

CHAPTER 14.

CO₂ removals and CO₂ capture with geologic storage

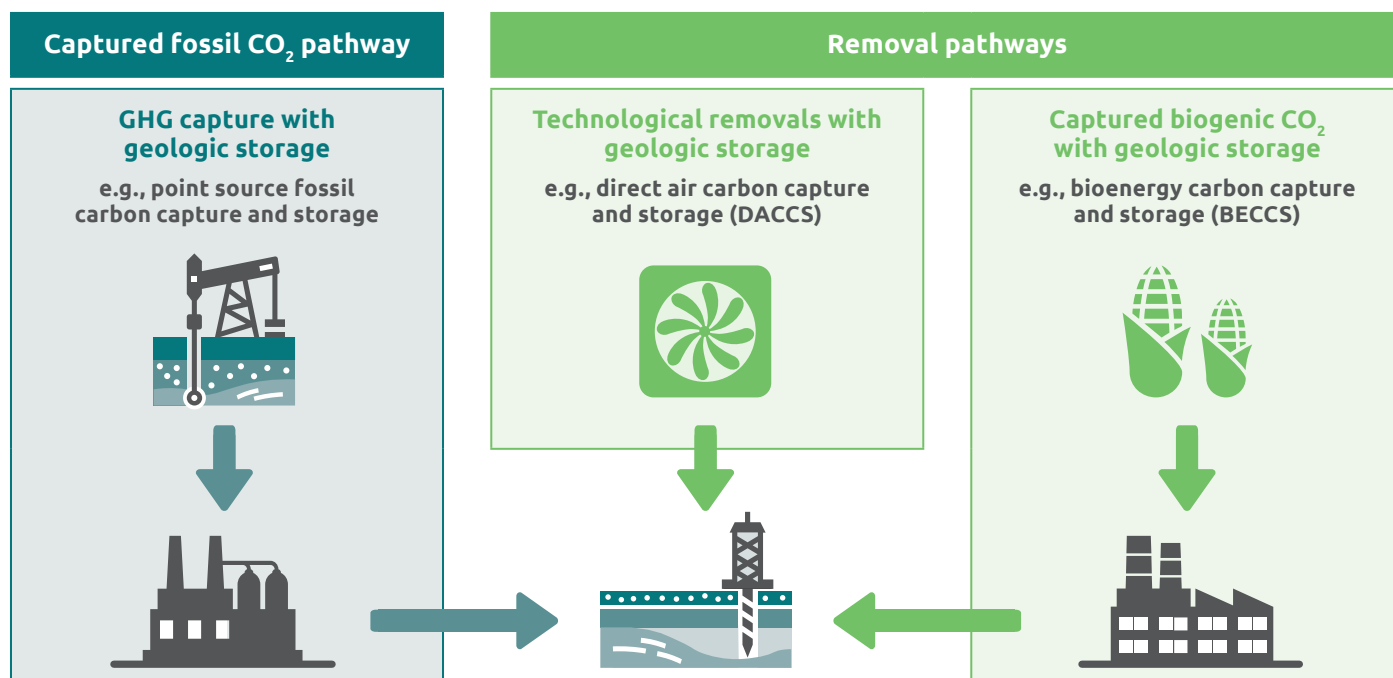
This chapter provides requirements on accounting for CO₂ removals and CO₂ capture with carbon storage in geologic reservoirs from both a scope 1 and scope 3 perspective.

14.1 Overview

A geologic storage pathway refers to the consecutive and interlinked stages associated with the acquisition and storage of carbon in geologic reservoirs. CO₂ stored in geologic reservoirs can derive from two types of pathways (Figure 14.1):

- **Captured CO₂:** CO₂ collected at a source (preventing an emission) and that continues to be stored in a non-atmospheric carbon pool. In this case, companies do not need to account for those emissions in the relevant scope if they meet the geologic storage requirements, but this is not accounted for and reported as a removal.
- **Removal:** CO₂ removed directly from the atmosphere with technologies (e.g., direct air capture), or via biogenic CO₂ capture (e.g., bioenergy with carbon capture and storage). These can be accounted for and reported as removals with geologic storage. Net removals with geologic storage are net CO₂ removals resulting from annual net increases to carbon stored in geologic carbon pools from carbon derived from biological or technological CO₂ sinks.¹

Figure 14.1 Illustration of geologic storage pathways



CO₂ removals with geologic storage and CO₂ capture with geologic storage are subject to the CO₂ removal requirements provided in Chapter 12. Additionally, they must meet the following requirements:

- Companies are required to account for all cradle-to-grave life cycle GHG emissions, land use, and land carbon leakage (where required) associated with the geologic storage pathway (see Requirement 19.GS).
- Companies need to have traceability from the point of CO₂ capture to the injection site (see Requirement 20.GS).
- Companies need to comply with the data quality criteria (see Requirement 21.GS).
- While many geologic reservoirs can store carbon on millennial timescales, ongoing monitoring needs to be met to ensure any CO₂ losses from the reservoir are detected and accounted for (see Requirement 23.GS).
- For captured biogenic CO₂ with geologic storage, companies must account and report for all life cycle GHG emissions related to the attributed land, and demonstrate that there are no significant land use change emissions (see Requirement 25).

14.2 Requirements

14.2.1 Accounting requirements

Note: Refer to Chapter 12 for general removals requirements.

REQUIREMENT 19.GS:

Removals and CO₂ capture with geologic storage (GS) accounting¹

If companies account for and report removals with geologic storage or CO₂ capture with geologic storage in their GHG inventory, they **shall** meet the following requirements:

- **Life cycle GHG emissions:** Companies **shall** account for all life cycle GHG emissions that occur throughout the geologic storage pathway (i.e., cradle to grave).
 - This includes GHG emissions, land use, and land carbon leakage (where required) from the product life cycle(s) associated with the stored CO₂ or carbon, and report them in the corresponding reporting category in scope 1, scope 2, and/or scope 3.
 - **Enhanced oil and gas recovery:** For geologic storage pathways with enhanced oil and gas recovery, companies **shall** account for all downstream GHG emissions associated with the extraction, processing, transportation, distribution, storage, and use (i.e., combustion) of oil, natural gas, or other hydrocarbons produced from the geologic reservoir and report such emissions in scope 1, scope 2, and/or scope 3.
- **Operational boundary:** To report scope 1 net removals with geologic storage when no single entity owns or controls both the sink and the pool of the CO₂ removals, the multiple entities involved in the geologic removal and storage pathway **shall** develop a contractual agreement which specifies:
 - The ownership (rights) of the CO₂ sinks and pools and resulting removals with geologic storage, and the responsibility (obligations) for the GHG sources and resulting emissions (including any losses of stored carbon) across the entire geologic removal and storage pathway; and
 - Which single entity, among the companies that own or control the sink, transportation, or the pool, accounts for the removals as scope 1, or specify how the scope 1 removals will be apportioned between the companies, and mechanisms to avoid double counting.

- In such cases, a single tonne of CO₂ removal with geologic storage **shall** not be reported by more than one entity under scope 1.
- The contractual agreement **should** include only the companies that could account for the removal in their scope 1, following the consolidation approach selected.
- The contractual agreement **should** be between, at a minimum, the party that captures the CO₂ (either through technological removal processes or resulting from the oxidation of the molecular carbon content of biogenic materials) and the party that stores the CO₂ in a geologic reservoir. Land managers and landowners are not required to be included in such contractual agreements if those land managers and landowners will not report such removals with geologic storage.
- The contractual agreement is not an instrument to transfer the scope 1 removal to an entity outside (i.e., that does not own or control a part) of the removal and storage pathway.

REQUIREMENT 20.GS:

Scope 3 geologic storage traceability

If companies account for and report scope 3 removals with geologic storage or CO₂ capture with geologic storage in their GHG inventory, they **shall** account for and report net removals with geologic storage (or no emissions associated with CO₂ capture with geologic storage) only if they have physical traceability (following Requirement 8)² to the entity (or entities) capturing the CO₂ received at the injection site or geologic storage hub system, and the entity (or entities) operating the CO₂ injection site(s) and geologic storage reservoir(s).

