Geologically Stored Carbon

Methodology for CO_2 Removal

Edition 2024 v.1

Puro Standard

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Contents

Glossary of Terms

> **REMARK:** This glossary provides only the most important definitions for the current methodology. Please note that further definitions are listed in the Puro Standard General Rules.

Activity – A practice or ensemble of practices that take place on a delineated area resulting in emissions or removals taking place. For example, a geological storage activity refers to all operations within the activity boundary of a particular geological CO_2 Removal project. An eligible activity is an activity that meets the qualification criteria in a given certification methodology or protocol.

Biomass – Organic matter recently derived from the biosphere, including crops, waste of crops, organic municipal waste, organic waste from paper and alcohol/ethanol production, and others.

Bubble point pressure – The pressure at which the first bubble of gas appears in a liquid at a specific temperature, particularly in the context of bubbles of gas (including CO_2) formed during the potential depressurization of water-dissolved CO_2 injected into the subsurface.

CO_2 Fluid – aqueous (water-dissolved) CO_2. In particular, this refers to CO_2 injected within its solubility trapping phase, i.e. when the CO_2 Stream is dissolved in water immediately before or during injection. As this *CO_2 charged* fluid is transported into the storage reservoir, mixing and reactions decrease the aqueous CO_2 concentration until the CO_2 is not elevated beyond the background reservoir water and cannot be considered to be CO_2 charged anymore, delimiting its extent in the underground in three dimensions.

CO_2 Plume – the extent of an underground injected CO_2 Stream, in three dimensions. More specifically, this refers to the CO_2 in the free phase, excluding e.g. CO_2 fully dissolved in water, or otherwise transformed through chemical reactions.

CO_2 Stream – carbon dioxide that has been captured either directly from the atmosphere or from an eligible biogenic source, together with incidental associated substances derived from the source materials and the capture process, or added to the stream to enable or improve the injection process. However, water added to the CO_2 for dissolution before or during injection is not considered as a part of the CO_2 stream (see also CO_2 Fluid).

Equation of state – an analytical expression relating the pressure, volume, and temperature of a pure substance or mixture, commonly utilized to describe the volumetric behavior, vapor/liquid equilibria, and thermal properties of substances in different conditions. Several different equations of state are commonly utilized in reservoir engineering, depending on the use case (e.g. thermodynamic properties modeled and type of reservoir fluids). Examples include the Soave-Redlich-Kwong (SRK) and Peng-Robinson (PR) equations of state.

External operator – any party (such as the capture site operator, the logistics operators, or the storage site operator), operating on behalf and at the direction of the CO_2 Removal Supplier for provision of services relating to the geological storage activity (however, not including the CO_2 Removal Supplier itself).

Geological Storage – the long-term containment of a gaseous, liquid, supercritical, or water-dissolved CO_2 Stream in subsurface geologic formations.

Geological Storage activity – see Activity.

Injection Zone – a geologic formation, group of formations, or part of a formation that is of sufficient areal extent, thickness, porosity, and permeability to receive carbon dioxide through an injection well or wells associated with a Geological Storage project.

Output – Volume of CO_2 Removal within a certain Monitoring Period which is eligible to receive CORCs. CORCs are always Issued for Net Carbon Dioxide Removal in the production process, which means that the total volume of Output is determined by subtracting the CO_2 emissions volume (generated directly or indirectly due to the production process or materials used, according to the applicable Methodology) from the CO_2 Removal volume.

Point source – A specific, identifiable source of pollution or emissions that can be pinpointed to a single location or a limited, well-defined area.

Reversal event – any event which results in CO_2 or other greenhouse gases being either i) no longer securely stored in the storage reservoir (breach of permanent storage, such as leakage from the storage reservoir to underground sources of drinking water), or ii) released from the storage reservoir into the atmosphere (i.e. re-emission, such as intentional venting due to wellbore maintenance, or unintentional emissions through transmissive faults or fissures, or improperly sealed legacy wells).

Storage area – The overall geological system comprising the geological storage reservoir(s) together with any overlying geological formations, covering the defined vertical and lateral limits of the CO_2 storage project.

Storage reservoir – An underground geological formation, group of formations, or part of a formation, suitable for Long-Term CO_2 Storage.

Storage site – The storage reservoir together with the surface and subsurface facilities required for the operation of the CO_2 storage project.

Sustainable biomass – Biomass that has been sourced according to the sustainability requirements of this methodology and other Puro Standard Requirements.

Tonne (t) – A unit of mass equivalent to 1000 kg, also known as ‘metric tonne’. In this methodology, the word ‘tonne’ always refers to metric tonnes.

Acronyms

BCS – Biomass carbon removal

BECCS – Bioenergy with carbon capture and storage

Bio-CCS – Biomass conversion with carbon capture and storage. Note that technically, bio-CCS is broader than BECCS, because it also includes processes that do not generate exclusively bioenergy, but also biomaterials, food and feed products. However, BECCS and bio-CCS are in the context of this methodology used interchangeably.

CCS – Carbon dioxide capture and storage

CDR – Carbon dioxide removal

DACCS – Direct air carbon capture and storage

GHG – Greenhouse gas

GSC – Geologically Stored Carbon

IPCC – Intergovernmental Panel of Climate Change

PyCCS – Pyrogenic Carbon Capture and Storage

tCO_2e – tonnes of CO_2 equivalents

Note to the reader

REMARK: This methodology provides general information as well as actual requirements which must be met by all projects seeking certification under the Puro Standard. Across the entire methodology, the requirements correspond to numbered rules with formatting conforming to the below example.

0.0.1 This is an example of a numbered rule. The requirements set within numbered rules must be followed by all projects seeking certification under the Puro Standard.

Please note that in addition to the requirements of this methodology document, all projects seeking certification under the Puro Standard must also comply with the Puro Standard General Rules and other Standard Requirements, as well as any applicable local laws, regulations, and other binding obligations.

For Puro Standard documents, see the Puro Standard documents library.

Note to the public consultation version

This is a **draft version** being shared for public consultation, and some temporary formatting elements have been left to make final publishing easier, or for ease of reading. For example:

Pink highlight in above paragraphs gives an overview of what the following content is about in *layman's terms*. This is intended to guide the reader efficiently and also provide a quick run through of the document where required, and to find specific sections of importance. It is also for ease of rearrangement of information flow, should more edits be required.

For example:

> Scope of capture & storage
>
> This methodology *quantifies* the **net CO_2 Removal** achieved over one thousand (1000) years by storing pure CO_2 or other eligible carbon-containing substances in certain types of industrial wells or deep geological formations.
>
> The **scope** of this methodology includes the *capture* and *storage* of CO_2 directly from the atmosphere (Direct Air Carbon Capture and Storage, **DACCS**), as well as from the production of bioenergy using eligible biomass (Bioenergy with Carbon Capture and Storage, **BECCS**).

Thank you in advance for the time taken to review and assist with updating this draft. All comments and feedback are very valuable and will be considered.

Puro.earth team

1. Introduction

1.1. Overview and scope

Net removal 1000+ years

This methodology sets the requirements for eligibility and quantification of the **net CO_2 removal** achieved over one thousand (1000)[1] years by storing eligible CO_2 streams in suitable geological storage sites, such as deep geological formations and certain types of industrial wells.

Concept

In this methodology, **Geological Storage of Carbon (GSC)** refers to the overall process of *storing* an eligible carbon dioxide (CO_2) stream in *underground geological formations* for the purpose of permanent CO_2 removal. However, the overall concept of 'geological storage' is *not entirely uniform*, but presents several potential variations in scope depending on various factors, such as:

- Type and origin of the stored CO_2 stream.
- Type and characteristics of the storage site.
- Type and mechanics of the injection process.

Scope - overall

In broad terms, the **scope** of this methodology includes the following **fundamental components**: *capture, transport,* and *injection and storage* of eligible **biogenic CO_2 streams or CO_2 streams from direct air capture**. All of the process steps (capture, transport, injection and storage) allow several different variations, which are summarized here and elaborated in further detail in section 4.

Scope - capture

The **capture** of CO_2 can occur directly from the ambient atmosphere (Direct Air Carbon Capture and Storage, **DACCS**), as well as from the production of bioenergy utilizing eligible biomass (Bioenergy with Carbon Capture and Storage, **BECCS**). Furthermore, this methodology includes certain other (sub)types of carbon capture, such as CO_2 captured from the oxidation or **fermentation** of biogenic materials in industrial processes. In this methodology, carbon dioxide from fossil sources is not eligible (e.g. point source capture from a coal power plant), but mixed sources (e.g. waste + CCS) can be utilized as long as the non-eligible fraction is reliably quantified and accounted for.

Scope - transport

The capture of the CO_2 stream rarely occurs at the storage site, and therefore needs to be transported from the capture site (e.g. a BECCS facility) to the storage location (e.g. an industrial well). Several potential methods with varying costs and capacity exist for the **transport** of CO_2 (Al Baroudi et al., 2021). For *small quantities,* transport by **truck** or **rail** can be utilized. For *larger quantities*, transport

[1] CO_2 must be sequestered (on a net basis) for *at least* 1000 years.

by **ship** can be a feasible alternative for many regions in the world,[2] but often the *most efficient method* is via **pipelines** (Lu et al., 2020). Pipelines to transport CO_2 are fairly common—although thus far heavily concentrated in the United States—and the development of many new pipelines around the world is underway or expected in the future (Greenfield et al., 2023). Carbon dioxide is non-flammable and non-toxic, and generally safe to transport via pipelines (in proper conditions, e.g. adequately dehydrated to manage corrosion risks), as evidenced by low accident rates (Duncan et al., 2009; Lu et al., 2020).

Scope - injection and storage

As with the capture and transport, the **injection** and geological **storage** of CO_2 can be achieved through several means. For example, CO_2 can be injected into **porous rock formations** in geological basins, or certain types of **industrial wells**. Dissolved carbon dioxide can also be injected into **subsurface basaltic or other mafic formations** for relatively rapid mineralization. Prior to injection, CO_2 gas is often pressurized into a liquid or supercritical fluid[3], or dissolved in water (Ali et al., 2022; Rochelle et al., 2004).

In general, there are *several types* of **geological formations** capable of permanently storing CO_2, such as:

- Deep saline aquifers
- Depleted hydrocarbon reservoirs
- Basaltic rocks
- Unmineable coal seams
- Organic-rich shales

Out of the types listed above, the first three (*deep saline aquifers, depleted hydrocarbon reservoirs, and basaltic rocks*) are considered as having the **most significant potential**, as all of them show vast storage capacity[4] and are abundantly present worldwide (Ali et al., 2022; Rasool et al., 2023; Snæbjörnsdóttir et al., 2020).

Injection depth - minimum

It is important that the storage reservoir is located deep enough underground to ensure efficient and secure storage. The elevated temperature and pressure deep underground increase the density of CO_2, leading to efficient utilization of the underground storage space, and prevent e.g. the degassing

[2] Thus far, transportation of CO_2 by ship has been mainly used in the food and brewery industries (Al Baroudi et al., 2021), but can be utilized for GSC projects as well, as exemplified by the Northern Lights project, where a key component is the transport of CO_2 by ship to an offshore geological storage site.

[3] A supercritical fluid is a particular state of matter, which exhibits characteristics from both the gaseous and liquid phases, such as the generally low viscosity of a gas and the high density of a liquid (Budisa & Schulze-Makuch, 2014). Carbon dioxide becomes a supercritical fluid above its critical pressure and temperature (roughly 73 atm and 31 °C). Besides geological storage, supercritical CO_2 is commonly used e.g. in oil and gas industry applications (such as enhanced oil recovery), and as an industrial solvent.

[4] Although there is significant uncertainty in the estimations of global geological CO_2 storage capacity (Anderson, 2017; Bachu, 2015), it is clear that the technically accessible CO_2 storage resources far exceed projections of aggregate demand for CO_2 storage capacity (Anderson, 2017; Dooley, 2013).

of any dissolved CO_2. For the injection of pure (undissolved) CO_2, the pressure and temperature inside the storage reservoir should be high enough to maintain any injected CO_2 in a liquid or supercritical state. The precise depth will depend on site specific factors such as the geothermal gradient (rate of temperature increase with depth), but suitable formations are usually found at depths greater than about 800 meters, where the natural temperature and fluid pressures are generally high enough for any injected CO_2 to reach a supercritical state (Benson et al., 2005). When the CO_2 is dissolved in water prior to injection (for rapid mineralization), the reservoir pressure needs to be high enough to ensure efficient mineralization and prevent degassing, and slightly shallower (500–900 m) reservoirs have been utilized in this approach (Snæbjörnsdóttir et al., 2020).

Injection depth - maximum

The maximum storage depth is mainly limited by cost and efficiency, as e.g. very deep sedimentary formations often lack sufficient porosity for large storage capacity, and sufficient permeability for high flow rates without overly high injection pressure (Anthonsen, 2012; Benson & Cole, 2008). Some studies have suggested an optimal depth window of around 800–2500 m (Anthonsen, 2012; Anthonsen et al., 2013; Chadwick et al., 2008; Raza et al., 2016), although CO_2 can be stored at depths greater than 4000 m if favorable reservoir conditions exist (Blondes et al., 2013).

1.2. Examples of geological storage

History of approach 70's

Geological storage of CO_2 is **not a new concept**. In fact, carbon dioxide capture and storage (CCS) facilities have been deployed around the globe since at least 1971, and have thus far collectively captured and stored around 300 Mt of CO_2 (Loria & Bright, 2021). The idea of utilizing geological formations in engineered greenhouse gas removal first surfaced in the late 1970s (Marchetti, 1977), although even before that, subterranean injections of CO_2 had been employed in the context of enhanced oil recovery (Han et al., 2010; Loria & Bright, 2021).

Further examples

Further **examples** of early utilization of geological storage sites include CO_2 injection into a deep saline aquifer at the Sleipner gas field since 1996 (Furre et al., 2017), and injection of acid gas[5] into depleted hydrocarbon reservoirs in the Alberta basin in Canada, operationalized in 1990 (Bachu & Gunter, 2005).[6] More recent years have seen the operationalization of several industrial scale CCS projects (Loria & Bright, 2021), such as the Archer-Daniels-Midland (ADM) ethanol production facility in Illinois, US (Gollakota & McDonald, 2012, 2014). Since 2012, CO_2 dissolved in water has been injected into reactive basaltic rock formations for subsurface mineralization at Hellisheiði in Iceland (Snæbjörnsdóttir et al., 2020).

[5] Acid gas is a mixture of CO_2 and H_2S (hydrogen sulfide) with minor traces of hydrocarbons. It is produced from certain oil and gas fields and must be removed before the product is sent to market.

[6] It should be noted that while both examples (the Sleipner gas field and acid gas injection) demonstrate utilization of geological CO_2 storage, they do not constitute as carbon removal as understood in this methodology due to the fossil origin of the injected CO_2. Furthermore, despite containing significant amounts of CO_2, the injection of acid gas was in fact originally motivated by the challenge of reducing atmospheric emissions of H_2S (Bachu & Gunter, 2005).

Naturally occurring phenomenon in earth's upper crust

Besides being a viable option for engineered greenhouse gas removal, GSC is also a **natural phenomenon** in the Earth's upper crust, which has been a part of the carbon cycle for hundreds of millions of years. Carbon-containing substances and CO_2 derived from chemical, biological or volcanic activities can naturally accumulate in subsurface environments and persist for extended periods of time in various forms. The subsurface is in fact by far the *largest carbon reservoir on Earth*, storing vast quantities of carbon in coals, oil, gas, organic-rich shales and carbonate rocks (Benson et al., 2005).

1.3. Operational principles

Typical process

A CO_2 capture and storage process usually consists of the fundamental components introduced in section 1.1. For example, in a typical underground storage operation, CO_2 is captured, liquefied and transported to the storage site where it is pumped from a surface facility into a saline aquifer or other suitable deep host formation. The increased temperature and pressure on the way down the borehole will then cause the CO_2 to become a supercritical fluid, which is initially stored as a free phase within the host formation. Another possibility is that CO_2 and water are simultaneously pumped down, and carbon dioxide enters the host formation in a dissolved state.

Safe storage underground & physical confinement

To mitigate climate impacts, it is critical that the injected CO_2 remains safely **stored underground**, and is not re-emitted back to the atmosphere. Once underground, the injected CO_2 can undergo a host of chemical and physical processes that affect its storage permanence, and it is therefore important that proper precautions are taken to guarantee safe and permanent geological storage. For example, a comprehensive characterization of the injection site[7] and careful screening via pilot and simulated experimental trials (Berger et al., 2019; Plaisant et al., 2017) are paramount in ensuring the **physical confinement** of the injected CO_2 and predicting how it will behave and migrate in the host formation over time.

Chemical confinement

In general, CO_2 is a fairly reactive substance, and its injection into the subsurface will result in a chemical disequilibrium and initiate multiple reactions which may help or hinder its **chemical confinement** (Czernichowski-Lauriol et al., 2006; Rochelle et al., 2004). These reactions can be divided into several categories, such as reactions with the minerals in geological host formation or the naturally occurring fluids within it, the caprock, the borehole materials, etc. The various CO_2–water–rock chemical reactions often help in trapping CO_2 securely for geologically important timescales (see section 1.4), but can in some instances also be deleterious, and actually aid the migration of CO_2. For example, reactions with basaltic rocks in the host formation can cause CO_2 to be trapped as solid carbonate minerals for geological timescales, but excessive precipitation might also block flow pathways needed to maintain high injection rates (Raza et al., 2022; Xiong et al.,

[7] Relevant characteristics include factors such as local geological, hydrogeological, and fluid chemical conditions, as well as any fractures, faults or inadequately plugged legacy boreholes where leaks might occur.

2017). Furthermore, mineral dissolution reactions might also open new flow pathways for CO_2 migration (Ali et al., 2022; Rochelle et al., 2004). In general, the types and rates of reactions that will occur depend upon various factors, such as the mineralogical composition of the surrounding rock, chemistry of the naturally occurring fluids, groundwater flow rates, and in-situ pressure and temperature (Rochelle et al., 2004).

1.4. CO_2 trapping mechanisms

Trapping - general statement

Trapping of CO_2 refers to the processes through which it is retained underground in porous formations after injection. Effective trapping is fundamental to prevent leakages from the storage site and re-emission of greenhouse gases. There are multiple physical and geochemical mechanisms responsible for trapping CO_2 in geological storage sites. **Four main types** of trapping mechanisms are often discussed in the scientific literature (Han et al., 2010):

- **Structural trapping**: confinement of the mobile CO_2 phase due to changes in lithology or stratigraphy of the reservoir rock, such as local variations in rock type, porosity, or permeability. In practice, the mechanism refers to e.g. trapping of CO_2 under low-permeability caprocks. The related term known as *stratigraphic trapping*[8] is sometimes used in addition to structural trapping, but for the purposes of this methodology, the two can be treated together.
- **Residual trapping**: confinement in porous media as an immobile CO_2 phase by surface tension (capillary force). During injection and subsequent migration, CO_2 invades the pore matrix of the geological formation, and a considerable volume of CO_2 becomes trapped in small and narrow pore spaces where it remains permanently immobilized by capillary forces. Residual trapping separates the large continuous CO_2 plume into multiple tiny pockets with increased ratio of surface area to volume, thus encouraging e.g. the chemical reactions that improve long-term trapping security (Sun et al., 2020). This mechanism has significant trapping potential in the short to mid-term timeframes (see figure 1.1), and is a dominant trapping mechanism in e.g. sedimentary formations (Iglauer et al., 2011; Pentland et al., 2011).
- **Solubility trapping**: confinement through the *in situ* dissolution of CO_2 into the naturally occurring fluids (such as oil, gas, or water) contained within the geological formation, i.e. the *formation fluid*. The primary benefit of solubility trapping is that the dissolved CO_2 is no longer driven upwards by the buoyant forces that affect CO_2 when it exists as a separate phase. Instead, the migration of dissolved CO_2 is controlled by the relatively slow deep groundwater flow patterns (Rochelle et al., 2004). Furthermore, the dissolved CO_2 can undergo various chemical reactions that increase the stability of the stored carbon, such as the formation of bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions (i.e. *ionic trapping*), or solid carbonate minerals (*mineral trapping*).

[8] Technically, structural traps are formed by tectonic deformation such as arching or faulting, while stratigraphic traps are caused by depositional differences between adjacent rock types. However, in many cases, traps cannot be clearly classified as either purely structural or stratigraphic, but rather a combination of the two.

- **Mineral trapping**: conversion of CO_2 to solid carbonate minerals through chemical reactions between CO_2 and the surrounding minerals. Mineral trapping of CO_2 is often considered the most secure and permanent form of trapping (Benson et al., 2005; Gunter et al., 2004; Mackay, 2013). Many of the precipitation reactions have very slow kinetics, and significant mineralization often requires a long time to occur, in the order of thousands of years or more. However, under certain conditions mineral carbonation can be promoted by injecting dissolved CO_2 into reactive ultramafic, mafic, intermediate or silicic rock formations, achieving mineral trapping within as little as two years (Matter et al., 2016; Snæbjörnsdóttir et al., 2020).

In addition to these main trapping categories, *several other mechanisms* can be defined. These can be e.g. variations or subtypes of the ones listed above, or mechanisms relevant in certain particular conditions. Examples of such **additional trapping mechanisms** include:

- **Hydrodynamic trapping**: effective confinement due to very long travel times of the CO_2 fluid to the surface following injection. The term is used to describe CO_2 that moves in the subsurface, as it finds its way from an injector to a structural trap. This mechanism is particularly relevant in laterally unconfined sedimentary basins with limited structural traps, but with large-scale flow systems and low groundwater and fluid flow rates (Rosenbauer & Thomas, 2010). Hydrodynamic trapping is sometimes considered together with (or as a component of) structural trapping.
- **Adsorption trapping**: confinement resulting from the preferential adsorption of CO_2 molecules onto microporous surfaces, such as coal seams or organic-rich shales. This trapping mechanism is relevant in e.g. the enhanced production of coal bed methane due to the coal's higher adsorption preference for CO_2 relative to CH_4 (C. M. White et al., 2005).

The relative importance of the various trapping mechanisms varies with time and other factors such as reservoir type and injection mechanism (see figure 1.1). The **most important mechanism** in the short term is usually **structural trapping**, and it is often a prerequisite for a storage site because it prevents the leakage of CO_2 through the caprock during the time required for other trapping mechanisms to gradually come into effect. However, other mechanisms such as **residual** and **solubility trapping** can also provide significant contributions to short term trapping. In fact, certain types of reservoirs and/or injection practices might even render structural trapping unnecessary, such as when CO_2 is injected within its solubility trapping phase (i.e. CO_2 is fully dissolved in water immediately before or during injection, and the reservoir pressure is high enough to prevent outgassing).

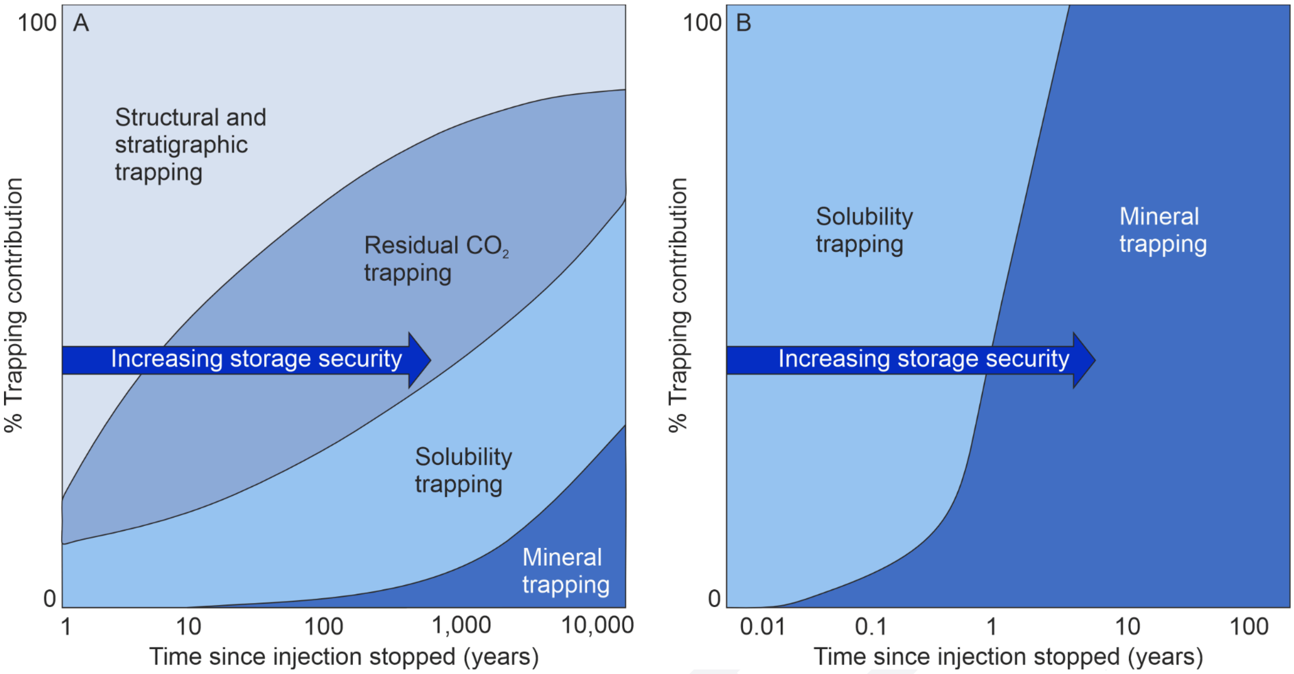

Figure 1.1. Various CO_2 trapping mechanisms with associated timescales and security of storage (after Snæbjörnsdóttir et al., 2020). Part **a** describes the injection of pure supercritical CO_2 into sedimentary basins, and part **b** the injection of water-dissolved CO_2 for mineralization.

