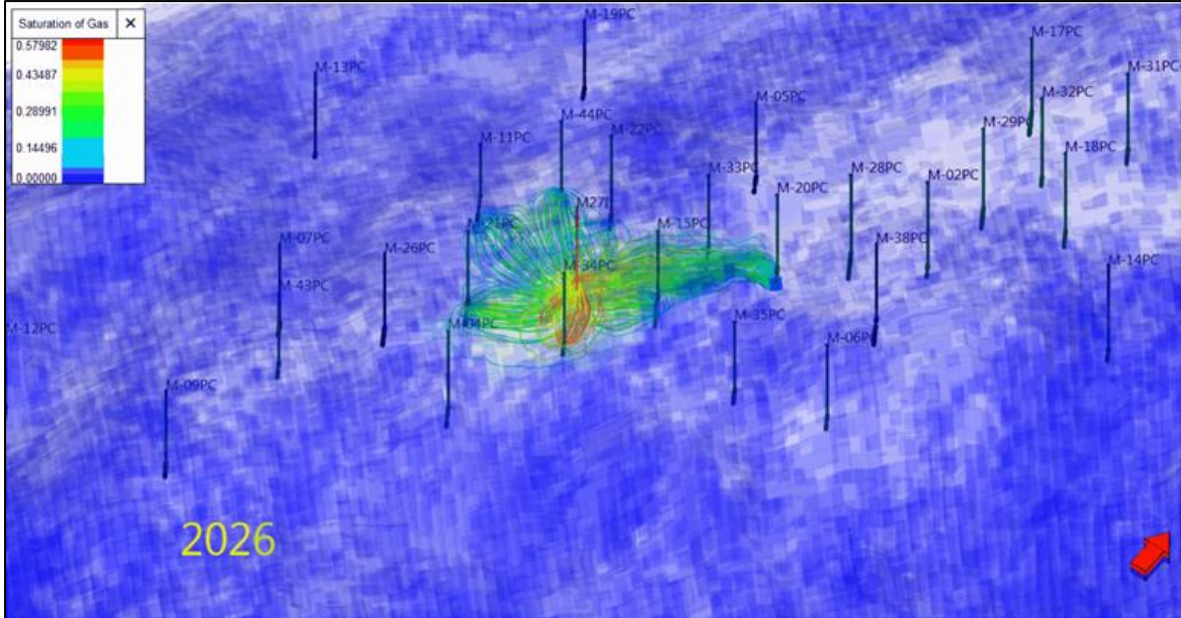


Figure 9-5 Illustrating the volumetric CO₂ trapped at end of injection in year eight (2031).

Figure 9-5, the volumetric CO₂ trap with the oil reservoir at end of injection in year 8

