Development of a CO₂ specification for a CCS hub network

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Abstract

The CarbonNet Project (CarbonNet) has developed a preliminary CO₂ specification for its carbon capture and storage (CCS) hub based network as part of its feasibility studies. This paper provides a summary of the approach CarbonNet used to develop the CO₂ specification, focusing on the main elements of the specification and the trade-offs required between the capture, transport and storage components of the CCS project chain.

CarbonNet is exploring the feasibility of a commercial scale CCS network delivering CO₂ captured from a range of source projects in the Latrobe Valley of Victoria, Australia, which contains one of the world’s largest brown coal deposits, to storage sites in the offshore Gippsland Basin, which has greater than 31 gigatonnes of CO₂ storage potential.

The CO₂ captured from potential source projects will contain minor components which may affect the physical properties and phase envelope of the stream, impact environmental and regulatory requirements, set the transportation and storage design and influence the storage site capacity and geochemistry.

The philosophy adopted by CarbonNet for the CO₂ specification was a risk based approach to not discourage or prevent potential sources connecting to the network and to allow whole of project CCS costs to be minimised, not just the transport and storage elements.

The CO₂ specification developed from consideration of limitations imposed by the subsurface, pipeline design and health and safety, reviewing business as usual and technically achievable limits of potential source proponents and considering future...
acceptance of the proposed specification by targeted assessments. Trade-off studies were completed on the water content, operating pressure and purity requirements. Commercial considerations were reviewed for cost recovery of increased transport and storage costs associated with lower purity CO₂ and/or high levels of specific minor components. The CarbonNet CO₂ specification has a lower and upper bound for many components and the specification will be further refined to meet the requirements of regulators, design limitations and/or commercial arrangements between source proponents and the transport and storage owner during the next stage of the project.

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1. Introduction

The CarbonNet Project (CarbonNet) is exploring the feasibility of a commercial scale CCS network delivering CO₂ captured from a range of potential source projects in the Latrobe Valley of Victoria, Australia, which contains one of the world’s largest brown coal deposits, to storage sites in the offshore Gippsland Basin.

CarbonNet has developed a preliminary CO₂ specification for its carbon capture and storage (CCS) hub based network as part of its feasibility studies. This paper will provide a summary of the risk based approach CarbonNet used to develop the specification, with a focus on the main elements of the specification and the trade-offs required between the capture, transport and storage components of the CCS project chain. A more detailed report on the development of the specification is available [1].

The CO₂ captured from potential source projects will contain minor components which may affect the physical properties and phase envelope of the stream and impact environmental and regulatory requirements. These factors will set the transportation and storage design and influence the storage site capacity and geochemistry.

The philosophy adopted by CarbonNet for the CO₂ specification was a risk based approach to not discourage or prevent potential sources connecting to the network and to allow total whole of project CCS costs to be minimised, not just the transport and storage elements.

In developing the CO₂ specification CarbonNet assessed the range of indicative CO₂ compositions from potential sources, in particular the differences between post-combustion, pre-combustion and oxy-fuel sources and investigated the impacts these may have on pipeline design and storage capacity and integrity. Business as usual and technically achievable limits for the various sources were identified and trade-off studies were completed on the water content, operating pressure and purity requirements. Commercial considerations were reviewed for cost recovery of increased transport and storage costs associated with lower purity CO₂ and/or high levels of specific minor components.

The CarbonNet CO₂ specification has a lower and upper bound for most minor components. Further consideration of potential source projects has identified a number of component limitations where techno-economic analysis of the trade-off between additional processing for the CO₂ sources and the impost on transport and storage would be beneficial. Marginal cost analysis of the impact between the lower and upper bounds of the CO₂ specification may be completed in the next stage of the project to assist in determining the components that have the greatest influence the total cost so that the CO₂ specification can remain as accommodating as possible to all prospective sources.

Assessment of the system acceptability of the preliminary specification will need to be completed as the project progresses.

2. Project Background

The CarbonNet Project’s vision is to develop a commercially viable CCS hub that provides a safe, competitive, flexible solution for Victoria to deal with its future carbon emissions from fossil fuels and support economic development opportunities, in Gippsland.

CarbonNet is exploring the feasibility of a commercial scale CCS network delivering CO₂ captured from a range of source projects in the Latrobe Valley, which contains one of the world’s largest brown coal deposits, via a high
pressure liquid/supercritical CO₂ pipeline to suitable storage sites in the offshore Gippsland Basin. The Gippsland Basin has greater than 31 gigatonnes of CO₂ storage potential.