2. Point of creation of the CO_2 Removal Certificate (CORC)

2.1. The CO_2 Removal Supplier

2.1.1. The CO_2 Removal Supplier is the party contractually authorized to represent the participants necessary to perform the end-to-end activities associated with a geological storage activity seeking certification under this methodology (see also section 3.3). Examples of entities commonly identified as the CO_2 Removal Supplier include but are not limited to the following:

- The operator of the carbon capture system.
- The owner of the carbon capture system.
- The owner of the captured CO_2.

In particular, the CO_2 Removal Supplier does not need to be the operator of the process creating the CO_2 to be captured (e.g. a biogas or bioenergy producer, or a waste treatment facility operator).

2.2. Point of creation

2.2.1. The point of creation of the CO_2 Removal Certificate (CORC) is the moment when the CO_2 Stream has been injected into the geological storage reservoir during the course of an eligible activity (see rule 3.2.1), and the data records thereof can be verified.[9]

[9] Time of injection is here defined as the point when a complete data trail is available for verification of the end-to-end quantities captured and stored.

3. Eligibility Requirements

3.1. Overall principles

In broad terms, an eligible activity is capable of permanently increasing the geological carbon stock by safely and durably storing CO_2 captured directly from the atmosphere or from sustainable biogenic sources. In practice, the CO_2 Removal is achieved by injecting a CO_2 Stream into a geological storage reservoir (Figure 2.1).

It is important that the requirements for geological storage activities ensure permanent, robustly quantifiable CO_2 Removal, conducted in a manner which leads to **no net harm**[10] to the environment (e.g. deforestation or loss of biodiversity), or to society (through e.g. loss of arable land, decreased food security, chemical emissions or health risks).

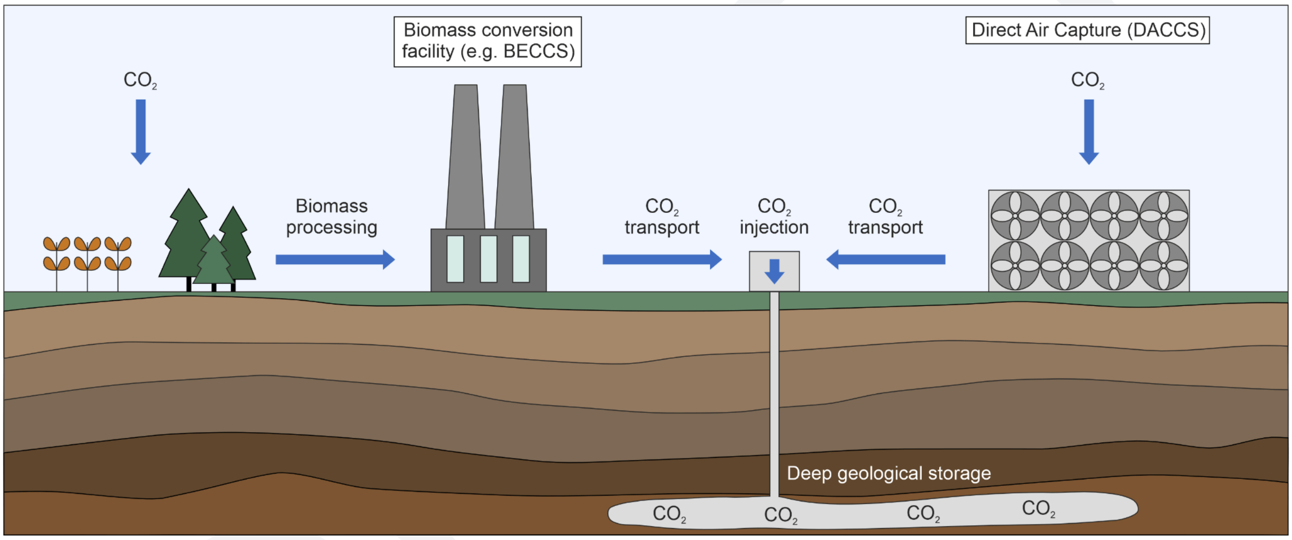

Figure 2.1. Schematic examples of CO_2 Removal activities within the scope of this methodology.

3.2. Requirements for general eligibility

3.2.1. An **eligible activity** is an activity where an eligible CO_2 Stream (see rule 3.2.2) is sourced and subsequently injected into a suitable underground geological storage reservoir (see rule 3.2.6) under conditions which ensure the safe and durable storage of CO_2, preventing its re-emission back to the atmosphere for at least 1000 years. The eligibility of the geological storage activity shall be determined during the Production Facility Audit.

3.2.2. An **eligible CO_2 Stream** shall consist overwhelmingly (at least 95% by volume) of carbon dioxide that has been captured from an eligible source of CO_2 (see rule 3.2.3). The CO_2 Stream may furthermore contain:

[10] While the capture and geological storage of CO_2 has significant potential to help mitigate the global effects of climate change, it is paramount that the capture and storage activities are conducted in a manner such that the benefits outweigh the disadvantages.

- Incidental associated substances from the source, capture or injection process.
- Trace substances added to assist in monitoring and verifying CO_2 migration.
- Substances added to the stream to enable or improve the injection process.

The CO_2 Stream may also be dissolved in water or seawater immediately prior to or during injection, for the purpose of injecting CO_2 within its solubility trapping phase.

3.2.3. The CO_2 injected into the geological storage reservoir shall be captured *directly from the atmosphere* or from a *sustainable biogenic source* as further detailed in subrules a and b (see also rules 3.2.4 and 3.2.5).

a. The following are considered **eligible sources of CO_2** (insofar as subrule b is not violated):
   - CO_2 from Direct Air Capture (DAC).
   - Biogenic CO_2 from the thermochemical treatment (e.g. combustion, gasification, or pyrolysis) of biomass, bioliquids or biogas (e.g. BECCS, bio-CCS).
   - Biogenic CO_2 from the incineration of biomass mixed with other substances (e.g. waste + CCS).
   - Biogenic CO_2 from biological treatment of biomass (e.g. anaerobic digestion for biogas + CCS, alcoholic fermentation for ethanol + CCS).
   - Biogenic CO_2 from other industrial processes (e.g. oxidation of biogenic materials).

b. The following are considered **ineligible sources of CO_2**:
   - Any CO_2 from fossil sources (i.e. any non-biogenic CO_2).
   - Any CO_2 (even biogenic) captured from activities relating to coal-fired electricity generation (e.g. a BECCS facility which co-fires biomass with coal).

3.2.4. In the case where CO_2 is captured from a biogenic source, the CO_2 Removal Supplier shall demonstrate that the **biomass is sourced sustainably** in accordance with local regulations and other requirements detailed in this methodology (see section 3.7) or the Puro Standard.

3.2.5. Carbon dioxide captured from eligible, non-eligible, or mixed sources may be alternatingly or simultaneously injected into the same geological storage reservoir provided that the **non-eligible fraction** of injected CO_2 is *reliably quantified* and *deducted* from the reported Output volume.[11]

[11] For example, CO_2 from mixed sources (e.g. from exhaust or flue gases containing both fossil and biogenic sources of CO_2) can be injected to a geological storage reservoir, but only the biogenic fraction of CO_2 is eligible and can be credited as CO_2 Removal Certificates (CORCs).

3.2.6. The CO_2 Stream shall be **injected** into an underground geological storage reservoir under conditions which ensure the safe and durable storage of CO_2, preventing its re-emission back to the atmosphere for at least 1000 years.[12]

The following general types of geological storage are eligible under this methodology:

- **Injection of pure CO_2**: Direct injection of a CO_2 Stream into a deep geological formation where the temperature and pressure in the storage reservoir are sufficient to maintain any injected CO_2 in a liquid or supercritical phase.[13] Examples of such reservoirs include deep saline aquifers, salt caverns, and depleted hydrocarbon reservoirs (see rule 3.2.7).
- **Injection of dissolved CO_2**: Injection of a CO_2 Stream dissolved in water or seawater (CO_2 fluid) into subsurface igneous (ultramafic, mafic, intermediate, or silicic) rock formations suitable for rapid mineralization. The injection of a dissolved CO_2 Stream shall occur in a manner which ensures immediate solubility trapping. Specifically, the pressure at the point of entry to the storage reservoir shall be greater than the bubble point pressure[14] of the injected liquid (see also rule 7.3.5). The temperature and pressure in the storage reservoir shall be sufficient to prevent degassing of CO_2.

The geological storage reservoir may be located either onshore or offshore. However, the CO_2 Stream must be injected into the Earth's crust, and shall not be stored in the water column (i.e. any body of water above the Earth's surface, such as the deep ocean), nor using any form of man-made buried container.

3.2.7. A **depleted hydrocarbon reservoir** may be utilized as a geological storage reservoir provided that the CO_2 Removal Supplier can evidence, to the satisfaction of Puro.earth, that no further hydrocarbon recovery from the storage reservoir will take place. The reservoir pressure shall not exceed the original pressure of the reservoir except locally around injectors during injection and well stimulation.

3.2.8. All geological storage sites shall be approved by the competent **local authority** or **regulatory body** and hold relevant permits for the injection and geological storage of CO_2.

3.2.9. All installations and operations relating to the geological storage activity shall comply with all applicable local **laws**, **regulations**, and other **statutory requirements** (including, but not limited to requirements for storage site characterization, injection operations, monitoring and reporting, as well as environmental, ecological, and social requirements).

[12] An extensive nonpermeable geological formation (e.g. caprock or salt dome) overlying the storage reservoir is a typical (but not ubiquitous) geological characteristic associated with storage reservoirs suitable for permanent CO_2 storage. For example, a caprock or similar is not necessary when a dissolved CO_2 Stream is injected under conditions which ensure immediate solubility trapping.

[13] The precise depth to maintain injected CO_2 in a liquid or supercritical phase depends on site specific parameters, but is usually greater than approximately 800 m (see section 1.1).

[14] The bubble point pressure is the pressure at which the first bubble of gas appears in a liquid at a specific temperature.

3.2.10. All capture, transport, and storage equipment shall be constructed or installed according to national best practices and in compliance with statutory requirements. All installations shall be **approved by local authorities** and hold relevant **permits** for their operation.

3.2.11. The injection of a CO_2 Stream into a geological storage reservoir shall only take place in jurisdictions with a **robust legal framework** for the environmentally safe geological storage of carbon dioxide. The specific requirements for eligible jurisdictions are laid out in subrules a–c.

a. The applicable legislation does not prohibit the geological storage of carbon dioxide.

b. All the following jurisdictions are *a priori* considered as having a robust legal framework for the environmentally safe geological storage of carbon dioxide, provided that they fulfill subrule a:

- The United States of America
- Any member state of the European Economic Area (EEA) Agreement[15]
- The United Kingdom of Great Britain and Northern Ireland

c. For any other jurisdiction fulfilling subrule a, except the ones explicitly mentioned in subrule b, the CO_2 Removal Supplier shall show that the applicable legal framework fulfills *all requirements* listed in table 1.1. Furthermore, Puro.earth reserves the right to determine the eligibility of a legal framework within the purview of subrule c based on evidence presented by the CO_2 Removal Supplier. The evidence shall be verified by the Facility Auditor.

Table 1.1. Requirements for a robust legal framework for the environmentally safe geological storage of carbon dioxide

Requirement	**EU CCS directive example[a]**	**US CFR example[b]**
The legal framework is designed for **permanent storage** of CO_2	Article 1.2	146.81(b)
The legal framework requires a **permit**, authorization, license, or equivalent regulatory control document for the operation of the storage site.	Article 6.1	144.11
The legal framework requires storage **site characterization** or other similar determination of minimum criteria of suitability for geological storage	Article 4.3	146.83
The legal framework includes a characterization of an **eligible CO_2 stream**	Article 12.1	146.81(d)

[15] The current members of the EEA Agreement are the member states of the European Union together with Iceland, Norway, and Liechtenstein. Note that currently (Nov 2023) certain member states of the EEA Agreement do not allow the geological storage of CO_2.

Requirement	EU CCS directive example[a]	US CFR example[b]
The legal framework requires appropriate **monitoring** of the injection facilities, the storage complex and the surrounding environment to ensure that the geologic storage project is operating as permitted and is not causing significant adverse effects.	Article 13	146.90
The legal framework requires at least periodical **reporting** to a competent authority to ensure that the geological storage project complies with storage permit conditions	Article 14	146.91
The legal framework includes requirements for **emergency and remedial response** in case of leakage or other significant irregularities	Article 16	146.94, 146.88(f)
The legal framework includes requirements for storage **site closure and post-closure site management**	Article 17	146.92, 146.93
The legal framework includes requirements for **financial responsibility** or other comparable mechanisms (e.g. transfer of responsibility to a competent authority) to ensure that the obligations arising under the issued geological storage permit can be met	Article 18, Article 19, Article 20	146.85

Note: The regulatory examples provided are not exhaustive and intended for information and clarification purposes only.

[a] Directive 2009/31/EC of the European Parliament and of the Council

[b] United States Code of Federal Regulations 40 CFR parts 144, and 146

3.2.12. The injected CO_2 Stream shall **not be utilized** for purposes other than permanent storage, including but not limited to:

- Injection for the purpose of current or future fossil fuel production (e.g. secondary hydrocarbon recovery and/or enhanced hydrocarbon recovery[16]). This includes both CO_2 injected during the actual hydrocarbon extraction phase as well as CO_2 injected before the extraction phase (e.g. for pressure maintenance) for the purpose of future hydrocarbon recovery.
- Injection for the purpose of recovering the stored CO_2 Stream for any reason, in full or in part, at any point in the future (i.e. temporary storage).

Note that the use of shared infrastructure is allowed to the extent laid out in rule 3.2.13.

3.2.13. The CO_2 Removal Supplier may utilize **shared infrastructure** for CO_2 transport, injection, or storage. Further requirements for the utilization of shared infrastructure is given in subrules a–c.

a. Shared infrastructure may be utilized even if such infrastructure is also utilized for non-eligible activities. However, the geological storage reservoir itself shall not be

[16] Enhanced hydrocarbon recovery refers to the practice of injecting substances such as CO_2, water, steam, or other chemicals into a storage reservoir for the purpose of recovering hydrocarbons additional to those produced by conventional methods of extraction. Enhanced hydrocarbon recovery covers such subtypes as enhanced oil recovery and enhanced coal bed methane recovery.

utilized for enhanced hydrocarbon recovery or any other activities in violation of rule 3.2.12.[17]

b. In cases where a part of the overall CO_2 Stream is utilized for non-eligible activities, the CO_2 Removal Supplier shall provide evidence that their CO_2 is intended for permanent storage in eligible storage sites. Such evidence shall be provided in the form of a contract or other binding arrangement.

c. The CO_2 Removal Supplier shall provide evidence of the amount of CO_2 injected into an eligible storage reservoir. Such evidence shall be provided in the form of mass balance data from the infrastructure provider.

3.3. Requirements for the CO_2 Removal Supplier

The activities associated with a particular geological storage project can involve multiple site operators collaborating within the project boundary. While the CO_2 Removal Supplier can act as the capture site operator, logistics operator and the storage site operator, the responsibility of these operations may also be transferred to *external operators* (see rule 3.3.2) by contractual agreements.

3.3.1. The CO_2 Removal Supplier shall provide a certified trade registry extract or similar official document stating that it is validly existing and in compliance with the legislation of the host jurisdiction.

3.3.2. The CO_2 Removal Supplier shall clearly establish and demonstrate the ownership of the CO_2 Removal project through either proof of direct ownership, or through contracts with external operators[18] where relevant. The CO_2 Removal Supplier shall furthermore prove with contracts or authorization documents its sole ownership of the permanently stored carbon (see also rule 3.6.1).

3.3.3. The CO_2 Removal Supplier shall provide, where applicable, evidence of valid permits, authorizations, licenses, or other equivalent regulatory control documents to operate any industrial facilities within the activity boundary, including but not limited to the storage site (see also rule 7.5.1). The CO_2 Removal Supplier shall furthermore provide evidence of possessing the rights to allow for appropriate monitoring at any stage within the activity boundary.

3.3.4. Where any part of the geological storage activity is contracted to an external operator, the CO_2 Removal Supplier shall establish a clear division of responsibilities and liabilities between the CO_2 Removal Supplier and the external operator, which shall at least address:

- Conducting the required monitoring activities, such as measuring device set-up, maintenance, and the monitoring of individual parameters.

[17] For example, the CO_2 Removal Supplier may transport CO_2 along a pipeline which also serves an enhanced oil recovery site, but may not inject CO_2 into a reservoir from which oil is recovered.

[18] An external operator is here defined as any party (such as the capture site operator, the logistics operators, or the storage site operator) operating on behalf and at the direction of the CO_2 Removal Supplier for provision of services relating to the geological storage activity.

- Preventive and corrective measures taken in case of a leakage, reversal or re-emission.
- Closure and post-closure requirements and expenses until the transfer of responsibility.

3.3.5. Where any part of the geological storage activity is contracted to an external operator, the the CO_2 Removal Supplier shall provide the contractual information necessary for assessing compliance with this methodology, the Puro Standard General Rules and other Standard Requirements, as well as any applicable local laws, regulations, or other binding obligations. This information shall at least include:

- Certified trade registry extracts or similar official documents stating that any and all external operators are validly existing and in compliance with the legislation of the host jurisdiction.
- Documentation that the CO_2 Removal Supplier is in contractual agreement with the external operator for the purpose of achieving permanent CO_2 Removal.
- In the case of an external storage site operator, documentation establishing that the captured CO_2 Stream received by the storage site operator will be injected and permanently stored into an eligible geological reservoir.
- Proof of sole ownership to the CO_2 captured, transported or stored, and attestation of no claim where necessary as per rule 3.6.1.
- Documentation establishing the right to audit the relevant documents and equipment belonging to the external operator for the purposes of CORC Issuance.

3.3.6. The CO_2 Removal Supplier is responsible for ensuring that sufficient data is available and accessible for auditing and verification that the geological storage activity is compliant with the requirements of this methodology and other applicable Puro Standard Requirements, as well as any applicable local laws, regulations, and other binding obligations. This includes but is not limited to delivering the necessary data to assess the eligibility of the activities, and quantify the predicted net carbon removal. In particular, the CO_2 Removal Supplier shall provide all calculation functions and parameters utilized for the quantification of net CO_2 Removal in a clear and consistent manner.

3.4. Requirement for baseline demonstration

The baseline is a conservative scenario of what likely would have happened without the geological storage activity and revenues from carbon finance. The baseline affects the determination of additionality (see section 3.5) as well as the determination of leakage (see section 6) and the determination of certain land use change emissions (see section 5.2). This section defines a set of baseline scenarios for various different removal pathways.

3.4.1. The CO_2 Removal Supplier shall select a baseline scenario among the ones listed in rules 3.4.2 and 3.4.3, and demonstrate eligibility for the selected baseline whenever applicable.

3.4.2. For projects utilizing direct air capture with geological storage of carbon dioxide (i.e. DACCS projects), the CO_2 Removal Supplier shall select the unique baseline called **DACCS New built** (no demonstration is hence required). In this baseline, it is assumed that the carbon capture facility is not built, the infrastructure for carbon dioxide transport is not built, and the carbon storage site is not built. Further, the land meant for construction remains in its historic state (pre-project land use).

3.4.3. For all other projects besides those within the purview of rule 3.4.2 (i.e. bio-CCS projects including waste-CCS, see eligible sources of biogenic CO_2 in rule 3.2.3), a baseline shall be selected and demonstrated among the following:

a. **Retrofitting of an existing biomass conversion facility**: in this baseline, called **bio-CCS Retrofit**, it is assumed that the biomass conversion facility already exists (and generates useful bioproducts, while CO_2 is emitted to the atmosphere), but it is not yet equipped with a carbon dioxide capture unit. Further, the infrastructure for carbon dioxide transport is not built, and the carbon storage site is not built. Further, the land where the biomass conversion facility is built is assumed to be already converted, while other land meant for construction remains in its historic state (pre-project land use). Finally, the biomass use or land use from where biomass is sourced (if applicable) is assumed to remain unchanged.

b. **Construction of a new biomass conversion facility**: in this baseline, called **bio-CCS New built**, it is assumed that neither the biomass conversion facility, the carbon capture facility, the infrastructure for carbon dioxide transport, nor the carbon storage site are built. Further, the land meant for construction remains in its historic state (pre-project land use). Finally, the previous use of the land where biomass is sourced from (if applicable, i.e. biomass from forest land or agricultural land) or the previous use of the biomass (if applicable, i.e. biomass from recycling streams, e.g. manure, industrial wastes, food waste) must be further specified on a project-basis for the determination of leakage (see section 6).

3.4.4. For a bio-CCS project to use the **bio-CCS New built** baseline, the CO_2 Removal Supplier shall demonstrate that the carbon capture unit has been installed within 48 months of the operational start of the biomass conversion facility. Otherwise, the bio-CCS project must use the **bio-CCS Retrofit** baseline.

a. In the special case of energy facilities that have recently been converted from fossil fuel to biomass (100% conversion), the operational start of the facility is defined as the time when the conversion to biomass is completed.

b. In the special case of biomass conversion facilities undergoing an expansion of their capacity (i.e. increased biomass consumption), while simultaneously installing a carbon capture unit, a case-by-case analysis shall be performed by the CO_2 Removal Supplier and the Issuing Body.

3.5. Requirements for additionality

3.5.1. To demonstrate additionality, the CO_2 Removal Supplier shall demonstrate that the geological storage activity is not required by existing laws, regulations, or other binding obligations. Further, the CO_2 Removal Supplier must convincingly demonstrate that the CO_2 removals are a result of carbon finance. Detailed requirements for this are set in the Puro Additionality Assessment Requirements.[19]

3.6. Requirements for prevention of double counting

3.6.1. The CO_2 Removal Supplier must ensure that the CO_2 removal is not double-counted in a manner that would infringe the Puro Standard General Rules. In particular, the General Rules entail that:

a. The CO_2 Removal Supplier shall evidence that it has the sole right to claim CORCs from the CO_2 placed in storage, and that other parties involved in the supply chain have no such right. This can be evidenced by contracts or attestations exhibiting the relation between the involved parties.

b. The CO_2 Removal Supplier or any party involved in the supply chain shall not associate any CO_2 removal claim (whether a marketing, branding, or footprint claim), to any other products or services delivered by the CO_2 Removal Supplier or involved party, including other types of environmental products (e.g. renewable energy certificates), unless the issued CORCs have been explicitly retired for this purpose.

c. The CO_2 Removal Supplier or any party involved in the supply chain may still report their direct emissions and removals in other sectoral GHG inventories (e.g. mandatory national reporting for UNFCCC, voluntary corporate reporting), making adequate disclosures regarding the issuance of CORCs.

d. The CO_2 Removal Supplier may decide that issued CORCs shall be used for Nationally Determined Contributions (NDCs) and other international mitigation purposes under the Article 6 of the Paris Agreement, and thereby shall follow the Puro Standard Article 6 Procedures.[20]

3.7. Requirements for biomass sustainability and traceability of origin

3.7.1. For all bio-CCS projects including waste-CCS (see eligible sources of biogenic CO_2 in rule 3.2.3), the CO_2 Removal Supplier shall demonstrate and keep records (i.e. traceability, chain of custody) of the **origin and type** of the biomass feedstock in order for the resulting CO_2 to be considered eligible. Any share of biomass feedstock for which **origin or type** cannot be demonstrated will not be eligible, and thereby its share of CO_2 will be excluded from the quantification of CORCs (see section 4.4, term $F_{eligible}$). Demonstration

[19] Available in the Puro Standard documents library.

[20] Available in the Puro Standard documents library.

of biomass feedstock origin applies regardless of the baseline scenario. The **origin and type** of biomass feedstock processed shall be demonstrated following the latest version of the *Puro Biomass Sourcing Criteria*, available separately.[21]

3.7.2. For all bio-CCS projects including waste-CCS (see eligible sources of biogenic CO_2 in rule 3.2.3), the CO_2 Removal Supplier shall demonstrate and keep records of the **sustainability** of the biomass feedstock in order for the resulting CO_2 to be considered eligible. Any share of biomass feedstock for which sustainability cannot be demonstrated will not be eligible, and thereby its share of CO_2 will be excluded from the quantification of CORCs (see section 4.4, term $F_{eligible}$). Demonstration of biomass feedstock sustainability applies regardless of the baseline scenario. The **sustainability** of biomass feedstock processed shall be demonstrated following the latest version of the *Puro Biomass Sourcing Criteria*, available separately.[22]

3.7.3. For all bio-CCS projects including waste-CCS, the CO_2 Removal Supplier shall categorize the biomass feedstock utilized for the geological storage activity into one or several of the following categories:

a. The non-sorted organic fraction of mixed municipal solid waste (typically used in waste-CCS), from normal municipal waste collection service.

b. Post-consumer source-separated food waste, post-production food waste, expired food, residues from food processing, other industrial food-related biowaste (e.g. sugar molasses, cooking oils), other farm-level food-related waste (e.g. spoiled food or feed harvest, expired seeds).

c. Post-consumer end-of-life paper, end-of-life textile, end-of-life wood materials (of different grades, e.g. untreated and treated), and assimilated biomaterials, from source-separated waste collection.

d. Non-hazardous municipal green waste from urban or rural areas (e.g. park and garden green waste, urban tree cuttings, river debris), including any fraction (e.g. foliage, roots, branches).

e. Abattoir waste and animal manure (typically processed via biological treatment, anaerobic digestion or fermentation) and its derivatives (e.g. digestate from manure and abattoir waste).

f. Sewage sludge and biosolids from municipal wastewater treatment

g. Forest biomass, including any primary (harvested from forest land) or secondary feedstock (generated during processing of primary feedstock) such as branches and tops, roots and stumps, thinnings, prunings, bark, woodchips, wood shavings, sawdust, black liquor.

h. Pulp and paper mill sludge, derived from processing of virgin fibers, recycled fibers or combination of sources.

