Santos Moomba to Cross-Border Carbon Capture and Storage Pipeline

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1 Introduction

In December 2020 Santos announced its ambitious new emissions reduction targets, including being net-zero by 2040. Upon receiving eligibility for Australian Carbon Credit Units (ACCUs), the Moomba Carbon Capture and Storage (CCS) Project will be an important component of achieving this industry-leading target. The Project will deliver a commercial large-scale CCS hub centred around the Moomba Gas Plant, targeting capture of 1.7 Mtpa CO2-e of vented greenhouse gas emissions for injection into depleted gas reservoirs in the Cooper Basin.

This paper will give background into the role of CCS, provide details of the current status of the project and the decisions made during the concept and FEED stage with particular focus on the pipeline design. The Moomba to Cross-Border CCS Pipeline is DN 250 and approximately 50 km in length, designed to transport CO_2 in dense phase at pressures between 10-15 MPa. The paper will discuss the process and mechanical challenges of transporting dense phase CO_2 and the application of the Appendix T in AS 2885-1.

Special design considerations include:

- Selection of dense phase CO_2 for transport to avoid two-phase flow and maintain stable operation throughout the injection regime
- Assessment of loss of containment risk leading to the route selection, and mitigations such as thicker wall “no rupture” pipe for sections of the alignment
- CO_2 dehydration to avoid corrosion and hydrate formation, considering normal and upset scenarios
- Low temperatures from blow down events leading to material selection, vent design and an operating philosophy supported by North American operating experience

2 Role of Carbon Capture Storage

For the world to transition to a more sustainable energy system, the development and scaling of new technologies will be required. Carbon Capture and Storage (CCS) is one such technology which is being called for on a global scale to enable the decarbonisation of the global energy system, while providing affordable energy supply to both advanced and developing economies.

The International Energy Agency (IEA) has identified carbon capture technology as playing a vital decarbonisation role in the power, energy transformation, and industry sectors under their Sustainable Development Scenario (SDS) and Net-zero by 2050 (NZE) scenario. To achieve these scenarios, a significantly accelerated adoption of carbon capture technology is required from today’s annual 40 Mt CO_2 as demonstrated in Table 2.1. Development of existing carbon capture technologies will also enable the development of additional vital technologies, such as low carbon hydrogen production, negative emission bio-energy production and carbon dioxide direct air capture.

Table 2.1: Global Carbon Capture Adoption required to achieve IEA and NZE scenarios

IEA Scenario	Scenario Objective	Global Carbon Capture Adoption ($Mt\ CO_2$ p.a.)		
		2020	2030	2050
SDS[1]	Achieve existing climate, clean air, and energy access goals	40	850	5,000
NZE[2]	Net-zero emissions in the energy sector by 2050 while achieving climate, clean air, and energy access goals	40	1,700	7,600

3 Carbon Capture Storage Technology Maturity

Carbon Capture and Storage is an established technology with large-scale projects having been implemented since the 1990's in Natural Gas Processing and Hydrogen Production facilities as shown in Table 3.1. These projects have typically been motivated by local government policy incentives or mandates, but nevertheless demonstrate the maturity of CCS technology.

Table 3.1: Global CCS projects of size greater than 0.5 Mt CO_2 p.a.

Project[3]	Location	Year Operational	Size (Mt CO_2 p.a.)	CO_2 Source
Sleipner	Norway	1996	0.9	Natural Gas Processing
In Salah	Algeria	2004 (ceased 2011)	1.0-1.2	Natural Gas Processing
Snohvit	Norway	2008	0.7	Natural Gas Processing
Quest	Canada	2015	1.2	Hydrogen Production
Gorgon LNG	Australia	2019	3.3-4.0	Natural Gas Processing
Qatar LNG CCS	Qatar	2019	2.1	Natural Gas Processing

It is expected that the continued development of national emission reduction targets and associated emission trading schemes, taxes and other incentives will financially motivate the development of more CCS projects. At the same time, the development of corporate emission reduction targets and an increase in Environmental, Social and Governance (ESG) focussed investment is expected to result in increased private sector investment into the developing CCS sector.