The network intends to possess the capability to initially capture, transport and store anticipated carbon emission volumes in the order of one to five million tonnes per year from 2025 or earlier as part of the foundation network and with capability of expansion thereafter through the introduction of multiple CO₂ capture sources and multiple storage basins in offshore Victoria. Refer to Figure 1 which presents the Area of Interest for the CarbonNet project.

The CO₂ specification therefore needs to be cognisant of the requirements to ensure that the network can service multiple prospective sources and does not discourage or prevent users from connecting into the network due to a very tight or restrictive CO₂ specification. This needs to be achieved whilst minimising the whole of project costs, across the entire CCS chain, not just the transport and storage components.

![Area of Interest](image)

**Figure 1: CarbonNet Project Area of Interest**

3. **CO₂ Specification Development**

3.1. **Objectives in developing a CO₂ Specification**

The development of a CO₂ specification is an important element of the project as it has implications across the entire CCS chain; it sets the processing requirements of the CO₂ source and capture technologies, drives the design of the transportation network and impacts the subsurface.
CarbonNet recognised the importance of developing a hub (i.e. industry cluster) based network to ensure economies of scale can be established and to lower the commercial barrier for entry for new source and capture projects. This influenced the philosophy adopted by CarbonNet for the CO₂ specification development to use a risk based approach to align with the key project drivers:
1. To not discourage or prevent users from connecting into the network due to a very tight or restrictive CO₂ specification, and
2. To minimise whole of project cost (not just focusing on minimising the cost for the transport component) – but considering the whole of project across the entire CCS chain, including storage and the implications on the source and capture proponents.

Developing a hub based network though adds challenges to the design of the project as there are a variety of CO₂ sources that could feed into the network. Each source is likely to have different conditions and composition and the method, technology and cost to further purify the CO₂ stream will vary for each source.

3.2. Background information

Whist CCS is a maturing technology, The CarbonNet Project was still able to draw upon the experience of the existing CO₂ networks, other CCS FEED studies, existing guidelines and developing research in the area. Key references used in the development of the specification include the Australian Standard AS2885 Appendix BB Guidelines for pipelines for the transport of CO₂ [2], DNV’s Recommended Practice (DNV-RP-J202 - Design and Operation of CO₂ pipelines) [3], The WRI CCS guidelines [4], DYNAMIS CO₂ quality recommendations [5], Vattenfall’s CO₂ Quality Requirements for a system with CO₂ capture [6], transport and storage, DRET CCS Task Force Support Carbon Dioxide Specification Study [7] and the published FEED study reports from UK CCS competition 1 [8]. The various references provided a range of specifications that are often project specific.

There are also over 6000 kilometres of CO₂ pipelines in North America, which the project were able to draw knowledge from. Some of these pipelines have been in operation since the 1970’s. The majority of the pipelines are for enhanced oil recovery using natural sources of CO₂ and started as a single source to sink and have expanded; the specifications can vary widely.

The UK Longannet and Kingsnorth CO₂ specifications were both single source to sink projects that utilised some existing infrastructure. As such, they had a prescriptive CO₂ specification based on the source capabilities and the requirements of existing infrastructure and site specific subsurface requirements.

CarbonNet, as one of the formative hub based projects designing for multiple potential CO₂ sources from the outset, elected to systematically investigate the entire CCS chain. The development included reviewing potential source proponents to understand their requirements and to adopt a risk based approach to defining the CO₂ specification with techno-economic considerations/optimisations to meet the project drivers.

3.3. Proposed CO₂ Specification

The CO₂ specification developed during the Feasibility Study for the CarbonNet CO₂ transport network is presented in Table 1. Whilst additional analysis will be required in the next (Front End Engineering and Design (FEED)) stage, it is considered that this specification provides flexibility for future potential source projects to connect to the network, minimises whole of project costs and limits the impurity range sufficiently to avoid their more severe impacts. The proposed specification will require further analysis to determine the acceptability of the proposed limits to the CCS system.

