Australian Government

Department of Climate Change, Energy, the Environment and Water

# Interim National Action List for offshore carbon dioxide sequestration

**Cataloguing data**

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**Acknowledgement of Country**

We acknowledge the Traditional Owners of Country throughout Australia and recognise their continuing connection to land, waters and culture. We pay our respects to their Elders past and present.

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# Introduction

Waters surrounding Australia's coastlines are protected from wastes and pollution being dumped at sea. This is by the *Environment Protection (Sea Dumping) Act 1981* (the Sea Dumping Act). The Sea Dumping Act fulfils Australia's international obligations as a Contracting Party to the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (the London Protocol).

The Sea Dumping Act regulates the dumping of controlled waste in Australian waters. This includes the loading of controlled waste in Australia for the purpose of dumping at sea. Controlled material includes carbon dioxide ($CO_2$) for offshore carbon capture and sequestration (CCS) into sub-seabed geological formations.

The 2006 amendment of Annex 1 of the London Protocol allows for the sequestration of domestic $CO_2$ streams in sub-seabed geological formations. Under Annex 2 of the London Protocol, Contracting Parties are required to assess the wastes or other materials listed in Annex 1 that may be considered for dumping. Part of this assessment is the assessment of wastes to be dumped against an Action List.

An Action List is a mechanism for screening candidate wastes and their constituents. This is based on their potential effects on human health and the marine environment. Priority for listing on the Action List shall be given to toxic, persistent and bioaccumulative substances from human sources. An Action List can also be used as a trigger mechanism for further waste prevention considerations.

An Action List shall specify a substance upper level to avoid acute or chronic effects on human health or on sensitive marine organisms representative of the marine ecosystem. Incidental associated substances within a $CO_2$ stream cannot exceed this level. This is unless a management process is applied. The Action List may also specify a lower level. The lower limits identify substance concentrations under which there should be little concern. Incidental associated substance concentrations that fall between these two limits will require further assessment. They may also require management processes.

# 1 Australia's National Action List for offshore carbon dioxide sequestration

## 1.1 Purpose and development

Before a person can apply and the Department of Climate Change, Energy, the Environment and Water can assess a domestic offshore CCS sea dumping permit application, two things are required. These are to comply with the Sea Dumping Act and London Protocol. They are:

1) an offshore CCS sea dumping permit application form – required by the Sea Dumping Act
2) an offshore CCS National Action List (NAL) – required by the London Protocol to meet our international legal obligations.

We are working with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to develop an offshore CCS NAL. This will allow the Australian Government to regulate offshore CCS projects in Australia in line with our obligations.

We are releasing this interim offshore CCS NAL based on current, robust science and our work with CSIRO. This is for use when preparing and assessing permit applications. At the same time, we are releasing the domestic CCS permit application form. This will allow the Australian Government to accept applications for sea dumping permits for offshore domestic CCS with $CO_2$ sourced from Australia.

Applicants should arrange a pre-application meeting to discuss their offshore CCS proposals. This should be early in the project planning, before submitting a permit application. Please contact the Sea Dumping Section at seadumping@dcceew.gov.au.

## 1.2 Offshore CCS NAL

We are planning on consulting with industry on the offshore CCS NAL in 2024. Through this consultation, we can address queries and make updates to clarify what is required to meet our Sea Dumping obligations so that our regulatory system remains robust. Industry consultation will help ensure that potential future carbon capture types are included in the offshore CCS NAL.

The applicant's proposed $CO_2$ stream may contain incidental associated substances which are not on the offshore CCS NAL. In such cases, applicants will be required to provide justification for them in their permit application. We will consider them in the application process. It is the applicant's responsibility to undertake the relevant studies. This is to justify the incidental associated substances and acceptable upper- and lower-limit thresholds.

The offshore CCS NAL will need updating approximately every five years. This is to address the changing nature of emissions, sources, methods of capturing $CO_2$ and approaches to offshore CCS over time.