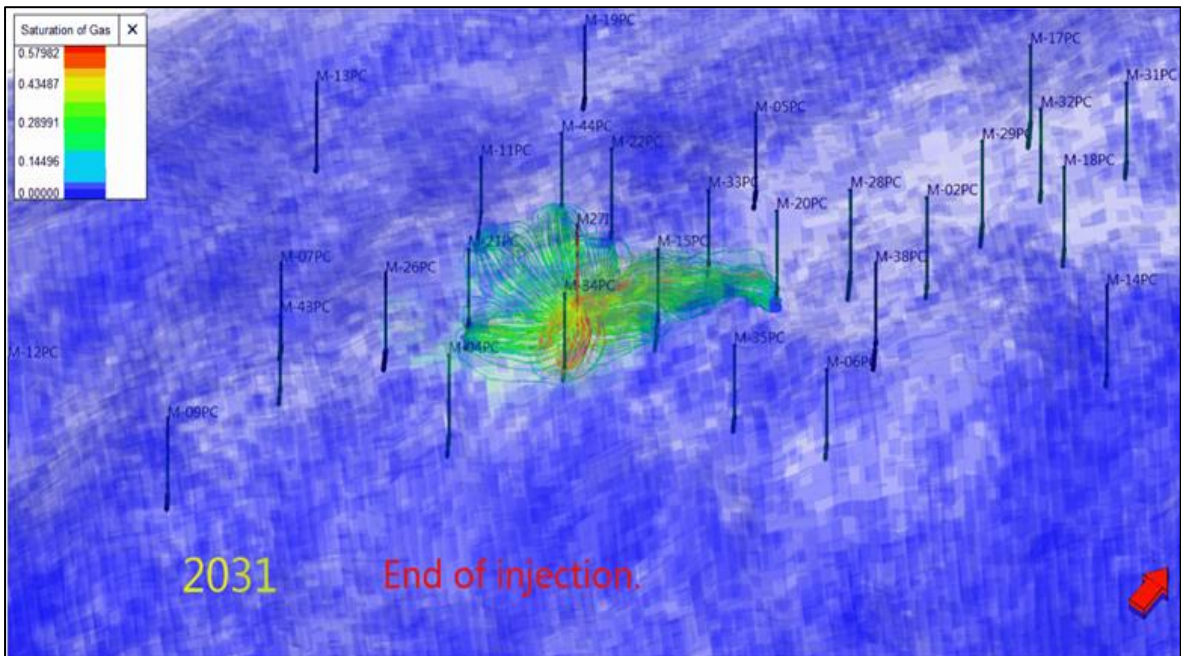
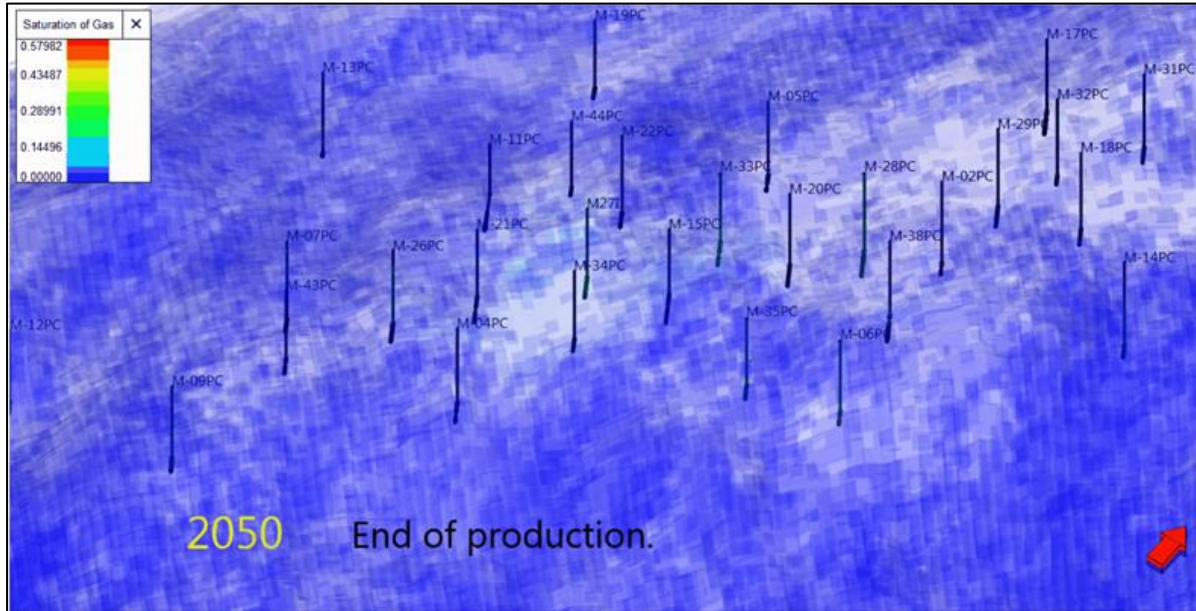


Figure 9-6 illustrates the volumetric CO₂ trapped within the oil reservoir at end of injection in year 2050.

Figure 9-6, the modelled volumetric extent of CO₂ in 2050



From the model the following figures 9-7, 9-8 and 9-9, illustrate the 3D saturation of CO₂ within the Precipice “oily water leg”. At three years from commencement of injection, at the end of injection in eight years and at end of production in 2050.