REQUIREMENT 21.GS:

Data quality for geologic storage

If companies account for and report removals with geologic storage or CO₂ capture with geologic storage in their GHG inventory, they **shall** meet the following requirements:

- **Data specific to sinks and pools:** Companies **shall** account for and report net removals with geologic storage (or no emissions associated with CO₂ capture with geologic storage) only if net CO₂ removals with geologic storage, CO₂ capture with geologic storage, and life cycle GHG emissions for the CO₂ stored in the geologic reservoir(s) are accounted for using data specific to the CO₂ injection site(s), geologic storage reservoir(s), and CO₂ inputs into the geologic storage reservoir(s).
- **Uncertainty:** Companies **shall** account for and report net removals with geologic storage (or no emissions associated with CO₂ capture with geologic storage) only if they provide quantitative uncertainty estimates.

Note: Requirement 22 appears in Chapter 12; Requirement 22 is a general removals requirement that applies to accounting for both land management CO₂ removals and CO₂ removals with geologic storage.

REQUIREMENT 23.GS:

Permanence for geologic storage

If companies account for and report removals with geologic storage or CO₂ capture with geologic storage in their GHG inventory, they **shall** adhere to the permanence principle by meeting the following requirements:

- **Ongoing storage monitoring:** Companies **shall** account for and report net removals with geologic storage (or no emissions associated with CO₂ capture with geologic storage) only if ongoing storage monitoring is

documented in a monitoring plan to ensure carbon remains stored in geologic reservoirs and the company can detect losses of stored carbon from relevant geologic carbon pools.

- **Losses of stored carbon:** Companies **shall** account for net geologic carbon stock losses of previously reported net removals or captured CO₂ with geologic storage in the year the losses occur, as either:
 - **Fossil fuel and industrial emissions**, if the carbon pools are part of the GHG inventory boundary in the reporting year; or
 - **Reversals** from geologic storage, if the carbon pools are no longer in the GHG inventory boundary in the reporting year.

If companies lose the ability to monitor geologic carbon stocks associated with previously reported removals, companies **shall** assume previously reported removals are emitted and report reversals from geologic storage.

Note: Requirement 24 appears in Chapter 15 and does not apply to geologic storage.

REQUIREMENT 25:

Land accounting for biogenic carbon storage in geologic reservoirs³

If companies account for and report captured biogenic CO₂ with geologic storage associated with agricultural products in their GHG inventory, they **shall** meet the following requirements:

- **Life cycle GHG emissions, land use, and leakage:** Companies **shall** account for all life cycle GHG emissions, land use, and land carbon leakage (where required) on lands where the biogenic CO₂ or carbon is sourced from, including land use change emissions, the annual net land carbon stock change, and land management production emissions.
- **No significant LUC emissions:** Companies **shall** demonstrate that there are no significant land use change emissions attributable to the biogenic materials.
 - Definition of “not significant”: If land use change emissions are reported, but less than 5 percent of the sourcing area (i.e., jurisdiction, sourcing region, or LMU) has experienced land use change, this criterion is met.
 - If any non-significant LUC emissions attributable to the biogenic materials occur, they **shall** be subtracted from the CO₂ or carbon added to the geologic or product carbon pool. These LUC emissions are counted as land emissions in the inventory and cannot be accounted for as removals with geologic storage or as product carbon storage. The portion of removals that did not generate LUC emissions can still be reported as removals.
 - Companies **may** use evidence from regulatory programs, certification programs, sustainability programs, or other mechanisms as a basis for providing information on biogenic product sourcing to determine land carbon stock changes related to this requirement. Such mechanisms **should** include quantitative information on land use change and land carbon stock changes, or proof that levels of land carbon stocks and sinks are maintained or strengthened over the long term (e.g., biomass sustainability certification, compliance with regulations or jurisdictional programs verified by national authorities, or independent third-party assurance fulfilling at a minimum ISAE 3000 limited assurance engagement).

This requirement does not apply to biogenic CO₂ or carbon associated with waste materials, following the recommendation on allocating upstream GHG emissions from waste in Section 6.3 (i.e., companies do not need to allocate any upstream GHG emissions to waste materials with no economic value).

14.2.2 Reporting requirements

Reporting requirements for geologic storage

If companies account for and report removals with geologic storage or CO₂ capture with geologic storage in their physical GHG inventory, they **shall** report:

- **Life cycle GHG emissions:** All life cycle GHG emissions that occur throughout the geologic storage pathway (i.e., cradle to grave), including:
 - Life cycle “fossil fuel and industrial emissions” and “land emissions” attributable to the CO₂ inputs in the relevant “emissions” accounting category and subcategory;
 - Fugitive CO₂ emission or other CO₂ losses to the atmosphere from geologic storage in the “gross CO₂ emissions from geologic storage” accounting category under “gross CO₂ fluxes,” separately from the physical GHG inventory; and
 - Net carbon losses from geologic reservoirs that are still within the inventory boundary in the “fossil fuel and industrial emissions” accounting category in the physical GHG inventory (following Requirement 23.GS on losses of stored carbon).
- **Removals** with geologic storage that meet the removals requirements under “removals” in the physical GHG inventory. Where data allows, companies **should** further disaggregate captured biogenic CO₂ from other technological CO₂ removals and report under the “captured biogenic CO₂ with geologic storage” and “technological CO₂ removals with geologic storage” accounting subcategories, respectively.
- **CO₂ capture:** CO₂ capture with geologic storage that meets the geologic storage requirements is not reported as emissions in the relevant scope.
 - Disclose the amount of CO₂ that is captured and stored in geologic reservoirs that meets the geologic storage requirements.
 - Fossil CO₂ capture that doesn’t meet the geologic storage requirement is reported as “fossil fuel and industrial emissions” in the relevant scope.
- **Reversals of CO₂ removals with geologic storage:** Net carbon losses from geologic reservoirs associated with previously reported scope 1 and/or scope 3 removals (no longer in the inventory boundary).
- **Reversals of CO₂ capture with geologic storage:** Net carbon losses from geologic reservoirs associated with previously disclosed captured CO₂ (no longer in the inventory boundary).

Additionally, they **shall** disclose the following information in their GHG report:

- **Operational boundary:** If applicable, description of contractual arrangements that specify which single entity (among the entities that own or control the removal and storage pathway, if more than one) accounts for removals as scope 1, including information on allocation of CO₂ related risks and obligations and avoidance of double counting of scope 1 removals between all entities in the geologic removal and storage value chain.

Companies accounting for and reporting “captured biogenic CO₂ with geologic storage” in their physical GHG inventory **shall** disclose the following information in their GHG report:

- **No significant LUC emissions:** Justification that there are no significant land use change emissions attributable to the biogenic materials the CO₂ is captured from.

- **Land use** associated with the biogenic materials the CO₂ is captured from in the “land occupation” accounting subcategory under “land use,” separately from the physical GHG inventory.
- **Land carbon leakage** associated with the biogenic materials the CO₂ is captured from, if relevant, in the “land carbon leakage” accounting category, separately from the physical GHG inventory.

14.3 Recommendations

Data specific to sinks and pools

Geophysical data, well data, and reservoir properties data **should** be collected for evaluation of the geologic storage reservoir.

Ongoing storage monitoring plan

The monitoring plan **should** include a site characterization, description of how the operations at the geologic reservoir and monitoring comply with applicable regulations, methods used to detect any fugitive CO₂ emissions, frequency of monitoring, and data quality control procedures.

- Where regulations include provisions for the transfer of liabilities associated with geologically stored CO₂ to the state and the geologic storage operator demonstrates that storage is permanent without risk of CO₂ losses from the reservoir, the date and condition of the transfer of liabilities **should** be clarified, and post-closure monitoring **may** follow regulatory guidance.

CO₂ custody transfer disclosure recommendation

For CO₂ inputs to geologic reservoirs, companies **should** report the net amount of CO₂ (in tonnes) at each custody transfer, where the net amount is the difference between CO₂ inputs and outputs, corrected by any changes in composition of the CO₂ stream, if applicable.



14.4 Guidance on the requirements and recommendations

To report removals of CO₂ that are stored in geologic reservoirs, companies must satisfy the specific requirements in Chapter 14 of the *Standard*. Companies must also satisfy the same relevant requirements to report capture of CO₂ (i.e., CO₂ emissions captured and prevented at a source) that was subsequently stored in geologic reservoirs. Chapter 12 in the *Standard* and *Guidance* provides general requirements and guidance that must be met for companies to report CO₂ removals (i.e., that applies to reporting removals in any removals accounting subcategory in this *Standard*).

For example, a company in a value chain with direct air capture with carbon storage (DACCS) must satisfy the requirements in Chapter 14 to report technological CO₂ removals with geologic storage. Similarly, a company in a value chain with fossil carbon capture and storage must satisfy the same requirements to not report fossil emissions of CO₂ that is captured and prevented at a source and ultimately stored in geologic reservoirs.