4 Moomba CCS Project Overview

Moomba is a natural gas processing hub in the South Australian portion of the Cooper Basin, purifying natural gas before distributing it to South Australia, New South Wales, and Queensland via the East Coast domestic gas pipeline network. One of the processing steps at Moomba is to remove the CO_2 from the natural gas, where it is then vented. The objective of the Moomba CCS project is to capture this vented CO_2 and instead store it back underground within depleted gas reservoirs, avoiding its release to the atmosphere.

[1] International Energy Agency (2020), World Energy Outlook, IEA, Paris
[2] International Energy Agency (2021), Net Zero by 2050, IEA, Paris
[3] MIT Carbon Capture & Storage Technologies Project Database: https://sequestration.mit.edu/tools/projects/storage_only.html

An overview of the Moomba CCS project is shown in Figure 4.1.

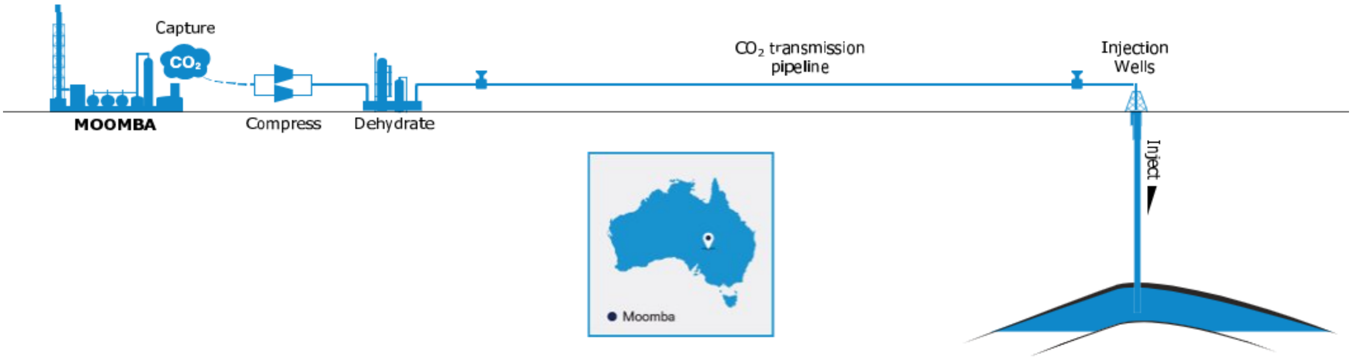

Figure 4.1: Moomba CCS Project Overview

To capture the CO_2 vented at Moomba and store it within Cooper Basin depleted gas reservoirs, there are five major steps:

- Capture: A stainless steel header is used to connect the four existing CO_2 removal units, collecting the CO_2, and delivering it to the CCS compressor at near atmospheric pressure.
- Compression: A four stage centrifugal compressor compresses the CO_2 up to a pressure of ~13 MPa. Compression of the CO_2 is required to push it through the pipeline and into the depleted gas reservoirs. The first three stages of compression also reduce the concentration of water in the CO_2, reducing the load on the Tri-Ethylene Glycol (TEG) dehydrator.
- Dehydration: A TEG dehydration package further removes moisture from the CO_2 prior to its entry to the pipeline. This is to ensure there is no formation of free water within the carbon steel CO_2 pipeline, preventing the occurrence of corrosion, and the formation of CO_2 hydrates.
- Transport: A 50 km carbon steel pipeline transports the compressed, dehydrated CO_2 from Moomba to the injection reservoir.
- Injection: Four injection well skids are used to monitor and control the rates of CO_2 injection at each well while ensuring the pipeline and depleted gas reservoirs stay within their operating windows.

The Moomba CCS project is advantaged due to its location within the Cooper Basin, a region that has been producing gas since the 1970s and therefore contains several well understood depleted gas reservoirs, with vast amounts of data and knowledge having been acquired through the reservoir's operation. The geological and production history provides confidence in the reservoirs ability to safely contain and permanently store CO_2 as well as its injectivity and volumetric properties.