Figure 9-7, 3D simulation of the extent of CO₂ saturation in the Precipice Oily Water Leg

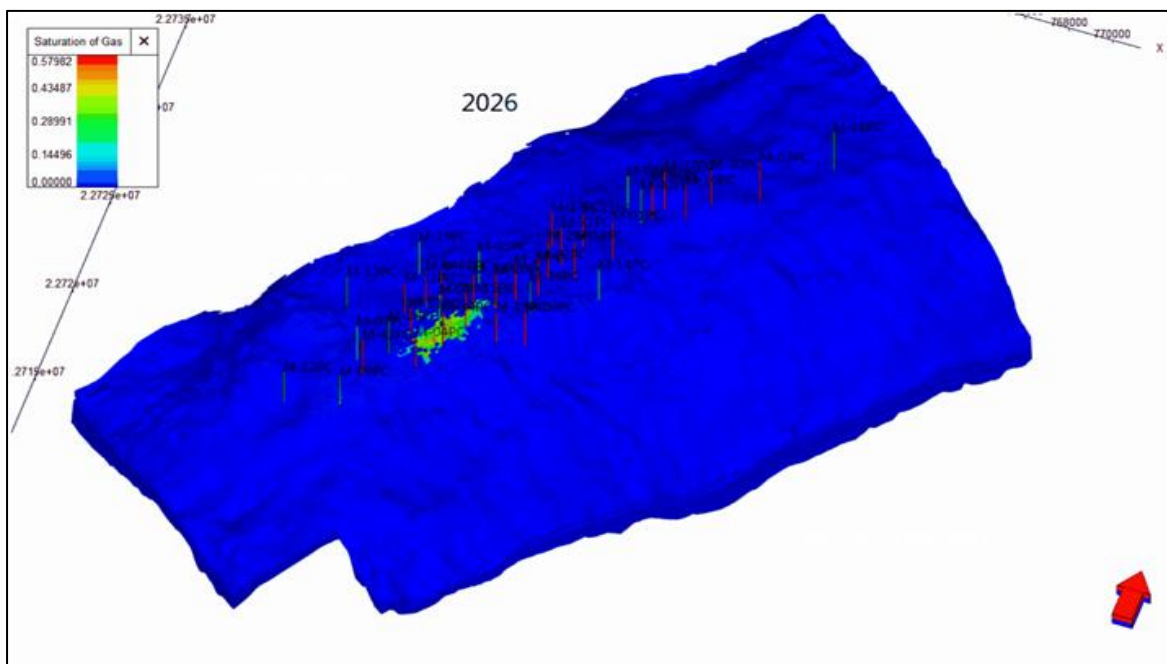


Figure 9.8, 3D illustration of the modelled CO₂ saturation in the Precipice oily water leg at end of injection

