Carbon Collectors CO_2 composition

In principle we take the CO_2 out of the emitters capture plant / process and will take care of the compression, conditioning (dehydration and where required oxygen reduction) and liquefaction (CCL plant) to get it to our transport conditions:

- We take the CO_2 straight out of the emitters capture plant or process and for commonly used post combustion or industrial process amine stripping, that means at pressures near atmospheric. We understand that, in case of hydrogen production using SMR / ATR / POx and natural gas processing can produce CO_2 at higher pressures.
- We design and install the onshore compression, conditioning and liquefaction package with the limited gas processing / treatment in the vicinity of the capture plant.
- CO_2 equilibrium transport conditions are @ 40 bar / 5°C (so closer to ambient temperature when compared to other liquefied CO_2 transport options).

The emitter might opt, from a system engineering and operations integration perspective, for the CCL facilities being better placed in their scope. If that is the case Carbon Collectors (CC) can certainly support such an effort in the design phase assuring compliance with the transport conditions and composition, within the boundaries allowed, as laid down in this note. For the avoidance of doubt these are non-negotiable.

Composition specification

This will be assessed on a case-by-case basis, but the below is provided for general guidance and has been developed with some of our storage partners, as some compositional criteria can be topsides or reservoir specific. When defining the CO_2 specification, it can be useful to think from the following perspectives:

- **The functional specification** - the impact the impurities have on the phase envelope that the transport and storage system can accept. By specifying a functional specification this allows different quantities of different non-condensables to be acceptable rather than selecting arbitrary values for components that each have an impact of differing magnitudes on the phase envelope and hence cannot be defined singularly when their impact needs to be additive.
- **Safety specification** - to not allow the concentration of any given impurity to have a greater impact on health, safety, or the environment than the impact of the much higher concentration of the CO_2. This allows a specification of the maximum concentration limits for each

hazardous / toxic substance. Such an approach simplifies the modelling / dispersion assessment to evaluate only the CO_2 concentration

- **Integrity specification** - throughout the entire chain from collection to storage including, tank, pipeline, topsides and well. Integrity defined as the potential corrosion, specifically the complex interaction of the acidic forming components, such as NOx, SOx, H_2S, water and oxygen.
- **Reservoir specification** – the interaction of the impurities with the individual storage reservoir will require evaluation to assess the interaction. Specifically, the chemical effects of impurities need to be considered particularly SOx, NOx and H_2S can lead to chemical reactions in the reservoir with dissolution and precipitation of minerals as a consequence. This can lead to a porosity reduction and hence a loss of injectivity

CO_2 specification from the 4 perspectives and additional information:

The functional specification

The composition of the CO_2 is such that the bubble point line at 5 ^{0}C is not greater than 1.5 bar above that of pure CO_2. (1.5 bar above pure CO_2 translates into 40.2 barg). This flexible specification allows the "non-condensable" components to be assessed for their cumulative impact on the phase envelope, allowing more of one component if another component is lower (compared to a prescriptive component by component list each with its own specific value).

The graph below, shows that the impact of the non-condensables of the phase envelope. For a given level of impurity, lower the temperature, the larger the pressure deviation, from pure CO_2, to achieve liquefaction.

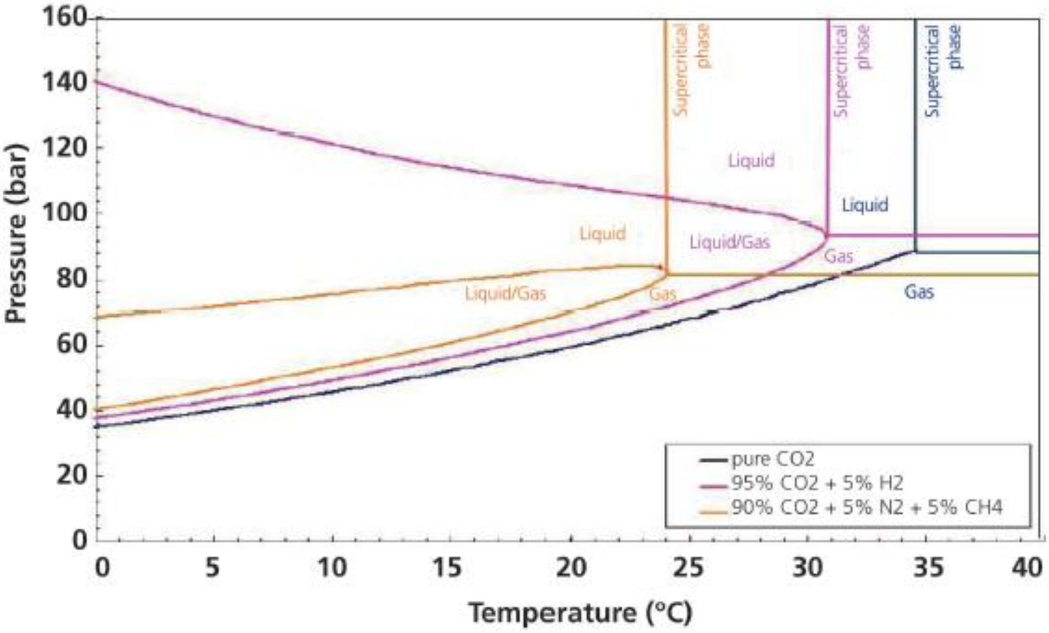

Figure 1: Impact non-condensables on CO_2 phase envelope[4]