[21] Available in the Puro Standard documents library [not yet available - see. separate draft].

[22] Available in the Puro Standard documents library [not yet available - see. separate draft].

i. Agricultural crops that are neither food nor feed crop (e.g. energy crops, biomaterial crops), cultivated on agricultural land.

j. Agricultural crops that are food or feed crops, whether or not used in such applications (e.g. corn or wheat fermented for biofuel, cereals fermented for beverage production), cultivated on agricultural land.

k. In-field agricultural residues, originating from the cultivation of a food or feed crop, e.g. cereal straw, rice straw, maize straw, stalks, pruning residues (trees, bushes).

l. Non-field agricultural residues, originating from the primary processing of a food crop in a factory, e.g. rice husk, maize cob, nut shell and husk, peels, fruit seeds, bagasse, coffee husk, cocoa pods.

m. Any biomass from palm tree plantations (which are not considered forests but agricultural plantations), e.g. palm oil and its fractions, empty fruit bunches, nuts and kernels, cakes, or other side-streams.

n. Invasive species whether on land, in freshwater, or in coastal areas, as well as any biomass from landscape management for conservation purposes of protected areas or assimilated, including forest wildfire mitigation.

o. Cultivated or harvested water-based plants or algae, and associated derivatives.

The list above is derived from the *Puro Biomass Sourcing Criteria,* in which strict type, origin and sustainability criteria are further defined.

REMARK ON THE *PURO BIOMASS SOURCING CRITERIA*

The biomass sourcing criteria are issued alongside the GSC methodology, but are meant to be ultimately applicable across all biomass-based CDR methodologies within the Puro Standard. The criteria will be refined and extended over time and the latest version of those criteria shall always be used when reporting CORCs.

The criteria distinguish (at time of publishing) between 15 categories of biomass feedstocks. For each feedstock category, the document details i) required feedstock origin and type disclosures (traceability), ii) required feedstock sustainability criteria, and iii) options to evidence the sustainability criteria. For certain feedstocks (e.g. post-consumer waste streams), the rules are limited to origin and type disclosures. For other feedstocks, such as forest biomass or purpose-grown biomass of different kinds, strict sustainability criteria apply covering both environmental and social aspects.

In practice, the CO_2 Removal Supplier must keep records of the biomass processed, alongside all information needed to demonstrate type, origin and sustainability. This information shall then be synthesized as part of the Output Audit procedures. Puro will make templates available to suppliers, to facilitate the reporting of this information.

Last, it must be highlighted that the biomass sourcing criteria are only a condition for eligibility of the feedstock, and that additional rules may apply in each methodology, e.g. rules relating to baseline and leakage.

3.8. Requirements for environmental and social safeguards

Please note that the Puro Standard General Rules contain the general requirements on environmental and social safeguards that apply to all methodologies (see also rule 3.8.1), while this section contains further details relevant to geological storage activities in particular.

3.8.1. The CO_2 Removal Supplier shall have in place, maintain, and abide by environmental and social safeguards to the extent required by this methodology, the Puro Standard General Rules, or any applicable local statutory requirements, in order to ensure that the geological storage activities do no net harm to the surrounding natural environment or local communities.

3.8.2. The CO_2 Removal Supplier shall provide all environmental permits, assessments, and other documents related to the analysis and management of environmental and social impacts of the geological storage activities that are required by the applicable local laws and regulations.

3.8.3. The CO_2 Removal Supplier shall undertake an assessment of the environmental and social impacts of the geological storage activities.

a. The scope of the assessment shall cover all stages (capture, transport, and injection) within the activity boundary (see rule 5.2.6).

b. The assessment shall at least include the following components:

- Description of the applicable legal and regulatory framework pertaining to the assessment and management of the environmental and social impacts of the geological storage activities.
- Description of the existing local environmental and socio-economic conditions (i.e. background information on the current environmental and socio-economic context in which potential impacts are assessed).
- Description of the geological storage activity in detail, including construction, operation, and decommissioning of infrastructure, and other aspects affecting the assessment of environmental and social impacts.
- Description of the anticipated environmental and social impacts. For example, such impacts might include any potential negative effects to:
    - Soil, air, and water quality (e.g. hydrological cycles, physical and biogeochemical properties).
    - Flora and fauna (e.g. biodiversity, habitats).
    - Human health and safety.
    - Socio-economic factors (e.g. related to land use or water resources).
    - Local communities (e.g. due to noise, vibration, and other nuisance factors, or induced seismicity).

- Sites of cultural significance.

- Description of the measures to mitigate the identified environmental and social impacts, including where relevant a description of the parameters and methods utilized to monitor the potential impacts.
- Description of public participation and consultation.

To address the above components partly or in full, the CO_2 Removal Supplier may utilize and refer to other documents (e.g. project description documents, stakeholder engagement reports, or legally mandated environmental and social impact assessment documents) containing the required information, provided that such additional documents are also included.

3.8.4. The CO_2 Removal Supplier shall record and disclose to the Issuing Body any negative environmental or social impacts (or claims thereof) occurred during the monitoring period, including but not limited to any legal actions and/or other written complaints filed by affected parties.

3.8.5. The CO_2 Removal Supplier shall comply with all applicable local laws and regulations relating to access and consumption of water resources. The CO_2 Removal supplier shall furthermore recognize, respect and promote the human rights to safe drinking water and sanitation[23] as well as the right to water as laid out in the General Comment No. 15 of the United Nations Committee on Economic, Social and Cultural Rights.[24] In particular, the CO_2 Removal Supplier shall not endanger the *availability*, *quality*, or *accessibility* of the local water supply, as defined in article 12 of General Comment No. 15.[25]

3.8.6. The CO_2 Removal Supplier shall prepare and abide by a plan to assess and mitigate exposure to harmful chemicals. The plan shall contain at least the following elements related to environmental risks and human health risks:

a. Identification and listing of any potentially harmful chemical compounds, such as sorbents and solvents (e.g. amines), used at any stage within the activity boundary.

b. Risk assessment and mitigation measures for chemical injuries (for example, due to inhalation, ingestion, or skin contact) considering all relevant exposure pathways (see also section 8.5 for general requirements on risk management).

c. Based on the local statutory requirements, a determination of threshold exposure values and/or other limit values to prevent chemically induced diseases (whether through direct exposure, or indirect exposure such as through environmental contamination where relevant), and a description of the measures to limit and monitor the exposure to harmful chemicals.

[23] The human rights to safe drinking water and sanitation, G.A. Res 78/206, U.N. Doc. A/RES/78/206 (Dec. 22, 2023).

[24] General Comment No. 15 (2002), The right to water (arts. 11 and 12 of the International Covenant on Economic, Social and Cultural Rights), U.N. Doc. E/C.12/2002/11 (Jan. 20, 2003).

[25] Ibid., p. 5.

d. Identification of any potential pathways for chemical spills or leakages, and a description of the measures to prevent leakages and mitigate any harm to the environment or human health.

e. Emergency preparedness plan, including appropriate response procedures in case a chemical spill has occurred. The plan shall at least address:

- How to prevent any further damage.
- Equipment and methods for cleanup.
- Evacuation zones and procedures.
- First-aid procedures.

4. Quantification of CO_2 Removal Certificates (CORCs)

4.1. General principles

In general, a **CORC** represents **net 1 tonne CO_2e** removed from the atmosphere. In the specific case of geologically stored carbon, the CO_2 removal results either from the physical removal of existing CO_2 from the atmosphere (DACCS), or from the interruption of a short-term carbon cycle by preventing CO_2 emissions from biomass decomposition (BECCS and other biogenic CCS approaches).

The overall principle of the CORC calculation (see figure 4.1) is that the CO_2 Removal Supplier first determines the **gross** amount (in metric tonnes) of CO_2 injected into the geological storage reservoir over a given monitoring period. Various deductions are then made, such as supply chain *emissions*, any potential *re-emissions,* and the effect of any unmitigated negative ecological, market, and activity-shifting *leakage*. The resulting **net amount** of **carbon sequestered** is converted to CO_2 equivalents and credited as CORCs. More details on the method of calculation are given in this section. For ease of reference, a summary of the variables utilized in this section can be found in table 4.1 at the end of this section.

$$\underbrace{\text{CORCs}} = \underbrace{C_{\text{stored}}} - \underbrace{E_{\text{project}}} - \underbrace{E_{\text{leakage}}} - \underbrace{E_{\text{reversal}}}$$

	CORCs	C_{stored}	E_{project}	E_{leakage}	E_{reversal}
Description	Net amount of CO_2 equivalents removed by the geological storage activity.	Gross amount of eligible CO_2 stored into the geological storage reservoir.	Total life cycle emissions arising from the whole supply chain of the geological storage activity.	Total GHG emissions due to unmitigated negative ecological, market, and activity-shifting leakage.	Total GHG emissions from the geological storage reservoir, if any.
Units	Tonnes of CO_2e	Tonnes of CO_2	Tonnes of CO_2e	Tonnes of CO_2e	Tonnes of CO_2e

Figure 4.1. CORC calculation equation.

4.2. Requirements for robust quantification of carbon removal and net-negativity

4.2.1. The length of the monitoring period can be decided by the CO_2 Removal Supplier, but shall *not exceed* one (1) year.

4.2.2. The CO_2 Removal Supplier must follow robust and auditable measurement practices and protocols for the data needed for the calculation of the quantity of CORCs resulting from the geological storage activity.

4.2.3. The CO_2 Removal Supplier must provide a life cycle assessment (LCA) quantifying the greenhouse gas emissions related to the geological storage activity, as per the scope and system boundaries defined in section 5, and following the general LCA guidelines described in the ISO 14040/44 standards.[26]

4.2.4. The CO_2 Removal Supplier must calculate the amount of sequestered carbon in the form of CO_2 Removal Certificates (CORCs) for each monitoring period, as per the requirements detailed in section 4 (see especially rule 4.3.1).

4.2.5. The CO_2 Removal Supplier shall have in place, maintain, and utilize an information system to keep records of any events affecting the amount of CORCs resulting from the geological storage activity.[27] These records must include time stamped, quantitative information such that their effect on the Output volume of the monitoring period can be quantified. These records must be available to the Auditor, for the Production Facility Audit and Output Audits.

4.2.6. The CO_2 Removal Supplier shall explicitly show, through comparison of data records, that the amount of CORCs (i.e. the total net amount of CO_2 removed, see rule 4.3.1) during a monitoring period does not exceed the amount (in tCO_2) of eligible CO_2 captured during the same monitoring period.

4.2.7. The CO_2 Removal Supplier must ensure that any instrumentation used for data collection is in place and adequately calibrated at all times (see also rule 7.2.8). The data records shall be kept in a reliable data system.

4.3. Overall equation

4.3.1. The overall number of CORCs (i.e., the total net amount of CO_2 removed) during a monitoring period shall be calculated as follows (see also figure 4.1 for an illustration):

$$CORCs = C_{stored} - E_{project} - E_{leakage} - E_{reversal} \qquad (4.1)$$

Variable	Description	Unit
$CORCs$	Net amount of CO_2 equivalents removed by the geological storage activity.	tCO_2e
C_{stored}	Gross amount of eligible CO_2 stored into the geological reservoir. Further requirements on the calculation of this term are given in section 4.4.	tCO_2
$E_{project}$	Total life cycle emissions arising from the whole supply chain of the geological storage activity. Further requirements on the calculation of this term are given in section 4.5.	tCO_2e

[26] ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework and ISO 14044:2006 Environmental Management - Life cycle assessment - Requirements and guidelines

[27] Examples of such events include any injection or re-emission events, as well as the construction or replacement of any facilities, machinery or equipment (which would affect overall supply chain emissions).

Variable	Description	Unit
$E_{leakage}$	Total GHG emissions due to unmitigated negative ecological, market, and activity-shifting leakage resulting from the geological storage activity. Further requirements on the calculation of this term are given in section 4.6.	tCO_2e
$E_{reversal}$	Total GHG emissions from the geological storage reservoir, if any. Further requirements on the calculation of this term are given in section 4.7.	tCO_2e

4.4. Carbon dioxide stored (C_{stored})

4.4.1. The gross amount of eligible CO_2 stored into the geological reservoir (C_{stored}) shall be calculated as follows

$$C_{stored} = (C_{injected} - E_{released}) \times F_{eligible} \times F_{supplier} \quad (4.2)$$

Variable	Description	Unit
C_{stored}	Gross amount of eligible CO_2 stored into the geological reservoir.	tCO_2
$C_{injected}$	Total amount of CO_2 injected at the storage site determined at the last monitoring point on the injection system.	tCO_2
$E_{released}$	Total amount GHGs released from the injection system downstream of the last monitoring point, but prior to final geological storage (i.e. injection leaks, such as accidental CO_2 leaks due to equipment failure, or other fugitive emissions during injection).	tCO_2e
$F_{eligible}$	Fraction of eligible CO_2 in the CO_2 Stream of the CO_2 Removal Supplier.	% mass
$F_{supplier}$	Fraction of the total gross amount of injected CO_2 attributed to the CO_2 Removal Supplier (e.g. when CO_2 Streams from several different operators are simultaneously injected into the same storage reservoir).	% mass

4.4.2. The CO_2 Removal Supplier shall quantify the total amount of CO_2 injected into the storage reservoir ($C_{injected}$) through direct measurements of the flow (either mass or volumetric flow, see rule 4.4.7 a) and composition of the injected CO_2 Stream.

a. In case mass flow measurements are utilized, $C_{injected}$ shall be calculated as

$$C_{injected} = m_{fluid} \times F_{CO_2} \quad (4.3)$$

b. In case volumetric flow measurements are utilized, $C_{injected}$ shall be calculated as

$$C_{injected} = V_{fluid} \times Q_{CO_2} \times \rho_{CO_2} \quad (4.4)$$

Variable	Description	Unit
$C_{injected}$	Total amount of CO_2 injected at the storage site, determined at the last monitoring point on the injection system.	tCO_2
m_{fluid}	Total mass of fluid injected at the storage site determined at the last monitoring point on the injection system.	tonnes
F_{CO_2}	Mass fraction of CO_2 in the injected fluid.	% mass
V_{fluid}	Total volume of fluid injected at the storage site, determined at the last monitoring point on the injection system, and at the CO_2 Removal Supplier's chosen reference conditions (see rule 4.4.7 b).	m^3
Q_{CO_2}	Volume fraction of CO_2 in the injected fluid at the CO_2 Removal Supplier's chosen reference conditions (see rule 4.4.7 b).	% vol
ρ_{CO_2}	Density of CO_2 at the CO_2 Removal Supplier's chosen reference conditions (see rule 4.4.7 b).	tCO_2/m^3

4.4.3. The CO_2 Removal Supplier shall quantify the mass or volume fraction of CO_2 in the injected fluid (F_{CO_2} or Q_{CO_2}, see rule 4.4.2) through direct measurement of the CO_2 concentration of the CO_2 Stream in accordance with rule 7.3.4.

4.4.4. The CO_2 Removal Supplier shall quantify any injection leaks ($E_{released}$). The term $E_{released}$ is defined as the total amount of greenhouse gases (in tCO_2e) released from the injection system downstream of the last monitoring point (i.e. from equipment located *on the surface* between the flow meter used to measure injection quantity and the injection wellhead).[28]

a. In cases where the flow meter measuring injection is placed directly on the injection wellhead(s), the value $E_{released} = 0\ tCO_2e$ shall be utilized.

b. In all other cases besides those within the purview of subrule a, the value of $E_{released}$ shall be determined in accordance with applicable local regulations[29] or, if no such regulations exist, by any of the following methods:

[28] Examples of injection leaks include unintentional leaks from equipment such as fittings, flanges, valves, connectors, or meters (e.g. due to equipment failure), as well as any vented CO_2 (e.g. for safety reasons from a pressure release device), and other fugitive emissions during injection.

[29] For example, a geological storage project in the US might fall under the reporting requirements of 40 CFR 98.443(f)(2), which further references 40 CFR Part 98 Subpart W for determination of equipment leaks and vented emissions.

- Documentation from the injection site operator quantifying $E_{released}$ and specifying the method of quantification.
- Direct measurement (e.g. if the injection wellhead and other infrastructure after the last monitoring point are located in an enclosed space, where gas sensors can effectively detect release).
- Conservative estimation (e.g. via component specific emission factors for potentially leaking equipment).

c. The term $E_{released}$ **shall not include** emissions from the geological storage reservoir itself (e.g. through fissures or inadequately plugged legacy injection wells), which are classified as reversals, and quantified in the term $E_{reversal}$ (see section 4.7).

4.4.5. The CO_2 Removal Supplier shall quantify the mass fraction of eligible CO_2 in the captured CO_2 Stream ($F_{eligible}$, see also rule 3.2.5).

a. For CO_2 Streams which do not include CO_2 from fossil fuels or feedstocks derived from fossil fuels (i.e. for CO_2 captured directly from the atmosphere or from purely biogenic sources), the value $F_{eligible} = 100\%$ shall be utilized if the CO_2 Removal Supplier provides operational data records that rule out fossil sources of CO_2 in the captured stream.[30] If the CO_2 Removal Supplier is unable to provide such data records, the fraction of eligible CO_2 shall be quantified through radiocarbon analysis as specified in subrule b.

b. For any other sources of CO_2 besides those within the purview of subrule a (e.g. waste + CCS, and other mixed sources), the fraction of eligible CO_2 ($F_{eligible}$) shall be quantified through radiocarbon (^{14}C) analysis following either the ISO 13833 or the ASTM D6866 standard test methods.[31]

4.4.6. The CO_2 Removal Supplier shall quantify the fraction of the total gross amount of injected CO_2 attributed to the CO_2 Removal Supplier ($F_{supplier}$). The fraction $F_{supplier}$ is defined as

$$F_{supplier} = m_{supplier\ CO_2} / m_{total\ CO_2} \tag{4.5}$$

a. The value $F_{supplier} = 100\%$ shall be utilized if the CO_2 Stream of the CO_2 Removal Supplier is not mixed with other CO_2 Streams prior to injection (e.g. if the CO_2 Removal Supplier is the sole user of the geological storage reservoir or if CO_2 Streams from different users are not simultaneously injected).

[30] For example, such data records might include records to show that 100% of feedstock is biogenic, capture plant design documents to show that e.g. CO_2 from fossil fuel combustion processes is not mixed with the captured CO_2 stream, or comparisons between mass of captured CO_2 and directly measured plant performance (for DAC).

[31] ISO 13833:2013 Stationary source emissions — Determination of the ratio of biomass (biogenic) and fossil-derived carbon dioxide — Radiocarbon sampling and determination, or ASTM D6866 Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis.

b. In all other cases besides those within the purview of subrule a, the CO_2 Removal Supplier shall provide documentation from the injection site operator certifying the fraction of the total gross amount of injected CO_2 attributed to the CO_2 Removal Supplier ($F_{supplier}$).

The values of $m_{supplier\ CO_2}$ and $m_{total\ CO_2}$ shall be determined in accordance with applicable local regulations or, if no such regulations exist, through any of the following methods:

- Direct measurement of the flow and composition of the delivered CO_2 Streams (similar to rule 4.4.2). In cases where CO_2 is delivered in containers, the mass may also be determined by weight measurement (e.g. via load cells or weighbridges). The measurements shall take place prior to any subsequent processing operations at the injection site (e.g. at a receiving custody transfer meter or similar).
- Documentation of delivered masses of CO_2 from shipping invoices, manifests, sales contracts or similar records.

Variable	Description	Unit
$F_{supplier}$	Fraction of the total gross amount of injected CO_2 attributed to the CO_2 Removal Supplier	% mass
$m_{supplier\ CO_2}$	Total mass of CO_2 delivered to the injection site by the CO_2 Removal Supplier during the monitoring period.	tCO_2
$m_{total\ CO_2}$	Total mass of all CO_2 delivered to the injection site during the monitoring period.	tCO_2

4.4.7. The CO_2 Removal Supplier shall monitor either i) the mass or ii) the volume and density of all captured and injected CO_2 Streams through direct measurement.

a. Any fluid flow measurements shall be performed using commercially available mass or volumetric flow meters. All flow meters shall be operated continuously (i.e. one measurement every 15 minutes or less) except as necessary for maintenance and calibration.

b. Any measurements of volume or other quantities derived from volume (e.g. density, volume fraction) shall be reported at the CO_2 Removal Supplier's chosen standard reference temperature (T_{ref}) and pressure (p_{ref}). The same reference values shall be used for all relevant quantities.[32]

[32] Definitions of standard reference conditions vary somewhat between different standards and jurisdictions. For example, the US mandatory greenhouse gas reporting regulations for the geologic sequestration of carbon dioxide require reporting of measured volumes of CO_2 at 60 °F and 1 atm (15.56 °C and 101.325 kPa) (40 CFR 98.444(f)(2)), while EU regulations use 0 °C and 1 atm (2018/2066 Article 3(52)). For the purposes of this methodology, the different definitions are not significant, as long as the CO_2 Removal Supplier consistently utilizes the same reference conditions for all relevant parameters.

Where necessary, volumes in non-standard conditions (T, p) shall be converted into volumes in standard conditions (T_{ref}, p_{ref}) via

$$V(T_{ref}, p_{ref}) = V(T, p) \times \rho(T, p)/\rho(T_{ref}, p_{ref}) \quad (4.6)$$

The values of $\rho(T, p)$ and $\rho(T_{ref}, p_{ref})$ shall be determined by measurement, or sourced from publicly available data.[33]

Variable	Description	Unit
$V(T_{ref}, p_{ref})$	Volume of the fluid at the CO_2 Removal Supplier's chosen reference temperature T_{ref} and pressure p_{ref}.	m^3
$V(T, p)$	Volume of the fluid at some non-standard temperature T and pressure p.	m^3
$\rho(T, p)$	Density of the fluid at some non-standard temperature T and pressure p.	t/m^3
$\rho(T_{ref}, p_{ref})$	Density of the fluid at the CO_2 Removal Supplier's chosen reference temperature T_{ref} and pressure p_{ref}.	t/m^3

4.5. Project emissions ($E_{project}$)

4.5.1. The total life cycle emissions arising from the whole supply chain of the geological storage activity (project emissions, $E_{project}$) shall be calculated as follows.

$$E_{project} = E_{capture} + E_{transport} + E_{injection} \quad (4.7)$$

Variable	Description	Unit
$E_{project}$	Total life cycle emissions arising from the whole supply chain of the geological storage activity.	tCO_2e
$E_{capture}$	Total life cycle emissions arising from the capture of the CO_2 Stream (see rule 5.2.6 a).	tCO_2e
$E_{transport}$	Total life cycle emissions arising from the transport of the CO_2 Stream (see rule 5.2.6 b).	tCO_2e
$E_{injection}$	Total life cycle emissions arising from the injection of the CO_2 Stream (see rule 5.2.6 c).	tCO_2e

4.5.2. The CO_2 Removal Supplier shall quantify the project emissions ($E_{project}$) based on a life cycle assessment of the geological storage activity, according to the requirements and system boundaries defined in section 5 of this methodology.

[33] In general, density can be calculated e.g. from an equation of state or from an empirical correlation formula. Easily accessible sources of data for carbon dioxide in conditions relevant for geological storage applications include the NIST Thermophysical Properties database (Lemmon et al., 2023) or an empirical correlation formula by Ouyang (Ouyang, 2011).

The term $E_{project}$ **shall not include** any emissions or removals already accounted for in the terms C_{stored}, $E_{leakage}$ and $E_{reversal}$.

4.5.3. The project emissions ($E_{project}$) shall be updated in each monitoring period with actual measured and recorded activity data (such as transport distances as well as fuel, energy, and material consumption).

4.6. Ecological, market, and activity-shifting leakage ($E_{leakage}$)

4.6.1. The total greenhouse gas emissions due to negative economic leakage resulting from the geological storage activity shall be calculated as follows.

$$E_{leakage} = E_{ECO} + E_{MA} \quad (4.8)$$

Variable	Description	Unit
$E_{leakage}$	Total GHG emissions due to unmitigated negative leakage resulting from the geological storage activity.	tCO_2e
E_{ECO}	Total GHG emissions due to unmitigated negative ecological leakage resulting from the geological storage activity (see section 6).	tCO_2e
E_{MA}	Total GHG emissions due to unmitigated negative market and activity shifting leakage resulting from the geological storage activity (see section 6).	tCO_2e

4.6.2. The CO_2 Removal Supplier shall quantify the total GHG emissions due to unmitigated negative leakage ($E_{leakage}$) based on an assessment of leakage due to the geological storage activity, in accordance with the requirements defined in section 6 of this methodology.

The term $E_{leakage}$ **shall not include** any emissions or removals already accounted for in the terms C_{stored}, $E_{project}$ and $E_{reversal}$.

4.7. Reversals ($E_{reversal}$)

4.7.1. The CO_2 Removal Supplier shall monitor and quantify any reversal events. For the purposes of this methodology, a reversal event is defined as any event which results in CO_2 or other greenhouse gases being either no longer securely stored in the storage reservoir (breach of permanent storage, such as leakage from the storage reservoir to underground sources of drinking water), or released from the storage reservoir into the atmosphere (i.e. re-emission, such as intentional venting due to wellbore maintenance, or unintentional emissions through transmissive faults or fissures, or improperly sealed legacy wells).