It is CarbonNet’s intention to retain a specification envelope to allow a range of potential sources to participate and an appropriate pricing mechanism to be developed. From a CO₂ source perspective, the upper limits are preferable as it allows more design choices and more flexible operation and is likely to result in a lower overall cost of capture which would improve the economic viability of the capture process. However, from a whole of project perspective the upper limit may not be the most cost effective due to increased design requirements and/or loss of capacity in the transportation and subsurface.
### Table 1: Proposed CO₂ Specification

<table>
<thead>
<tr>
<th>Component</th>
<th>Units</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>vol%</td>
<td>Balance of stream (&gt; 93.5)</td>
<td>100</td>
</tr>
<tr>
<td>H₂O</td>
<td>Max. ppmv</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>N₂</td>
<td>Max. vol%</td>
<td>2 (total non-condensables)</td>
<td>5 (total non-condensables)</td>
</tr>
<tr>
<td>H₂</td>
<td>Max. vol%</td>
<td>2 (total non-condensables)</td>
<td>5 (total non-condensables)</td>
</tr>
<tr>
<td>Ar</td>
<td>Max. vol%</td>
<td>2 (total non-condensables)</td>
<td>5 (total non-condensables)</td>
</tr>
<tr>
<td>O₂</td>
<td>Max. vol%</td>
<td>2 (total non-condensables)</td>
<td>5 (total non-condensables)</td>
</tr>
<tr>
<td>CH₄</td>
<td>Max. vol%</td>
<td>2 (total non-condensables)</td>
<td>5 (total non-condensables)</td>
</tr>
<tr>
<td>CO</td>
<td>Max. ppmv</td>
<td>900</td>
<td>5000</td>
</tr>
<tr>
<td>H₂S</td>
<td>Max. ppmv</td>
<td>100</td>
<td>100¹</td>
</tr>
<tr>
<td>SO₂</td>
<td>Max. ppmv</td>
<td>200</td>
<td>2000</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Max. ppmv</td>
<td>250</td>
<td>2500</td>
</tr>
<tr>
<td>HCN</td>
<td>Max. vol%</td>
<td>250</td>
<td>2500</td>
</tr>
<tr>
<td>Other hydrocarbons</td>
<td>Max. vol%</td>
<td>0.5% on total “Other Hydrocarbons”</td>
<td>0.5% on total “Other Hydrocarbons”</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>Critical Point ³</td>
<td>50</td>
</tr>
<tr>
<td>Pressure</td>
<td>bar</td>
<td>Subject to hydraulic modelling and the location of the CO₂ source</td>
<td></td>
</tr>
</tbody>
</table>

¹Studies subsequent to the pipeline Feasibility Study note the potential to relax to at least 150 ppmv.

²A materiality threshold is proposed for all Minor Components. The threshold proposed is Australian STEL values. Those Minor Components exceeding the STEL are to be considered on a case by case basis from a Health and Safety perspective.

³Adopted for the Feasibility Study. Lower operating temperatures would be acceptable given the pipeline is maintained at supercritical pressures, such that the stream would not enter the two-phase region.

### 3.4. Approach to developing the CO₂ specification

It was recognised that developing a CO₂ specification for a CCS hub network was complex, as consideration had to be given to multiple potential source proponents each with their unique CO₂ composition, while at the other end of the network there was, at the time, a limited understanding of the subsurface requirements due to undefined regulatory requirements, and specific geophysical / geomechanical limitations that were yet to be defined. The controlling components across each element of the CCS chain were identified and are presented in Figure 2.

![Figure 2: Controlling components across the CCS chain](image-url)
Therefore the general methodology to defining the CO₂ specification, outlined in Figure 3 followed a risk based approach with techno-economic considerations rather than being overly prescriptive, in order to determine an optimal and cost-effective specification.

The components that make up the CO₂ stream can generally be grouped based on their primary impact on pipeline design and operation as shown in Table 2.

Table 2: Primary impact by component

<table>
<thead>
<tr>
<th>Health and safety</th>
<th>Pipeline integrity</th>
<th>Economic impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO, H₂S, SO₂, NOₓ, amines, HCN, Hg</td>
<td>H₂O</td>
<td>N₂, Ar, O₂, CH₄, H₂</td>
</tr>
</tbody>
</table>
4. Guidance on CO₂ Specification Limits

In developing the specification, preliminary guidance was obtained through consideration of the regulatory requirements, reviewing the applicable recommendations on health and safety, the pipeline integrity and the subsurface requirements.