## 1.3 Interim offshore CCS NAL

As required by the London Protocol, this interim offshore CCS NAL identifies the upper limit thresholds that incidental associated substances within a $CO_2$ stream should not exceed (Section 2.4). However, it does not provide a lower limit. This is planned to be incorporated in the future offshore CCS NAL. For radioactive substances, please refer to Section 4 of the Sea Dumping Act and Annex 1 of the London Protocol.

The interim offshore CCS NAL's design assumes that $CO_2$ streams will consist overwhelmingly of $CO_2$. It is also assumed that the percentage composition of $CO_2$ captured, transported, and sequestered will be 95% or greater[1].

It is assumed in this interim offshore CCS NAL that the $CO_2$ component within a $CO_2$ stream itself represents the highest human health risk. Exposure to $CO_2$ concentrations above the 30,000 ppm Short Term Exposure Limit (STEL $CO_2$, 15 min, (3%)) are hazardous. Over 40,000 ppm (4%) are Immediately Dangerous to Life and Health (IDLH).

The incidental associated substances that make up this interim offshore CCS NAL include 27 elements or compounds. These are listed in Table 2. Section 2 provides explanations on how these upper-limit thresholds have been calculated.

A $CO_2$ stream may contain compounds with an incidental associated substance concentration level below the upper limit threshold stated in this interim offshore CCS NAL. In such cases, the incidental associated substance may be acceptable. This is only if the applicant can justify in their application that they can maintain that concentration level throughout the life of any granted sea dumping permit.

While developing this interim offshore CCS NAL, CSIRO have reviewed literature and collated $CO_2$ gas specification data for CCS projects from Australia and around the world, where relevant to regulating offshore CCS in Australia. This allowed comparison of chemical concentrations between pre- and post-capture $CO_2$ and the gas specification data from these CCS projects.

When considering $CO_2$ incidental associated substances and their potential effects on human health and the marine environment, incidental associated substances that have toxic impacts were considered. Substances of concern for project proponents were also examined. For example, water within $CO_2$ does not represent a human health or environmental risk. However, water will be of concern for any proponent. This is because it could have impacts on infrastructure safety, longevity, and performance.

[1] ISO 27913 (Carbon dioxide capture, transportation and geological storage - Pipeline transportation systems), ISO 27914 (Carbon dioxide capture, transportation and geological storage - Geological storage) and Australian Standard (AS) ISO 27914:2019 (Carbon dioxide capture, transportation and geological storage - Geological storage).

A $CO_2$ stream which contains incidental associated substances exceeding the upper-limit thresholds may not be sequestered offshore. This is unless it is made acceptable for dumping using management techniques or processes. The minister or delegate will consider any exceedances to the upper-limit thresholds during the assessment of your permit application. You will likely be asked to provide further information to support and justify why exceedances are manageable within environment protection requirements. Applicants should manage $CO_2$ stream contaminants below the interim offshore CCS NAL upper-limit thresholds.

We welcome feedback from industry. We will also consider incidental associated substances not included in this interim offshore CCS NAL. Applicants should provide justification in their permit application for any substances not considered here.

## 1.4 $CO_2$ sequestration value chain

To understand the composition of $CO_2$ streams that may be transported and stored offshore, you must understand the CCS value chain (Figure 1) and how it may affect the $CO_2$ composition.