4.7.2. The total greenhouse gas emissions due to reversal ($E_{reversal}$) shall be calculated as follows.

$$E_{reversal} = \sum_{i=1}^{n} mCO_2e_i \tag{4.9}$$

Variable	Description	Unit
$E_{reversal}$	Total mass of GHGs emissions due to reversal events from the subsurface storage reservoir.	tCO_2e
mCO_2e_i	Total mass of GHGs emitted during reversal event i.	tCO_2e
i	Enumeration of reversal events, see also rule 4.7.3.	unitless
n	Total number of reversal events.	unitless

4.7.3. The CO_2 Removal Supplier shall quantify the total amount of CO_2 released during each reversal event (mCO_2e_i , see rule 4.7.2) through direct measurement or conservative estimation. Where the quantification of emissions from release events through direct measurement is unfeasible or impossible, the CO_2 Removal Supplier shall conservatively estimate the released amount based on the duration of the reversal event (ΔT_i) and estimated average flux of GHGs released (R_i) as follows.

$$mCO_2e_i = R_i \times \Delta T_i = R_i \times (T_{i,\,end} - T_{i,\,start}) \tag{4.10}$$

a. The average flux from a reversal event (R_i) shall be quantified through measurement and/or other relevant operational data.

b. The duration of a reversal event (ΔT_i) is defined as the number of days between the start date ($T_{i,\,start}$) and end date ($T_{i,\,end}$) of the event (both dates included).

c. The start date ($T_{i,\,start}$) of a reversal event is defined as the last date for which evidence of no reversal (related to event i) is available. If no such evidence is available, the start date is defined as the date when CO_2 injection started as part of the geological storage activity credited under this methodology.

d. The end date of a reversal event is defined as the date by which appropriate remedial measures have been undertaken to such an extent that reversal can no longer be detected.

e. Instead of estimating the total amount of CO_2 released during a reversal event (mCO_2e_i by utilizing equation 4.10, the CO_2 Removal Supplier may, where possible, quantify mCO_2e_i directly through measurement (e.g. in the context of intentional reversal during maintenance or monitoring operations, such as when pumping small amounts of fluids from the storage reservoir for monitoring purposes without re-injection).

Variable	Description	Unit
mCO_2e_i	Total mass of GHGs emitted during reversal event i.	tCO_2e
R_i	Estimated average flux of GHGs released during reversal event i.	tCO_2e / day
ΔT_i	The duration or estimated duration of reversal event i.	days
$T_{i,\,end}$	The date by which remedial measures have been undertaken to such an extent that reversal can no longer be detected.	days
$T_{i,\,start}$	One of the following dates: a. The last date when evidence of no reversal was identified from the site monitoring b. The date the CO_2 injection started as part of the activity credited under this methodology, if no available evidence exists to show that no reversal has been previously detected.	days

4.8. Quantification uncertainty assessment

Besides being able to quantify the amount of CO_2 Removal achieved in a project, it is also important to be able to estimate the uncertainty in the quantified value to ensure that the CO_2 Removal issued as CORCs is not overstated. This subsection considers uncertainty in the sense of quantification error, i.e. the difference between a measured/calculated value of a quantity and its unknown 'true' value. Uncertainty in a more general sense is further considered in section 8.

4.8.1. The CO_2 Removal Supplier must use conservative assumptions, values, and procedures to ensure that the CO_2 Removal issued as CORCs is not overstated.

4.8.2. The CO_2 Removal Supplier shall identify and report all material sources of uncertainty in the Output volume, considering at least the following common sources of material uncertainty:

- Representativeness of the parameters utilized (e.g. the statistical dispersion in the value utilized for the mass fraction of eligible CO_2 in the captured CO_2 Stream)
- Measurement errors (e.g. the measurement/calibration error of the flow meter utilized for quantification of the injected CO_2)
- Assumptions or estimations utilized by the CO_2 Removal Supplier (e.g. typical/estimated uncertainties of reference data sourced by the CO_2 Removal supplier, such as the density of CO_2 at reference conditions).

A material source of uncertainty is here defined as any source of uncertainty, whose effect to the total Output volume during the monitoring period is, or can be reasonably assumed to be, 1% or greater (see also rule 4.8.3).

4.8.3. For the purposes of this methodology, uncertainties associated with the emission factors utilized for the determination of greenhouse gas emissions are considered non-material (and therefore need not be considered), provided that the emission factors originate from LCA databases, local regulations, or other official sources, and that those factors include upstream and downstream as required in section 5. For emission factors originating from other sources, a flat uncertainty of 20% of the value of the emission factor shall be assumed.

4.8.4. The CO_2 Removal Supplier shall quantify the uncertainties in the Output volume as detailed in subrules a-c.

a. The CO_2 Removal Supplier shall quantify each identified material uncertainty (see rule 4.8.2) following the procedure in subrule b.

b. The CO_2 Removal Supplier shall directly quantify uncertainties (e.g. via calibration records, or statistical methods based on project data) where possible. Uncertainty estimations from external sources (such as peer-reviewed scientific literature or local regulations) or expert judgment may be utilized when necessary.

c. The CO_2 Removal Supplier shall calculate the overall uncertainty (i.e. estimated standard deviation) in the Output volume utilizing a quantitative, scientifically justifiable method for the propagation of uncertainty such as the variance propagation formula, or Monte Carlo simulations.

4.8.5. The CO_2 Removal Supplier shall conduct the uncertainty assessment before the 1st Output Audit, and thereafter update it at least annually.

Table 4.1. Summary of parameters utilized in this section.

Variable	Description	Unit	Reference
$C_{injected}$	Total amount of CO_2 injected at the storage site, determined at the last monitoring point on the injection system.	tCO_2	Rule 4.4.2.
m_{fluid}	Total mass of fluid injected at the storage site determined at the last monitoring point on the injection system.	tonnes	Rule 4.4.2.
F_{CO_2}	Mass fraction of CO_2 in the injected fluid.	% mass	Rule 4.4.2.
V_{fluid}	Total volume of fluid injected at the storage site, determined at the last monitoring point on the injection system, and at the CO_2 Removal Supplier's chosen reference conditions.	m^3	Rule 4.4.2.
Q_{CO_2}	Volume fraction of CO_2 in the injected fluid at the CO_2 Removal Supplier's chosen reference conditions.	% vol	Rule 4.4.2.

Variable	Description	Unit	Reference
ρ_{CO_2}	Density of CO_2 at the CO_2 Removal Supplier's chosen reference conditions.	tCO_2/m^3	Rule 4.4.2.
$E_{released}$	Total amount GHGs released from the injection system downstream of the last monitoring point, but prior to final geological storage.	tCO_2e	Rule 4.4.4.
$F_{eligible}$	Fraction of eligible CO_2 in the CO_2 Stream of the CO_2 Removal Supplier.	% mass	Rule 4.4.5.
$F_{supplier}$	Fraction of the total gross amount of injected CO_2 attributed to the CO_2 Removal Supplier.	% mass	Rule 4.4.6
$m_{supplier\ CO_2}$	Total mass of CO_2 delivered to the injection site by the CO_2 Removal Supplier during the monitoring period.	tCO_2	Rule 4.4.6
$m_{total\ CO_2}$	Total mass of all CO_2 delivered to the injection site during the monitoring period.	tCO_2	Rule 4.4.6
$V(T_{ref}, p_{ref})$	Volume of the fluid at the CO_2 Removal Supplier's chosen reference temperature T_{ref} and pressure p_{ref}.	m^3	Rule 4.4.7
$V(T, p)$	Volume of the fluid at some non-standard temperature T and pressure p.	m^3	Rule 4.4.7
$\rho(T, p)$	Density of the fluid at some non-standard temperature T and pressure p.	t/m^3	Rule 4.4.7
$\rho(T_{ref}, p_{ref})$	Density of the fluid at some non-standard temperature T and pressure p.	t/m^3	Rule 4.4.7
$E_{project}$	Total life cycle emissions arising from the whole supply chain of the geological storage activity.	tCO_2e	Rule 4.5.1
$E_{capture}$	Total life cycle emissions arising from the capture of the CO_2 Stream.	tCO_2e	Rule 4.5.1
$E_{transport}$	Total life cycle emissions arising from the transport of the CO_2 Stream.	tCO_2e	Rule 4.5.1
$E_{injection}$	Total life cycle emissions arising from the injection of the CO_2 Stream.	tCO_2e	Rule 4.5.1
$E_{leakage}$	Total GHG emissions due to unmitigated negative leakage resulting from the geological storage activity.	tCO_2e	Rule 4.6.1
E_{ECO}	Total GHG emissions due to unmitigated negative ecological leakage resulting from the geological storage activity.	tCO_2e	Rule 4.6.1
E_{MA}	Total GHG emissions due to unmitigated negative market and activity shifting leakage resulting from the geological storage activity.	tCO_2e	Rule 4.6.1
$E_{reversal}$	Total mass of GHGs emissions due to reversal events from the subsurface storage reservoir.	tCO_2e	Rule 4.7.2
mCO_2e_i	Total mass of GHG emitted during reversal event i.	tCO_2e	Rule 4.7.2
i	Enumeration of reversal events.	unitless	Rule 4.7.2

Variable	Description	Unit	Reference
n	Total number of reversal events	unitless	Rule 4.7.2
R_i	Estimated average flux of GHGs released during reversal event i.	tCO_2e / day	Rule 4.7.3
ΔT_i	The duration or estimated duration of reversal event i.	days	Rule 4.7.3
$T_{i, end}$	The date by which remedial measures have been undertaken to such an extent that reversal can no longer be detected.	days	Rule 4.7.3
$T_{i, start}$	One of the following dates: c. The last date when evidence of no reversal was identified from the site monitoring d. The date the CO_2 injection started as part of the activity credited under this methodology, if no available evidence exists to show that no reversal has been previously detected.	days	Rule 4.7.3

5. Assessment of life cycle greenhouse gas emissions

5.1. Generic life cycle assessment requirements

LCA principles and scope

5.1.1. The CO_2 Removal Supplier must conduct a life cycle assessment (LCA) for the geological storage activity. The LCA must follow the general principles defined in ISO 14040/44 and the scope defined in sections 4 and 5 of this methodology.

Report and calculation files

5.1.2. The LCA must include a report, which explains and justifies the data and modeling choices made, as well as supporting calculation files, which will be used for calculation of CORCs.

Climate metric

5.1.3. The LCA must calculate the climate change impact of the activity, characterized using 100-year global warming potentials (GWP_{100}, from the latest version available). Other environmental impact categories may be included but are not required.

Type of emission factors

5.1.4. The emission factors used in the LCA must at least include the contribution of major greenhouse gases (fossil CO_2, biogenic non-renewable CO_2, CH_4 , N_2O). The emission factors used in the LCA must include a full-scope of emissions (i.e., including upstream and downstream emissions, or so-called supply chain emissions, as opposed to emission factors used for greenhouse gas inventory purposes).

Disaggregated results for auditing

5.1.5. For transparency, interpretability and auditing purposes (i.e., verification of claims), the climate change impact calculated in the LCA must be presented in a disaggregated way exhibiting the contributions of the different life cycle stages described in figure 5.1 and table 5.1 as well as the contribution of major greenhouse gases (i.e., providing the total in tCO_2e but also the specific contributions of CO_2, CH_4, N_2O and other greenhouse gas to this total climate impact). In case any of contributions defined in figure 5.1 or table 5.1 is deemed to be not relevant or null, an explicit motivation must be provided in the LCA report and calculation files.

Aggregated results for public disclosure

5.1.6. The verified LCA results (i.e., after audit) that are made publicly available in the Puro Registry may be aggregated to a sufficient level as to protect sensitive information or licensed LCA data, as agreed with the Issuing Body. The aggregation must at minimum disclose the level 1 and level 2 contributions defined in table 5.1, and to some extent the level 3 contributions as defined in table 5.1 (e.g. direct land use change emissions).

Modeling of secondary resources

5.1.7. In the event that waste, recycled or secondary resources are used as input to the activity (e.g., recycled steel or plastic), it is permissible and recommended to apply in the LCA the cut-off approach[34] for waste, recycled and secondary products. Specifically, the environmental burdens from production of secondary resources may be excluded from the system boundary, but the supply, transformation and handling of the secondary resources must be included.

Handling of valuable by-products

5.1.8. In the event that by-products are generated during the activity and that these by-products have a useful use outside of the process boundaries, then an allocation of the relevant life cycle stages between the co-products may be applied. Determination of an appropriate allocation rule shall follow principles from ISO 14040/44.

Cooperation between operators for LCA

5.1.9. Data required for performing the LCA of a geological storage activity originates from multiple parties, and most importantly from the capture site operator, the logistics operators, and the storage site operator. The CO_2 Removal Supplier must coordinate data collection and LCA modeling with the operators.

5.2. Methodology-specific life cycle assessment requirements

Functional unit

5.2.1. The **functional unit** of the LCA shall be "the capture, transport, and storage of 1 metric tonne of carbon dioxide" in a specific geological reservoir. Results of the LCA are expressed per dry metric tonne of carbon dioxide captured, transported, and stored.

Spatial boundaries

5.2.2. The **spatial boundaries** of the LCA must be defined. This includes: the areas from which biomass is sourced (for any biomass-based capture activity), the location of the capture site(s), the main transport routes, as well as the location of the storage site(s).

Time boundaries

5.2.3. The **time boundaries** of the LCA must be defined. This includes specifying the planned duration of the carbon capture activities, carbon injection activities (until site closure), storage site monitoring activities (until liability transfer to national entity or equivalent), and the planned lifetime of key infrastructure (e.g. facilities, pipelines). It is required to disclose in the LCA both technical design lifetimes, as well as any useful lifetimes, because useful lifetimes may be shorter than technical design lifetimes. Those lifetimes may affect how embodied emissions are amortized (see below).

Activity boundary

[34] Description of the cut-off system model is available on the website of the ecoinvent life cycle database.

5.2.4. The **activity boundaries** that must be included in the LCA to represent the carbon capture and storage activity are defined in figure 5.1, from capture of the carbon stream to injection of the carbon stream. The LCA report must include a project-specific process-flow diagram that details each of the main stages defined in figure 5.1.

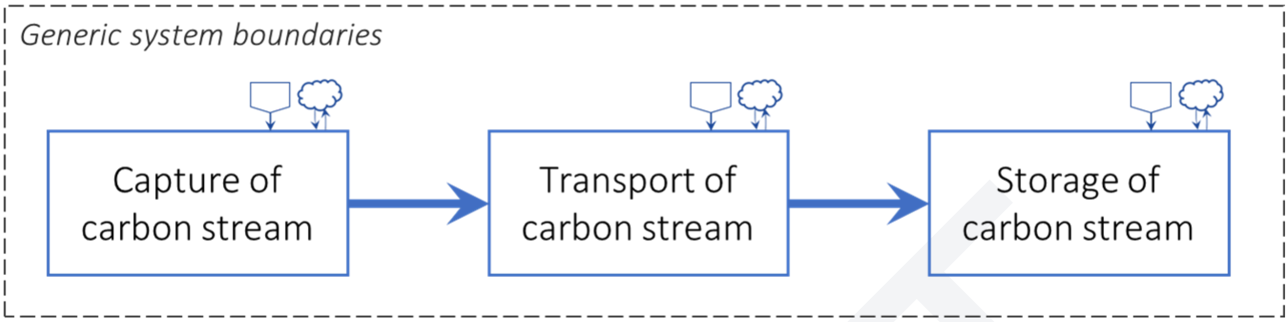

Figure 5.1. Process boundaries for the life cycle assessment (LCA) of a GSC activity.

Accounting for embedded (or embodied) and operational carbon emissions separately

5.2.5. Each stage included in the **activity boundaries** includes both embedded emissions (e.g., infrastructure and machinery) and operational emissions (e.g., energy and material use). These two types of emissions shall be specified and accounted for in the LCA.

a. **Embedded or embodied emissions** of infrastructure and/or equipment represent the carbon emitted in the land-use conversion (when applicable) and the fabrication, construction, maintenance, and demolition of these assets. These emissions shall be calculated and amortized against the gross carbon captured according to the rules described in 5.2.14 to 5.2.17.

b. **Operational emissions** of facilities or other types of infrastructure and machinery includes the energy used to operate these assets and the material inputs necessary for operation (e.g., biomass supply, solvents). These emissions are subtracted from the gross carbon captured.

Description of main stages

5.2.6. Each stage included in the **activity boundaries** must represent a complete life cycle, for which the full scope of emissions must be included. A full scope of emissions imply that infrastructure and equipment requirements, material and energy consumption, as well as treatment of waste materials must be included (i.e., upstream and downstream activities). The three main stages are briefly described below:

a. **Capture of carbon stream** refers to all activities required for sourcing, capturing and processing the carbon stream at the capture facility. Depending on the specific capture pathway, this stage may also include activities related to biomass production and sourcing (see 5.2.8 and 5.2.9). This stage terminates with the *carbon stream captured and ready for transport*. LCA data for this stage is expected to originate mainly from the *capture site operator*.

- Embodied emissions: This includes emissions related to the construction, maintenance and disposal of any equipment (buildings, machines) needed for sourcing, capturing and processing the carbon stream at the capture facility.
- Operational emissions: energy use by the capture process, material and chemical use by the capture process (e.g., sorbents), energy use by any further processing step of the carbon stream (e.g. dehydration, liquefaction), material and chemical use by any further processing step of the carbon stream, and treatment of any waste arising during operations.
- Biomass supply emissions: when applicable, biomass production and sourcing as per rules 5.2.8 and 5.2.9 below.

b. **Transport of carbon stream** refers to all activities required for transporting the carbon stream from the capture site to the storage site, whether by pipeline, rail, road, shipping, or a combination of transportation modes, and whether mixed with other carbon streams or not. It also includes any transfer steps, intermediary storage steps and processing of the carbon stream, as well as potential carbon losses during those steps. This stage terminates with the *carbon stream delivered to the storage site.* LCA data for this stage is expected to originate mainly from the *logistic operators*.

- Embodied emissions: This includes emissions related to construction, maintenance, and disposal of any infrastructure and equipment (i.e., buildings, machines, vehicles, pipelines).
- Operational emissions: the emissions of all transport and hub operation activities of the transport chain and all emissions of energy provisions of those activities for all transport chain elements (TCE). This stage shall be calculated in accordance with ISO 14083:2023[35] and using the GLEC Framework v3. In addition, material and chemical use, and treatment of any waste arising during transportation should be included.

c. **Injection of carbon stream** refers to all activities required for injecting the delivered carbon stream into the storage site, as well as the monitoring of the storage site until liability transfer. This stage terminates with the *carbon stream injected at the storage site.* LCA data for this stage is expected to originate mainly from the *storage site operator*.

- Embodied emissions: This includes emissions related to the construction, maintenance and disposal of any equipment (buildings, machines) needed for the storage site,
- Operational emissions: This includes emissions related to i) energy use by the injection process, ii) material and chemical use by the injection

[35] ISO 14083:2023 Greenhouse gases - Quantification and reporting of greenhouse gas emissions arising from transport chain operations

process, and iii) treatment of any waste arising during operations. These stages are further specified in the following requirements.

CO_2 contributions organized by main stages

5.2.7. The CO_2 Removal Supplier shall collect and organize the elements and processes that contribute to generate the project emissions ($E_{Project}$) both embodied and operational emissions according to the levels of information described in table 5.1 below.

Table 5.1. Stages that must be included in the life cycle assessment of the removal activity. LCA results must be provided in a disaggregated way exhibiting the contributions of each main stage and substage. Each sub-stage can be further divided into contributions (level 3) relevant for each project type. If a contribution is deemed not relevant or equal to 0, an explicit motivation shall be provided (see. 6.1.4). The contributions noted with an asterisk (*) must at minimum be publicly disclosed in the Puro Registry as part of annual Output Audit.

Main stages Level 1 contributions	Sub-stages Level 2 contributions	Further sub-stages Level 3 contributions	Comment
*$E_{capture}$	*Operational emissions of carbon capture	Energy use (heat, electricity, fuel) Material use Waste treatment	
	*Biomass production, supply and conversion (if applicable)	Production Supply Conversion *dLUC	Either fully attributed to CORCs or partly allocated to CORCs via share of internally use bioenergy
	*Embodied emissions of carbon capture	Construction, maintenance, and disposal of infrastructure and equipment *dLUC.	Maintenance can be demonstrated to be neglectable, in annual reporting
*$E_{transport}$	*Operational emissions of carbon transport	Energy use (heat, electricity, fuel) Material use	Third-level contributions may be split in sub-stages as relevant for each supply-chain.
	*Embodied emissions of carbon transport	Construction, maintenance, and disposal of infrastructure and equipment *dLUC.	Maintenance can be demonstrated to be neglectable, in annual reporting
*$E_{injection}$	*Operational emissions of carbon injection	Energy use (heat, electricity, fuel) Material use Waste treatment	

Main stages Level 1 contributions	Sub-stages Level 2 contributions	Further sub-stages Level 3 contributions	Comment
	*Embodied emissions of injection/storage	Construction & disposal Maintenance *dLUC	Maintenance can be demonstrated to be neglectable, in annual reporting
	*Storage site monitoring		Can be demonstrated to be neglectable, as per 5.2.18.

Biomass supply-chain emission attribution

5.2.8. For the stage **Capture of carbon stream**, the following rule further applies to any **biomass-based capture** activity regarding attribution of emission from production, supply and conversion of biomass feedstock:

a. If the activity is associated with **the production of one or several biomaterial or bioenergy products**, then the emissions associated with the production and supply of the biomass feedstock are *in the general case* fully attributed to those products. If any of those main products are then utilized in the capture process (e.g. steam or electricity used in capture process), the emissions associated with the share utilized are included in the stage Capture of carbon stream.

This applies for instance to **anaerobic digestion** facilities (producing biomethane for heat and power production, upgraded biomethane for vehicle fuel or industrial fuel usage, and digestate for use as fertilizer), **fermentation facilities** (producing ethanol-products, either for consumption or fuel usage), **thermochemical conversion facilities** (producing heat, steam, power, fuel, biochar or a combination of these, whether via combustion, pyrolysis, gasification of biomass).

Exceptions to the general case:

- Alternatively, the CO_2 Removal Supplier may also decide to fully attribute emissions from production, supply and conversion of biomass to the Carbon capture activity, and thereby consider the co-produced bioenergy and biomaterials as burden-free, provided this is allowed and compatible with other greenhouse gas reporting schemes the operator is subject to. This is conservative from the perspective of CORCs but not required.
- Alternatively, the Puro Standard reserves the right to issue rule clarifications for specific removal pathways in which emissions from biomass feedstock production and supply may need to be allocated in other ways between the material/energy products and the carbon stream captured. This might apply to specific pathways where the conversion of the biomass and the capture and storage of carbon dioxide take place simultaneously and cannot be dissociated.

Further, the emission partitioning rules used to perform the allocation between co-products shall be consistent with any other accounting performed by the operator, whether required in the jurisdiction of the project or voluntary. If no such system is in place, the emission partitioning rules must follow any industry best-practice, e.g. based on GHG Protocol guidance for CHP plants,[36] or default to the general principles of allocation defined in ISO 14040/44.

b. If the activity is **not associated with the production of any main material or energy product**, then the emissions associated with the production, supply and conversion of the biomass feedstock must be included in the stage **Capture of carbon stream**. This applies to any activities using purpose-grown biomass or secondary biomass streams (e.g. agricultural residues, urban biomass waste) for the sole purpose of carbon capture and storage, without any co-products.

Biomass supply-chain emission quantification

5.2.9. For the stage **Capture of carbon stream**, the following rule further applies to any **biomass-based capture** pathway regarding quantification of emission from production, supply and conversion of biomass feedstock:

a. Production: Biomass production shall include:

- In the case of purpose-grown biomass, emissions arising from all activities involved in biomass cultivation and harvesting, such as the use of machinery and fuel, the production of fertilizers, emissions from soils following fertilizer use, machinery manufacturing and disposal.
- Further, if the biomass production process is multi-functional such as producing different biomass fractions for different purposes (e.g. hemp cultivation producing stalks and seeds), allocation may be used, motivating the selection of an adequate partitioning rule (e.g. dry mass, carbon content, or economic value allocation partitioning, or by-product cut-off).
- Further, if the biomass feedstock is residues from forestry activities for timber production (e.g., residues at final felling, residues from thinning, bark, sawdust), the production of the biomass stream is considered burden free, only its supply and conversion shall be included. Likewise, for biomass generated during processing of primary forest biomass (e.g. sawmill residues), the production of the biomass stream is considered burden free, only its supply and conversion shall be included.
- In the case of post-consumer or secondary biomass streams (e.g. biomass from recycling or landscaping activities in urban areas), the production of the biomass stream is considered burden free, only its supply and conversion shall be included.

[36] Allocation of GHG Emissions from a Combined Heat and Power (CHP) Plant. Guide to calculation worksheets (September 2006) v1.0 A WRI/WBCSD GHG Protocol Initiative calculation tool. Available at: https://ghgprotocol.org/sites/default/files/2023-03/CHP_guidance_v1.0.pdf

- Direct land use change due to sourcing of primary biomass from forest land or agricultural land must be demonstrated to be null, which is achieved by demonstrating that the biomass feedstock meets the sustainability criteria as per rule 3.7.2, which conditions eligibility. Further, situations of shifting biomass use, which potentially leads to indirect leakage effects, must be tackled according to section 6 (Determination of leakage), depending on the baseline.

b. <u>Supply</u>: Biomass supply shall include, as applicable:

- Harvesting of the biomass in the field or forest (e.g., farm or forest management practices).
- Transport of the biomass from the production site to the conversion facility.
- Any other processing of the biomass, anywhere along the supply chain, such as chipping or drying.
- Any significant emissions from biomass decay during storage, if relevant.

c. <u>Conversion</u>: Biomass conversion shall include, as applicable:

- Energy inputs, e.g., start-up or ancillary fuel usage, external electricity usage.
- Material inputs, e.g., consumables used for flue gas treatment systems such as chemicals, bag filters, water.
- Disposal of waste streams (e.g., ash disposal in biomass combustion plants, disposal of other consumables from flue gas treatment systems, wastewater).
- Direct greenhouse gas emissions from the biomass conversion process (e.g., CH_4, N_2O at the facility), either derived from measurements specific to the facility, default values used for national greenhouse gas inventory reporting, or as per default conservative values provided in table 5.2 (if available).
- Embodied emissions of infrastructure and equipment, if applicable.