4.1. Regulatory Context

In Victoria, geological sequestration of CO₂ is governed onshore by the Greenhouse Gas Geological Sequestration Act 2008, in state waters by the Offshore Petroleum and Greenhouse Gas Storage Act 2010 and in Commonwealth waters by the Offshore Petroleum and Greenhouse Gas Storage Act 2006. In each of these acts the greenhouse gas substance that is covered by the act can be carbon dioxide, another prescribed greenhouse gas, one or more incidental substances related to the carbon dioxide or prescribed greenhouse gas or a mixture, so long as the mixture consists overwhelmingly of carbon dioxide or another prescribed greenhouse gas. No waste can be added to the greenhouse gas stream. The deliberate use of the word ‘overwhelmingly’ carbon dioxide, or another prescribed greenhouse gas, puts the onus back onto the project to define what ‘overwhelmingly’ means for the project and the onus on the project to consider all health, safety and environmental implications of the stream.

4.2. Health and Safety

Transporting large volumes of CO₂ via pipeline has the potential to impact on nearby receptors in the event of planned or unplanned releases of the process fluid from the pipeline. Some of the components with potential to be present in the CO₂ stream (e.g. CO, H₂S, SO₂) are significantly more toxic than CO₂. Therefore all components of the stream (including CO₂) need to be considered when assessing the level of risk and the associated pipeline design requirements.

Initial guidance was that a desirable starting point was to base the limits for minor components in the stream on the Australian Occupational Health & Safety Short Term Exposure Limits (STEL’s). However, the Australian STEL’s were found to be lower than what can be achieved by commercially available purification equipment. In addition, taking this approach is overly conservative as it is equivalent to assuming the sensitive receptor is inside the pipeline. Except that, the CO₂ concentration would be indicatively 33 times the CO₂ STEL and therefore not comply with this guidance. The project next looked overseas at the DYNAMIS CO₂ quality Recommendations [5] which take the approach that CO₂ should be the most critical component. All other components are limited to a concentration based on the ratio of the STEL of the component to the STEL of CO₂. The DYNAMIS approach used a safety factor of 5 on that concentration to account for unknowns in the effects of the diffusion and synergy of multiple components. Australian STEL’s are lower than the equivalent in Europe and therefore the pipeline specification would be lower using this approach. This raises the question of the ability of commercial purification equipment to economically meet these targets. Therefore, to minimise barriers of entry for new sources, CarbonNet elected to review the whole CCS chain when determining the limits on the pipeline and use a risk based approach to the CO₂ specification; where CO₂ does not have to be the most critical component, and the concentrations of all important components at the receptor are managed to safe levels. This will require evaluation of the pipeline design as the project progresses to ensure the required levels of safety and operability.

4.3. Australian Standards

The Australian Standard for gas and liquid petroleum (AS2885) has a section (Appendix BB) on the Guidelines for pipelines for the Transport of CO₂ [2]. Under the AS2885.1, the pipeline route is allocated location classes that reflect threats to pipeline integrity, and risks to people, property and the environment. Location classes are assigned based on the most demanding land use within the measurement length. Based on the most demanding location class, the design requirements will vary to manage the risks to acceptable levels.

AS2885 notes that “Until further research on dispersion of CO₂ releases is completed, the measurement length for definition of the location class limits may be estimated on the basis that the pipeline is transporting methane (see
4.3.2 and Appendix Y); however, the measurement length should be extended locally wherever the landform suggests that spread of the gas cloud in a particular direction may be promoted by gravity drainage.” When the relative harm associated with thermal radiation from combustion of a natural gas pipeline rupture versus CO₂ plume dispersion are considered, this approach is considered conservative. It also states “…it is possible that the danger from a cloud of released gas may be governed by the H₂S concentration rather than the CO₂ concentration. The effects of H₂S become dominant if the proportion of H₂S in the transported gas exceeds about 0.2 % [2000 ppm]...”. Whilst H₂S is explicitly identified the same is true of other potential trace components.

Appendix BB does not preclude the use of a more onerous measurement length if the composition of the pipeline is more hazardous. Depending on the local circumstances the more onerous measurement length might result in certain sections of the pipeline being uprated to a location class requiring higher cost design solutions.