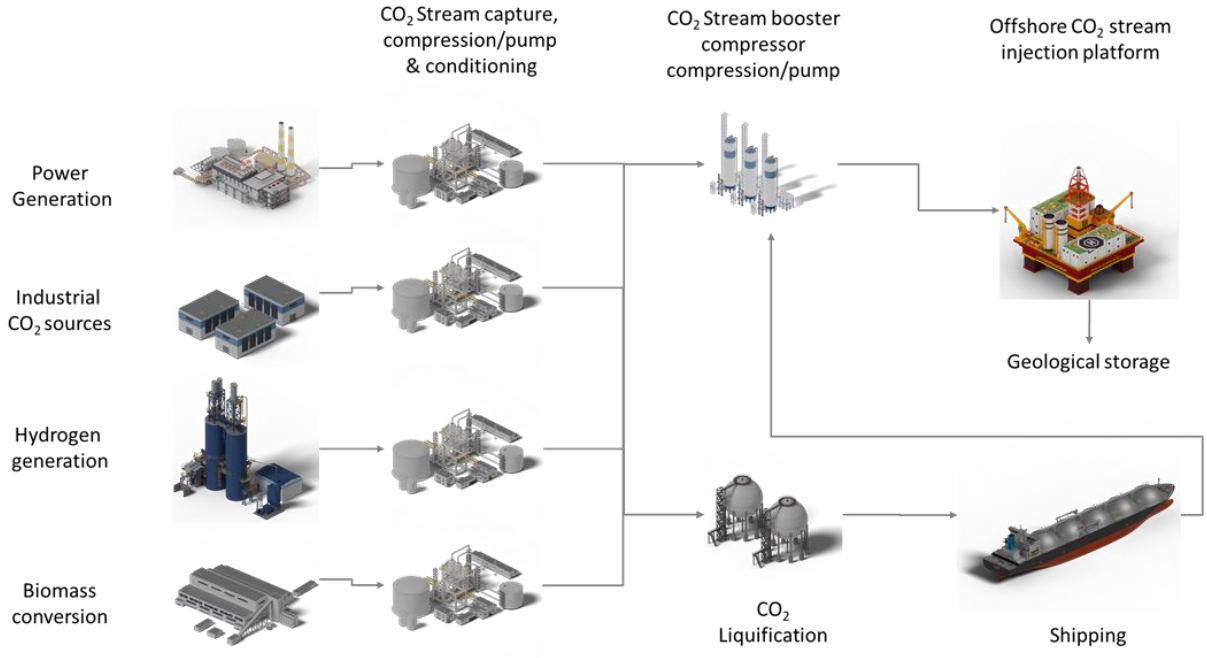
The $CO_2$ stream value chain starts at the point of capture. $CO_2$ can be captured from several sources (Figure 1). This can include capture from:

- power generation (e.g., coal-fired power, gas-fired biomass energy power stations)
- industrial processes (e.g., cement manufacture, steelmaking, chemicals manufacture, minerals processing)
- oil and gas processing, and
- emerging areas such as direct air capture.

$CO_2$ from these sources is captured through several different methods. It is treated to remove contaminants from both the original $CO_2$ stream and those introduced during the capture process. Many of the potential contaminants of concern are typically removed early in the value chain. This is due to the nature of the processes and how pre-treatments occur before these process streams reach points of separation (e.g., amine scrubbing).

The $CO_2$ stream is then compressed and pumped through pipelines to booster compressors or liquification facilities (e.g., ship transport or supercritical $CO_2$ pipeline transfer). The gathering of $CO_2$ in a pipeline system may combine $CO_2$ streams from various sources, in the case of a CCS hub concept. $CO_2$ may also be derived from a single source. From the booster compressor, the $CO_2$ moves down pipelines and is then injected from wells into deep sub-seabed geological formations.

**Figure 1 CCS value chain**




Source: CSIRO

## 1.5 Further information

For information regarding sea dumping permits and regulatory requirements, please visit our website at: https://www.dcceew.gov.au/environment/marine/sea-dumping

For information regarding offshore CCS and sea dumping, please visit our website at: https://www.dcceew.gov.au/environment/marine/sea-dumping/dispose-co2

If you have any queries about how to utilise this interim offshore CCS NAL or have any questions regarding your offshore CCS activity and sea dumping permits, please contact us at: seadumping@dcceew.gov.au.

# 2 Interim NAL for offshore carbon dioxide sequestration

## 2.1 States of $CO_2$

$CO_2$ can exist in four different states of matter. These states are dependent upon temperature and pressure. These are usually represented on a pressure versus temperature phase diagram. The four states of matter are:

- gas
- liquid
- solid, and
- supercritical fluid.