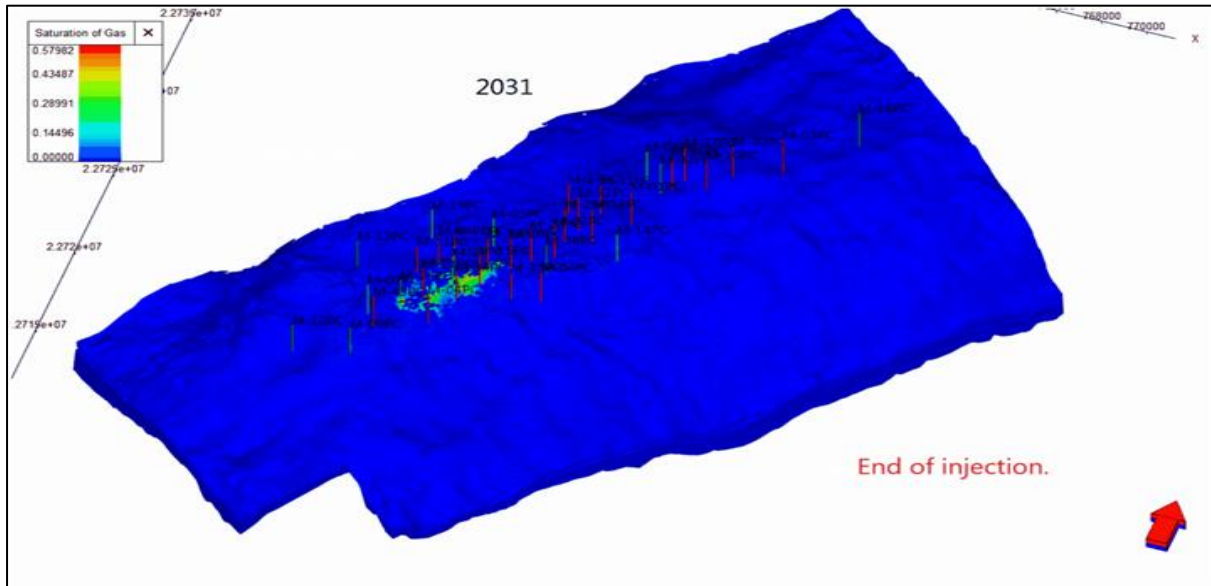
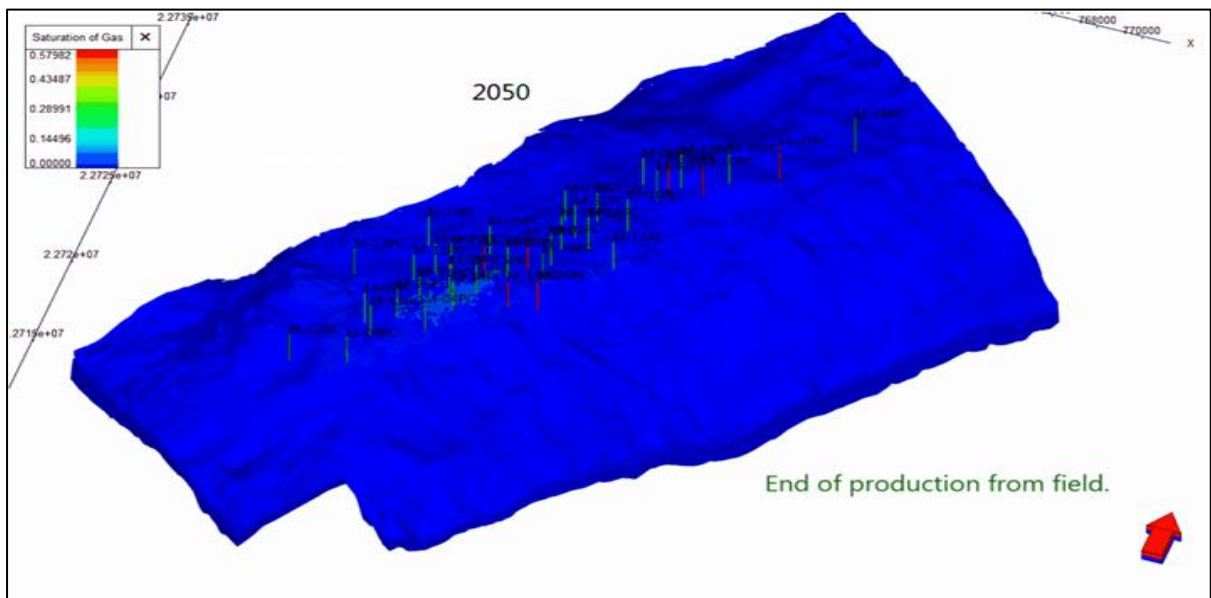


Figure 9.9, 3D illustration of the modelled CO₂ saturation in the Precipice oily water at end of production 2050.



The following figure 9-10, 9-11 and 9-12, illustrate the CO₂ saturation in 2D over the same time span.

Figure 9-10, from the model 2D illustration of CO₂ saturation at the end of 3 years of injection.