Subsequent to the CO₂ specification development, CarbonNet commissioned a report on Dispersion modelling techniques for CO₂ pipelines in Australia [9]. The report reviews the application of AS2885.1 for CO₂ pipelines as well as a review of the available dispersion models that can be used in designing a CO₂ pipeline system. The report found that use of the measurement length based on the pipeline transporting methane, as per the recommendations of Appendix BB, is appropriate in the preliminary design stage. In the detailed design stage consequence analysis is required to identify the appropriate measurement length. During the detailed design stage it will be important to identify the maximum impurity concentrations so that dispersion modelling can provide appropriate risk analysis results especially where the threshold levels of harm may not be set by CO₂.

4.4. Pipeline Integrity

Water is the primary consideration for pipeline integrity. It is acknowledged and widely accepted that free water combined with CO₂ is very acidic. The wet CO₂ is very corrosive and therefore poses a threat to carbon steel pipeline system integrity. Since carbon steel is commonly used for most pipelines due to economic considerations, the maximum water content should not exceed the saturation level or solubility limit, i.e. no free water present. The solubility limit is dependent on the operating pressure, temperature and composition of the stream. A variety of water concentration limits have been published for various projects globally and range from 20 ppmv to 650 ppmv [10]. The limit depends mostly on the amount of sulphur and other impurities in the stream. Lower moisture range is typically set for higher sulphur content and the higher range for lower sulphur content. Due to the risks associated with corrosion and hydrate formation in the pipeline the water content should be controlled at a safe margin below the saturation point of the pipeline operating conditions including the conditions that will be present at start-up and during depressurisation events. The main driver is to ensure no free water will be present in the pipeline at any time. Since the system design life for the pipeline network is 40 years, a lower specification will minimise the opportunity for internal corrosion and damage in the pipeline throughout its extended operating life. Due consideration is also required on the effect of each component and the total stream on pipeline fatigue, embrittlement and fracture.

4.5. Geology

The geological storage of CO₂ has its own set of requirements driving the purity level of CO₂ and the level of impurities within the CO₂ stream. During the feasibility study the CarbonNet’s Geoscience Exploration and Development team advised that the contaminants should be limited to less than 2 vol% total which was based on the following rationale:

- Loss of reservoir capacity due to lower compressibility of non-condensables and changes to CO₂ solubility due to condensables (SO₃)
- Potential mineral depositions as a result of reactions between condensable components (NOₓ, SOₓ)
- As research continues in the subsurface it may be that storage may impose more stringent conditions or more relaxed conditions than those currently specified and the CO₂ specification would need to be revisited and reconsidered in light of enhanced knowledge.
5. Technically Achievable Specifications

In order to minimise the whole of project costs high level techno-economic trade off assessments were conducted. This involved evaluating the technically achievable limits for the range of carbon capture technology groups. These technology groups included Oxy-fuel, Post Combustion Capture (PCC) and Pre-combustion Capture technologies. The range of technologies within each group in most cases are likely to produce similar CO₂ purity levels, as part of their Business As Usual (BAU) process. BAU is considered as the process design or operating conditions that would occur as normal practice by the source when there are no limitations being imposed by the pipeline specification. However, the presence of impurities/trace components varies between the technology groups due to the type of feed stock and the specific solvent or other separation technology utilised.

The approach to determining the Technically Achievable Limits included:

- Evaluation of the BAU product qualities of each technology group without additional purification technologies to determine the upper limit
- Evaluation of the technically achievable lower limit of each technology group based on the removal efficiencies of commercial / near commercially available purification technologies.

Note that the term “commercially available” is not entirely accurate as many purification technologies, particularly for Oxy-fuel and PCC for large scale CCS projects. In this context those technologies that are the closest to commercialisation have been considered.

The likely business as usual outcome across the three capture technologies for each of the main components in the CO₂ stream are summarised in Table 3. Green shading in the table represents the lower limits of the CO₂ specification (as presented in Table 1) that can be achieved as part of BAU, with no additional treatment or purification required. Orange shading represents levels achieved as part of BAU that then can be reduced further with the addition of commercially available technologies.