Companies can account for and report technological removals with geologic storage or captured biogenic CO₂ emissions with geologic storage only if the requirements on traceability (20.GS), data quality (21.GS), and permanence (23.GS) are satisfied. The information in Section 14.4 provides specific guidance for satisfying the requirements for removals with geologic storage. Section 12.4 provides guidance for satisfying the general requirements applicable to all removals.

14.4.1 Guidance for removals and captured CO₂ with geologic storage accounting requirements

The guidance in the following sections provides an overview of geologic storage pathways (Section 14.4.1.1) and an overview of the accounting approach for each pathway (Section 14.4.1.2). Companies must also account for all life cycle GHG emissions that occur throughout the geologic storage pathway (Section 14.4.1.3). Guidance for determining where to account for impacts in the inventory (i.e., scope 1 or scope 3) is provided in Section 14.4.1.4.

14.4.1.1 Overview of geologic storage pathways

All integrated assessment models that define pathways to reach the 1.5°C target in the IPCC's *Sixth Assessment Report* consider technologies that remove CO₂ from the atmosphere (i.e., technological carbon dioxide removal [TCDR] processes).⁴ Storage of carbon in geologic reservoirs can have different impacts on the climate depending on:

- The origin of the stored CO₂ or carbon (e.g., captured fossil CO₂ from an industrial point source, captured biogenic CO₂ from an industrial point source, or direct air capture of atmospheric CO₂);
- The GHG emissions associated with the life cycle processes in the geologic storage pathway; and
- The permanence of the geologic storage.

This section provides descriptions and examples of different geologic storage pathways based on the origin of the stored CO₂ or carbon, summarized in Table 14.1 below and in Figure 14.1.



Table 14.1 Description of geologic storage pathways

Geologic storage pathway	Type of geologic storage	Pathway description	Examples	Does this constitute a removal?
Captured CO₂ pathway	CO ₂ capture with geologic storage	CO ₂ is captured from an industrial point source prior to release to the atmosphere and stored in geologic reservoirs	Point source fossil carbon capture and storage (CCS)	No^a
Removal pathway	Technological CO ₂ removals with geologic storage	CO ₂ is removed from the atmosphere via technological sinks and stored in geologic reservoirs	Direct air carbon capture and storage (DACCS) Enhanced weathering processes ^b	Yes^a
	Captured biogenic CO ₂ with geologic storage	CO ₂ is removed from the atmosphere via biological sinks, harvested, and used as a product, after which the biogenic CO ₂ is captured and stored in geologic reservoirs	Bioenergy carbon capture and storage (BECCS)	Yes^a

Note: a. Reporting net emissions from captured CO₂ pathways and net removals with geologic storage are both also subject to meeting the removal requirements in Chapter 12 and this chapter; b. Detailed guidance on accounting for removals due to enhanced rock weathering is not provided in this version of the Guidance due to the need for additional research and methodology development at the time of publication.

“CAPTURED CO₂” PATHWAYS

- **CO₂ capture with geologic storage** occurs when CO₂ is captured prior to release to the atmosphere and stored in geologic reservoirs, rather than being emitted to the atmosphere from a facility. Capturing CO₂ (e.g., at a point source) requires technological solutions to capture and separate GHGs at the source. The impact of CO₂ capture is reflected in a GHG inventory by not reporting emissions that have instead been prevented. Captured emissions can result in reduced emissions over time if, in previous years, CO₂ was emitted from a company’s operations or value chain and in the reporting year, CO₂ is instead captured and stored. In captured CO₂ pathways, companies do not report emissions in the respective scope 1, scope 2, or scope 3 category for any CO₂ that is captured and stored in geologic reservoirs (i.e., if the geologic storage requirements in Section 14.2 of the *Standard* are met). Any CO₂ that is not captured, and all GHG emissions due to the capture process itself, must be fully accounted for. Complete accounting for the captured CO₂ pathway requires ongoing storage monitoring of geologic reservoirs to detect potential losses (emissions) and is subject to reversals accounting (Requirement 23.GS) and the other relevant requirements for geologic storage (Requirements 20.GS and 21.GS).
 - *Fossil carbon capture and storage (CCS)*: In a fossil CCS pathway, CO₂ from fossil fuel and industrial sources is captured on site at a point source. The capture process can involve purifying the CO₂ before transportation and injection into geologic reservoirs. Captured CO₂ pathways with geologic storage where the stored carbon is derived from fossil fuels or other carbon resources that are part of the long-term carbon cycle (e.g., CO₂ capture of process emissions from cement production) are not accounted for as CO₂ removals. Instead, capture of fossil CO₂ from a point source prevents emissions if that CO₂ is captured and stored. All GHG emissions from fugitive losses and processes associated with the geologic storage pathway must be accounted for and reported (see Requirement 19.GS and reporting requirements in Section 14.2.2).

- **Captured CO₂ emissions with product storage or use** as an input for other production purposes (e.g., greenhouse fertilization) do not represent a captured CO₂ pathway with geologic storage (i.e., does not include permanent storage in geologic reservoirs). Carbon captured and stored in products represents temporary storage, followed by re-release to the atmosphere at the end of the product lifecycle. Reporting product carbon storage is optional in this *Standard*. Companies that choose to report product carbon storage must satisfy the requirements in Chapter 15.

“CO₂ REMOVAL” GEOLOGIC STORAGE PATHWAYS

Carbon or CO₂ stored in geologic reservoirs can be accounted for as CO₂ removals if the CO₂ originates from biological or technological sinks that are part of the short-term carbon cycle (e.g., CO₂ is removed from the atmosphere in the reporting year or is associated with recent biomass growth). Removals with geologic storage are net increases in geologic carbon stocks from biogenic or technologically removed CO₂.

Removals with geologic storage can be separately accounted for and reported in the inventory as:

- **Technological CO₂ removals with geologic storage**, if stored CO₂ is derived from technological removal pathways, for example, via:
 - *Direct air carbon capture and storage (DACCS)*: DACCS systems remove CO₂ directly from ambient air and then separate the CO₂ into a relatively pure stream, which is stored in geologic formations. Conceptually, the CO₂ capture step is similar to the capture of CO₂ from flue gases or other concentrated sources (i.e., in captured CO₂ pathways), but DACCS is part of a CO₂ removal pathway since it removes CO₂ from the atmosphere. There are important technological differences compared to capture processes for concentrated sources, due to the relatively low concentration of CO₂ in air (about 420 ppm or 0.04 percent compared to typically 3–20 percent for concentrated sources). Active materials with a strong affinity for CO₂ are required to bind CO₂ effectively, despite the low concentration. DACCS systems typically have a high thermal and/or electrical energy demand but do not need to be coupled with an emission source and can be placed near a geologic storage location.
- **Captured biogenic CO₂ with geologic storage**, if stored CO₂ is derived from biogenic removal pathways, for example, via:
 - *Bioenergy or biogenic carbon capture and storage (BECCS or Bio-CCS)*: Gross CO₂ removals attributable to biomass growth can be transferred to storage in harvested biogenic products, whereupon the biogenic carbon in those products is ultimately captured and stored in geologic carbon pools. BECCS systems rely on technologies that capture the biogenic CO₂ that is produced when biomass is converted into energy (heat, electricity, or fuel). Other types of biogenic CO₂ capture and storage (Bio-CCS) can come from the capture of other concentrated biogenic CO₂ sources (e.g., fermentation systems). The captured biogenic CO₂ is then transferred and injected into geologic storage. BECCS and Bio-CCS may provide a net benefit to the climate if GHG emissions and land carbon leakage (see Chapter 8) over the complete removals and geologic storage pathway (i.e., from growing, harvesting, transporting, and processing the biomass and capturing, transporting, and storing the CO₂) are less than the biogenic carbon captured and stored in geologic reservoirs. The process should also not increase the global dedicated use of land, as accounted for in the “land use” accounting category (see Chapter 8).

GEOLOGIC RESERVOIRS

Geologic reservoirs for storing CO₂ vary in their underlying characteristics, the mechanisms used to trap CO₂, and the type of injection. Box 14.1 explores some of the key considerations for different geologic reservoirs and CO₂ injection types.

Box 14.1 Geologic reservoirs and injection types

The information in this Box provides a general overview of types of geologic reservoirs and injection types.