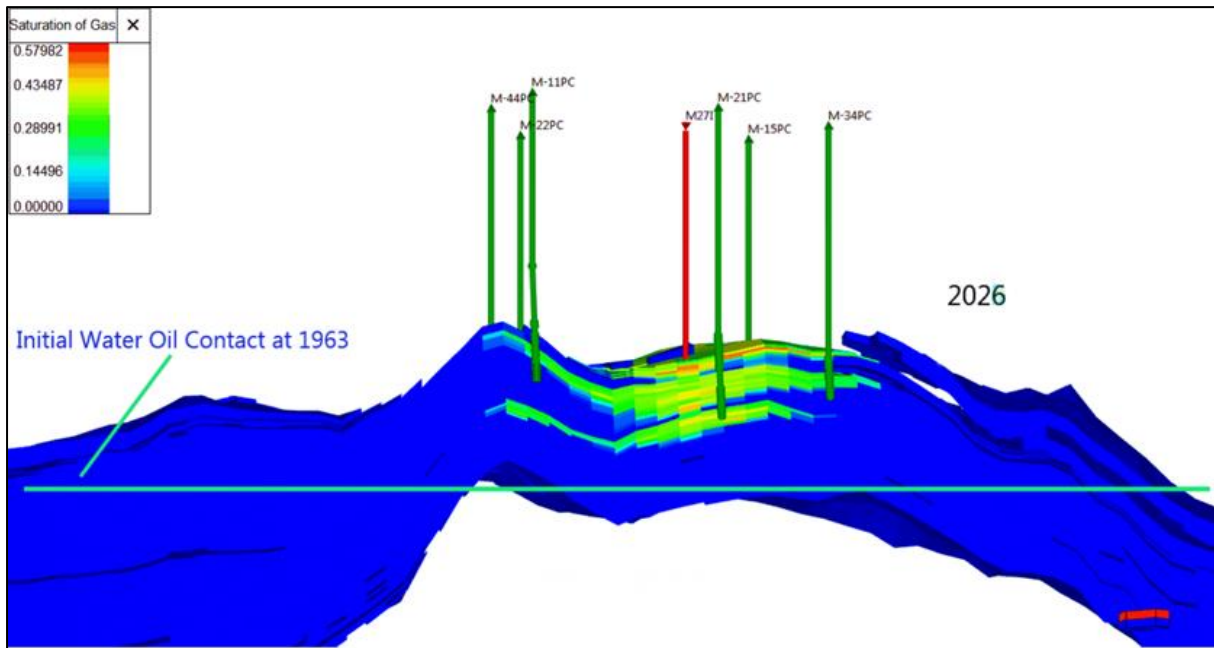


Figure 9-11, from the model 2D illustration of CO₂ saturation at the end of injection at 8 years