$CO_2$ usually behaves as a gas in air at standard temperature and pressure (STP). It can also act as a solid called dry ice when frozen. Supercritical $CO_2$ is a fluid state of $CO_2$ where it is held at or above its critical temperature and pressure. If the temperature and pressure are both increased from STP to be at or above the critical point for $CO_2$, it can adopt properties midway between a gas and a liquid.

Since $CO_2$ can have four different states with widely differing properties and densities, the liquid $CO_2$ properties used here are defined as:

1) Pressure > 5.2 bar (5.1 atm, 75 psi)
2) Temperature < 30.9780°C (304.128 K, critical point temperature)
3) Temperature > -56.6°C (temperature of triple point)

## 2.2 Other substances in a $CO_2$ stream

This section describes the way the data and upper-limit thresholds for the various incidental associated substances in $CO_2$ have been derived in Table 2.

The minimum concentration of $CO_2$ in a $CO_2$ stream is defined as 95%. As this concentration is defined and fixed, the sum of all the other incidental associated substance concentrations should not exceed 5% of the $CO_2$ stream. Of the remaining 5% of the $CO_2$ stream, the permanent and non-condensable gases will likely make up ≤ 4%. This group includes the typical gas components: argon (Ar), methane ($CH_4$), hydrogen ($H_2$), nitrogen ($N_2$) and oxygen ($O_2$).

These typical gas components have no specified exposure limits for the protection of the environment or human health. They are therefore considered permanent gases and are grouped under a collective ≤ 4% (< 40,000 ppm). The component values of this group can vary individually but their sum cannot exceed 4% of the $CO_2$ stream by volume. This is the only group of components that are specially clustered together under one collective upper-limit value.

Having now accounted for 99% of the $CO_2$ composition, the remaining allowance of 1% is then reserved for all other listed possible incidental associated substances in the liquid $CO_2$ stream. From an industry consideration, the actual purity of the $CO_2$ will likely be greater than 95% due to a few factors, including:

1) transporting a significant proportion of non-condensable gases (up to a maximum of 4%) in the $CO_2$ stream is costly, as it increases the compression energy required to liquefy the $CO_2$
2) the volume taken up by 4% non-condensable gases does not qualify for any carbon offset credits hence their presence is a costly diluent being transported
3) the presence of condensable phases like water and hazardous components like hydrogen sulphide risk significant corrosion problems to pipelines, bulk storage tanks and wellhead infrastructure.

## 2.3 Upper-limit calculations

Calculation of upper-limit values for incidental associated substances in Table 2 are based on the approach of de Visser et al. (2008). The maximum concentration levels of incidental associated substances in $CO_2$ streams were determined using exposure limits and the expansion ratio for liquid $CO_2$ of 1:535.

1) Using carbon monoxide (CO) as an example incidental associated substance, the calculation results used to derive the CO upper level in liquid $CO_2$ are shown in Table 1.
    a) Initially, the $CO_2$ is set to 100% and a STEL of 5,000 ppm. From this it is derived that at the time of release, the STEL of $CO_2$ is exceeded by a factor of 100.
    b) This factor is then applied to the STELs of incidental associated substances of interest in the $CO_2$ to obtain a maximum concentration (not corrected).
    c) A safety factor of 5 is then applied to the determined threshold values to reach the recommended values.
2) Example calculation:
    a) carbon monoxide (CO) STEL = 100 ppm
    b) maximum (not corrected) concentration in $CO_2$ = 100 ppm x 100 factor = 10,000 ppm
    c) safety factor of 5 applied = 10,000 ppm/5 = 2000 ppm (maximum upper limit of CO in liquid $CO_2$)

**Table 1 Example calculations for CO**

| Component | STEL (ppm) | Max. (not corrected) | Safety Factor | Recommended Max. Level (ppm) |
|---|---|---|---|---|
| CO (carbon monoxide) | 100 | 10,000 | 5 | 2,000 |

The maximum level of dissolved CO allowed in liquid $CO_2$ in a pipeline is 2,000 ppm (Table 1). In the worst case of a catastrophic rupture to air however, the liquid $CO_2$ will immediately expand in air by an expansion ratio of 1:535 to gaseous $CO_2$. i.e., 1 L of liquid $CO_2$ will expand to 535 L of gaseous $CO_2$.