5 Project Status

The Moomba CCS project has undergone extensive engineering development and is technically ready for execution upon receiving eligibility for ACCU generation. The pipeline has been designed through the concept and FEED stages in collaboration with multiple Australian based engineering and construction firms including Fyfe, GHD and MPC Kinetic.

The pipeline design is in accordance with AS2885, however since CO_2 pipeline design standards are rapidly developing with continued research, Santos has also consulted with international guidelines and relied on input from pipe suppliers. The project has also brought in international expertise in the form of industry review from Occidental Petroleum, a North American operator with extensive CO_2 pipeline operational experience.

Given that once constructed, this pipeline will be the longest CO_2 transmission pipeline in Australia, the project saw it critical to engage both domestic and international experience, ensuring a safe and operable design while building domestic capability and knowledge within the Australian Gas and Pipeline industry.

To further share capability and knowledge within the industry, design considerations which were encountered during the Moomba CCS Project and are unique to CO_2 pipeline service are detailed in the following sections.

6 Supercritical Transport

Long distance transport of CO_2 is typically achieved in the state of a supercritical fluid, which refers to a fluid above its critical pressure and temperature. For pure CO_2, this critical point is reached above a pressure of 7,400 kPag and temperature of 31°C. At these conditions, distinct liquid and gas phases do not exist and efficient transport benefits from a high fluid density.

The Moomba to Cross-Border CCS Pipeline is similarly designed to transport CO_2 as a supercritical fluid to benefit from a high fluid density while avoiding operation within a region of where two-phase flow and slugging can occur. While it is possible that the pipeline temperature can fall below the fluid's critical temperature during low ambient conditions, the pipeline conditions are to be always maintained well above the fluids critical pressure to avoid two-phase flow. This is achieved at the pipeline inlet by controlling the Moomba compressor, with pipeline outlet pressure maintained at the injection skid control valves.

While transportation in the gaseous phase is also possible, a similar pipeline constraint would need to be imposed to avoid two-phase flow, limiting the operational pressure to below 4,000 kPag for ground temperatures potentially reaching 5°C. Such gaseous phase transport is possible, however does not benefit from the increased CO_2 density achieved by transitioning to a supercritical phase, thus requiring a much larger diameter pipeline for the same flow rates. The conditions of the target CO_2 sequestration reservoirs also need to be considered as they may require injection pressures greater than 4,000 kPag. This is the case for the Moomba CCS project whereby the initial required injection pressure of ~4,000 kPag increases as CO_2 fills the depleted gas reservoirs. If the CO_2 were to be transported in gas phase, it would therefore require additional compression at the remote injection wells, adding cost and system complexity.

The supercritical/dense phase and gaseous phase transport regimes are highlighted in the below phase envelope diagram (Figure 6.1), demonstrating the region to be avoided where two-phase flow is possible under low pipeline temperature conditions. It should be noted that the phase envelope will be project specific depending on impurities within the CO_2 streams composition. The below phase diagram represents the Moomba CCS Project composition based on sampled process data and differs to a pure CO_2 stream. Overlayed on the phase diagram is an indicative CO_2 phase path for the Moomba CCS Project at initial injection conditions. As the injection reservoir builds pressure, the extent of injection throttling will reduce.