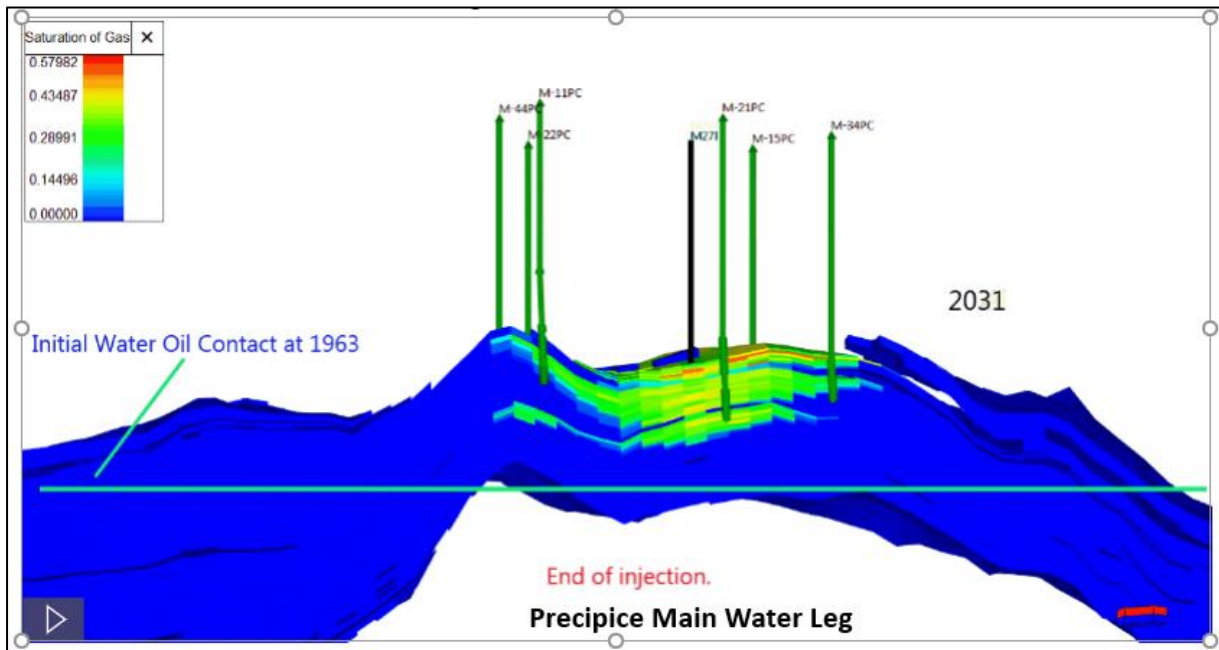
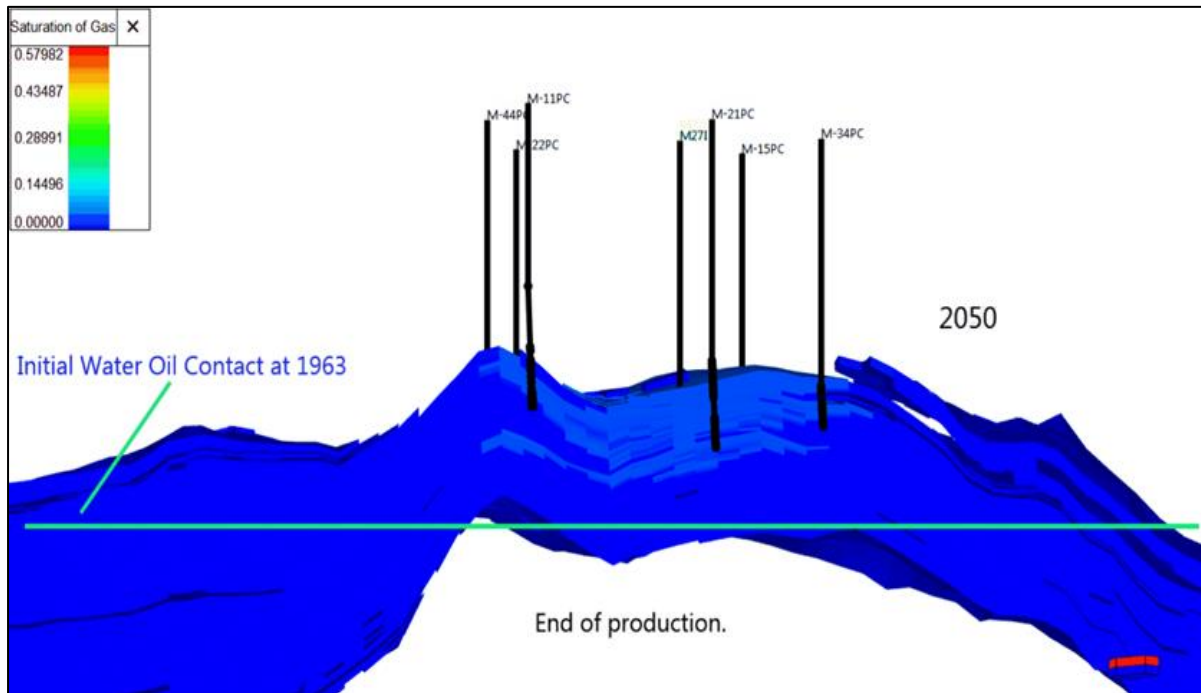


Figure 9-12, from the model 2D illustration of CO₂ saturation at the end of field production 2050



9.6 scCO₂ Phase Behaviour

The pressure of the CO₂ is increased from storage conditions, then pre-heated at surface prior to controlled injection to prevent thermal effects.

CO₂ remains in a supercritical state at reservoir conditions but will “gasify” within producing wells (post-emergence from the reservoir) as pressure reduces towards the surface. Similar in fashion to opening a carbonated drink.

Remaining CO₂ volume is entrapped in the oil reservoir and will compress/shrink after production ceases and reservoir pressure returns to original.