Consequently, 2,000 ppm of dissolved CO in liquid $CO_2$ becomes 3.7 ppm in the expanding gaseous $CO_2$ cloud. This is due to the expansion ratio of pressurised liquid $CO_2$. This does not factor in any subsequent dilution of the expanding gaseous $CO_2$ cloud by air, where the effective CO would become even lower. This explains why the upper-limit thresholds in Table 2 are higher than the exposure limits. The exposure limits are based on STEL data and derived in atmospheric air, which is why the state of the $CO_2$ (temperature and pressure) being defined is critical.

## 2.4 Interim offshore CCS NAL

**Table 2 Interim offshore CCS NAL with upper limits in liquid $CO_2$**

| Contaminant | Upper Limit | Rationale for Limit |
|---|---|---|
| **CO (carbon monoxide)** | 2,000 ppm | • Health and safety aspects<br>• Engineering with respect to mitigation of stress cracking of steels due to carbide formation |
| **COS (carbonyl sulphide)** | 100 ppm | • Health and safety aspects |
| **$H_2S$ (hydrogen sulphide)** | 200 ppm | • Health and safety aspects<br>• Engineering with respect to mitigation of stress cracking of steels due to hydride formation |
| **HCl (hydrogen chloride)** | 40 ppm | • Health and safety aspects<br>• Engineering with respect to mitigating metal corrosion<br>• Environmental with concerns about dissolution of carbonate minerals, especially in sub-surface rock formations or well-bore cements due to acidic nature of HCl in water (forms hydrochloric acid) |
| **HF (hydrogen fluoride)** | 10 ppm | • Health and safety aspects<br>• Engineering with respect to mitigating metal corrosion<br>• Environmental with concerns about dissolution of carbonate or silicate-rich minerals, especially in sub-surface rock formations or well-bore cements due to acidic nature of HF in water (forms hydrofluoric acid) |
| **$CH_3OH$ (methanol)** | 4,000 ppm | • Health and safety aspects |
| **$NH_3$ (ammonia)** | 700 ppm | • Health and safety aspects<br>• Engineering with respect to mitigation of stress cracking of steels due to hydride formation and corrosion of copper-based alloys |
| **$NO_x$ (nitrogen oxides)** | 4 ppm | • Health and safety aspects<br>• Engineering with respect to mitigating metal corrosion<br>• Environmental with concerns about dissolution of carbonate minerals, especially in sub-surface rock formations or well-bore cements due to acidic nature of $NO_x$ in water (forms nitrous and nitric acids)<br>• Microbiological with respect to any nitrites and nitrates (formed by the acid reaction) acting as electron acceptors in the anaerobic sub-surface formations with multi-step reductions to nitrous oxide ($N_2O$, small amounts) and nitrogen ($N_2$, main product)<br>• Chemical with respect to possible reaction with other contaminant species to form new compounds |