GEOLOGIC RESERVOIRS

Geological storage sites have the following characteristics:

- Formations have enough porosity to provide the capacity to store the CO₂
- Pores in the rock are sufficiently connected and provide permeability to accept the CO₂ at the rate it is injected, to allow the CO₂ to move and spread out within the formation
- Formations have a (physical and/or chemical) trapping mechanism to contain the CO₂ and prevent it from migrating to the surface

The table below provides an overview of the subsurface reservoirs that have been tested and developed for geologic carbon storage, which fall into three major categories. The following sections provide a general description of these different subsurface reservoirs.

Table B14.1-1 Types of subsurface reservoirs for geologic carbon storage

Reservoirs for geologic storage	Examples
Sedimentary rocks with intergranular porosity	<ul style="list-style-type: none"> • Saline aquifers • Depleted oil or gas reservoirs
Sedimentary rocks that have significant CO ₂ reactivity, where flow occurs through fractures	<ul style="list-style-type: none"> • Coal seams • Organic-rich shales
Mafic or ultra-mafic rocks, feasible for CO ₂ mineral storage	<ul style="list-style-type: none"> • Basalt • Peridotite

Sedimentary rocks with intergranular porosity store fluids, including CO₂ compressed into a supercritical fluid, principally in pores between mineral grains that are larger than a nanometer in size. These rocks are often further classified by the fluids they contain. Examples include:

- Freshwater aquifers: most are protected resources into which injection is prohibited
- Deep saline aquifers or saline reservoirs: formations that are below the depth to which freshwater circulates and at which CO₂ becomes dense
- Hydrocarbon reservoirs or fields: formations that contain hydrocarbons (oil or gas)
- Depleted hydrocarbon reservoirs: hydrocarbon reservoirs that have reached the end of their economic life

The CO₂ storage mechanisms for sedimentary rocks with intergranular porosity include the following:

- Trapping CO₂ beneath a non-transmissive, ultra-low-permeability confining system that prevents upward and outward migration of buoyant CO₂
- Capillary trapping, which results in trapping of the non-wetting CO₂ as snapped-off “bubbles” unable to move through the small spaces between the grains
- CO₂ dissolved into brine, absorbed onto organic constituents in the rock, or precipitated as new minerals from solution

CO₂ storage in both deep saline aquifers and depleted hydrocarbon reservoirs is a proven technology that has completed testing and validation for CO₂ storage and is currently in the commercial deployment stage.

At depletion, oil fields still contain a significant fraction of the original oil, which is trapped in the pores and can be extracted by injecting materials like CO₂ to help mobilize the trapped oil. This process is known as enhanced oil recovery (EOR). During EOR production, mixtures of oil, CO₂, oil-CO₂ solution, and brine are brought to the surface. At surface pressure, the CO₂ separates from the oil and brine. The CO₂ is then cleaned, compressed, and reinjected. The CO₂ that is injected for EOR is therefore retained in the reservoir in long-term isolation from the atmosphere.

Box 14.1 Geologic reservoirs and injection types (cont.)

Despite the recovery and retention of injected CO₂ within the EOR system, the full life cycle of the produced oil or natural gas must be considered to determine the net CO₂ flux of the operation from the geologic reservoir.^a Where the net geologic carbon stock change is positive and greater than the life cycle GHG emissions of the geologic storage with EOR pathway (i.e., the carbon injected in the reservoir is greater than the carbon removed from the reservoir in the form of produced oil or natural gas and other life cycle GHG emissions), the EOR can provide climate benefits. Where the net geologic carbon stock change is negative, it leads to net CO₂ emissions from geologic storage. See Section 14.5.6 for calculation guidance for estimating the carbon losses from EOR.

Sedimentary rocks where flow occurs through fractures are suitable for storage, especially in rocks that have significant reactivity to CO₂ because of a high organic content. The CO₂ storage mechanism for such formations is CO₂ absorption onto the surfaces of organic materials that are found in coal, lignite, and organic-rich shales. The CO₂ enters via the fracture network, and it is trapped via absorption on surfaces as it flows past organic materials. Fractures can be either natural or man-made.

This type of storage has been tested, but the large-scale deployment of CO₂ storage in sedimentary rocks where flow occurs through fractures has been far less frequent than the deployment in sedimentary rocks with intergranular porosity.

Mafic or ultra-mafic rocks are rich in iron, magnesium, calcium, or other elements that are known to react with CO₂ through natural weathering processes (e.g., basalts and peridotites).^b This process can be imitated and accelerated by injecting CO₂ dissolved in water into the rock formations to react, leading to the saturation of carbonate minerals such as calcite, magnesite, and/or siderite in the pore water (Ca, Mg, or Fe carbonates). In the short term, ongoing CO₂ storage in such formations is achieved by the negligible risk of the CO₂ migrating back to the atmosphere (due to the density-related inhibition from dissolved CO₂). In the long term, ongoing CO₂ storage occurs via the precipitation of solid carbonate minerals within pores and fractures, leading to stability over geologic time scales.

Mineral storage in mafic rocks has been demonstrated in Iceland and the United States, where CO₂ is dissolved and injected into a basaltic reservoir, where rapid mineralization occurs. Further studies and pilots are underway to demonstrate the potential of mineral storage in other geological settings (igneous rocks such as peridotite, andesite, etc.) and to assess the feasibility of using seawater as the solvent. CO₂ mineral storage is now in the commercial deployment stage.^c

INJECTION TYPES

Geological storage can be further distinguished by the phase under which CO₂ is injected into the geologic formation, as described in the table below. To ensure CO₂ injection leads to secure and permanent storage, the injection type must be suited to the geologic storage reservoir, have an appropriate monitoring program, and meet transportation safety requirements and other best practices.

Table B14.1-2 CO₂ injection methods and their specifications for carbon storage in geologic reservoirs

CO ₂ injection methods	Specifications to achieve permanent carbon storage
Supercritical CO₂ injection	<ul style="list-style-type: none"> • Injected at a reservoir depth sufficient to ensure a supercritical state (e.g., a depth typically greater than 800 m) • Storage achieved through physical trapping to prevent buoyancy-driven upward flow
Dissolved CO₂ injection	<ul style="list-style-type: none"> • Amount of CO₂ injected is limited by the maximum solubility of CO₂ in the solvent • Injected at a reservoir depth sufficient to ensure the CO₂ remains in solution (e.g., a depth typically greater than 400 m) • Storage achieved through immediate solubility trapping, provided the injection of CO₂ meets specified requirements

Note: a. Núñez-López et al. 2019; b. Kelemen et al. 2019; c. National Academies of Sciences, Engineering, and Medicine 2019.

14.4.1.2 Accounting approaches for geologic storage pathways

ACCOUNTING APPROACH FOR “CO₂ REMOVALS” PATHWAYS

To report removals with geologic storage companies must meet the requirements and criteria for reporting removals, including the general requirements (Requirement 19.GS), as well as requirements on traceability (Requirement 20.GS), data quality (Requirement 21.GS), and permanence (Requirement 23.GS). Emissions and other metrics attributable to the CO₂ removal processes and geologic storage pathway are separately accounted for and reported as emissions in the relevant scope (see “Life cycle GHG emissions” in Requirement 19.GS).

Removals with geologic storage are accounted for based on net geologic carbon stock increases in geologic reservoirs (see “Accounting approach” in Requirement 19). Removals with geologic storage are accounted for in separate accounting categories depending on whether the net increase is derived from inputs of CO₂ from biological or technological sinks.

While removals with geologic storage are accounted for based on net geologic carbon stock changes, for transparency, companies may also report gross CO₂ fluxes associated with gross technological CO₂ removals. Table 14.2 provides an overview of reporting net removals with geologic storage versus gross technological CO₂ removals. See Section 3.4.4 for additional details on the difference between stock change and flow accounting.

Table 14.2 Accounting for net and gross technological removals accounting categories

Removals accounting subcategory	Accounting approach	Description
Technological CO ₂ removals with geologic storage	Stock change	Net CO ₂ removals resulting from annual net increases to carbon stored in geologic carbon pools from carbon derived from technological sinks.
Gross technological CO ₂ removals	Flow accounting	Gross CO ₂ removals from atmospheric CO ₂ , transferred via technological sinks to technological CO ₂ removal (TCDR)-based product carbon pools or geologic carbon pools.

ACCOUNTING APPROACH FOR CO₂ CAPTURE WITH GEOLOGIC STORAGE

CO₂ that is captured and stored in geologic reservoirs does not have to be reported as emissions if the geologic storage requirements and criteria for reporting removals, including the general requirements (Requirement 19.GS), and requirements on traceability (Requirement 20.GS), data quality (Requirement 21.GS), and permanence (Requirement 23.GS), are met.