Table 5.2. Default factors for direct emission of CH_4 and N_2O at the biomass conversion plant, per pathway and feedstock type, whenever available. The emission factors are expressed in kg of greenhouse per TJ of biomass on a lower heating value basis, or per tonne waste processed on a dry basis. Note that project and technology specific values can be used instead, if supported by evidence, e.g. for fluidized bed combustion, gasification. Default values for other technologies may be added in future revisions.

Conversion pathway	Biomass feedstock	kg CH_4	kg N_2O	Unit	Source
Combustion, conventional technology	Wood	100	15	per TJ biomass	Volume 2, Chapter 2, Table 2.2, upper values, in IPCC 2006
	Municipal	100	15	per TJ	Volume 2, Chapter 2, Table 2.2, upper

Conversion pathway	Biomass feedstock	kg CH_4	kg N_2O	Unit	Source
	solid waste			biomass	values, in IPCC 2006
	Black liquor	18	21	per TJ biomass	Volume 2, Chapter 2, Table 2.2, upper values, in IPCC 2006
Anaerobic digestion	Manure, food waste, sludge	20	Negligible	per dry tonne biomass	Volume 5, Chapter 4, Table 4.1, upper value, in IPCC 2006

Sorbents and solvents used for carbon capture

5.2.10. For the stage **Capture of carbon stream**, whether for direct air or for flue gas capture, emissions from sorbent or solvent usage shall include: manufacturing of the sorbent, supply of the sorbent from production site to capture facility, and disposal of the sorbent. Manufacturing of sorbent must include energy inputs, material inputs, and disposal of waste arising during production (e.g. wastewater). Determination of the climate footprint of such chemicals may be performed in a separate LCA study, provided it complies with the rules defined here and the calculations are made available for auditing. Further, the calculations and reporting shall also make explicit the assumed or demonstrated useful lifetime and efficiency of the sorbents or solvents.

Capture of carbon dioxide for multiple end-uses

5.2.11. For the stage **Capture of carbon stream**, the following rule further applies to any project where a fraction of the captured carbon stream is used for permanent storage (i.e. CCS) and another fraction is utilized or sold for other purposes (i.e. CCU): the emissions from the stage Capture of carbon stream may be split between the two carbon streams, based on the mass of carbon. The carbon utilized or sold for CCU applications shall be reported with a product footprint consistent with the accounting rules applied here.

Numerical example: If the stage Capture of carbon stream is associated with supply-chain emissions of 150 kg CO_2e for 1000 kg of CO_2 captured, out of which 30% is meant for CCU applications and 70% is meant for CCS. Then, 30% of the 150 kg CO_2e are attributed to the CO_2 meant for CCU (not included in LCA), while 70% are attributed to the CO_2 meant for CCS, and thereby included in the LCA.

Capture of mixed carbon sources

5.2.12. For the stage **Capture of carbon stream**, the following rule further applies to any **mixed capture** activity where both non-eligible (i.e., fossil C, non-eligible biogenic C) and eligible carbon fractions (biogenic C, atmospheric C) are captured jointly, regarding the attribution of emissions between the eligible and non-eligible carbon sources: the emissions from the stage Capture of carbon stream are fully attributed to the eligible carbon fraction, regardless of the fact that the non-eligible fraction is also injected to permanent storage. This applies in particular to solid waste incinerators (waste-CCS) where fossil plastic materials and biogenic materials are combusted together.

Transport and storage of mixed carbon sources

5.2.13. For the stages **Transport of carbon stream** and **Storage of carbon stream**, the following rule further applies to any **mixed transport** or **mixed injection** activities, where both eligible carbon sources from the supplier is mixed with either non-eligible carbon sources from the supplier and/or carbon sources (of unknown eligibility) from other projects:

a. The CO_2 Removal Supplier shall account for emissions for the total of its volume processed, including both eligible and non-eligible fractions, which is conservative and consistent with rule 5.2.12.

b. The operators shall differentiate between operational and embodied emissions, which have different attribution/amortization rules.

c. For operational emissions related to recurring energy use and material use, the operators shall attribute the emissions per gross tonne of CO_2 processed by considering the total volume of carbon dioxide processed over the monitoring period (e.g. year), regardless of the nature or eligibility of the CO_2 processed. In case of using pipeline transport, this entails the energy used by pumps when the product is in transit and requires that the operator of the pipeline provide emission intensity expressed in GHG emissions per tonne km of product throughput, averaged on an annual basis.

d. For embodied emissions related to foreground infrastructure construction, maintenance activities and disposal, and to direct land use change from infrastructure construction, the operators shall amortize the embodied emissions per gross tonne of CO_2 processed as detailed in the rule 5.2.15.

Inventory modeling of embodied emissions

5.2.14. For emissions related to infrastructure (equipment, building, machinery) at any stage in the foreground system (i.e. capture facility, transport infrastructure, and storage facility), the inventory modeling shall include at minimum the following elements: production of key materials (concrete, asphalt, steel, wood), transport of key materials to site, energy usage during construction (fuels, electricity), disposal of waste arising during construction (e.g., excavated material sent for disposal), and disposal of key materials at end-of-life (e.g. using default processes available in LCA databases for disposal).

a. For the process-based LCA calculation of whole building and infrastructure projects, the following standards are referenced as general guidance: EN 15804+A2[37], EN 15978[38] and ISO 21930:2017.[39]

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[37] EN 15804:2012+A2:2020 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.

[38] EN 15978:2012 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.

[39] ISO 21930:2017 Sustainability in buildings and civil engineering works - Core rules for environmental product declarations of construction products and services.

b. Alternatively, and only if available in the countries where facilities are built, recent monetary emission factors (e.g. kg CO_2e per USD spent) may be used as a proxy for estimating embodied emissions based on capital expenditure (CAPEX), since such factors are in general more conservative.

c. Further, a distinction is made between the two baselines for bio-CCS pathways. For bio-CCS New Built, the biomass conversion facility is part of the capture facility, and embodied emissions are calculated for both assets. For bio-CCS Retrofit, the biomass conversion facility is considered burden-free (i.e. the embodied emissions are neglected), only emissions from the capture facility are included.

Amortization of embodied emissions

5.2.15. In the context of this methodology, the amortization of an asset (infrastructure or equipment) is the process of spreading the embodied emissions associated with the production, maintenance, and decommissioning of the asset in a period of time in line with its expected operational life or the project's lifetime assumption. It is possible that unplanned maintenance or infrastructure changes are necessary for the proper operation of the facility/infrastructure. In this case, the additional accrued carbon emissions shall be added to the embodied emissions and amortized accordingly.

a. The amortization period of the embodied carbon cannot exceed 10 years or the lifetime assumption of the asset, whichever is shorter. This period starts with the operational start of the facility.

b. After the first 10 years, recurring maintenance-related emissions shall be amortized annually, if significant.

c. In case the facility or transport infrastructure is shared with other operators outside of the project boundaries, the embodied emissions shall be allocated based on the share of operation or use calculated on an annual basis within the 10 years period. *This typically applies to shared logistic chains and shared storage sites.*

Numerical example:

Assume a project that shares an infrastructure facility (e.g. storage site) with another supplier. The total embodied emissions including the expected maintenance is approximately 1000 tCO_2e. This amount is equally divided across 10 years. As the use of the facility could vary amongst the different users, it was agreed that the portion of the embodied emissions will be calculated annually based on the % share of the infrastructure use (table 5.3).

Table 5.3. An example of amortized infrastructure embodied emissions.

	Estimated embodied emissions, amortized annually (tCO_2e)	Share of infrastructure use by supplier (%)	Amortized embodied emissions allocated to given supplier (tCO_2e)
Year 1	100	45%	45

	Estimated embodied emissions, amortized annually (tCO_2e)	Share of infrastructure use by supplier (%)	Amortized embodied emissions allocated to given supplier (tCO_2e)
Year 2	100	40%	40
Year 3	100	50%	50
Year 4	100	65%	65
Year 5	100	70%	70
Year 6	100	60%	60
Year 7	100	60%	60
Year 8	100	55%	55
Year 9	100	55%	55
Year 10	100	60%	60
Total	1000	56%	560

Direct land use change for infrastructure

5.2.16. For embodied emissions related to the construction of infrastructure (e.g. facilities, pipelines), the following rules apply regarding **direct land use change** (dLUC):

a. dLUC emissions shall be considered and included in the LCA, as part of the emissions related to the construction of infrastructure (in each relevant stages, capture, transport, injection). For instance, the construction of a pipeline for CO_2 transport may require clearing parts of forest land, which constitutes dLUC and must be included. Likewise, construction of facilities on land entails land conversion. This is captured under the parameter E_{dLUC}.

b. dLUC shall be assessed relative to the land area remaining in its historical state prior to the carbon removal project (new built or retrofit).

c. dLUC shall include any loss of aboveground and belowground biogenic carbon stocks, relative to the historical state of the land. dLUC shall also include any greenhouse emissions arising during the land conversion such as emissions associated with land clearing by fire as these may include significant amounts of methane (CH_4) and dinitrogen monoxide (N_2O).

d. These emissions shall be quantified either using default values for land conversion, as available in IPCC National Inventory Guidelines (2006, 2019) default values (Tier 1) or country-specific (Tier 2), or by specific data from the project (Tier 3).

e. The calculation shall be performed using the equations 5.1 and 5.2 below:

$$E_{dLUC} = 44/12 * (CS_B - CS_P) * A + E_{conversion}, \quad (5.1)$$

where the carbon stock per unit area is defined as:

$$CS_X = C_{VEG_X} + C_{DOM_X} + SOC_X \quad (5.2)$$

Variable	Description	Unit
E_{dLUC}	Absolute direct land use change associated with the construction of infrastructure.	tCO_2e
CS_B	Carbon stock per unit area associated with the baseline land use	$tC\ ha^{-1}$
CS_P	Carbon stock per unit area associated with the project land use	$tC\ ha^{-1}$
A	Area of land converted	ha
$E_{conversion}$	Greenhouse gas emissions associated with the land use conversion activities, e.g. fuel usage for clearing the land, direct emissions from fire	tCO_2e
CS_X	Carbon stock per unit area with the project or baseline land use, where subscript X indicates the type of land use	$tC\ ha^{-1}$
C_{VEG_X}	Above and below ground living biomass carbon stock	$tC\ ha^{-1}$
C_{DOM_X}	Dead organic matter or litter biomass carbon stock	$tC\ ha^{-1}$
SOC_X	Soil organic carbon stock	$tC\ ha^{-1}$

The parameters C_{VEG_X}, C_{DOM_X}, and SOC_X should be determined using the equations presented in volume 4 of the Guidelines for National Greenhouse Gas Inventories (IPCC 2006, 2019) and the EU Commission decision on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC[40]. In addition, Puro.earth will make available calculation tools and data to CO_2 Removal Suppliers.

Maintenance of foreground infrastructure

5.2.17. For emissions related to infrastructure (equipment, building, machinery) at any stage in the foreground system (i.e. capture facility, transport infrastructure, and storage facility), the following rule applies regarding **maintenance**:

a. The CO_2 Removal Supplier or each operator shall keep records of maintenance and repair works performed on the infrastructure, and estimate emissions associated with those works (from material production, sourcing, and energy usage; i.e. following the same inventory modeling as detailed in rule 5.2.14).

[40] 2010/335/: Commission Decision of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC (notified under document C(2010) 3751).

b. On an annual basis, if emissions related to infrastructure are material i.e. larger than 5% of the total supply-chain emissions of the stage in which they occur (either Capture, Transport, Storage), then those emissions must be reported for inclusion in CORC quantification as part of the remaining embodied emissions to be amortized.

> **REMARK ON BACKGROUND INFRASTRUCTURE EMISSION:** The rules 5.2.14 to 5.2.17 above deal with foreground infrastructure emissions, as opposed to background infrastructure emissions. Background infrastructure refers to, for instance, the infrastructure needed in production of electricity that is consumed by the project. Background infrastructure emissions are already included in the emission factors used in the LCA, with their own modeling of lifetime, maintenance etc. The CO_2 Removal Supplier does not need to modify or verify those assumptions; background emission factors can be used as-is.

Monitoring and post-closure monitoring of storage site

5.2.18. For emissions related to monitoring and post-closure monitoring of the storage site (i.e. all activities performed to ensure the integrity of the CO_2 storage), as part of the stage **Carbon storage**, the following rule applies:

- The storage site operator shall determine, based on best available knowledge, an estimate for the number of years that the storage site will be in operation, denoted T_o (in years), as well as the amount of carbon dioxide projected to be stored during that time, denoted C_o (in tonnes of CO_2). The time T_o shall be capped to a maximum of 10 years, conservatively.
- The storage site operator shall report the duration of the time period for post-closure monitoring required until liability transfer to a national entity, denoted T_m (in years).
- Emissions from monitoring of the storage site for 1 year shall be conservatively estimated based on best available knowledge (e.g. based on energy use or budgeted spending), denoted M (in kg of CO_2e per year).
- Emissions shall then be scaled per tonne of CO_2 injected, denoted M_s (in kg CO_2e per tonne CO_2 stored), using the following equation:

$$M_s = M \times (T_o + T_m) / C_o \quad (5.3)$$

- If the resulting monitoring emissions scaled per tonne of CO_2 injected are lower than 1% of the emissions of the Storage stage (per tonne of CO_2 stored), then monitoring emissions can be neglected. Otherwise, the calculated value shall be included in the quantification.

Variable	Description	Unit
M_s	Emissions related to monitoring and post-closure monitoring of the storage site scaled per tonne of CO_2 injected.	$kgCO_2e/tCO_2$
M	Emissions from monitoring of the storage site for 1 year.	$kgCO_2e/yr$
T_o	Number of years that the storage site will be in operation	yr
T_m	Number of years of post-closure monitoring required until liability transfer.	yr
C_o	Carbon dioxide projected to be stored during operational time T_o.	tCO_2

Renewable energy inputs from a grid or network

5.2.19. Whenever external energy inputs are used along the supply chain, e.g. electricity from the grid or steam/heat from a local network, the CO_2 Removal Supplier can make use of renewable energy certificates (REC), Guarantees of origin (GOO), direct purchase agreements (DPA), and similar renewable low-carbon energy supply schemes, and thereby correspondingly adjust the emission factors used in the LCA, provided that:

a. The purchased certificates originate from the same physical grid or network as where they are consumed (i.e. same spatial resolution).

b. The purchased certificates have been issued within the same calendar year as when they are consumed (i.e. same temporal resolution). Note: in line with other regulations and trends, Puro.earth envisions that in the future, temporal matching is likely to gradually shift from annual to hourly matching, but it does not seem yet feasible.

c. The purchased certificates specify the energy source or mix of sources, so that a climate change footprint can be calculated and used in the LCA (i.e. non-zero value).

d. The amount of purchased certificates matches with the amounts of low-carbon energy declared in the LCA calculations.

e. The CO_2 Removal Supplier provides evidence of purchased certificates at each Output Audit, or alternatively reverts to using market average emission factors if certificates are no longer purchased.

Elements considered non-material

5.2.20. The following elements are considered to be non-material, and therefore do not need to be included in the LCA modeling: site selection and feasibility studies, monitoring activities (other than storage site monitoring), staff transport.

5.3. Activity monitoring for life cycle assessment calculations

5.3.1. During each verification cycle, the CO_2 Removal Supplier must collect data according to its monitoring plan, so as to be able to update its LCA calculations and report operational emission as categorized in table 5.1. These contributions will be accounted towards the project emissions ($E_{Project}$) for the verification cycle. *Note: the monitoring plan for the LCA calculations can be part of the LCA report, part of a broader monitoring plan of the activity, or a standalone document.*

5.3.2. The parameters monitored by the CO_2 Removal Supplier for LCA calculations shall be described in the monitoring plan. Information to be compiled for parameters monitored shall follow the format shown in table 5.4. In particular, this must include a quantified error value, and how any significant uncertainties in the monitored parameter are conservatively tackled in subsequent calculations.

Table 5.4. Information to be compiled in the monitoring plan for each relevant parameter involved in the LCA calculations.

Parameter	Description
Parameter ID	A unique identifier of the parameter or data point
Data/Parameter	The name of the data point or parameter
Data unit	The unit of the data point or parameter
Description	A brief text describing what the parameter is about, and how it is used in calculations.
Source of data	A brief text describing where the data is sourced from.
Measurement procedures and conservativeness	A brief text describing how the data is obtained, via what measurements, and why the value selected is conservative in light of possible error or uncertainty.
Measurement error	An estimation of the error associated with the measurement, and how it is determined
Monitoring frequency	The frequency of monitoring of the parameter or data point
QA/QC procedures	Quality assurance and quality control procedures in place
Comments	Free text comments

6. Determination of leakage

As defined in the Puro General Rules, leakage refers to indirect effects, associated with a removal activity and dependent on the selected baseline, which may lead to an increase or decrease in greenhouse gas emissions or removals outside of the system boundaries of the activity. Only the increase in GHG emissions or decreases in carbon stocks are quantified and the removal activity is penalized if those effects are not avoided or mitigated. Positive effects are not included in the quantification of CORCs.

This chapter defines what leakage sources are relevant to consider for bio-CCS (including BECCS and waste-CCS) and DACCS projects of different kinds, following the three-step approach defined in the Puro General Rules: i) identify and characterize leakage sources, ii) mitigate leakage sources, and iii) quantify non-mitigated leakage sources.

The rules for leakage determination are summarized in tables 6.1 to 6.3, at the end of the section, for the most common bio-CCS and DACCS pathways.

6.1. Identification and characterisation of leakage sources

Scoping of leakage sources

Removal pathways that lead to geological storage of carbon dioxide are energy intensive processes, most often because of the carbon capture process. These processes also rely on resources available in limited amounts. In particular, the availability of renewable and low-carbon energy is an important factor for direct air carbon capture, while the availability of renewable, low-carbon and sustainable biomass is important for bio-based carbon capture. Therefore, DACCS and bio-CCS projects can potentially lead to *market and activity shifting leakage, relating to bioenergy, biomaterials, renewable energy, biomass markets, or land markets.*

As any infrastructure project, bio-CCS and DACCS projects may have negative effects on nearby land and ecosystems e.g. due to land drainage for construction purposes, or deforestation for enabling construction. Nearby land and ecosystems here refers to the physical areas directly surrounding the project area (but excluding the actual project area). Similarly, biomass production and sourcing may also be associated with similar effects on nearby land and ecosystems, e.g. due to land drainage to enable use of heavy machinery for harvesting, or deforestation for roads used for transporting the biomass. Those potential negative effects on nearby land and ecosystems are here called *ecological leakage*.

Dependence of leakage effects on the baseline scenario

Leakage sources (regardless of the category, i.e. ecological leakage, market and activity shifting leakage) may materialize differently depending on the baseline scenario applicable to a given removal pathway. Therefore, the leakage sources identified in this methodology are further characterized for each possible baseline scenario and removal pathway, to specify under which conditions they are material, and how they can be mitigated or quantified. The main distinctions are introduced for bio-CCS pathways, where two baseline scenarios exist, as well as multiple types of biomass feedstocks and conversion pathways. For DACCS pathways, as all facilities are considered new built, the same leakage rules apply to all projects.

> **REMARK:** the *sustainability* of any biomass feedstock must be demonstrated as per the rules in section 3.7, regardless of the baseline scenario and the leakage situations described here. The biomass sustainability criteria are meant to also minimize the situations of ecological, market and activity shifting leakage, as well as direct land use change.

6.1.1. All the sources of leakage identified as applicable for a given removal pathway and baseline scenario in this methodology must be assessed by the CO_2 Removal Supplier. Each leakage source must either be mitigated by the fulfillment of the rules in section 6.2 or quantified as per the rules in section 6.3.

6.1.2. For **DACCS** pathways under the **New Built** baseline, the identified sources of leakage are:

a. Ecological leakage, relating to negative effects on the nearby land and ecosystems surrounding the areas where facilities (capture, logistics, storage facilities) are built or extended, either via land drainage or land cover change.

b. Market and activity shifting leakage, relating to use of renewable electricity for the capture process only, when electricity is from a grid.

c. Market and activity shifting leakage, relating to use of renewable electricity for the capture process only, when electricity is from an off-grid source already in-use for other productive purposes.

d. Market and activity shifting leakage, relating to use of renewable thermal energy for the capture process only, when thermal energy is from a network.

e. Market and activity shifting leakage, relating to use of renewable thermal energy for the capture process only, when thermal energy is from an off-network source already in-use for other productive purposes.

Further, it is considered that increased use of sorbents, solvents or their constituents is not a relevant leakage source, as the emissions related to their production are included in the supply-chain emissions, assuming new production and the capacity to increase production of said materials (non-constrained market).

6.1.3. For **bio-CCS** pathways under the **New Built** baseline, the identified sources of leakage are:

a. Ecological leakage, relating to negative effects on the nearby land and ecosystems surrounding the areas where facilities (capture, logistics, storage facilities) are built or extended, either via land drainage or land cover change.

b. Ecological leakage, relating to negative effects on the nearby land and ecosystems surrounding the areas where biomass is sourced from, either via land drainage or land cover change (e.g. tree felling).

c. Market and activity shifting leakage, relating to use of a biomass feedstock or the use of land that were already in-use for other productive purposes.

6.1.4. For **bio-CCS** pathways under the **Retrofit** baseline, the identified sources of leakage are:

a. Ecological leakage, relating to negative effects on the nearby land and ecosystems surrounding the areas where facilities (capture, logistics, storage facilities) are built or extended, either via land drainage or land cover change.

b. Ecological leakage, relating to negative effects on the nearby land and ecosystems surrounding the areas where biomass is sourced from, either via land drainage or land cover change (e.g. tree felling).

c. Market and activity shifting leakage, relating to reduced bioenergy of biomaterial output due to retrofitting of the conversion facility (e.g. most commonly, reduced power output due to self-use of energy for the capture process).

6.1.5. In case the specifics of the removal activity proposed by the CO_2 Removal Supplier do not conform with the situations described in this methodology (e.g. atypical pathways, mixed baseline), the CO_2 Removal Supplier shall re-assess potential leakage sources, in cooperation with the Issuing Body, who will in turn issue a rule clarification statement. This might apply to projects where e.g. a facility is retrofitted to both expand its biomass processing capacity and add a capture module, or other unforeseen situations.

6.2. Mitigation of leakage sources

The CO_2 Removal Supplier may demonstrate that an identified source of leakage has no significant effect in the project area or that it can deploy measures to mitigate its effects. If this can be demonstrated following the rules defined below, then the specific leakage source can be set to zero in the CORC quantification. In some cases, demonstration of mitigation of a leakage source may be a requirement conditioning eligibility of the project.

Ecological leakage mitigation

6.2.1. For *ecological leakage, relating to negative effects on the nearby land and ecosystems surrounding the areas where facilities are built or extended*, the following applies:

a. This leakage source shall be evaluated by the CO_2 Removal Supplier during the design phase of the project, as part of an environmental impact assessment (EIA) study or in a standalone assessment.[41]

b. The following high-level guidance is provided for conducting such an assessment: the assessment shall i) define the areas of land and ecosystems potentially affected (e.g. spatial extent, locations, soil types, hydrology, land cover, cultural

[41] For facilities that have been designed or built prior to the publication date of this methodology, a retrospective assessment shall be performed.

and biodiversity values), ii) determine whether or not the planned construction works will affect the local **hydrology**, iii) determine whether or not the planned construction works will affect the **land cover**, and finally, iv) conclude on whether the nearby land and ecosystems will suffer from loss of carbon stocks or from emissions of other greenhouse gases.

c. If the assessment concludes that nearby land and ecosystems are not affected, then this leakage source is considered mitigated and can be set to zero in the quantification. Otherwise, the project shall perform an ex-ante quantification of the loss of carbon stocks and emission of greenhouse gases, which must then be included in the CORC quantification as per rule 6.3.1 below. The ex-ante quantification shall be either based on methods derived from IPCC Guidelines for National Greenhouse Gas Inventories, or based on site-specific quantification approaches.

d. In case the assessment concluded that nearby land and ecosystems would indeed be affected, but that quantification is not possible, the project is then not eligible in its current design. However, construction plans or locations may be changed for the project to become eligible.

e. In case the assessment concluded that nearby land and ecosystems would not be affected, but that later events and grievances demonstrate otherwise, penalties will apply retrospectively, following the Puro Standard General Rules for reversals.