Table 3: Typical Source Component Limits

<table>
<thead>
<tr>
<th>Components</th>
<th>Post-combustion</th>
<th>Pre-combustion</th>
<th>Oxy-fired</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>&gt;98 vol%</td>
<td>&gt;98 vol%</td>
<td>&gt;85 vol%</td>
</tr>
<tr>
<td>H₂O</td>
<td>PCC solvent technologies show produced CO₂ streams with high moisture levels (up to 5wt%) before compression. After compression moisture levels will be less than 2200ppmv. Drying is required to lower the moisture further.</td>
<td>The moisture content from pre-combustion technologies can reach below 100ppmw without the use of a drying plant, depending on the solvent used.</td>
<td>Coal based oxy-firing typically produces very high moisture (up to 20wt% moisture) levels in the flue gas stream from combustion of moisture in coal.</td>
</tr>
<tr>
<td>SO₂</td>
<td>Post combustion capture technologies require low SO₂ levels of &lt;10ppmv to reduce amine based solvent losses. Achieving low levels of SO₂ (i.e. STEL type levels) is common practice.</td>
<td>The reducing environment of a gasifier result in low SO₂ levels as part of business as usual.</td>
<td>Sulphur from coal is converted into SO₂ in the combustion process. Sulphur concentrations for Latrobe Valley coals are commonly 0.4% Sulphur (by mass). This implies an unabated SOₓ level of up to 2,000ppmv in the CO₂ flue gas.</td>
</tr>
<tr>
<td>NOₓ</td>
<td>PCC solvents are sensitive to NOₓ in flue gas. Recommended tolerance levels are generally below 100ppmv. Product NOₓ levels for therefore tend to be low.</td>
<td>During gasification, most of the coal bound nitrogen is converted to nitrogen gas. BAU is therefore virtually zero NOₓ.</td>
<td>Oxy-fired plants have seen higher NOₓ concentrations than air blown boilers due to higher combustion temperatures and a more concentrated flue gas stream.</td>
</tr>
<tr>
<td>H₂S</td>
<td>Produce virtually H₂S free CO₂ streams.</td>
<td>BAU is to recover H₂S as a separate stream in the AGR unit using the Selexol or Rectisol process.¹</td>
<td>Produce virtually H₂S free CO₂ streams.</td>
</tr>
<tr>
<td>Non-condensables</td>
<td>Low levels (2-3vol%) of these components could be expected as part</td>
<td>Low levels (&lt;2-3vol%) of these components could be expected as</td>
<td>Contains large amounts of Ar, N₂ and O₂ non-condensables.</td>
</tr>
</tbody>
</table>
Components Post-combustion Pre-combustion Oxy-fired

Hg Removed as part of the process to below detectable limits in order to protect downstream equipment. Removed as part of the process to below detectable limits in order to protect downstream equipment. Requires the installation of mercury control equipment.

CO CO levels in flue gas are minimised as part of business as usual. Syngas formed from gasification largely contains H₂ and CO. Solvents removing H₂S and CO₂ from syngas have a mild selectivity for CO₂ so trace levels of CO are carried into the CO₂ stream. Water gas shift, utilised for H₂ production and IGCC with high CO₂ capture rates, converts CO to CO₂ minimising CO carryover. CO levels in flue gas are minimised as part of business as usual.

1 The feasibility study assumed BAU using physical solvents, where H₂S and CO₂ are produced in separate streams. Certain applications may favour the use of chemical solvents with H₂S and CO₂ produced as a single stream. The implications of higher H₂S levels in the specification compared to the cost to further treat the CO₂ to remove/oxidise the H₂S may be assessed during later stages of the project.

6. Trade off Studies

The proposed CO₂ specification has been determined taking into consideration what is possible from the sources with and without additional processing, what is required to maintain pipeline integrity, what is required from a health, safety and environment perspective and taking into account the requirements for geological storage. Given the tension between these considerations for setting limits for certain elements of the specification, a number of trade-off studies were completed to resolve these limits.

6.1. Moisture Content versus Pipeline Materials

The proposed specification includes a maximum of 100 ppmv of water based on the need to minimise the potential for free water in the stream. This limit would not be achieved through mechanical drying but requires additional drying technologies (Refer to Figure 4). A limit of 500 ppmv provides a good safety margin in preventing free water formation in the pipeline and protects pipeline integrity for carbon steel pipes. The limit was set to that which can be achieved through standard absorption (Tri-ethylene-glycol (TEG)) processes and provides a sufficient safety margin and wide operating window. The marginal costs to reduce the moisture limit from 500 ppmv down to approximately 100 ppmv have not been found to be significant. Noting that TEG systems may require advanced processes or refrigeration to achieve 100 ppmv and therefore a detailed trade-off study could be completed to confirm the exact moisture specification that should be set.