ACCOUNTING APPROACH FOR GEOLOGIC STORAGE WITH ENHANCED OIL AND GAS RECOVERY

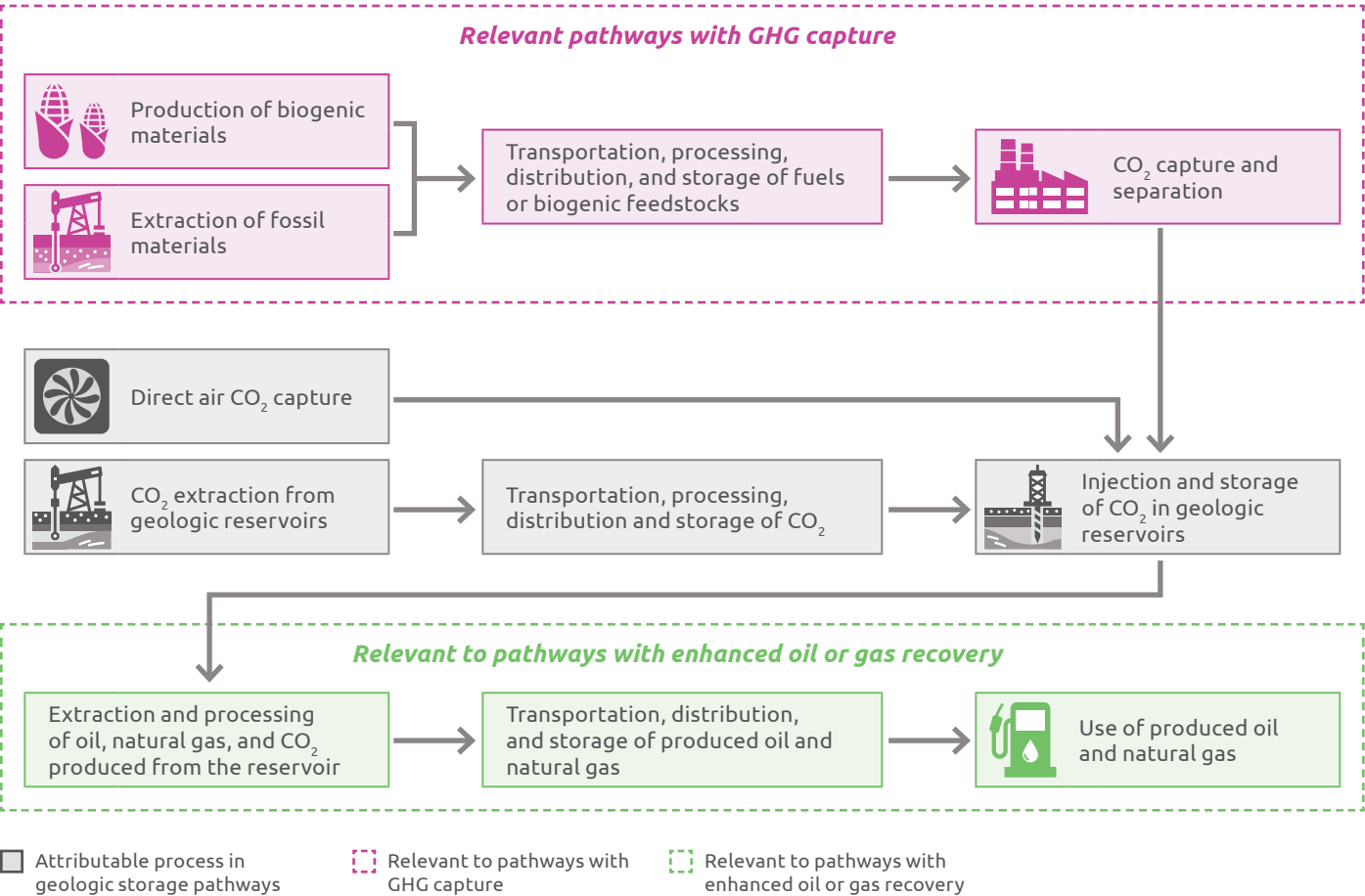
In some geologic storage pathways, CO₂ is used for enhanced oil and gas recovery to extract additional fossil carbon resources (e.g., oil or natural gas). See Box 14.1 for additional details. For geologic storage pathways with enhanced oil and gas recovery, the change in annual net geologic carbon stocks is determined based on the CO₂ inputs injected into the geologic reservoir, the fossil carbon removed from the reservoir, fugitive CO₂ emissions at the injection or recovery site, and recycling of CO₂ reinjected back into the formation.

For the CO₂ inputs injected into the geologic reservoir, companies must determine the share of the inputs and resulting geologic carbon stock change that represents CO₂ removed via biological or technological CO₂ sinks (relevant to removals) and the share that represents CO₂ from fossil or other non-atmospheric carbon origins (not relevant to removals).

14.4.1.3 Reporting life cycle GHG emissions and other metrics

Geologic storage pathways consist of all processes from the removal of CO₂ from the atmosphere and/or capture of CO₂ from a facility, to the transportation, injection, and storage of CO₂ in the geologic reservoir. Such processes may include upstream land GHG emissions, land use, land carbon leakage associated with captured biogenic CO₂ storage pathways, and downstream GHG emissions from oil and gas extracted from geologic storage operations with enhanced oil and gas recovery (see Figure 14.2).

Figure 14.2 Attributable processes for geologic storage pathways



EMISSIONS ASSOCIATED WITH CO₂ REMOVALS WITH GEOLOGIC STORAGE PATHWAYS

The following guidance is used to account for emissions associated with CO₂ removals with geologic storage pathways, organized by removals accounting subcategories:

- Technological CO₂ removals with geologic storage:** The emissions associated with the CO₂ capture process (e.g., direct air capture facility) include operations within the boundary of the capture site. This encompasses the capture facility, as well as auxiliary equipment associated with the CO₂ capture and compression systems. Emissions from purchased electricity or thermal energy to operate the DAC facility and auxiliary equipment must also be accounted for, as either scope 2 or 3, depending on the reporting company’s position in the TCDR value chain. If the project is part of an industrial complex (e.g., for heat recovery) with many processes unaffected by or independent of the CO₂ capture activities, only those processes directly impacted by the CO₂

capture process are included. The boundary of the capture site extends to the point at which the captured CO₂ is transferred to the operator of the subsequent pool (e.g., geologic storage operator or CO₂ pipeline).

To calculate GHG emissions from CO₂ capture and compression, the following emissions must be included (note that this list is non-exhaustive):

- Emissions from the primary process that have not been captured by the process, including intentional and unintentional emissions from the venting of CO₂ during capture and compression, and emissions from the fugitive release of CO₂ during capture and compression
- Emissions from the on-site use of fossil fuels to operate equipment for the CO₂ capture and compression facilities
- Emissions from purchased electricity and thermal energy used to operate the CO₂ capture and compression system
- Life cycle emissions associated with inputs to the capture and compression process (e.g., production of the sorbent material, conveyance of water to the DAC facility, etc.)



Enhanced rock weathering (ERW) is another type of technological removal following a similar process using materials that show a strong affinity for CO₂ capture (e.g., olivine or basalt dust).⁵ When exposed to air with atmospheric carbon concentrations, these materials react with CO₂ to form carbonate minerals. The process is similar to DAC adsorption of CO₂, but ERW involves passive treatment that waits for the reactions to naturally occur only once, over a longer time scale, rather than applying active engineering.

- **Captured biogenic CO₂ with geologic storage:** Geologic storage of captured biogenic CO₂ has additional considerations to ensure that the biogenic material, from which the captured biogenic CO₂ originates, is derived from atmospheric carbon pools via recent growth of, and not existing, land-based carbon pools. Companies must demonstrate that there are no significant land use change emissions attributable to the biogenic materials (see Requirement 25). To ensure full accounting of the life cycle emissions and other metrics attributable to the captured biogenic CO₂ and activities on lands where the biogenic CO₂ or carbon is sourced from, companies must account for GHG emissions, land use, and land carbon leakage, where required (see Requirement 25). To determine the attributable productive lands in the value chain of biogenic materials, see Chapter 5.

If captured biogenic CO₂ stored in geologic reservoirs is derived from biogenic wastes with no market value, Requirement 25 does not apply. Companies are not required to account for net land carbon stock changes, other GHG emissions, or land carbon leakage from the processes that generate biogenic waste materials or further processes upstream (see Section 6.4.5 for guidance on allocating emissions, removals, and other metrics from waste). All subsequent emissions in the life cycle of the biogenic waste materials (after the process that generates the waste) are accounted for (e.g., GHG emissions from transportation of agricultural residues to a biogenic CO₂ capture facility).