The Safety Specification

For liquid CO_2 transportation by ship, the required CO_2 concentration will be typically 99.5% or higher. Work done by reference [1], calculated the concentration of typical components found in waste CO2 streams that were materially equivalent to the toxicity of the CO2 stream. The values for are shown below based on a pipeline concentration of ~ 96% CO2 and therefore are conservative for a shipping scenario. It can be seen that these allowable values are far higher than the likely acceptable values for either the phase envelope impact or for the corrosion impact. Further details of recommended limits, from a safety perspective, for a full list of potential toxic contaminants are in Reference[1]

- H_2S 2,490 ppm (0.249 %)
- CO 29,100 ppm (2.91 %)
- SO_2 2,490 ppm (0.249 %)
- NO_2 320 ppm (0.032 %)

The Integrity Specification

As the complex interaction of the acidic forming components, such as NOx, SOx, H_2S, water and oxygen is still uncertain, the emitter's (or combination of emitters) composition will be physically tested. Given that "unpublished in-house results at IFE indicate that acid formation may take place for even lower impurity concentrations at low temperature." [1] the compositions of the higher-pressure transport would result in more tolerant limits compared to the published compositions of the lower, medium pressure transport operators.

The absence of a component, in an emitter's composition, could be worse than a minimum value being present, therefore, the concept of providing a component-based specification list in which the stream is deemed safe by being below a threshold limit value without testing is being challenged. The currently "safe" upper limits, however, are not the worst case and recent insight revealed that under some scenarios the absence of a component may be worse than its upper limit. For example, less H2S may lead to a shift in the equilibrium and cause HNO3 and H2SO4 to be formed at higher concentrations than at its upper limit. These types of scenarios must also be addressed for a CO2 project specification[1].

Considering the probability of the formation and liquid drop-out of Sulphuric or Nitric acids and given the relative lack of experimental data, it is likely that the final compositional combination will be subject to verification testing throughout the range of operating conditions that will be encountered along the complete chain. This will impact the level of "purification" required at the emitter's site to a level acceptable to Carbon Collectors.

Considering the above, specifically in relation to safeguarding the system integrity, this approach will give rise to different impurity specifications on a project-by-project basis, because it is now recognised that "depending on the mix of emitters, each specific hub project should define a project specific, optimal CO2 specification" [2]. Whereas issuing a generic specification, such as those published offering "Open access CO2 transport requires stringent limit setting on impurity concentration for the whole range of expected conditions in the stream" [2]. The latter will give rise to increased costs for the emitters to achieve a tight specification that may not be required when a more optimal project by project view is taken.

Reservoir specifications

The CO2 is also expected to contain:

- No solids and gums
- No metals with a concentration greater than 1 mg/Nm3
- H_2O shall be low enough to prevent hydrate formation or free water in the well bore or in the reservoir.

  The Carbon Collectors CCL plant will take care of the water dew pointing as part of the CCL plant, this will typically be <30 ppm(molar) depending on the storage provider selected. The water dew point at this level or down to single digit ppm(molar) values is achievable and relatively insensitive to cost[3].
  If required, the oxygen level can also be reduced as part of the CCL process unit, the choice of method will be dependent on the stream composition.

Concluding:

Carbon Collectors will take your CO2 at the outlet of the capture facilities.

- CC will provide transport conditions that minimise the requirement for the CO2 waste purification (compared to other transport conditions).
- CC will provide a flexibly functional specification for non-condensables to minimise any further component removal
- CC will evaluate your composition on a project-by-project basis to ensure an optimum safe specification and thus minimising waste purification (compare to open access systems)
- CC will provide a dew pointing service (and oxygen reduction if required) as part of the Compression, Conditioning and Liquefaction plant that meets the needs of the full transport chain, including storage.

References

[1] Industry Guidelines for Setting the CO2 Specification in CCUS Chains (https://www.woodgroup.com/insights/reports/Industry-Guidelines-for-Setting-the-CO2-Specification-in-CCUS-Chains)

[2] "Impurity threshold definition for non-corrosive CO2 transport - chemical equilibrium calculations and laboratory testing". J. SONKE, Y. Zheng, R.I. Slavchov, R.M. Walker, S. M. Clarke, H. Morland

[3] IEAGHG, "Evaluation and analysis of the performance of dehydration units for CO2 Capture", by AMEC 2014

[4] Reference Energy Institute, "Good plant design and operation for onshore carbon capture installations and onshore pipelines". A Recommended Practice Guidance Document. First edition, September 2010