| Contaminant | Upper Limit | Rationale for Limit |
|---|---|---|
| **$SO_x$ (sulphur oxides)** | 5 ppm | • Health and safety aspects<br>• Engineering with respect to mitigating metal corrosion<br>• Environmental with concerns about dissolution of carbonate minerals to form sulphates, especially in sub-surface rock formations or well-bore cements due to acidic nature of $SO_x$ in water (forms sulphurous and sulphuric acids)<br>• Microbiological with respect to sulphates (formed by the acid reaction) acting as a sulphur source in the anaerobic sub-surface formation with indigenous sulphate reducing bacteria (SRB) to form hydrogen sulphide souring<br>• Chemical with respect to possible reaction with other contaminant species to form new compounds |
| **$C_6H_6$ (benzene)** | 20 ppm | • Health and safety considerations |
| **BTEX (benzene, toluene, ethylbenzene, xylenes)** | 20 ppm | • Health and safety considerations |
| **PFC-116 (hexafluoroethane), a perfluorocarbon** | 1.36 ppm | • Environmental with respect to its persistent organic chemical nature in marine sediments, groundwater aquifers, and damage to the ozone layer in the stratosphere via decomposition with UV energy from the sun to form fluorine radicals |
| **$CH_2$=O (formaldehyde)** | 6 ppm | • Health and safety considerations |
| **$CH_2$=O & $CH_3OH$ (formaldehyde & methanol)** | 6 ppm | • Health and safety considerations<br>• Note: Where there is formaldehyde and methanol, formaldehyde is chosen for its lower exposure threshold |
| **MEA (monoethanolamine)** | 120 ppm | • Health and safety considerations |
| ***Specific gas components:*** *The sum of the following must = <4% due to engineering considerations* | | |
| **Ar (argon)** | <40,000 ppm (4%) | • Engineering consideration, classed as a non-condensable gas which results in increased compression energy required (two phase flow/change of fluid properties, volumetric pumping efficiency) |
| **$CH_4$ (methane)** | <40,000 ppm (4%) | • Engineering consideration, classed as a non-condensable gas which results in increased compression energy required (two phase flow/change of fluid properties, volumetric pumping efficiency)<br>• Physical properties consideration as increasing levels of $CH_4$ decreases solubility of $H_2O$ in $CO_2$<br>• Note: At <4% $CH_4$ (40,000 ppm) the water solubility limit is above the 500 ppm water concentration limit |
| **$N_2$ (nitrogen)** | <40,000 ppm (4%) | • Engineering consideration, classed as a non-condensable gas which results in increased compression energy required (two phase flow/change of fluid properties, volumetric pumping efficiency) |
| **PFC-14 (tetrafluoromethane), a perfluorocarbon not considered toxic** | <40,000 ppm (4%) | • Environmental with respect to its persistent organic chemical nature in marine sediments, groundwater aquifers, and damage to the ozone layer in the stratosphere via decomposition with UV energy from the sun to form fluorine radicals |
| **PFC-218 (octafluoropropane), a** | <40,000 ppm (4%) | • Environmental with respect to its persistent organic chemical nature in marine sediments, groundwater aquifers, and damage to the ozone layer in the stratosphere via |

| Contaminant | Upper Limit | Rationale for Limit |
|---|---|---|
| **perfluorocarbon not considered toxic** | | decomposition with UV energy from the sun to form fluorine radicals |
| ***Group of Cd (cadmium), Hg (mercury), Tl (thallium) and the 3 elements grouped limit value:*** *transition metals classed as heavy metal contaminants that have broadly similar modes of toxicity and persistence in the environment. Grouped value required due to derived heavy metal analytical methods that do not speciate individual metal species. The combined sum of the 3 heavy metal concentrations may become of human or environmental concern. Individual values required as the chemical and physical properties vary such that they also need individual entries for their exposure limits* | | |
| **Cd (cadmium)** | 0.022 ppm | • Health and safety considerations<br>• Environmental with respect to persistent and bio-accumulative heavy metal compounds |
| **Hg (mercury)** | 0.06 ppm | • Health and safety considerations<br>• Environmental persistent pollutant<br>• Microbiological with respect to anaerobic bacteria forming methylated mercury compounds that are toxic, volatile, fat soluble and bio-accumulative<br>• Engineering consideration in respect to condensable under certain temperature and pressure regimes and can cause corrosion and stress cracking via formation of metal amalgams<br>• Note: Hg can exist as a liquid metal with appreciable vapour pressure hence can migrate as a vapour through gases |
| **Tl (thallium)** | 0.24 ppm | • Health and safety considerations<br>• Environmental with respect to persistent and bio-accumulative heavy metal compounds |
| **Cd, Tl, Hg (cadmium, thallium, mercury)** | 0.022 ppm | • Health and safety considerations<br>• Environmental with respect to persistent and bio-accumulative heavy metal compounds.<br>• Note: In this suite of heavy metals, Cd exposure limits chosen for its slightly lower exposure limits |
| ***Group of ethane ($C_2H_6$), propane ($C_3H_8$) and CFC-13 (chlorotrifluoromethane):*** *The sum of the following cells must = <0.2% due to engineering considerations* | | |
| **$C_2H_6$ (ethane)** | <2,000 ppm (0.2%) | • Health and safety aspects<br>• Engineering consideration in that $C_2$ decreases solubility of $H_2O$ in $CO_2$ and can condense under certain temperature and pressure regimes<br>• Note: grouped with other limited set of compounds that fall under one limit (<0.2%); in calculations based on its exposure limit, up to 1.6% would be allowable under health and safety grounds but unacceptable due to engineering considerations with a lower limit of <0.2% in total |
| **$C_3H_8$ (propane)** | <2,000 ppm (0.2%) | • Engineering consideration in that $C_3$ decreases solubility of $H_2O$ in $CO_2$ and can condense under certain temperature and pressure regimes; grouped with other limited set of compounds that fall under one limit (<0.2%)<br>• Note: In calculations based on its exposure limit, up to 2% would be allowable under health and safety grounds but unacceptable due to engineering considerations with a lower limit of <0.2% in total |
| **CFC-13 (chlorotrifluoromethane)** | <2,000 ppm (0.2%) | • Health and safety considerations<br>• Environmental with respect to its persistent organic chemical nature in marine sediments, groundwater aquifers, |