Case Study: Climeworks and Carbfix—Direct air capture and rapid carbon mineralization in Iceland

In 2021, the Swiss company Climeworks began operating Orca, the world's first plant that removes carbon dioxide through direct air capture of CO₂ and stores the captured CO₂ through geological storage. Three years later, in 2024, Climeworks launched Mammoth, with a 10-fold scale-up in nameplate capacity (i.e., maximum output under ideal conditions) compared to Orca. Both plants work with Carbfix, an Icelandic company that injects the CO₂ underground so that it mineralizes into stable carbonates that store the CO₂ on geological timescales.

Carbfix has received funding from the European Union's Horizon 2020 research and innovation program and the Innovation Fund for its projects in Iceland.

The process works as follows:

1. The Climeworks DAC modules use a filter containing a solid sorbent material that selectively binds CO₂ from ambient air.
2. Once the sorbent is saturated with adsorbed CO₂, it is heated by low-grade waste heat from the geothermal plant.
3. The CO₂ is released and dissolved in water.
4. The carbonated water is injected underground.
5. It then reacts with the basaltic bedrock, forming solid minerals.

The Carbfix technology imitates natural processes but speeds them up rapidly. The potential of scaling up this effective CO₂ storage is large: it unlocks possibilities in Iceland and numerous other regions in the world with similar geological foundations of basalt.

EMISSIONS ASSOCIATED WITH CO₂ CAPTURE WITH GEOLOGIC STORAGE

Companies with CO₂ capture with geologic storage in their value chain must account for any GHG emissions from processes in the geologic storage pathway in scope 1, scope 2, and/or scope 3. This includes any upstream GHG emissions from the extraction, transportation, processing, distribution, and storage of the materials the captured CO₂ is derived from, and fugitive emissions of captured CO₂ (see Requirement 19.GS), following the guidance in Section 14.5.

EMISSIONS ASSOCIATED WITH GEOLOGIC STORAGE WITH ENHANCED OIL AND GAS RECOVERY

To ensure the complete accounting of the climate impact of geologic storage pathways with enhanced oil and gas recovery, companies must account for GHG emissions and CO₂ removals on a cradle-to-grave basis. As set forth in Requirement 19.GS, companies must account for all life cycle GHG emissions and other metrics that occur throughout the geologic storage pathway (i.e., cradle to grave), including GHG emissions from the product life cycle(s) associated with the stored CO₂ or carbon, land occupation, and land carbon leakage (where required). Specifically for geologic storage pathways with enhanced oil and gas recovery, cradle-to-grave accounting must include all downstream GHG emissions associated with the extraction, processing, transportation, distribution, storage, and use (i.e., combustion) of oil, natural gas, or other hydrocarbons produced from the geologic reservoir and report such emissions in scope 1, scope 2, and/or scope 3.

Alternative methods to quantify global impacts using consequential or intervention GHG accounting methods are described in Chapter 16. Such methods can be applied to quantify the impacts of EOR production, which would include the displacement of non-EOR oil and gas production.



14.4.1.4 Operational boundary

This section provides guidance for correctly reporting scope 1 or scope 3 impacts in geologic storage pathways. Tables 14.3, 14.4, and 14.5 provide further examples to guide the correct reporting of CO₂ removals with geologic storage and/or CO₂ capture with geologic storage, based on the ownership or control of the geologic reservoir storing the carbon and the sink or facility that captures CO₂.

ACCOUNTING FOR SCOPE 1 AND SCOPE 3 REMOVALS IN “CO₂ REMOVALS” GEOLOGIC STORAGE PATHWAYS

Scope 1 removals: A removal is accounted for as a scope 1 removal with geologic storage if the removal and storage pathway occurred within the same operational boundary, where the reporting company owns or controls both the sink (that transfers CO₂ from the atmosphere, such as land growing biomass

or a technological removal process) and the pool (that stores the CO₂ or carbon, such as a geologic reservoir).

Geologic removal and storage pathways will present circumstances where no single entity owns or controls all the relevant processes. In such circumstances, companies that own or control the transportation, the sink, or the pool (see guidance on consolidation approaches in Chapter 4) may establish contractual arrangements to specify ownership and responsibilities associated with scope 1 removals with geologic storage (e.g., through CO₂ storage as a service; see Requirement 19.GS). Table 14.3 provides descriptions of scope 1 removals with geologic storage, by accounting subcategory.

Scope 3 removals: A removal is accounted for as a scope 3 removal with geologic storage in cases where the sink (that transfers CO₂ from the atmosphere) and/or the pool (that stores the CO₂ or carbon) is not owned or controlled by the reporting company, but by another entity in the value chain. Companies should report scope 3 removals with geologic storage in the scope 3 category relative to their activities associated with the geologic storage pathway. If the reporting company only owns or controls one aspect of the geologic storage pathway, the company reports removals in the scope 3 category relative to the sink or storage they do not own or control. Table 14.4 provides descriptions of scope 3 removals with geologic storage, by accounting subcategory.

Table 14.3 Examples of scope 1 removals with geologic storage, by accounting subcategory

Accounting subcategory	System	Description of ownership or control
Technological CO ₂ removals with geologic storage	DACCS	A company that owns or controls both: <ol style="list-style-type: none"> 1. the direct air capture facility; and 2. the geologic reservoir, or owns or controls the stored CO₂
Captured biogenic CO ₂ removals with geologic storage	BECCS	A company owns or controls: <ol style="list-style-type: none"> 1. the biogenic CO₂ capture facility; and 2. the geologic reservoir, or owns or controls the stored CO₂

Table 14.4 Examples of scope 3 removals with geologic storage, by accounting subcategory

Accounting subcategory	System	Description of ownership or control ^a	Scope 3 category
Technological CO ₂ removals with geologic storage	DACCS	A company owns or operates a DAC facility and transfers the CO ₂ for long-term storage in a geologic reservoir owned or controlled by another entity. The company that owns or controls the DAC facility does not have control over the stored CO ₂ .	Scope 3, category 12 (End-of-life treatment of sold products)
Technological CO ₂ removal with geologic storage Captured biogenic CO ₂ with geologic storage	DACCS or BECCS	A company operates a geologic reservoir and acquires biogenic or technologically removed CO ₂ for long-term geologic storage.	Scope 3, category 1 (Purchased goods and services)
Captured biogenic CO ₂ with geologic storage	BECCS	<p>Example 1: A landowner or land manager removes CO₂ from the atmosphere through crop growth and sells the harvested biomass to a BECCS facility that combusts the biomass, captures the biogenic CO₂, and transfers it to a geologic storage company for long-term geologic storage.</p> <p>Example 2: A company owns or operates a biomass power plant that sources biomass, combusts the biomass, captures the biogenic CO₂, and transfers it to a geologic storage company for long-term geologic storage.</p> <p>Example 3: A company purchases electricity, steam, heating, or cooling from a biomass power plant that captures biogenic CO₂ and transfers it to a geologic storage company for long-term geologic storage.</p>	<p>Example 1: Scope 3, category 12 (End-of-life treatment of sold products)</p> <p>Example 2: Scope 3, category 12 (End-of-life treatment of sold products)</p> <p>Example 3: Scope 3, category 3 (Fuel- and energy-related activities not included in scope 1 or scope 3)</p>

Note: a. Under these ownership scenarios, companies could only report scope 3 removals with geologic storage if all the removals requirements are met.

ACCOUNTING FOR SCOPE 1, SCOPE 2, AND SCOPE 3 EMISSIONS IN “CAPTURED CO₂” PATHWAYS

Companies that own or control a facility that captures CO₂ that is subsequently stored in a geologic reservoir:

- Do not report scope 1 emissions for the CO₂ that is captured and stored in a geologic reservoir;
- Report any fugitive emissions of captured CO₂ released at that facility in scope 1;
- Report emissions from other processes in the geologic storage pathway and any fugitive emissions of captured CO₂ not occurring at the capture facility in the relevant scope 3 category;
- Reflect the captured CO₂ as a reduction in scope 1 emissions compared to previous years, if CO₂ was emitted from the facility in prior years.