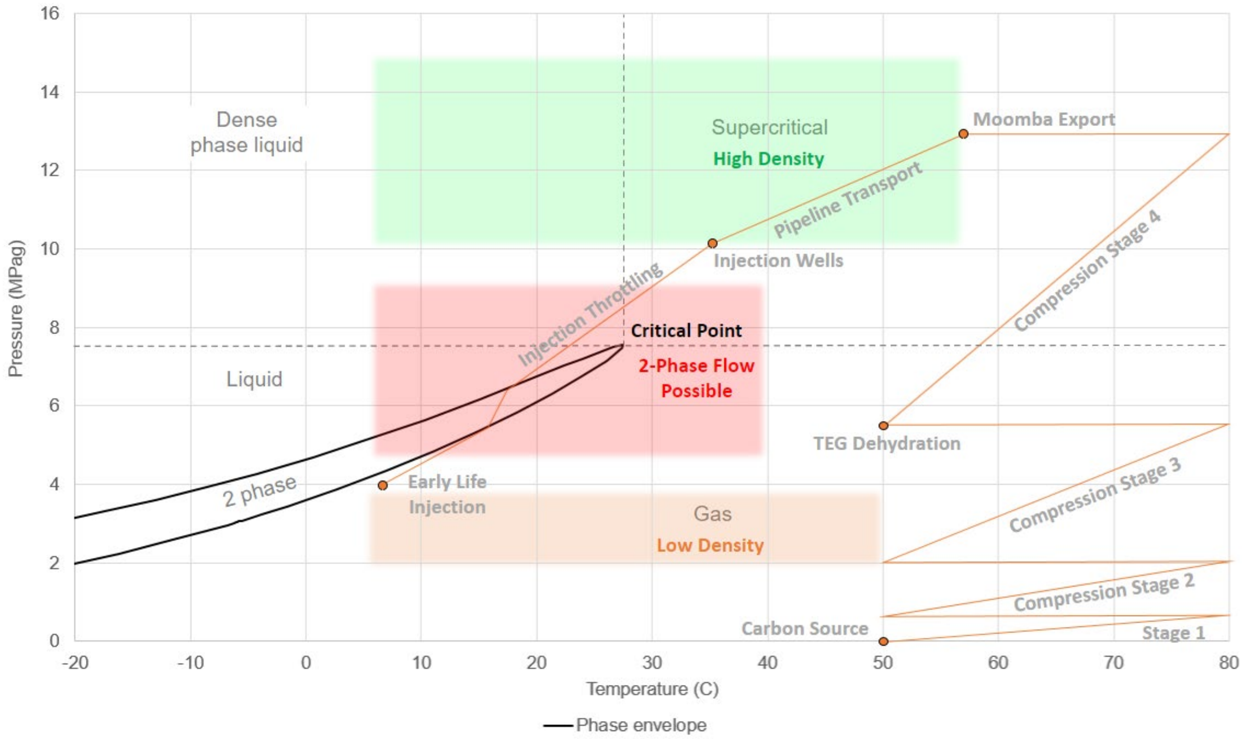

Figure 6.1: Moomba CCS Indicative CO_2 Operating Envelope

To ensure that two-phase flow does not occur within the upstream compression and dehydration processes, conditions are maintained to be above the critical temperature, ensuring gas or supercritical conditions are maintained. Two-phase flow is expected to occur under some conditions downstream of the injection well skid, however this is considered within the injection skid and well designs.

7 Safety Management

The Moomba to Cross-Border CCS Pipeline runs approximately 50 km east from the Moomba Plant CCS Facility to depleted reservoirs in the Marabooka and Strzelecki fields which have been selected for the first phase of injection (Figure 7.1). The route has been selected to avoid populous areas, maintaining an R1 classification for the great majority of the alignment. Where this was unavoidable, for example, at the exit of the CCS facility, a heavy wall / no rupture pipe has been selected.

The above controls have been to mitigate personnel exposure to CO_2. Full-bore rupture dispersion modelling of the 5% CO_2 concentration radius has informed the safety management study as per AS2885.6[4]. Since the safety implications of CO_2 release are driven by exposure, this is treated as the traditional radiation contour of hydrocarbon pipelines. Hydrogen Sulphide (H_2S) within the fluid stream has also been considered for toxicity on release but is in low concentration and non-dominant for the pipeline safety management.