A trade-off study was conducted to compare the economics of using carbon steel pipelines and drying for each source compared to using stainless steels pipelines with a relaxed moisture limit to remove the need for additional drying. The study revealed that it is more economical to install a drying process to each source (up to at least 5 sources of CO₂) than install stainless steel piping.
6.2. Operating Pressure

The most efficient way to transport CO₂ is in a supercritical or liquid phase, as for a given pipe diameter it allows for substantially higher throughput than transporting at a lower pressure gas phase, however operating in gas phase allows the use of lower rated pipelines. A trade-off study was completed to confirm the operating phase, the study considered three different scenarios for the CarbonNet transport network: dense phase (16.5 MPa inlet pressure, 20 MPa design pressure), gas phase (5 MPa inlet pressure, 7 MPa design pressure) and gas phase for future dense phase operation. The study sought to identify (at a concept level) a close-to-optimal design concept for the transport of 5 Mtpa for each scenario in terms of pipeline diameter and frequency of intermediate compressor stations. The net present cost (NPC) of the dense phase operation is approximately 10 % lower than the NPC of operating in gas phase. In dense phase operation there is no requirement for booster compression given the expected high basin injectivity and relatively short pipeline distance (~150 km) between the potential CO₂ sources in Latrobe Valley and the nearshore Gippsland basin.

6.3. Tariff versus Purity

A theoretical concept-level example of how pipeline tariffs might vary for a pure versus impure CO₂ stream was considered. The actual tariff structure will depend heavily on the commercial structure ultimately selected for CarbonNet, along with the expectations of how and when costs will be recovered from commercial users of the network. A concept level study assessed the different cost per tonne of CO₂ required for the different fractions of pipeline and storage capacity that occurs between pure CO₂ and lower purity CO₂ sources. The study indicated that (as expected) low purity CO₂ should rightly incur higher CCS network usage tariffs, but not significantly higher to be prohibitive for those sources. In normal operation the low purity source would also experience slightly higher...
operating costs for their compression plant, as an incrementally higher delivery pressure into the network would be required.

Allowing a variable tariff approach in a transport network should allow for new CO₂ sources to make their own economic assessment of CO₂ purification requirements. The source proponents can determine their own minimum total cost for CO₂ abatement by optimising the purification and transport and storage costs.

7. Reflections and Future Considerations

The development of a CO₂ specification for a CCS hub network is a complex and unique process due to the consideration of multiple factors and requirements across the entire CCS chain.

In an attempt to not discourage or prevent users from connecting into the network due to a very tight or restrictive CO₂ specification, an envelope specification was provided to allow prospective source proponents to understand their own commercial implications of achieving the upper or lower limit.

The upper limit was typically determined by the level that could be achieved by all of the capture technology groups as part of their business as usual to minimise commercial implications for the potential source proponents. The lower limit considered STEL levels, Dynamis approach and subsequently the levels that could be achieved by the addition of commercially available technologies such as dehydration and desulphurisation.

It is recognised that in future stages, further analysis is required to understand the implications of the increased limits (compared with STEL and Dynamis approach) of trace components through dispersion modelling of the upper and lower limits to determine the acceptability for atmospheric and storage basin releases from a health, safety and environment perspective.

The resultant CO₂ purity level was lower than the geoscience guidance provided (i.e. limit to < 2 vol%). From a health, safety and environment perspective the proposed limits of 5 vol% (upper limit) and 2 vol% (lower limit) of non-condensables are not seen to present a risk. The proposed limits on non-condensables is most likely to impact only oxy-fuel streams (with pre-combustion and post-combustion technology groups generally achieving >98% CO₂) and the implications are a reduction in the transport and sequestration efficiency. In future stages more analysis needs to be completed on the geochemical and geomechanical issues associated with minor components.

The specified moisture limit of 100 ppmv is in line with the guidance to minimise the risk of free water and is based on readily achievable limits of most technologies.

Further consideration of potential source projects has identified a number of component limitations where techno-economic analysis of the trade-off between additional processing for the CO₂ sources and the impact on transport and storage would be beneficial. Marginal cost analysis of the impact between the lower and upper bounds of the CO₂ specification may be completed to assist in determining the components that influence the total cost so that the CO₂ specification is as accommodating as possible to all prospective sources.

Further assessment of the system acceptability of the proposed specification will need to be completed in the next stages of the project.

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References