Companies that purchase electricity, steam, heat, or cooling from a facility that captures CO₂ that is then stored in a geologic reservoir:

- Do not report scope 2 emissions for the CO₂ that is captured and stored in a geologic reservoir;
- Report any fugitive emissions of captured CO₂ released at that facility in scope 2;

- Report emissions from other processes in the geologic storage pathway and any fugitive emissions of captured CO₂ not occurring at the capture facility in scope 3, category 3 (fuel- and energy-related activities);
- Reflect the captured CO₂ as a reduction in scope 2 emissions compared to previous years, if CO₂ was emitted from the facility in prior years.

Companies that have facilities in their value chain (not already included in scope 1 or scope 2) that capture CO₂ that is then stored in a geologic reservoir:

- Do not report scope 3 emissions for the CO₂ that is captured and stored in a geologic reservoir;
- Report any fugitive emissions of captured CO₂ released at that facility in scope 3;
- Report emissions from processes in the geologic storage pathway and any fugitive emissions of captured CO₂ in the relevant scope 3 category;
- Reflect the captured CO₂ as a reduction in scope 3 emissions compared to previous years, if CO₂ was emitted from the facility in prior years.

ACCOUNTING FOR SCOPE 3 EMISSIONS ATTRIBUTABLE TO GEOLOGIC STORAGE PATHWAYS

To determine the appropriate scope 3 category to report emissions attributable to geologic storage pathways, companies should treat captured CO₂ as a product. For example, a company that owns or controls a facility equipped with carbon capture technology would report GHG emissions from the transportation of captured CO₂ from the facility to a geologic reservoir in scope 3, category 9 (Downstream transportation and distribution), and any GHG emissions from injection into geologic reservoirs or GHG emissions associated with oil and gas produced through enhanced oil recovery in scope 3, category 12 (End-of-life treatment of sold products).

SCOPE 3 ALLOCATION FOR GEOLOGIC STORAGE PATHWAYS

In cases where companies supply, or are in value chains that supply, only a portion of the CO₂ inputs to an injection site or a geologic storage hub system, companies should allocate GHG emissions from the attributable processes in the geologic storage pathway (e.g., GHG emissions from transportation of CO₂, or operations of the injection facility) based on physical allocation of the volume of CO₂ supplied (see Chapter 6 for further guidance on allocation).

DETERMINING OWNERSHIP AND CONTROL OF GEOLOGIC STORAGE

The operator of a geologic storage reservoir is the entity that holds a well permit or license approved for CO₂ storage by the relevant authorities of the jurisdiction(s). This permit or license commonly includes:

- Proof of the technical competence of the operator
- Characterization of the storage complex



- Specifications related to CO₂ to be injected (total quantity, composition, pressure, and temperature)
- Assessment of the security of the storage, as well as preventive and corrective measures in case of leakage or irregularities
- A monitoring plan and post-closure plan
- Proof of financial security

The authority to issue a geologic storage permit for CO₂ is typically managed by the jurisdiction and should include an integrated risk assessment that identifies, mitigates, and manages risks and uncertainties to ensure the safety of any CO₂ storage site (i.e., ensures secure storage, minimizes risks of fugitive CO₂ emissions from leakage, and requires adequate remediation if any damage occurs). Both the geologic storage reservoir and the injection facilities should be covered in such a permit.

The geologic storage permit should cover the full life cycle of the project (i.e., development, operations, closure, and, if covered by regulations, transfer of liabilities to the state). From the start of injection up to the cessation of injection and closure, the following should be performed by the geologic storage operator:

- Site inspections
- Reviews of operations in accordance with the storage permit
- Monitoring and reporting on geologic carbon
- Approval of monitoring/corrective measures plan updates
- Implementation of approved corrective measures
- Periodic adjustment of financial security

The geologic storage operator should regularly report monitoring results and any corrective measures taken to the competent authority. The relevant authority should perform a regular review of the storage permit (after the first five years and every 10 years thereafter).

When further development and drilling activities are undertaken, the risk assessment performed by the authority should be extended and updated accordingly, and data from new wells or development should be used by the operator to verify and update the characterization of the storage complex, as well as modeling and risk assessment.

DETERMINING OWNERSHIP AND CONTROL TO ACCOUNT FOR SCOPE 1 REMOVALS WITH GEOLOGIC STORAGE

When accounting for removals with geologic storage, in circumstances where no single entity owns or controls all the relevant processes (i.e., both sink and pool), a contractual agreement is necessary among the entities involved in the geologic storage pathway to report scope 1 removals with geologic storage, following Requirement 19.GS. The contractual agreement must include:

- The consolidation approach that each party involved has selected to define ownership or control
- Identification of the entity that owns or controls each of the following stages within the removals and storage pathway, if relevant:
 - Technological sink: the facility that removes CO₂ from the atmosphere or captures biogenic CO₂
 - Transportation: transport of CO₂ from the technological sink to the capture and injection facility
 - Capture (if relevant): the facility that prevents the CO₂ from being emitted to the atmosphere

- Injection (if relevant): the facility that injects the CO₂ into the geologic reservoir
- Pool: the geologic reservoir where the CO₂ is stored

Additional entities that don't own or control any relevant processes (i.e., sink and pool) in the geologic storage pathway cannot be defined as the entity that accounts for the removals with geologic storage in their scope 1 inventory boundary. The scope 1 inventory boundary must be defined according to a consolidation approach (see guidance on consolidation approaches and setting organizational boundaries in Chapter 4).

INVESTMENTS IN TECHNOLOGICAL REMOVALS

How companies account for and report scope 1 or scope 3 removals with geologic storage attributable to investments in DAC companies/facilities depends on the consolidation method selected for defining the organizational boundary and share in ownership of the company/facility (see Chapter 4 for details), and is also subject to the requirements in this chapter.

If multiple companies have ownership or control in the DAC company or facility, contractual agreements are necessary that should specify which entity (or entities) account for scope 1 removals with geologic storage such that total scope 1 removals are not overreported across companies (see Requirement 19.GS).

Companies should refer to the *Scope 3 Standard* guidance on scope 3, category 15 (Investments), on how to account for equity investments, debt investments, project finance, and other types of investments, and the Partnership for Carbon Accounting Financials (PCAF) guidance.⁶

Table 14.5 Reporting categories for geologic carbon storage based on ownership and control

Entity that owns or controls the sinks or facility that captures CO ₂	Entity that owns or controls the CO ₂ stored in geologic reservoirs	Examples	Relevant reporting category for reporting company ^a
CO₂ sinks owned or controlled by the reporting company	CO ₂ stored in geologic reservoirs owned or controlled by the reporting company	A company that both owns the direct air capture facility and manages the geologic reservoir, or owns/controls the stored CO ₂ (DACCS)	Scope 1 technological CO ₂ removals with geologic storage
	CO ₂ stored in geologic reservoirs is owned or controlled by another entity in the value chain of the reporting company	A farmer whose harvested biomass is sold to an ethanol facility equipped with biogenic CO ₂ capture technology, where the captured biogenic CO ₂ is then stored in a geologic reservoir (BECCS)	Scope 3 captured biogenic CO ₂ with geologic storage. If the farmer seeks to account for the removals in their scope 1 instead, a contractual agreement needs to be developed
		A direct air capture company that does not manage the geologic reservoir or have ownership or control of the stored CO ₂ (DACCS)	Scope 3 technological CO ₂ removals with geologic storage. If the direct air capture company seeks to account for the removals in its scope 1 instead, a contractual agreement needs to be developed
CO₂ sinks in the value chain of the reporting company	CO ₂ stored in geologic reservoirs owned or controlled by the reporting company	A geologic storage company that acquires captured biogenic CO ₂ from a biomass power plant (BECCS)	Scope 3 captured biogenic CO ₂ with geologic storage. If the geologic storage company seeks to account for the removals in its scope 1 instead, a contractual agreement needs to be developed

Table 14.5 Reporting categories for geologic carbon storage based on ownership and control (cont.)