A vent station is included in the design for the case that the pipeline needs to be depressured. The location for the vent station has been selected based on pipeline depressuring dynamics and to allow for an exclusion zone to avoid personnel exposure to CO_2. Local vents for release of small

[4] AS/NZS 2885.1:2018, Pipelines – Gas and liquid petroleum Part 1: Design and construction, Standards Australia.

volumes such as at station piping facilities and injection skids are included and designed to discharge at a safe height.

A mass balance leak detection has been included in the design to promptly notify the control operator should any CO_2 leaks develop.

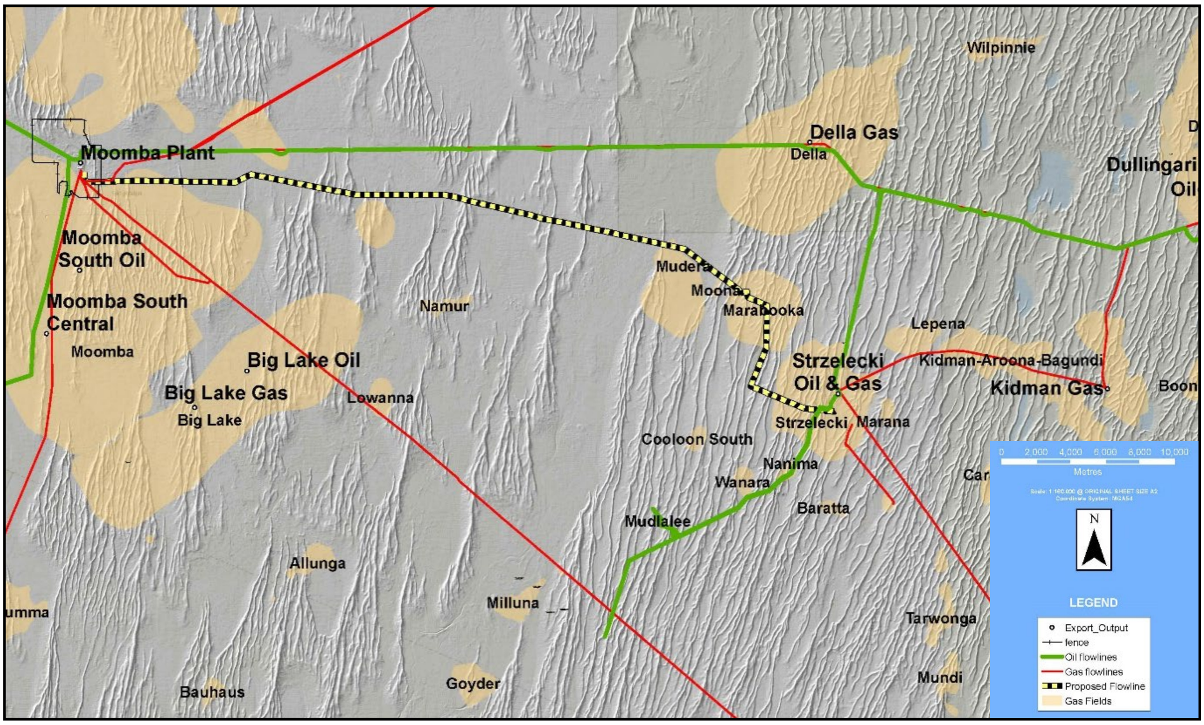

Figure 7.1: Moomba to Cross-Border CCS Pipeline Alignment

8 Dehydration

Dehydration of the CO_2 fluid is required prior to entering the Moomba CCS pipeline. Primarily, this is to avoid the formation of free water in the high-pressure CO_2 environment which would lead to corrosion of the carbon steel pipeline. Secondarily, this is to avoid the formation of CO_2 hydrates across throttling valves at pipeline de-pressuring vents and at the injection wells.

A TEG dehydration package is used to reduce the moisture content of the CO_2 such that formation of free water and hydrates is avoided under all routine operating scenarios. This is ensured via an on-line moisture analyser which diverts any off-specification CO_2 from entering the pipeline. Pigging facilities have been included to the design to allow prompt removal of free water in the remote case of a significant moisture excursion. The avoidance of remnant water following the construction hydrostatic test is also of critical importance and has led to procedures to ensure the pipeline is dried to a stringent dewpoint during commissioning.