6.2.2. For ecological leakage, *relating to negative effects on the nearby land and ecosystems surrounding the areas <u>where biomass is sourced from</u>*, the following applies:

a. This leakage source shall be evaluated by the CO_2 Removal Supplier as part of the biomass procurement planning and eligibility assessment of the biomass. This shall be assessed for each biomass source used and updated if procurement of biomass changes during the certification period.

b. The following high-level guidance is provided for conducting such an assessment: the assessment shall i) for each biomass origin, define the areas of land and ecosystems potentially affected (e.g. spatial extent, locations, soil types, hydrology, land cover, cultural and biodiversity values), ii) determine whether the sourcing of the biomass will affect the local **hydrology**, iii) determine whether the sourcing of the biomass will significantly affect the **land cover**, and finally, iv) conclude on whether the nearby land and ecosystems will suffer from loss of carbon stocks or from emissions of other greenhouse gases.

c. If the assessment concludes that nearby land and ecosystems are not affected, for each biomass origin, then this leakage source is considered mitigated and can be set to zero in the quantification. Otherwise, the specific biomass feedstocks are deemed not eligible.

d. In case the assessment concluded that nearby land and ecosystems would not be affected, but that later events and grievances demonstrate otherwise, penalties will apply retrospectively, following the Puro General Rules for reversals.

Market and activity shifting leakage mitigation - DACCS

6.2.3. For market and activity shifting leakage, in a DACCS context, relating to use of renewable electricity for the capture process only, when electricity is from a grid or from an off-grid source already in-use for other productive purposes, the following procedure shall be applied to mitigate leakage:

a. The CO_2 Removal Supplier must measure and declare the amount of electricity consumed for the capture process.

b. Leakage can be deemed mitigated, and thereby set to 0 in the quantification, if one of the following conditions is demonstrated by the CO_2 Removal Supplier on an on-going basis (i.e. at each Output Audit):

- The capture facility is connected to an electricity grid (as defined by the bidding zone, or alternatively by national boundaries) in which the average proportion of renewable electricity (i.e. excluding nuclear power) exceeded 90% in the previous calendar year or in which the emission intensity of electricity is lower than 18.0 gCO_2eq/MJ (i.e. 64.8 gCO_2eq/kWh) as determined by national statistics. The limits set here are indicating an electricity grid largely dominated by renewable or low-carbon electricity.
- The capture facility is connected to an electricity grid (as defined by the bidding zone, or alternatively by national boundaries) that is part of a cap and trade mechanism for emission reductions. *The Issuing Body reserves the right to declare, prior to audit, a specific cap and trade mechanism as not sufficient in case it is not stringent enough to ensure emission reduction (e.g. too many allowances).*
- The CO_2 Removal Supplier purchases annually low-carbon or renewable electricity production certificates (e.g. Renewable Energy Certificates, Guarantees of Origin) in an amount corresponding to the amount of electricity consumed for the capture process, following the same purchase rules as specified in rule 5.2.19.
- The capture facility is consuming electricity that used to be sold to specific end-users (i.e. not as part of a grid, but rather direct supply), and the CO_2 Removal Supplier can demonstrate that previous end-users of the electricity have deployed or are planning to deploy other low-carbon means of meeting their energy demand (e.g. via energy efficiency measures or deployment of new energy systems).

c. If none of the conditions above apply or can be demonstrated, then leakage remains non-mitigated and must be quantified as per rule 6.3.2.

6.2.4. For market and activity shifting leakage, in a DACCS context, relating to use of renewable thermal energy for the capture process only, when thermal energy is from a network or from an off-network source already in-use for other productive purposes, the following procedure shall be applied to mitigate leakage:

a. The CO_2 Removal Supplier must measure and declare the net amount of thermal energy consumed for the capture process, as well as its quality (i.e. exergy).

b. Leakage can be deemed mitigated, and thereby set to 0 in the quantification, if one of the following conditions is demonstrated by the CO_2 Removal Supplier on an on-going basis (i.e. at each Output Audit):

- The capture facility is connected to a thermal energy network (e.g. district heating network) in which the average proportion of renewable thermal energy exceeded 90% in the previous calendar year.
- The capture facility is connected to a thermal energy network that is part of a cap and trade mechanism for emission reductions. *The Issuing Body reserves the right to declare, prior to audit, a specific cap and trade mechanism as not sufficient in case the is not stringent enough to ensure emission reduction (e.g. too many allowances).*
- The capture facility is consuming thermal energy that used to be sold to specific end-users (i.e. not as part of a network, but rather direct supply), and the CO_2 Removal Supplier can demonstrate that previous end-users of the thermal energy have deployed or are planning to deploy other low-carbon means of meeting their energy demand (e.g. via energy efficiency measures or deployment of new energy systems).

c. If none of the conditions above apply or can be demonstrated, then leakage remains non-mitigated and must be quantified as per rule 6.3.2.

Market and activity shifting leakage mitigation - bio-CSS New Built

6.2.5. For market and activity shifting leakage, relating to **use of biomass feedstock or use of land that were already in-use for other productive purposes**, the following situations are distinguished:

a. **Cultivation on agricultural land of a food crop or energy crop** for non-food bio-CCS purposes:

The CO_2 Removal Supplier must demonstrate on an on-going basis (i.e. at each Output Audit), for all biomass feedstock, that one of the following conditions is met:

- The food crop or energy crop is produced on agricultural land as part of a crop rotation that includes food or feed production.
- The food crop or energy crop is produced on agricultural land as an intermediary or cover crop.
- The food crop or energy crop is produced on marginal land, degraded or contaminated land, not suited for food or feed production.

If none of the conditions above can be demonstrated, the biomass feedstock is not eligible. If one of the conditions above can be demonstrated, no leakage occurs.

b. **Use of nutrient rich (N, P, K) waste streams** (e.g. animal manure) from which nutrients were previously recovered (e.g. via digestate, composting, or direct land application) and are now used for bio-CCS **via a thermochemical conversion process**, leading to nutrient losses:

The CO_2 Removal Supplier must first quantify the amount of nutrients (N, P, K) which are no-longer recycled to soils, on an annual basis (tonnes per year). If the feedstock diversion leads to a net decrease in nutrient recycling, then negative leakage occurs. However, leakage is deemed mitigated, and thereby set to 0 in the quantification, if one of the following conditions can be demonstrated by the CO_2 Removal Supplier:

- The project area suffers from an over-supply of nutrients that has demonstrated negative effects on water resources.
- A significant share of nutrient rich feedstocks are inadequately managed or disposed of in landfills in the project area.

If none of the conditions above can be demonstrated, the non-mitigated leakage shall be quantified as per rule 6.3.3.

c. **Use of forest residues or crop residues that were already in-use** for another known and identified productive purpose (i.e. not left to decay in the field or forest floor, not sourced from a market):

The CO_2 Removal Supplier must first identify the previous use of the biomass, characterize the change in product generation entailed by the feedstock diversion (i.e. gains and losses in material and energy products), and motivate why feedstock diversion is deemed environmentally favorable in the context of the project. Leakage is deemed mitigated or not-applicable, and thereby set to 0 in the quantification, if one of the following conditions can be demonstrated by the CO_2 Removal Supplier:

- Previous use is scheduled to be discontinued or phased-out (e.g. factory reaching end-of-life, regulation planning to phase-out a technology)
- Previous use is less efficient, and thereby produces less valuable material and/or energy products
- Previous use is associated with large negative direct environmental or social impacts (e.g. incomplete combustion, improper flue gas treatment, unsafe working conditions)

If none of the conditions above can be demonstrated, the leakage source shall be further assessed as in rule 6.2.6 (similar to bio-CCS retrofit).

Remark: For forest residues or crop residues that were not already in-use, but were instead left to decay in the field or forest floor, or for forest residues sourced from a market, their harvesting or purchase for bio-CCS New Built purposes does not constitute a leakage source (indirect effect), but a direct land use change (dLUC) related to land use intensification, which is part of the system boundaries and included in the supply-chain emissions, whenever applicable. Further, the biomass sustainability criteria defined in section 3.7 shall ensure that such land use intensification effects are adequately minimized or managed to the benefit of the ecosystem from where biomass is sourced.

Remark: For waste streams such as municipal solid waste, abattoir waste, animal manure, sewage sludge, or food waste, the New built baseline scenario implies that the bio-CCS facility is built as a response to an increase in waste generation in the project area, waste that must be treated. Thereby, the use of those feedstocks does not constitute a leakage source. It is only in the case where feedstock already treated is diverted from its previous treatment that leakage may occur.

Remark: Additional situations may be added in the future.

Market and activity shifting leakage mitigation - bio-CCS Retrofit

6.2.6. For market and activity shifting leakage, relating to **reduced bioenergy or biomaterial output due to retrofitting of the conversion facility**, the following procedure shall be applied:

a. The CO_2 Removal Supplier must provide a mass and energy balance for the facility before and after retrofitting, under normal conditions. The mass and energy balance must be quantified in annual amounts (per year), scaled to the same amount of input feedstock (typically tonnes of biomass feedstock used per year), and quantify all inputs (e.g. biomass, external energy sources), all bioenergy or biomaterial outputs, the captured CO_2 output, as well as waste streams (e.g. ashes sent for disposal). Bioenergy or biomaterial outputs may include, depending on the facility type, e.g. electricity, heat, steam, biogas, liquid fuel, animal feed, food products, fertilizers, chemicals, and materials. Any amount of bioenergy used internally e.g. for operating the capture process shall be excluded from the bioenergy outputs.

   Note: For certain energy systems, the mass and energy balance can include net system effects on bioenergy or biomaterial outputs. Associated calculations and evidence must be provided. This applies e.g. to the case of combined heat and power plants retrofitted for carbon capture that are connected to large district heating networks. In this case, retrofitting usually leads to an increased heat output and a decreased electricity output. However, the increased heat output can reduce electricity consumption from large-scale heat pumps in the same direct heating network, thereby partly reducing the net electricity loss to the electricity grid entailed by retrofitting.

b. If retrofitting of the conversion facility does not lead to any decrease in bioenergy or biomaterial outputs, then no negative leakage occurs, and it can be set to zero in the quantification. *This is typically the case for retrofitting of anaerobic digestion and alcoholic fermentation facilities.* If retrofitting leads to an increase in bioenergy or biomaterial output (without any other decrease), then positive leakage occurs, but no benefits are granted as part of the CORC quantification: leakage is also set to zero. *This might be the case when retrofitting of an existing facility also introduces new energy efficiency measures.*

c. If retrofitting of the conversion facility leads to a decrease in one or several bioenergy or biomaterial outputs, then negative leakage occurs for those outputs. For the outputs where negative leakage occurs, leakage is deemed mitigated, and thereby set to 0 in the quantification, if one of the following conditions can be demonstrated by the CO_2 Removal Supplier on an on-going basis (i.e. at each Output Audit):

For reduced **electricity** output:

- The facility is connected to an electricity grid (as defined by the bidding zone, or alternatively by national boundaries) in which the average proportion of renewable electricity (i.e. excluding nuclear power) exceeded 90% in the previous calendar year or in which the emission intensity of electricity is lower than 18.0 gCO_2eq/MJ (i.e. 64.8 gCO_2eq/kWh) as determined by national statistics[42]. The limits set here are indicating an electricity grid largely dominated by renewable or low-carbon electricity.
- The facility is connected to an electricity grid (as defined by the bidding zone, or alternatively by national boundaries) that is part of a cap and trade mechanism for emission reductions. *The Issuing Body reserves the right to declare, prior to audit, a specific cap and trade mechanism as not sufficient in case the is not stringent enough to ensure emission reduction (e.g. too many allowances).*
- The CO_2 Removal Supplier purchases annually low-carbon or renewable electricity production certificates (e.g. Renewable Energy Certificates, Guarantees of Origin) in an amount corresponding to quantified power loss, following the same purchase rules as specified in rule 5.2.19.

For reduced **thermal energy** (heat or steam) output:

- The facility is connected to a thermal energy network (e.g. district heating network) in which the average proportion of renewable thermal energy exceeded 90% in the previous calendar year.
- The facility is connected to a thermal energy network that is part of a cap and trade mechanism for emission reductions. *The Issuing Body reserves the right to declare, prior to audit, a specific cap and trade mechanism as not sufficient in case the is not stringent enough to ensure emission reduction (e.g. too many allowances).*
- The facility was delivering thermal energy to specific end-users (i.e. not as part of a network, but rather direct supply), and the CO_2 Removal Supplier can demonstrate that previous end-users of the thermal energy have

[42] The quantitative limits in this rule are derived from the EU Commission Delegated Regulation 2023/1184 on rules for the production of renewable liquid and gaseous transport fuels of non-biological origin.

deployed or are planning to deploy other low-carbon means of meeting their energy demand (e.g. via energy efficiency measures or deployment of new energy systems).

For reduced **gas** or **liquid fuel** output:

- No mitigation rules are defined yet in the methodology. *Those may be added in the future. This leakage source must be quantified.*

For reduced **biomaterial output** (animal feed, food product, chemicals, materials):

- No mitigation rules are defined yet in the methodology. *Those may be added in the future. This leakage source must be quantified.*

Note: This situation typically materializes when retrofitting power plants or combined heat and power plants fuelled by either solid biomass (e.g. forest residues) or municipal solid waste, where a large share of the energy would be used in the carbon capture process, diminishing the amount of electricity supplied to the local grid (and often increasing the amount of heat supplied).

d. If none of the conditions above apply or if they cannot be demonstrated for the applicable output, then leakage remains non-mitigated and must be quantified as per rule 6.3.4.

6.3. Quantification of non-mitigated leakage sources

Ecological leakage quantification

6.3.1. For *ecological leakage, relating to negative effects on the nearby land and ecosystems surrounding the areas where facilities are built or extended*, the following applies for the scaling of emissions per tonne of CO_2 processed:

a. The Environmental Impact Assessment has quantified emissions related to the land disturbance, in absolute terms, noted EL_x (in tCO_2e), for a given facility x (either capture facility, transport and logistics, or injection facility).

b. The absolute impact EL_x shall then be added to the term E_{ECO} under $E_{leakage}$ and amortized following the same rule as for embodied emissions, namely rule 5.2.15.

Market and activity shifting leakage quantification - DACCS

6.3.2. Non-mitigated leakage relating to electricity or thermal energy consumption during the capture stage shall be quantified as follows:

$$L_{MA} = Q_{el} \times EF_{el} + Q_{th} \times EF_{th} \quad (6.1)$$

The term L_{MA} is the market and activity leakage term for the monitoring period (typically one year) expressed in tCO_2e, Q_{el} and Q_{th} are the amount of electricity and thermal energy consumed during the monitoring period and for which leakage was not mitigated, and

EF_{el} and EF_{th} are emission factors for electricity and thermal energy. Further, the following applies for each term:

a. The term L_{MA} is defined as a nonnegative number (higher than or equal to zero). The term L_{MA} cannot be negative.

b. The terms EF_{el} and EF_{th} are defined as positive numbers, updated annually, and determined as follows:

- For electricity, EF_{el} is the average emission factor of the grid as defined by the bidding zone, or alternatively by national boundaries, to which the facility is connected.
- For thermal energy (heat or steam), EF_{th} is the average emission factor of the network to which the facility is connected or the most likely non-constrained substitute off-network thermal energy source available in the area where the facility is located.

Variable	Description	Unit
L_{MA}	Market and activity leakage for the monitoring period.	tCO_2e
Q_{el}	The amount of electricity consumed during the monitoring period for which leakage was not mitigated.	kWh
EF_{el}	Emission factor for electricity.	tCO_2e/kWh
Q_{th}	The amount of thermal energy consumed during the monitoring period for which leakage was not mitigated.	kWh
EF_{th}	Emission factor for thermal energy.	tCO_2e/kWh

Market and activity shifting leakage quantification - bio-CCS New Built

6.3.3. Non-mitigated leakage relating to decrease in nutrient (N, P, K) recycling via diversion of a nutrient-rich feedstock, shall be quantified as follow:

$$L_{MA} = max(0\, ,\ \sum_{i \in S} \Delta O_i \times EF_i) \quad (6.2)$$

Where L_{MA} is the market and activity leakage term for the monitoring period (typically one year) expressed in tCO_2e, ΔO_i is the net change in nutrient recycling for the nutrient i (limited to N, P, K) following feedstock diversion, and EF_i is an emission factor representative of production of an alternative source of nutrient i. Further, the following applies for each term:

a. The term L_{MA} is a number higher or equal to zero. L_{MA} cannot be negative.

b. The term ΔO_i is positive in case of a net loss of nutrient recycling i, and is negative in case of a net gain nutrient recycling i. Both gains and losses can thereby be considered within the same leakage category here, to calculate a net leakage effect.

c. The term EF_i is a positive number, updated annually, and derived from an LCA database.

Variable	Description	Unit
L_{MA}	Market and activity leakage for the monitoring period.	tCO_2e
ΔO_i	Net change in nutrient recycling for the nutrient i	tonnes
EF_i	Emission factor representative of the production of an alternative source of nutrient i	tCO_2e/ tonne
i	Summation index (an element in the set of nutrients S)	unitless
S	The set of nutrients $\{N, P, K\}$ (nitrogen, phosphorus and potassium).	unitless

Market and activity shifting leakage quantification - bio-CCS Retrofit

6.3.4. Non-mitigated leakage, relating to reduced bioenergy or biomaterial output due to retrofitting of the conversion facility, shall be quantified as follows:

$$L_{MA} = max(0\,,\ \sum_{i \in S} \Delta O_i \times EF_i) \quad (6.3)$$

The term L_{MA} is the market and activity leakage term for the monitoring period (typically one year) expressed in tCO_2e, ΔO_i is the net change in bioenergy or biomaterial output i following retrofitting, for the monitoring period, and EF_i is an emission factor representative of the service delivered by the output i. Further, the following applies for each term:

a. The term L_{MA} is a number higher or equal to zero. L_{MA} cannot be negative.

b. The term ΔO_i is positive in case of a net loss of output i, and is negative in case of a net gain of output i. Both gains and losses can thereby be considered within the same leakage category here, to calculate a net leakage effect.

c. The term EF_i is a positive number, updated annually, and determined as follow depending on the type of output:

- For **electricity**, EF_i is the average emission factor of the grid as defined by the bidding zone, or alternatively by national boundaries, to which the facility is connected.

- For **thermal energy** (heat or steam), EF_i is the average emission factor of the network to which the facility is connected or the most likely non-constrained substitute off-network thermal energy source available in the area where the facility is located.
- For **gas** or **liquid fuel**, EF_i is the most likely non-constrained substitute fuel source available in the area where the facility is located.
- For **biomaterial output** (animal feed, food product, chemicals, materials), EF_i is the most likely non-constrained substitute material available in the area where the facility is located.

Variable	Description	Unit
L_{MA}	Market and activity leakage for the monitoring period.	tCO_2e
ΔO_i	Net change in bioenergy or biomaterial output i following retrofitting	tonnes
EF_i	Emission factor representative of the service delivered by the output i.	tCO_2e/ tonne
i	Summation index (an element in the set of outputs S)	unitless
S	The set of relevant bioenergy or biomaterial outputs (e.g. electricity, thermal energy, gas or liquid fuels, and biomaterials).	unitless

The rules for leakage determination are summarized in tables 6.1 to 6.3 below for the most common bio-CCS and DACCS pathways.

Table 6.1. Practical summary of identified leakage sources, mitigation options, and quantification rules for DACCS pathways.

Removal pathway and baseline	Identified leakage sources	Mitigation options	Quantification of non-mitigated leakage
DACCS New Built	Ecological leakage, from construction works.	Perform EIA during design phase of project, as per rule 6.2.1.	See rule 6.3.1.
	Market and activity shifting, from use of renewable grid electricity or in-use off-grid electricity.	Demonstrate any of the following, as per rule 6.2.3: 1. Grid already 90% renewable or emission intensity below 18.0 gCO_2e/MJ. 2. Grid part of a cap and trade mechanism. 3. Purchase low-carbon or renewable energy certificates. 4. Previous user of off-grid power not affected by diversion.	See rule 6.3.2.

	Market and activity shifting, from use of renewable thermal energy, from a network or in-use off-network source.	Demonstrate any of the following, as per rule 6.2.4: 1. Network already 90% renewable. 2. Network part of a cap and trade mechanism. 3. Previous user of off-grid thermal energy not affected by diversion.	See rule 6.3.2.

Table 6.2. Practical summary of identified leakage sources, mitigation options, and quantification rules for typical bio-CCS Retrofit pathways.

Removal pathway and baseline	Identified leakage sources	Mitigation options	Quantification of non-mitigated leakage
bio-CCS Retrofit Biological conversion of biomass streams <u>Feedstocks</u>: e.g. manure, food waste, industrial waste slurries, sewage sludge, crop residues, primary crop (e.g. wheat, corn, sugarcane) <u>Process</u>: e.g. anaerobic digestion, alcoholic fermentation	Ecological leakage, from construction works.	Perform EIA during design phase of project, as per rule 6.2.1.	See rule 6.3.1.
	Ecological leakage, from biomass sourcing.	Perform EIA during design phase of project, as per rule 6.2.2.	Not applicable. Biomass not eligible if associated with ecological leakage.
	Market and activity shifting, from decreased output of valuable products due to CCS retrofit (e.g. lower biogas or bioethanol output).	Typically not needed, because retrofitting of such facilities does not affect biogas or ethanol output.	
bio-CCS Retrofit Thermochemical conversion of biomass or waste <u>Feedstocks</u>: e.g. forest biomass, crop residues, municipal solid waste*, manure, sludge* <u>Process</u>: e.g. combustion, gasification, pyrolysis	Ecological leakage, from construction works.	Perform EIA during design phase of project, as per rule 6.2.1.	See rule 6.3.1.
	Ecological leakage, from biomass sourcing.	Perform EIA during design phase of project, as per rule 6.2.2.	Not applicable. Biomass not eligible if associated with ecological leakage.
	Decrease in net bioenergy production to downstream consumer (heat and power) due to CCS retrofit. *Typically, reduced power output, with increased heat output in case of CHP systems.*	Demonstrate any of the following, as per rule 6.2.6 (for reduced power): 1. Grid already 90% renewable or emission intensity below 18.0 gCO_2e/MJ. 2. Grid part of a cap and trade mechanism. 3. Purchase low-carbon or renewable energy certificates.	See rule 6.3.4.

Table 6.3. Practical summary of identified leakage sources, mitigation options, and quantification rules for typical bio-CCS New Built pathways.

Removal pathway and baseline	Identified leakage sources	Mitigation options	Quantification of non-mitigated leakage

bio-CCS New Built Biological conversion of waste streams Feedstocks: e.g. manure, food waste, industrial waste slurries, sewage sludge, crop residues Process: e.g. anaerobic digestion or alcoholic fermentation	Ecological leakage, from construction works	Perform EIA during design phase of project, as per rule 6.2.1.	See rule 6.3.1.
	Ecological leakage, from biomass sourcing.	*Typically, none for waste streams in a New Built context, as the demand for treatment arises from an increased generation of waste from other sectors.*	
	Market and activity shifting, from use of feedstock or land that were already in-use for other productive purposes.	*Typically, none for waste streams in a New Built context.*	
bio-CCS New Built Biological conversion of primary food or energy crop Feedstocks: e.g. wheat, corn, sugarcane Process: e.g. anaerobic digestion or alcoholic fermentation	Ecological leakage, from construction works	Perform EIA during design phase of project, as per rule 6.2.1.	See rule 6.3.1.
	Ecological leakage, from biomass sourcing	Perform EIA during design phase of project, as per rule 6.2.2.	Not applicable. Biomass not eligible if associated with ecological leakage
	Market and activity shifting, from use of feedstock or land that were already in-use for other productive purposes: a. *Cultivation on agricultural land.*	Demonstrate any of the following: 1. The primary crop used for bio-CCS is produced on agricultural land as part of a crop rotation including food or feed production. 2. The primary crop used for bio-CCS is produced on agricultural land as an intermediary or cover crop 3. The primary crop used for bio-CCS is produced on marginal, degraded or contaminated land, not suited for food or feed production.	Feedstock is not eligible if not mitigated.
bio-CCS New Built Thermochemical conversion of biomass or waste Feedstocks: e.g. forest biomass, crop residues, municipal solid waste* Process: e.g. combustion, gasification, pyrolysis	Ecological leakage, from construction works.	Perform EIA during design phase of project, as per rule 6.2.1.	See rule 6.3.1.
	Ecological leakage, from biomass sourcing.	Perform EIA during design phase of project, as per rule 6.2.2	Not applicable. Biomass not eligible if associated with ecological leakage.
	Market and activity shifting, from use of feedstock or land that were already in-use for other productive purposes: b. *Forest or crop residue already used.*	Identify, characterize and discuss previous use of forest or crop residue. Demonstrate any of the following, as per rule 6.2.5: 1. Previous use to be discontinued. 2. Previous use less efficient, diversion no inducing leakage. 3. Previous use with large negative impacts.	See rule 6.2.6, and further rule 6.3.4
bio-CCS New Built Thermochemical conversion of nutrient-rich feedstocks Feedstocks: e.g. biosolids, manure, sludge, food waste Process: e.g. combustion, gasification, pyrolysis	Ecological leakage, from construction works.	Perform EIA during design phase of project, as per rule 6.2.1.	See rule 6.3.1.
	Ecological leakage, from biomass sourcing.	*Typically, none for waste streams in a New Built context, as the demand for treatment arises from an increased generation of waste from other sectors.*	
	Market and activity shifting, from use of feedstock or land that were already in-use for other productive purposes: c. *Loss of nutrient (N, P, K) recirculation*	Quantify nutrient loss, and if losses exist, demonstrate any of the following, as per rule 6.2.5: 1. Local over supply of nutrients with effects on water quality 2. Local inadequate management of the feedstock or landfilling	See rule 6.3.3.

7. Data collection and monitoring

7.1. Overall principles

Monitoring, data collection and reporting is essential to ensure that the requirements prescribed in this methodology have been fulfilled. Due to the technical complexity of deep geological storage, as well as the substantial risks involved with a poorly chosen or managed storage site, it is paramount that a robust local legal framework is in place to regulate the geological storage operations and mitigate risks. This methodology only allows geological storage operations in jurisdictions where such a framework already exists (see rule 3.2.11). As a design principle, this methodology aims to rely on—rather than reduplicate—local regulations to ensure a safe and operationalizable result.