| Contaminant | Upper Limit | Rationale for Limit |
|---|---|---|
| | | and damage to the ozone layer in the stratosphere via decomposition with UV energy from the sun to form chlorine and fluorine radicals<br>• Note: In calculations based on its exposure limit up to 9% would be allowable under health and safety grounds but unacceptable due to engineering considerations with a lower limit of <0.2% in total |
| ***Special exceptions:*** *substances with no human exposure limits, but need limiting due to engineering or subsurface considerations* | | |
| **$O_2$ (oxygen)** | 100 ppm | • Engineering consideration with respect to increased corrosion rates of metals<br>• Engineering consideration, classed as a non-condensable gas which results in increased compression energy required (two phase flow/change of fluid properties, volumetric pumping efficiency)<br>• Microbiological with respect to limit the oxidation potential of the anaerobic sub-surface geological formations so as to not allow any aerobic organisms to thrive (potentially carried in by the injected $CO_2$) |
| **$H_2$ (hydrogen)** | 5,000 ppm | • Engineering consideration with respect to mitigation of stress cracking of steels due to hydride formation<br>• Engineering consideration, classed as a non-condensable gas which results in increased compression energy required (two phase flow/change of fluid properties, volumetric pumping efficiency)<br>• Microbial consideration in that $H_2$ is an almost universal electron donor within anaerobic sub-surface environments<br>• Note: Rapid utilisation of $H_2$ by bacteria and archaea can cause proliferation of microbial cells resulting in formation pores and well injection sites to block up with biofilm |
| **$H_2O$ (water)** | 500 ppm | • Engineering considerations with respect to corrosion mitigation by formation of acids from certain contaminant gases ($NO_x$, $SO_x$, HCl, HF) when dissolved in water<br>• Engineering considerations with respect to blocking of pipelines and valves due to solid hydrate formation and erosional damage to compressors |

Notes:

1) Limits on permanent and non-condensable gases are fixed and cannot change, only individual component concentrations can vary within the overall limit values.
2) For hazardous or toxic components, STEL, Long Term Exposure Limit or IDLH values were used, typically those which are applied in Australia, the European Union or the United States of America.
3) Conversions are on a molar basis, i.e., % = moles contaminant (in gas phase)/moles solute (gas phase), collated sources are assumed to be in gas phase unless explicitly stated otherwise.
4) Parts per million (ppm) values are expressed in terms of molar ratio.
5) Where % is quoted in Table 2, it is volume (vol) % if contaminant is normally in a gaseous phase.
6) Assuming ideal gas behaviour for gas phase contaminants, vol % and mol % are considered interchangeable.
7) For contaminants that are not normally in the gas phase at STP, molar expressions are used.

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