9 Low Temperature Design

Reduction in pressure of dense phase CO_2 pipelines can result in extreme cooling. This is due to both the CO_2 refrigerant cooling effect as the fluid de-pressures through its two-phase region and the Joule-Thompson (JT) cooling effect as with conventional gas pipelines.

Modelling of the pipeline temperature profile when venting the full volume has shown that an extended duration blowdown, holding at the two-phase transition pressure to allow the liquid CO_2 to vaporise allows the pipeline to be safely vented without exceeding minimum temperature limits for carbon steel line pipe. This approach was confirmed with North American operator blowdown procedures for similar pipelines.

This operating philosophy coupled with restriction orifices and globe valves ensure that the rate of blowdown will not cause low temperature excursions in the pipeline. Continuous temperature monitoring points are also included at each of the pipeline stations to ensure the minimum design temperature is not exceeded. Where unavoidable severe low temperatures are expected such as blowdown piping at the vent station and downstream of the injection skid choke, stainless steel materials have been selected.

10 Pipeline Fracture Mitigation

Designing to mitigate pipeline fracture propagation is standard practice as per AS 2885 and has been incorporated in the project line pipe specification. For CO_2 pipelines, low energy running ductile fracture control requires particular attention due to the High Vapour Pressure (HVP) characteristics of the fluid which vary with the composition.

For the Moomba CCS process conditions, running ductile fracture is controlled with an increased wall thickness and Charpy toughness at the pipeline design minimum temperature. The increased toughness has been confirmed in consultation with suppliers as the most economic method of fracture control. Crack arresters have also been considered but deemed unnecessary due to the toughness of steel available on the market.

Calculation methods for tearing fracture control arrest toughness are continuously developing for CO_2 pipelines based on new research. To ensure the best available methods are employed for the project, both the traditional Two Curve Method calculations and the recently published DNV recommended practice[5] has been used for selection of required toughness.

11 Material Selection

The project material selection has been driven by the special design considerations unique to CO_2 pipelines as detailed in the above sections – refer a summary of the driving considerations in Table 11.1.

The pipeline material selection has been driven by economics and the details in previous sections. As the standard wall line pipe selection is governed by fracture control requirements the adoption of more costly high yield grades of pipe was not warranted. Additionally, sour service NACE MR0175 pipeline materials are specified to prevent the rapid onset of sulphide stress corrosion cracking due to the small presence of H_2S within the process stream.

Non-metallic materials such as O-rings, valve seats and seals have been selected to be impervious to CO_2 to avoid swelling and rapid gas decompression that is caused as CO_2 diffuses into elastomers and cannot diffuse out of the material at the same rate the system is depressurising.

[5] DNVGL-RP-F104 (February 2021) - Design and Operation of Carbon Dioxide Pipelines

Table 11.1: Summary of material selection driving considerations

Component	Driving Considerations
Line Pipe	Penetration resistance (Heavy wall / no rupture sections) Fracture Control NACE Requirements Minimum temperatures Cost and availability
Vent Pipework / Downstream of Choke	NACE Requirements Severe Low Temperatures
Valves	NACE Requirements CO_2 effect on soft goods Minimum Temperatures
Station Piping	NACE Requirements Minimum Temperatures

12 Conclusion

The continued development and implementation of CCS technology is required for the world to transition to a more sustainable decarbonised energy sector. While CCS is a relatively new technology to Australia, there is significant international experience which can be drawn on, with further industry collaboration accelerating its deployment as a safe, economic, and sustainable method of energy decarbonisation.

The Moomba CCS Project represents an exciting, low-cost CCS project which, once in operation, will place Australia at the leading edge of CCS globally. The project leverages inherent advantages of the Moomba facility and well understood depleted gas reservoirs. Project success will open the door for additional CCS opportunities as well as demonstrate a key element required for additional technologies such as the production of low emission hydrogen from natural gas.