In general, abundant external resources on the design and operation of the geological storage activity are available to the CO_2 Removal Supplier. The below-listed examples of such resources contain useful information, outlines and recommendations on risk assessment, injection operations, monitoring, and other practicalities.

- Regulatory guidance documents from the United States Environmental Protection Agency
  - Class VI - Wells used for Geologic Sequestration of Carbon Dioxide
  - Final Class VI Guidance Documents
  - Class VI Permit Application Templates
  - Table of EPA's Draft and Final Class VI Well Permits (see "Permit Documents")
  - General Technical Support Document for Injection and Geologic Sequestration of Carbon Dioxide: Subparts RR and UU
- Regulatory guidance documents from the European Union for the implementation of directive 2009/31/EC on the geological storage of carbon dioxide
  - CO_2 storage life cycle risk management framework
  - Characterisation of the storage complex, CO_2 stream composition, monitoring and corrective measures
  - Criteria for transfer of responsibility to the competent authority
  - Article 19 Financial Security and Article 20 Financial Mechanism
- Regulatory guidance documents from the United Kingdom North Sea Transition Authority
  - Guidance on Applications for a Carbon Storage Permit
  - Guidance on the content of an Offshore Carbon Storage Permit Applications
- ISO Standards
  - ISO 27914:2017 Carbon dioxide capture, transportation and geological storage

- ISO 14064-2:2019 Greenhouse gases—Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements

While adherence to the above external documents is not required in this methodology (except if/when explicitly stated in a numbered rule, or required by local regulations), they can be a useful source of background information to assist the CO_2 Removal Supplier in creating a well designed and monitored geological storage project.

In practice, the monitoring, reporting and verification procedure followed in this methodology consists of monitoring and reporting by the CO_2 Removal Supplier, verification by a recognized third-party auditor, and finally issuance of CO_2 Removal Certificates (CORCs). A key step in verifying the monitoring data consists of inspection of relevant evidence and corroborating calculations by the auditor. Depending on the requirement, the pieces of evidence themselves can take various forms, such as data records, permits, official documents, or other relevant information which demonstrate compliance with the requirements, and enable claims to be verified. If the auditor concludes, based on the evidence presented, that the carbon removal activity is compliant with the requirements of this methodology, the validated amount of CORCs is then issued to the CO_2 Removal Supplier.

Note that while this section contains several overarching requirements on the data collection, monitoring, and reporting requirements concerning the geological storage activity, additional requirements on these topics are included in other sections of this methodology as well.

7.2. General monitoring requirements

The main objectives for monitoring the geological storage activity are:

- **Confirm** the containment of CO_2.
- **Alert** to increased risk of adverse events (e.g. CO_2 leaks, environmental contamination).
- **Verify** that the injected CO_2 behaves as expected.
- **Identify** any occurring adverse events.
- **Enable** reliable quantification of stored carbon and any emissions.

It is important to note that these goals can be achieved through several routes, and multiple monitoring techniques can often be utilized for the same parameter. As different approaches might be preferred in different situations, the CO_2 Removal Supplier should always consider **site-specific needs** and choose a suite of monitoring technologies that enable the volume and location of injected CO_2 to be verified at the levels of resolution and certainly required by the applicable local regulations and this methodology.

While the resolutions or accuracies of individual tools in the monitoring suite may vary, it is the cumulative data from the monitoring approach as a whole (including e.g. reservoir modeling and careful monitoring of injection rates and other parameters) that yields the necessary level of detail to determine with a very high degree of certainty that the CO_2 is effectively stored; that groundwater, surface resources, and the environment are being protected; and that any irregularities can be detected and addressed before they escalate.

7.2.1. The CO_2 Removal Supplier shall prepare and make available to the Auditor documentation that demonstrates conformity of the geological storage activity with the requirements of this methodology, as well as the Puro Standard General Rules and other Standard Requirements.

7.2.2. The CO_2 Removal Supplier shall have in place, maintain, and utilize an **information system** to keep records of all monitoring activities associated with the geological storage activity. These records shall at least include information on the parameter or process monitored (i.e. what was monitored and how), as well as results of any measurements performed.[43] The information shall be time-stamped and quantitative (where applicable). These records shall be available to the Auditor, for the Production Facility Audit and Output Audits.

7.2.3. The terminology used in this methodology in relation to monitoring frequency shall be interpreted as detailed in subrules a and b:

a. The following definitions apply to the description of monitoring frequency:

- **Continuous** monitoring is defined as at least once every 15 minutes.
- **Monthly** monitoring is defined as at least once per calendar month.
- **Quarterly** monitoring is defined as at least four times per calendar year (once every three months).
- **Semi-annual** monitoring is defined as at least twice per calendar year (once every six months).
- **Annual** monitoring is defined as at least once per calendar year.
- **Periodical** monitoring is defined as monitoring at predetermined, regular temporal intervals decided by the CO_2 Removal Supplier based on site-specific needs as well as any applicable regulations. The monitoring frequency and rationale thereof shall be explained in the monitoring plan.

b. Monitoring activities with a predefined cadence (e.g. quarterly monitoring) shall be evenly distributed throughout the monitoring period (e.g. once every three months for quarterly monitoring). The CO_2 Removal Supplier may make reasonable adjustments to the monitoring schedule for reasons of necessity or practicality, but such adjustment shall not result in any undue or disproportionate delays to the monitoring activities.

7.2.4. Unless otherwise specified, all monitoring shall be based on data specific to the CO_2 Removal activity and sites of operation (e.g. capture/injection site).

7.2.5. The CO_2 Removal Supplier shall prepare, maintain, and comply with a monitoring plan for the geological storage activity, as further described in subrules a-e.

[43] Note also rule 4.2.5 on keeping records of events that affect the quantification of CORCs. Note that these records are at least partly separate, as not all monitoring activities or results thereof necessarily affect the number of CORCs.

a. The monitoring plan shall be tailored to the specific characteristics and requirements of all stages (capture, transport, and injection) within the activity boundary (see rule 5.2.6).

b. The monitoring plan shall describe procedures for measuring, calculating and analyzing data and information to ensure that the storage reservoir conforms to expected behavior, and that any injected CO_2 remains securely contained. To this end, the monitoring plan shall at least:

- Identify potential vulnerabilities and propose solutions to mitigate recognized vulnerabilities.
- Specify monitoring parameters and define monitoring tasks.

c. The monitoring plan shall cover activities throughout the duration of the geological storage activity, including:

- Baseline data gathering and storage site characterization (pre-injection period).
- Performance of the storage reservoir during operations (injection period).
- Closure of the storage site and post-closure monitoring (post-injection period).

d. The monitoring plan shall describe how the CO_2 Removal Supplier will provide monitoring data for the variables and quantities required by this methodology. This description shall at least include:

- Parameters monitored.
- Monitoring methods employed (including measurement device type and quantification accuracy where applicable) and rationale for choice of method.
- Monitoring locations and spatial sampling rationale.
- Frequency of application and temporal sampling rationale.
- Normal and alert thresholds for monitored parameters, including corresponding mitigation activities (see also rules 7.2.7 and 7.6.2).

e. The monitoring plan shall be periodically evaluated and updated to ensure that the monitoring practices continue to be appropriate and effective. The evaluation shall include a re-assessment of the site-specific monitoring requirements and risks. For example, updates to the monitoring plan might be necessary due to:

- Monitoring and site performance data.
- New scientific knowledge.
- Improvements in best available technology.

7.2.6. The monitoring plan shall include a detailed description of at least the following aspects:

- Operational monitoring of the CO_2 Stream.
- Monitoring the CO_2 plume or fluid.[44]
- Monitoring pathways for potential release based on risk-assessment.
- Environmental monitoring for detection and quantification of release from the storage site.

7.2.7. The monitoring plan shall describe how the CO_2 Removal Supplier plans to respond to any significant irregularities in the performance of the monitoring or storage systems during the capture, injection and storage operations (contingency monitoring).

7.2.8. All measurement devices shall be installed, operated and calibrated according to the device manufacturer's specifications or according to an appropriate industry consensus standard.

7.2.9. All measurement devices shall be calibrated to an accuracy of at least 5% (i.e. the calibration error of any measurement device shall not exceed 5%). Calibration records shall be made available for third-party verification.

This requirement does not apply to energy (heat, electricity, fuel) billing meters, provided that the energy supplier and the CO_2 Removal Supplier do not have any common owners and are not owned by subsidiaries or affiliates of the same company.

7.3. Monitoring of the CO_2 Stream and related parameters

7.3.1. The CO_2 Removal Supplier shall continuously monitor the mass flow rate of CO_2 entering the storage reservoir through direct measurement of the flow in accordance with rule 4.4.7. In the case of a geological storage activity utilizing injection of dissolved CO_2 (see rule 3.2.6), the CO_2 Removal Supplier shall also continuously monitor the mass flow rate of the water stream entering the storage reservoir through an equivalent direct measurement of the water flow.

7.3.2. The CO_2 Removal Supplier shall continuously monitor the temperature and pressure of the storage reservoir (for example, by means of downhole pressure and temperature gauges) to determine CO_2 phase behavior and state.

7.3.3. The CO_2 Removal Supplier shall at least quarterly monitor the chemical composition of the CO_2 Stream. For the purposes of this rule, 'chemical composition' refers to both the chemical constituents[45] of the CO_2 Stream as well as their concentrations.

a. The chemical composition analysis shall be performed with a commercially available device. The analysis shall be performed with a method in accordance

[44] The term 'CO_2 fluid' is utilized in this methodology to refer to the body of injected water-dissolved CO_2 (as opposed to 'CO_2 plume' which refers to free-phase CO_2 in the subsurface). See also glossary entries for CO_2 Fluid and CO_2 Pume.

[45] The CO_2 Stream consists overwhelmingly of CO_2, but depending on the capture process it might also contain other impurities and trace substances such as water (H_2O), hydrogen (H_2), hydrogen sulfide (H_2S), carbon monoxide (CO), nitrogen (N_2) and its oxides (e.g. N_2O), sulfur oxides (SO_x), oxygen (O_2), methane (CH_4), and argon (Ar), which can affect the chemical and physical properties of the CO_2 Stream and its behavior and reactions underground (A. Razak et al., 2023).

with applicable local regulations or, if no such regulations exist, in accordance with an appropriate standard method published by a consensus-based standards organization, or industry standard practice. Potential methods include, but are not limited to gas chromatography, mass spectrometry, and infrared spectroscopy.

b. The sampling of the CO_2 Stream for the chemical composition analysis shall be performed as close to the injection wellhead as feasible. However, the sampling shall be performed prior to mixing with any other CO_2 Streams (e.g. in cases where the CO_2 Stream is transported via shared infrastructure or CO_2 Streams from several different sources are mixed prior to injection into a shared geological storage reservoir).

7.3.4. The CO_2 Removal Supplier shall at least quarterly monitor the mass fraction (in % mass) or volume fraction (in % vol) of CO_2 in the injected fluid through direct measurement of the CO_2 concentration of the CO_2 Stream (i.e. the parameters F_{CO_2} or Q_{CO_2}, in accordance with the type of flow measurements utilized, see rule 4.4.2).

a. Any of the following methods may be utilized for the determination of the CO_2 concentration of the CO_2 Stream:

- Direct measurement of the entire chemical composition of the CO_2 Stream in accordance with rule 7.3.3.
- Direct measurement of the CO_2 concentration (i.e. the CO_2 concentration alone as opposed to the entire chemical composition including impurities) with a CO_2 sensor or other suitable measurement device. The CO_2 Removal Supplier shall nevertheless follow the measurement process requirements laid out in subrules 7.3.3 a and b.

b. To ensure the representativeness of the determined values, the CO_2 Removal Supplier shall, when necessary, increase the quantification frequency based on the variability (or expected variability) of the CO_2 concentration of the CO_2 Stream due to factors specific to the geological storage activity (such as capture technology and post-capture treatment).

7.3.5. In the case of a geological storage activity utilizing injection of dissolved CO_2 (see rule 3.2.6), the CO_2 Removal Supplier shall at least monthly monitor the bubble point pressure of the CO_2 fluid as described in subrules a and b.

a. The CO_2 Removal Supplier shall calculate the bubble point pressure utilizing an equation of state appropriate for the computation of gas/liquid equilibria in reservoir fluid systems, such as the Peng-Robinson equation.[46] The calculation shall be based on representative operational monitoring data (e.g. mass flow rates, temperatures, and chemical composition of the fluids entering the injection well).

[46] Note that while there is no all-in-one equation of state that will give the best prediction of all thermodynamic properties of different types of reservoir fluids, the Peng-Robinson equation (Peng & Robinson, 1976) has shown excellent performance for phase transitions, and it is commonly utilized in reservoir engineering (Ashour et al., 2011).

b. The CO_2 Removal Supplier shall ensure that the reservoir pressure is higher than the bubble point pressure by a safety margin of at least 5 bar (500 kPa). For any occasion where this requirement is not met, the injected mass of CO_2 leading to the bubble point pressure exceeding its limits shall be treated as a reversal, and attributed to $E_{reversal}$ (see rule 4.7.2).

7.4. Capture site and transport monitoring

7.4.1. The CO_2 Removal Supplier shall continuously monitor the amount of CO_2 captured (in tonnes) at the capture site through direct measurement of the flow in accordance with rule 4.4.7.

7.4.2. The CO_2 Removal Supplier shall at least semi-annually monitor the fraction of eligible CO_2 in the captured CO_2 Stream through radiocarbon analysis in accordance with rule 4.4.5 b. This rule does not apply to cases where the CO_2 Stream is captured directly from the atmosphere, or from purely biogenic sources, provided that the CO_2 Removal Supplier provides operational data records that rule out fossil sources of CO_2 in the captured stream (see rule 4.4.5 a).

7.4.3. The CO_2 Removal Supplier shall monitor the consumption (in kg) and consumption rate (in kg per tonne of CO_2 captured) of any sorbents or solvents used for the CO_2 capture process, including initial consumption at the start operations as well as all subsequent re-fills. The monitoring shall be based on actual operation data.

7.4.4. The CO_2 Removal Supplier shall monitor the quantity of CO_2 transported from the capture site to the storage site (unless the capture site coincides with the storage site).

a. In the case where CO_2 is transported via pipeline, the CO_2 Removal Supplier shall provide data and documentation on the amount of CO_2 (in tonnes) fed into the pipeline system.

b. In the case where CO_2 is transported in containers (e.g. via cargo ship, rail, or trucks), the CO_2 Removal Operator shall provide documentation from the logistics operator on the amount of CO_2 (in tonnes) delivered to the storage site.

7.5. Storage site monitoring

7.5.1. The CO_2 Removal Supplier shall provide a permit, authorization, license, or equivalent regulatory control document showing that the storage site is duly approved for permanent geological storage of carbon dioxide to the extent required by local regulation.

7.5.2. The CO_2 Removal Supplier shall provide documentation of the characterization of the storage site and its suitability for permanent geological storage of CO_2. The documentation shall show that the storage site fulfills the minimum criteria of suitability for geological storage to the extent defined in the applicable local regulations.[47] Furthermore,

[47] Note that as per rule 4.2.11, geological storage of CO_2 is only allowed in jurisdictions where such minimum criteria exist.

the documentation shall detail the manner in which the suitability was assessed. For example, such documentation might include:

- Description of local requirements for storage site characterization.
- Descriptions and/or results of the experimental and computational methods utilized to assess the storage site (e.g. storage capacity; areal and vertical extent of the storage reservoir and pore space; and geomechanical, geochemical and flow properties of the reservoir), such as results from seismic and geologic surveys, or data from offset wells, geological earth models, or other numerical simulations.
- A discussion of the site characterization results and their implications for long-term behavior of the storage site (such as changes in injectivity, or the nature of CO_2 trapping), and how this information relates to storage permanence and monitoring needs.

7.5.3. The CO_2 Removal Supplier shall periodically monitor the well construction materials (e.g. cement and casings) for signs of corrosion (such as loss of mass or thickness, cracking, or pitting) to ensure that any injected CO_2 remains properly contained, and that the utilized materials have sufficient structural strength to meet the requirements of the applicable local regulations. The monitoring shall be conducted with a method in accordance with applicable local regulations or, if no such regulations exist, in accordance with industry standard practices (e.g. corrosion coupons, electrical resistance probe, or other corrosion probes or sensors).

7.6. Monitoring CO_2 release and reversal

7.6.1. The CO_2 Removal Supplier shall periodically monitor the geological storage reservoir and its surroundings (to the extent defined in subrule a) for any release of greenhouse gases or other reversal events (see rule 4.7.1).

a. The monitoring region shall cover the geological storage reservoir and the surrounding region which may be endangered or otherwise negatively affected by the injection activity. The CO_2 Removal Supplier shall determine the extent of this region based on locally applicable regulations. For example, this area corresponds to the *area of review* as defined in the United States Code of Federal Regulations,[48] or the *storage complex and surrounding area* in the sense of Directive 2009/31/EC of the European Parliament and of the Council,[49] or other similarly defined areas based on locally applicable regulations.

b. The choice of monitoring technology shall be based on best practice available at the time of design, and detailed in the monitoring plan. The following options shall be considered and used as appropriate:

[48] 40 CFR 146.81(d) "Area of review"

[49] 2009/31/EC Article 4(3)

- Technologies that can detect the presence, location, and migration paths of CO_2 in the subsurface and at surface.
- Technologies that provide information about the pressure-volume behavior, and areal/vertical distribution of the CO_2 plume or fluid to refine numerical 3D simulations for geological models of the storage formation.
- Technologies that can provide a wide areal spread in order to capture information on any previously undetected potential leakage pathways across the areal dimensions of the monitoring region in the event of significant irregularities or migration of CO_2 out of the storage reservoir.

Potential monitoring techniques include but are not limited to various subsurface, near surface, or remote monitoring techniques, such as wireline-deployed well logging tools, e.g. acoustic and resistivity; wellbore-deployed pressure and temperature gauges or fluid monitoring tools; electrical resistance tomography and similar electromagnetic surveys; seismic geophysical monitoring; sampling of the soil, vadose zone or groundwater; isotopic or chemical tracers; surface gas flux monitoring; and satellite or other remote imaging.[50]

c. The CO_2 Removal Supplier shall quantify and account for the amount (in tCO_2e) of GHGs released in each reversal event according to the requirements of section 4.7.

d. In case a reversal event is detected, the CO_2 Removal Supplier shall without delay take action to:
- Prevent further reversal from occurring.
- Determine the cause of the reversal event and apply appropriate corrective measures.
- Notify the Issuing Body.

Note that subrule c does not apply to cases where minimal CO_2 release or other reversal occurs due to monitoring or maintenance operations, provided that such events are planned, controlled and unavoidable (e.g. when small amounts of fluids are pumped from the storage reservoir for monitoring purposes without re-injection).

e. The CO_2 Removal Supplier shall keep a detailed, time-stamped record of all release events from the storage reservoir.

7.6.2. The CO_2 Removal Supplier shall set normal, alert and threshold values for monitored parameters, and design and implement operating procedures in case the alert or threshold value is reached. The values shall be derived from applicable local regulations or, if no such regulations exist, from other relevant sources, such as peer-reviewed scientific literature or industry best practice. The values shall be periodically reviewed to ensure the safety of the operations.

[50] For a review of potential monitoring techniques, see e.g. (Mortezaei et al., 2020; NETL, 2017; Verkerke et al., 2014)

7.6.3. The CO_2 Removal Supplier shall at least monthly monitor the injection facility for any injection leaks from the wellheads and other relevant infrastructure at the injection site (e.g. pipes, valves, etc.) through visual inspection by an operator equipped with a CO_2 detector or other appropriate sensing equipment. Any detected injection leaks shall be attributed to $E_{released}$, and quantified and accounted for according to the requirements in subsection 4.4 (see especially rule 4.4.4).

7.7. Site closure and post-injection monitoring

7.7.1. The CO_2 Removal Supplier shall retain access to the storage site for monitoring purposes throughout the post-closure period.

7.7.2. The CO_2 Removal Supplier shall continue to monitor for release of CO_2 to verify the storage permanence during and after site closure (post-injection period) as stated in the applicable legal framework (see rule 3.2.11), until the transfer of responsibility.[51] The monitoring frequency may be reduced during the post-injection period and site closure, as long as the level of monitoring allows for detection of reversals or irregularities. Similarly, if a reversal is detected, the monitoring frequency shall be intensified.

7.7.3. The CO_2 Removal Supplier shall periodically monitor that the pressure decay in the reservoir and location of the CO_2 plume or fluid conform to the predictions derived from the reservoir model and relevant monitoring data collected during the pre-injection and injection periods. The predicted behavior of the subsurface CO_2 shall be periodically updated based on the ongoing site monitoring. The post-injection period monitoring frequency shall be based on the predicted timeframe of the pressure decay and plume or fluid migration.

7.7.4. The CO_2 Removal Supplier shall identify criteria to ensure that the injected CO_2 will be retained within the geological storage during post-injection period and site closure. The criteria shall be based on the requirements of this methodology and the applicable local legislation and regulations. The CO_2 Removal Supplier shall demonstrate compliance with the criteria during the closure period. The criteria shall at least include the following:

a. The site shall meet the established project objectives, including absence of CO_2 leakage and impacts to social and environmental resources.

b. The storage reservoir shall be sufficiently understood to assess the extent of CO_2 trapping, and future evolution of the CO_2 plume or fluid distribution, dispersion and migration.

c. The likelihood of future leakage shall be demonstrated to be negligible, and the accuracy of predictive models shall be proven.

d. All wells shall be plugged and sealed according to the local regulations, taking into account the post-injection period monitoring requirements. When the injection has ceased, the CO_2 Removal Supplier may for example:

[51] The precise length of the time period required for post-injection monitoring can vary based on e.g. local regulations and site performance records (see rule 7.2.2).

- Seal the injection well immediately upon cessation of injection.
- Convert an injection well to a monitoring well. Monitoring wells not used for sampling during the post-injection period should be plugged to eliminate the potential to become conduits for fluid movement.

e. Surface facilities and equipment associated with the geological storage activities shall be removed, except to the extent required for monitoring purposes. Facilities and equipment integral to other operations or intended for different uses need not be removed.

7.7.5. The CO_2 Removal Supplier shall assess the internal and external integrity of the monitoring wells at regular intervals until the wells have been sealed.

7.7.6. After site closure, the CO_2 Removal Supplier shall create a site closure report including relevant information for the future landowners and planners. Such information may for example include:

- Information of the relevant entities and authorities relevant to any possible future drilling activities.
- Documentation on the injection and monitoring well sealing.
- Maps and cross-sections indicating the location of the injection and monitoring wells and the CO_2 plume or fluid.
- Documentation of the timeline of the operations (e.g. injection-phase, post-injection phase, site closure).
- Information on the storage site characteristics.

8. Risk and uncertainty management

8.1. Overview

The primary objective of identifying risks and uncertainties is to detect early and ongoing events and ambiguities that could affect the predetermined objectives of the storage project. While it is important to manage and mitigate both risks and uncertainties, it is useful to separate the concepts. Here, *risk* refers to events and situations, whose outcomes and occurrence probabilities are (reasonably well) known in advance, while *uncertainty* refers to aspects of decision-making which are not easily quantified (Park & Shapira, 2017).[52]

There are many different ways to further categorize both risks and uncertainties into different types (Bevan, 2022; Hopkin, 2017), such as the simple classification presented in table 8.1.

Table 8.1. Classification of risks and uncertainties

Risks	Uncertainties
Pure Speculative	Irreducible (aleatoric) Epistemic Knightian

Risks can be classified based on the type of potential outcome. With *pure risk*, there is no possibility of gain and the outcome is either 'loss' or 'no loss' (e.g. machinery breakdown), whereas with *speculative risk*, there is also a chance of a positive outcome (e.g. project financing decisions) (Hopkin, 2017; Mahjour & Faroughi, 2023). Uncertainties can be classified in terms of their relation to additional data and knowledge. *Irreducible uncertainty* refers to the inherent randomness and unpredicted variability of certain processes (e.g. unexpected fluctuations in reservoir geology or CO_2 behavior, or damage due to natural disasters). Such uncertainties cannot be reasonably mitigated with additional data, and are thus a constant source of 'background uncertainty' (Mahjour & Faroughi, 2023). On the other hand, *epistemic uncertainty* results from missing or incomplete information (e.g. missing measurement data, undocumented legacy wells in the project area), and can be diminished by gathering more data (Mahjour & Faroughi, 2023; Riesch, 2013). Additionally, there is often a third categorization referred to as *Knightian uncertainty*, or the '*unknown unknowns*', i.e. situations where there is a deep level of ambiguity about the process itself and the means to evaluate its effects (e.g. predicting technical development) (Mahjour & Faroughi, 2023; Sakai, 2016).

Several risks and uncertainties concerning the technical and non-technical (e.g. financial or political) aspects of geological storage of CO_2 have been identified across the entire activity boundary, including risks to human health, climate, and key environmental factors such as ecosystems and groundwater (Mahjour & Faroughi, 2023; Pawar et al., 2015; Xiao et al., 2024). This methodology, together with applicable local legislation and regulations, sets guidelines and rules to mitigate the possible risks and ensure that the CO_2 is safely retained in the selected geological storage reservoir. Appropriate and transparent collection of data as well as regularly updated monitoring plans are key

[52] Note that the word 'uncertainty' is often used in other contexts as well, such as in reference to quantification uncertainty, i.e. measurement error.

factors in managing and mitigating risks, but effective risk mitigation also requires efficient and transparent communication and collaboration between the CO_2 Removal Supplier and the local authorities and stakeholders.