9.7 Relative densities of scCO₂, oil and water

At reservoir conditions, scCO₂ is less dense than water and oil and will tend to remain at the top of the oil reservoir.

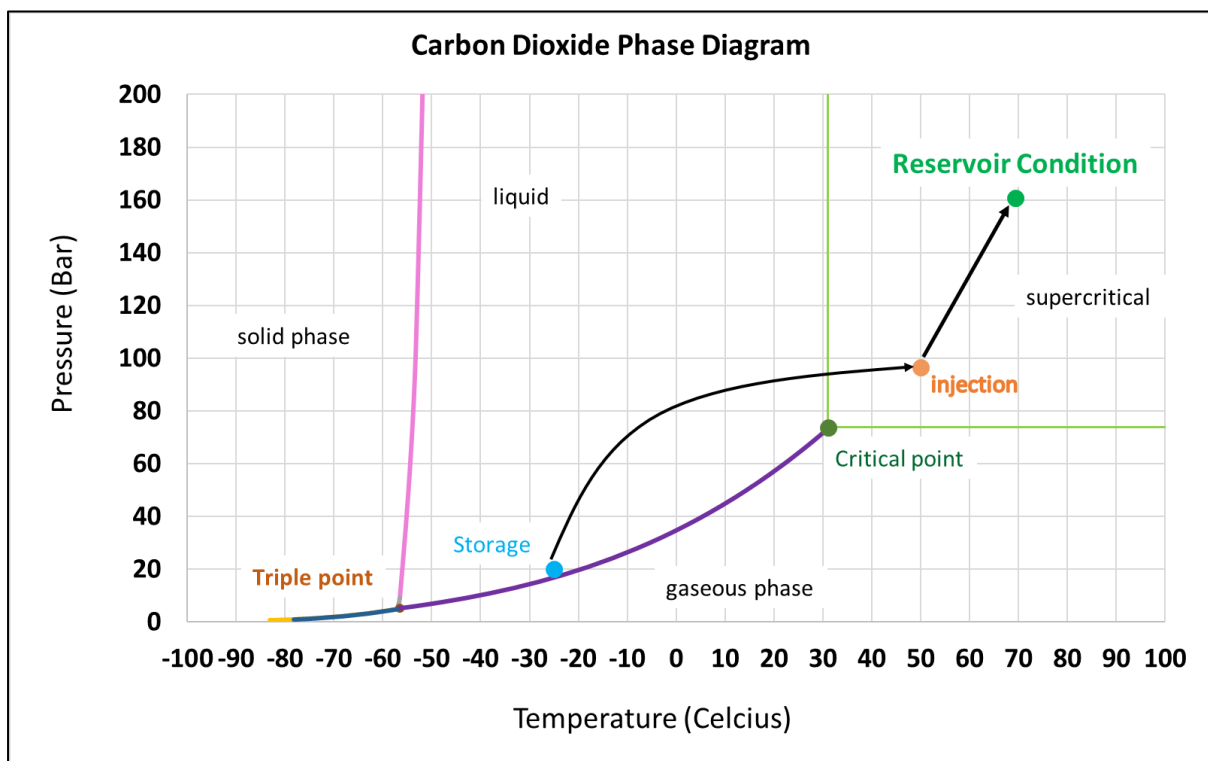
Table 9-2 below lists the various relative substance densities and illustrates the CO₂ density is lighter than oil or water and will tend to remain above the oil and water.

Table 9-2, Relative Densities of CO₂ Oil and Water

Relative Density	kg/m ³
scCO ₂	555
Moonie Crude Oil	741
Water	1,002

Figure 9-13 below illustrates the changes in CO₂ phases with changes in pressure and temperature.

Figure 9-13, The Carbon Dioxide Phase Change Diagram



“Supercritical CO₂ (scCO₂)” is a fluid state of CO₂, where it is held at or above its critical temperature and pressure (the Critical Point). scCO₂ will expand to fill its container like a gas, but with a density like a liquid. The maintenance of the supercritical CO₂ phase is crucial to the EOR process whereby some of the oil fraction becomes more miscible and can flow to the receiving production wells.