8.2. Storage permanence and risk of reversal

Carbon capture and geological storage is generally considered a secure and effective option for climate change mitigation (Xiao et al., 2024). The IPCC Special Report on Carbon dioxide Capture and Storage (Benson et al., 2005) concluded that:

> “For large-scale operational [geological] CO_2 storage projects, assuming that sites are well selected, designed, operated and appropriately monitored, the balance of available evidence suggests the following:
>
> - It is very likely the fraction of stored CO_2 retained is more than 99% over the first 100 years
> - It is likely the fraction of stored CO_2 retained is more than 99% over the first 1000 years.”

While the general understanding on the assessment and management of risks related to CO_2 release from geological storage has improved since the publication of the IPCC Special Report (Brown et al., 2023; Choi et al., 2013; Deng et al., 2017; Gerstenberger et al., 2013; Hnottavange-Telleen et al., 2011; Hnottavange-Telleen, 2013; Koornneef et al., 2012; Q. Li & Liu, 2016; Mahjour & Faroughi, 2023; Pawar et al., 2015; Samadi, 2012; Xiao et al., 2024), similar estimations of the overall storage permanence have been published more recently as well (Alcalde et al., 2018). The IPCC has also recently reiterated that “if the geological storage site is appropriately selected and managed, it is estimated that the CO_2 can be permanently isolated from the atmosphere.” (Calvin et al., 2023, p. 21). Furthermore, the storage capacity, permanence and effectiveness of the stored CO_2 may also increase over time due to geochemical interactions of CO_2 with the surrounding rock and formation water (Benson et al., 2005).

Even in scenarios that assume pessimistic input parameters and poor management of the injection site, leakage of CO_2 to the atmosphere has been estimated small or moderate, and the associated economic costs minor (Alcalde et al., 2018; Bielicki et al., 2016; Deng et al., 2017; Xiao et al., 2024). In a worst case scenario of a CO_2 storage project carried out in a poorly regulated environment (characterized e.g. by unknown or unidentified abandoned wells in the project area and limited wellbore integrity), the fraction of stored CO_2 retained was estimated to be be around 80% over the first 1000 years and around 70% over the first 10,000 years (Alcalde et al., 2018).[53] In another study, it was noted that “even at unrealistically high well permeability, leaked CO_2 is very unlikely to be released to the atmosphere because of the interception by overlying geologic strata” (Deng et al., 2017). The associated economic costs of leakage (the monetized leakage risk) have been estimated to be likely

[53] The median retention estimate in a poorly regulated environment was significantly lower, amounting to approximately 92% of stored CO_2 retained over the first 1000 years and 78% over the first 10,000 years.

orders of magnitude below storage costs (Bielicki et al., 2016), and their impact to CCS deployment negligible under a realistic leakage scenario, or at most minor in the worst case (Deng et al., 2017).

It is important to note that a low overall permanence risk does not imply the absence of risk entirely, nor the lack of need to assess and manage risks in geological storage projects. Indeed, the low risk estimates cited above rely on the concept of a *well selected and managed* storage site, of which proper risk management is an integral part. To ensure the long-term safety of a geological storage project, it is essential that the CO_2 Removal Supplier carries out comprehensive risk and uncertainty assessment and mitigation.

Due to the above considerations on storage permanence and risk of reversal, and given that this methodology imposes requirements to ensure that the storage site is well selected and the geological storage project well managed as a whole, it is considered that in this methodology, there is no such material risk of reversal (in the sense defined in the Puro Standard General Rules) that would necessitate a default percentage deduction from the Output volume for all projects.

8.3. Key risks and uncertainties

All stages of the geological storage value chain possess associated risks and uncertainties. These are, however, mostly well understood and have been comprehensively reviewed in the scientific literature—see e.g. (Mahjour & Faroughi, 2023; Xiao et al., 2024) and references therein. Table 8.2 summarizes and categorizes some of the risks and uncertainties that might materialize in the various stages of a geological storage project.

Table 8.2. Potential risks and uncertainties associated with geological storage of CO_2 (Mahjour & Faroughi, 2023).

<table>
<tr><th>Project stage</th><th colspan="2">Technical risks and uncertainties</th><th colspan="3">Non-technical risks and uncertainties</th></tr>
<tr><th></th><th>Site characterization</th><th>Operational</th><th>Financial</th><th>Political</th><th>Social</th></tr>
<tr><td>Capture</td><td>Device installations and operational defects

Measurement errors</td><td>Exhaust gases

Liquid and solid waste

Waste by-products

CO₂ stream impurities

Equipment failures</td><td>Plant design and operation

Economic and financial factors</td><td rowspan="2">National:
Government funding crises

Government preferences for investments

Restrictions of CCS projects due to pollution and/or geological characterisation

Lack of government support or incentives

Licencing requirements, absence of a clear regulatory framework</td><td rowspan="2">Public opinion:
Lack of public awareness and support

Misinformation

Education:
Insufficient knowledge and understanding

Limited awareness of the potential benefits and limitations

Safety and Health:
Risks associated with storage and transportation of CO₂

Health concerns</td></tr>
<tr><td>Transportation</td><td>Pipeline accidents

Pipeline corrosion

Equipment breakdown</td><td>Technical or mechanical breakdowns of equipment

Seal and valve failures

Formation of stable precipitates</td><td>Technological feasibility and cost-effectiveness (e.g. transport distance, terrain, route)</td></tr>
</table>

		Collisions Pipeline explosions		Absence of frameworks for e.g. leakage liability	related to CO_2 leakage
Storage	Chemical reactions Model oversimplifications	Groundwater contamination CO_2 migration Wellbore and seal integrity Induced seismicity Fracture and fault development and propagation Unwanted chemical reactions affecting reservoir properties	Geological reservoir characteristics Reservoir scale Managing pressure build-up	Policy changes Corruption **International:** Lack of advanced technologies Political controversies between countries Inefficiency and non-binding nature of international agreements	

While the risks presented in table 8.2 vary in terms of likelihood and severity, several key risks can be identified throughout the activity boundary (Mahjour & Faroughi, 2023; Pawar et al., 2015; Xiao et al., 2024). Such identified key risks in the various stages of the activity boundary are elaborated and discussed below. Note that some risks affect one another, and might have important compounding effects. For example, induced seismicity might damage surface equipment or compromise storage reservoir integrity and thus increase risk of CO_2 leakage.

Capture

Waste products

Description

Depending on capture technology and feedstock utilized, various potentially harmful solid and liquid wastes and exhaust gases might be generated during the capture phase, necessitating proper waste management procedures to avoid environmental and health-related risks (Mahjour & Faroughi, 2023). Some waste products, such as air pollution control residues from municipal solid waste incineration, are considered hazardous in many jurisdictions, and can be highly alkaline, corrosive, and contain elevated concentrations of soluble salts (e.g. chlorides and calcium compounds), heavy metals (e.g. lead, nickel, and cadmium), and other toxic compounds and pollutants (Quina et al., 2008).

Example

Waste products might include various types of combustion residuals (e.g. fly ash, bottom ash, and air pollution control residues); waste water; and degraded flue gas filtering or CO_2 absorbent materials (e.g. amine reclaimer wastes).

Mitigation

Waste management practices and regulations surrounding e.g. flue gas management have significantly improved over the last few decades (Bisinella et al., 2021), and it is important to integrate proper waste treatment and management practices into the capture operation. Recycling is generally agreed to be the best management strategy for waste that has already been created, and landfills should be avoided as much as possible, although applications for hazardous wastes are often limited (Quina et al., 2008). For air pollution control residues and similar alkaline wastes, treatment options such as accelerated carbonation might be utilized to lower their toxicity (Fernández Bertos et al., 2004; Gunning et al., 2010).

CO_2 stream impurities

Description

Depending on capture technology and feedstock utilized, the captured CO_2 stream may contain several chemical impurities, which can have significant practical, health, safety, and environmental implications for the CO_2 transport and storage systems unless properly managed. Even a small number of impurities can cause the CO_2 stream properties to change (A. Razak et al., 2023). Some impurities such as H_2S or SO_2 are toxic and may result in acute damage to the environment or human health if leaked (A. Razak et al., 2023; Mahjour & Faroughi, 2023; Murugan et al., 2020). Impurities may also affect the phase behavior and properties of the CO_2 stream/plume (e.g. density, buoyancy, saturation pressure, and critical temperature); impact key operational parameters (e.g. storage capacity and injectivity of the reservoir); cause damage to equipment; lead to undesired chemical reactions inside the reservoir (e.g. pore blockage or fluid-caprock interactions); promote corrosion of e.g. pipeline or injection well materials; or result in degradation of absorbent materials (A. Razak et al., 2023; Mahjour & Faroughi, 2023; Murugan et al., 2020).

Example

Impurities might include water (H_2O), hydrogen (H_2), hydrogen sulfide (H_2S), carbon monoxide (CO), nitrogen (N_2) and its oxides (e.g. N_2O), sulfur oxides (SO_x), oxygen (O_2), methane (CH_4), and argon (Ar) (A. Razak et al., 2023; Murugan et al., 2020).

Mitigation

From a technical standpoint, the composition of the CO_2 stream and the impurities therein can be efficiently detected and monitored with modern analytical techniques, such as gas chromatography, mass spectrometry, or various types of spectroscopy (Murugan et al., 2020). Financially, the cost to capture and separate the CO_2 stream is often high, and can affect the feasibility of the project (A. Razak et al., 2023). Nevertheless, due to the potentially severe consequences that might be caused by impurities, it is important to conduct proper purity analysis and monitoring of the captured stream at regular intervals. There is an industry need for guidance on performing purity analysis before carbon dioxide is transported and stored (A. Razak et al., 2023; Murugan et al., 2020). Various national regulatory authorities and global standard-setting organizations have established regulations, guidelines and best practices regarding CO_2 stream composition and impurities[54] (A. Razak et al., 2023).

[54] For example, ISO/TR 27921:2020 Carbon dioxide capture, transportation, and geological storage — Cross Cutting Issues — CO_2 stream composition.

Transportation

CO_2 leakage

Description

Depending on the mode of transportation utilized, CO_2 leaks during transportation might cause severe acute damage to human beings and ecosystems (Kim et al., 2019; Lu et al., 2020; Mahjour & Faroughi, 2023; Witkowski et al., 2013). The captured CO_2 will be transported to the storage site via pipeline or road, rail, or marine tankers, all of which might leak, ranging from slow insidious seepage from joints and seams to a catastrophic leak from a pipeline failure. Although CO_2 is non-toxic *per se*, it is an asphyxiant, and exposure to elevated concentrations might lead to drowsiness, hypoxia, or even death.[55] Being denser than air, leaked CO_2 might furthermore accumulate in low-lying areas in stable atmospheric conditions with low wind speeds, exacerbating the hazard (Lu et al., 2020; Steven et al., 2010). High levels of CO_2 leaked e.g. from buried pipelines can also be harmful to plants, microbes, the soil environment and ecosystems in general (Kim et al., 2019; Steven et al., 2010).

Example

CO_2 leakage might occur through seal or valve malfunctions, or leaks and ruptures caused by e.g. vibrations, stress, corrosion, pressure fluctuations, extreme weather events or natural disasters (Mahjour & Faroughi, 2023; Steven et al., 2010). In the worst case scenario of a catastrophic pipeline rupture, the hazard zone might extend several hundred meters from the source of the leak (Witkowski et al., 2013), which could severely impact the environment and communities nearby.

Mitigation

As CO_2 is usually transported in large quantities at elevated pressures, ensuring the robustness of the transportation infrastructure is paramount to avoid risk of large-scale leakage events. Particularly in the case of transport via pipelines, although the accident rate is low (Lu et al., 2020; Steven et al., 2010), the consequences of leakage can be severe, and safety aspects need to be properly taken into account during the design, construction, operation, maintenance, and monitoring of the pipelines (Lu et al., 2020; Mahjour & Faroughi, 2023). For example, the United States (where a significant majority of the world's CO_2 pipelines are located) has implemented strict CO_2 pipeline management requirements (Lu et al., 2020).

Storage

CO_2 leakage

Description

Depending on the nature and characteristics of the storage site and its surroundings, the release of CO_2 into the atmosphere, groundwater aquifers, shallow soil zones, or natural resource reservoirs can lead to environmental or health risks and economic losses (Mahjour & Faroughi, 2023; Mortezaei et

[55] Concentrations of around 1% CO_2 might cause drowsiness, followed by hypoxia and dizziness (4% CO_2), asphyxia and loss of consciousness (10% CO_2), and finally death at around 20% CO_2 (Lu et al., 2020; Mahjour & Faroughi, 2023; Witkowski et al., 2013).

al., 2020). The CO_2 will spread out underground during and after injection, and might travel distances of several kilometers and reach e.g. abandoned wells in the storage formation, which can then leak if degraded or inadequately sealed (Guoxiang Liu, 2012; Mortezaei et al., 2020). Furthermore, CO_2 might escape the storage reservoir through transmissive faults or fractures, which might be pre-existing or generated by pressure and temperature changes in the reservoir during injection (Mortezaei et al., 2020; Rutqvist, 2012).

Example

CO_2 leakage might result from compromised integrity of either active or abandoned injection wells (e.g. due to mechanical and chemical stress, corrosion, material degradation or human errors in design or sealing), or through natural pathways such as faults or fractures (Alcalde et al., 2018; Mortezaei et al., 2020). It's worth noting that in certain regions, such as North America, the long legacy of oil and gas exploration has left behind huge numbers of exploration and production wells, and in some locations a plume of injected CO_2 might realistically encounter several such existing wells (Nordbotten et al., 2009).

Mitigation

The risks of leakage from the storage reservoir can be efficiently mitigated through proper site selection and characterization, as well as careful well design and monitoring (see also section 8.2).

Groundwater contamination

Description

Leakage of CO_2 or brine from the storage reservoir (see above) might also impact shallow groundwater resources and compromise the quality of drinking water resources (Birkholzer et al., 2009; Keating et al., 2013; Z. Li et al., 2018; Mahjour & Faroughi, 2023; Pawar et al., 2015). Introduction of CO_2 into groundwater aquifers through underground leaks from the storage reservoir may result in formation of carbonic acid and subsequent decrease in water pH. Changes in pH enhance the solubility of hazardous trace elements and other contaminants naturally found within the aquifer rocks, and ultimately lead to contamination of water resources (Damen et al., 2006; Fogarty & McCally, 2010; Z. Li et al., 2018; Mahjour & Faroughi, 2023). Trace metals might also be transported into the freshwater aquifer through leaking fluids, which might even be a more significant source of trace metals than the *in situ* mobilization due to pH change (Keating et al., 2013).

In the case of storage in saline aquifers, the injected fluids may cause large-scale pressure changes and displacement of native brines, impacting subsurface volumes much larger than the CO_2 plume itself (Birkholzer et al., 2009). In the case the storage formation is hydraulically communicating with freshwater resources (e.g. through high-permeability conduits such as transmissive faults or abandoned boreholes), the brine displacement and subsequent mixing into the freshwater might jeopardize the quality of drinking water resources even if the CO_2 itself is securely trapped (Bergman & Winter, 1995; Birkholzer et al., 2009).

Example

Contaminants might include trace metals such as lead (Pb), arsenic (As) or mercury (Hg); organic compounds; or brine (Birkholzer et al., 2009; Fogarty & McCally, 2010; Z. Li et al., 2018). Changes in pH might also result in other water quality problems such as increased water hardness due to calcium dissolution (Damen et al., 2006).

Mitigation

The risks of leakage from the storage reservoir can be efficiently mitigated through proper site selection and characterization, as well as careful well design and monitoring (see also section 8.2).

Induced seismicity

Description

Injection of large amounts of high-pressure CO_2 into the subsurface can affect the original mechanical equilibrium state of the reservoir and trigger seismic events (Cheng et al., 2023). In general, the connection between fluid injection and the risk of increased seismic events is well established, and such induced seismic events have been observed in CO_2 injection projects as well (Cheng et al., 2023; Mahjour & Faroughi, 2023; Pawar et al., 2015; Rutqvist, 2012; J. A. White & Foxall, 2016; Zoback & Gorelick, 2012). However, in the context of geologically stored carbon dioxide, induced seismicity has not been a major operational issue in the past (Rutqvist, 2012; J. A. White & Foxall, 2016), and the vast majority of recorded events have been limited to microseismicity,[56] i.e. events so minor that they are not perceptible at the surface (Cheng et al., 2023; NASEM, 2019; J. A. White & Foxall, 2016). Nevertheless, the risk exists and needs to be addressed, as some induced seismic events can well be large enough to be a nuisance, and at worst, capable of property damage and human harm (NASEM, 2019; J. A. White & Foxall, 2016). Large magnitude events could damage injection wells or surface infrastructure, but even a small to moderate earthquake (e.g. of magnitude M ~4) might jeopardize the reservoir integrity by introducing fractures (and/or increasing the permeability of thereof) within the caprock, thus increasing risk of CO_2 leakage to the surrounding strata (Cheng et al., 2023; Zoback & Gorelick, 2012). Furthermore, perceptible seismic events can disturb the local population even when not large enough to cause human harm or damage, and significantly affect the public perception of the project (Pawar et al., 2015).

Example

In general, induced seismic events result from changes in pore pressure following injection, which can alter the effective stresses in the reservoir formation and lead to deformation or seismic events by reopening or creating faults or fractures, particularly in regions with pre-existing tectonic activity (Cheng et al., 2023; Mahjour & Faroughi, 2023; Zoback & Gorelick, 2012). It is in fact not uncommon for microseismic events to be observed during CO_2 injection operations, and very small events numbering in the thousands have been measured in several projects (Cheng et al., 2023; J. A. White & Foxall, 2016).

Mitigation

[56] Microseismicity usually implies an earthquake with a moment magnitude M less than about 2 or 3 (Cheng et al., 2023; Pawar et al., 2015). For reference, in parts of the world with good construction practices, earthquakes smaller than approximately M 6 do not usually result in significant human harm or property damage (Zoback & Gorelick, 2012). Note that while seismic events within the caprock might compromise its integrity and should be avoided, microseismicity within the confines of the storage reservoir might also have positive aspects due to enhanced permeability (Mahjour & Faroughi, 2023).

The risk of induced seismicity can be at least somewhat mitigated through careful geological characterization during site selection, by e.g. avoiding sites with extensive faults (the magnitude of an earthquake produced by a fault slip correlates with the size of the fault), or favoring highly porous and permeable laterally extensive reservoirs where the resulting pore pressure increase as a result of CO_2 injection is smaller (Zoback & Gorelick, 2012).

There are various statistical, numerical and other methods geared towards forecasting induced seismic events, although significant knowledge gaps in that respect—owing to the fact that fault systems in general are difficult to detect and have complex activation mechanisms—render prediction and control of CO_2 injection induced seismicity extremely difficult (Cheng et al., 2023). As to the assessment of damage and nuisance risks, there is a significant body of experience dealing with *natural* seismic hazards, which can provide a rational basis for deciding whether risks are acceptably low and safely manageable in a given project. In particular, the probabilistic seismic hazard assessment (PSHA) and probabilistic seismic risk assessment (PSRA) methods are mature and widely used in the natural hazard and structural engineering communities, although some adaptation from natural to induced hazards is necessary[57] (Cheng et al., 2023; Pawar et al., 2015).

8.4. Risk and uncertainty assessment

The overall risk of an event or situation is often defined as the combination of two parameters: the *probability* (likelihood) for the event to be realized, and the *severity* of the event, if realized. In broad terms, risk management is composed of three main steps: analysis, evaluation and treatment of risk (Samadi, 2012 and references therein). In the case of geological storage of CO_2, effective risk management is based on systematic risk identification, ranking, quantitative assessment and a treatment or mitigation plan (Gerstenberger et al., 2013).

There are multiple methods to quantify risks and uncertainties, each with their advantages and limitations (for a comprehensive review, see Mahjour & Faroughi, 2023). Regardless of the approach, it is important to identify and assess the potential risk scenarios *before they occur*, in order to develop effective mitigation plans, address potential issues, and improve the overall success of the project (Xiao et al., 2024). A risk matrix, such as exemplified in table 8.3, is often utilized to identify and assess the severity and likelihood of risks, and has also been applied in the context of geological storage (Hnottavange-Telleen, 2013; Hnottavange-Telleen et al., 2011; Q. Li & Liu, 2016; Xiao et al., 2024). It is designed to aid in risk management by setting threshold values and recommended actions for different levels of risk: negligible risks may be ignored, but if a risk is deemed as e.g. undesirable or intolerable, mitigation measures need to be applied.

While a risk matrix is a useful general tool, it is important to realize that the severity and likelihood of risks depend on the context, and must be separately and carefully considered for each individual risk. For example, the acceptable likelihood of occurrence for safety-related risks is significantly lower than for risks related to project financing or timelines. The severity of a particular type of event is highly specific as well. For instance, the impact of a CO_2 leakage event significantly depends on the pathways and spatial distribution of the flux (Koornneef et al., 2012): a high, localized flow rate (e.g.

[57] For instance, the natural earthquake frequency is often stable in time whereas the injection induced seismicity depends on the temporal and spatial variations related to injection behaviors (Cheng et al., 2023).

pipeline explosion) poses an acute risk to human health and safety, but a similar total amount of CO_2 leaked with a low, dispersed flow rate (e.g. well leakage) would not have as severe acute consequences to human health, although climate or environmental impacts would still persist.

Table 8.3. An example of a risk matrix utilized in the context of geological storage of carbon. Modified from (Q. Li & Liu, 2016; Xiao et al., 2024).[a]

20–25	Non-operable	
10–16	Intolerable	
4–9	Undesirable	
2–3	Acceptable	
1	Negligible	

Categories/Groups:

- Air/Atmosphere
- Surface – Near Surface
- Subsurface
- CO_2 Transportation
- Ownership and Environment
- Community

Control measures			Very Low 1	Low 2	Medium 3	High 4	Very High 5
			LIKELIHOOD →				
Light	1	SEVERITY ↓	**1**	**2**	**3**	**4**	**5**
Serious	2		**2**	**4**	**6**	**8**	**10**
Major	3		**3**	**6**	**9**	**12**	**15**
Severe	4		**4**	**8**	**12**	**16**	**20**
Extreme	5		**5**	**10**	**15**	**20**	**25**

[a] Originally based on the Schlumberger Hazard Analysis and Risk Control Standard SLB-QHSE-S020 (Hnottavange-Telleen et al., 2011).

8.5. Requirements for risk and uncertainty management

Note that the Puro Standard General Rules contain requirements on risk assessment and management, particularly in the context of permanence and risk of reversal. Note that requirements relating to an important aspect of risk management, i.e. the assessment and mitigation of environmental and social impacts, are also included in section 3.8.

8.5.1. The CO_2 Removal Supplier shall establish and maintain a comprehensive and project-specific risk assessment and mitigation process complying with the requirements of this methodology, the Puro Standard General Rules and other Standard Requirements, as well as any applicable local laws, regulations, and other binding obligations.

8.5.2. The CO_2 Removal Supplier shall create, maintain, and periodically update a comprehensive risk assessment of the geological storage activity. The risk assessment shall encompass all stages of the activity boundary, and include a qualitative and/or quantitative analysis evaluation of risks and their significance as described in subrules a-c.

a. The methods utilized for the analysis and evaluation of risks must be scientifically justifiable and detailed in the risk assessment. For example, the CO_2 Removal Supplier may utilize risk assessment frameworks stemming from applicable local statutory requirements, relevant international standards (such as ISO 31000),[58] scientific literature, or industry best practices.

b. The risk assessment shall at least consider the risks and potential negative impacts to:

- The environment (including but not limited to soil quality, water contamination, ecosystems, habitats, and biodiversity).
- The atmosphere.
- Human health and safety.
- Local communities and their socio-economic situation.

c. The risk assessment shall at least contain the following components, encompassing the entire activity boundary:

- Risk identification, including characterization of each identified risk related to the geological storage activity; the conditions and context in which the individual risks might be realized; and the potential impacts of each identified risk.
- Risk analysis and estimation, including characterisation of the risk likelihood and severity, assessing the significance of the risk to the CO_2 Removal project.
- Risk evaluation, determining whether the risk likelihood and its severity are at an acceptable or tolerable level.
- Risk management measures, including a plan to mitigate and prevent the identified risks. Preventive and corrective measures shall be identified or planned as contingency measures to reduce risks and uncertainties.

[58] ISO 31000:2018 Risk management — Guidelines.

8.5.3. As a part of the risk assessment, the CO_2 Removal Supplier shall assess whether there exist any such project-specific risk factors (such as those related to the specific infrastructure or storage reservoir utilized) that might lead to an elevated overall risk of reversal (in the sense described in section 8.2). In the case where, based on the assessment, the fraction of stored CO_2 retained is likely less than 99% over the first 1000 years, the CO_2 Removal Supplier shall undertake appropriate mitigation measures to reduce the overall risk of reversal to an acceptable level[59] or, if no such measures are feasible, apply a commensurate deduction to the reported Output volume.

8.5.4. The risk assessment shall, to the extent possible, be based on actual project data acquired during all stages of the geological storage activity. The risk assessment shall be periodically updated together with the monitoring plan. The CO_2 Removal Supplier shall set and periodically review appropriate preventive and corrective safeguards based on the risk assessment.

8.5.5. The CO_2 Removal Supplier shall record and disclose to the Issuing Body any risk realization events (including corrective measures taken and potential new safeguards or preventive measures set), as well as any resulting negative impacts or claims thereof, including but not limited to any legal actions and/or other written complaints filed by affected parties. The records shall be made available to the Auditor.

[59] An acceptable level of overall risk of reversal is defined as being likely that the fraction of stored CO_2 retained is more than 99% over the first 1000 years.

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