Entity that owns or controls the sinks or facility that captures CO ₂	Entity that owns or controls the CO ₂ stored in geologic reservoirs	Examples	Relevant reporting category for reporting company ^a
CO₂ sinks in the value chain of the reporting company (cont.)	CO ₂ stored in geologic reservoirs owned or controlled by the reporting company	A geologic storage company that acquires technologically removed CO ₂ from a direct air capture facility (DACCS)	Scope 3 technological CO ₂ removals with geologic storage. If the geologic storage company seeks to account for the removals in its scope 1 instead, a contractual agreement needs to be developed
	CO ₂ stored in geologic reservoirs is owned or controlled by another entity in the value chain of the reporting company	A biomass power plant capturing biogenic CO ₂ and transferring it to a geologic storage company (BECCS), if the power plant company can establish the origin of the biomass and that geologic storage is the eventual fate of the captured biogenic CO ₂	Scope 3 captured biogenic CO ₂ with geologic storage. If the biomass power plant seeks to account for the removals in its scope 1 instead, a contractual agreement needs to be developed
		A company purchasing electricity, steam, heating, or cooling from a biomass power plant capturing biogenic CO ₂ and transferring it to a geologic storage company (BECCS)	Scope 3 captured biogenic CO ₂ with geologic storage
CO₂ derived from fossil carbon captured in facilities owned or controlled by the reporting company	CO ₂ stored in geologic reservoirs is owned or controlled by another entity in the value chain of the reporting company	A fossil fuel power plant capturing fossil CO ₂ and transferring it to a geologic storage company (CCS)	No emissions reported in scope 1 for the captured and stored CO ₂
CO₂ derived from fossil carbon captured in the value chain of the reporting company	CO ₂ stored in geologic reservoirs is owned or controlled by the reporting company	A geologic storage company that acquires captured fossil CO ₂ from a fossil fuel power plant (CCS)	No emissions reported in scope 3 for the captured and stored CO ₂
	CO ₂ stored in geologic reservoirs is owned or controlled by another entity in the value chain of the reporting company	A company purchasing electricity, steam, heating, or cooling from a fossil fuel power plant capturing fossil CO ₂ and transferring it to a geologic storage company (CCS)	No emissions reported in scope 2 for the captured and stored CO ₂

Note: a. If the requirements for reporting removals or CO₂ capture with geologic storage are met.

14.4.2 Traceability for geologic storage

To ensure complete life cycle GHG accounting (i.e., cradle-to-grave) in the geologic storage pathway and identification of the relevant geologic carbon stock changes, companies that choose to report CO₂ removals with geologic storage or no emissions associated with captured CO₂ with geologic storage must meet the following traceability criteria set forth in Requirement 20.GS:

- Companies that are in the value chain of a geologic storage pathway but do not own or control the geologic reservoir must have physical traceability (following Requirement 8)⁷ to the:
 - Entity (or entities) capturing the CO₂ received at the injection site or geologic storage hub system; and
 - Entity (or entities) operating the CO₂ injection site(s) and geologic storage reservoir(s).
- Companies that are in the value chain of a captured biogenic CO₂ and geologic storage pathway but do not own or control facilities with technological sinks (e.g., a facility capturing biogenic CO₂) should, at a minimum, have traceability to the country of origin (or more precise levels of traceability) for any biogenic materials associated with the captured biogenic CO₂ to evaluate net land carbon stock changes on attributable productive lands and other life cycle GHG emissions associated with the biogenic materials (see Requirement 25 for details).

14.4.3 Data quality for geologic storage

To satisfy Requirement 21.GS, companies must meet the following criteria related to data quality:

Data specific to sinks and pools

To account for and report net removals with geologic storage or no emissions associated with CO₂ capture with geologic storage, companies must use data specific to the CO₂ injection site(s), geologic storage reservoir(s), and CO₂ or carbon inputs into the geologic storage reservoir(s). Data used to assess CO₂ inputs, net CO₂ removals with geologic storage, and CO₂ capture with geologic storage, for the geologic storage reservoir or across all geologic carbon pools in the geologic storage hub, must come from direct measurements at the reservoir(s) or calibrated models, and from CO₂ input suppliers within the geologic storage pathway. This ensures sufficient data quality and that the relevant GHG accounting principles in this *Standard* are met. For example, for direct air capture removals with geologic storage, specific data would include measurements of CO₂ removed at the DAC facility, metering of CO₂ transferred to a geologic storage injection site, and direct measurements or calibrated modeling of the CO₂ stored in the formation based on observations.

As set forth in the relevant recommendation in Section 14.3, the following data should be collected for evaluation of the geologic storage reservoir:

- Geophysical data (e.g., seismic surveys, natural seismicity)
- Well data (e.g., well logs, flow tests, geo-mechanical data)
- Reservoir properties data (e.g., reservoir pressure and temperature, core data, reservoir fluids data, petrophysical data, geochemical data)

Companies in a geologic storage value chain operated as a hub with multiple geologic reservoirs can meet the requirement for data specific to sinks and pools by using data provided by the hub operator on a hub-average basis across the different reservoirs. Estimates of net CO₂ removals with geologic storage or CO₂ capture with geologic storage in geologic storage hubs can be allocated based on the amount and type of CO₂ inputs supplied by the reporting company, or other entities in the reporting company's value chain, to the hub.

More site-specific data will result in a more accurate description of the subsurface carbon storage. Where such data are not available, proxy or regional average data from other known locations of similar geology may be used to supplement geologic storage estimates. DAC project operators should use empirical data measured at the facility to the largest extent possible. The use of proxy or regional average data is restricted to calculations of the GHG emissions associated with the construction of DAC plants. In this case, data from peer-reviewed life cycle assessment literature is used to inform a conservative estimate.

Uncertainty

To satisfy Requirement 21.GS, quantitative uncertainty estimates for geologic storage must include:

- Uncertainty associated with direct measurement of CO₂ inputs at the CO₂ injection well
- Uncertainty for the amount of CO₂ inputs sourced from biogenic or technologically removed carbon
- Confidence intervals for the annual net CO₂ removals with geologic storage or CO₂ capture with geologic storage for the geologic storage reservoir or across all geologic carbon pools in the geologic storage hub
- Quantitative risk assessments of the permanence of geologic carbon storage

Companies in a geologic storage value chain operated as a hub with multiple geologic reservoirs can use uncertainty data provided by the hub operator on a hub-average basis.

14.4.4 Permanence of geologic storage

To satisfy Requirement 23.GS, companies must follow the criteria below:

Ongoing storage monitoring

If net removals with geologic storage are reported or no emissions associated with CO₂ capture are reported, ongoing storage monitoring of geologic carbon storage is required to ensure carbon remains stored and to detect and report losses of stored carbon. Ongoing storage monitoring is required to report both scope 1 and scope 3 removals with geologic storage and to report no emissions for CO₂ capture with geologic storage:

- **Scope 1 removals with geologic storage:** Ongoing storage monitoring of geologic reservoirs owned or controlled by the reporting company.
- **Scope 3 removals with geologic storage:** Ongoing storage monitoring of geologic reservoirs in the value chain of the reporting company, where the company previously reported removals with geologic storage.
- **No emissions reporting for CO₂ capture with geologic storage:** Ongoing storage monitoring of geologic reservoirs in the value chain of the reporting company, where the company previously did not report scope 1, scope 2, or scope 3 emissions associated with CO₂ capture with geologic storage.

The monitoring needed to detect any emissions from the geologic reservoir will differ depending on the geology of the reservoir, the CO₂ injection technologies, the methods used to estimate stored carbon, and the monitoring technologies used. Net geologic carbon losses could be due to fugitive CO₂ losses detected from wells or injection sites, after seismic events, or from net carbon losses associated with produced oil and gas from enhanced oil recovery (EOR) operations.

Monitoring plan

According to the relevant recommendation in Section 14.3, ongoing monitoring should be detailed through a monitoring plan that includes the following elements:

- Site characterization that includes a description of the geologic reservoir, expected CO₂ trapping mechanisms, and the location of known wells into the reservoir
- How the CO₂ injection, geologic carbon storage, and monitoring comply with all applicable laws and regulations
- Methods used to detect any fugitive CO₂ emissions from the injection or production wells
- Methods used for subsurface monitoring of geologic carbon stocks to confirm the fate of stored carbon and to detect any fugitive CO₂ emissions
- Frequency of monitoring
- Data quality control procedures and instrument calibration

Monitoring

Monitoring requirements include measurements of relevant parameters to account for all supplemental energy inputs (e.g., fossil fuels and electricity) required for the operation of the DAC facility. Data capture must be sufficient to ensure that the quantification and documentation are replicable and verifiable. The following guidance should be followed when monitoring CO₂ removals from DAC facilities:

- Monitoring should include direct measurements of relevant parameters to account for the flow rate of transferred fluids, the concentration of the fluid stream, and the energy inputs required for operation.
- DAC project monitoring techniques should use calibrated metering equipment such as fluid flow meters, utility meters (gas/electricity), and fluid chemistry analyzers.
- Meters should be maintained to operate consistently with manufacturer specifications and calibrated at regular intervals according to these specifications and industry standards.
- Flow meters should be located such that accurate measurements can be collected for accounting purposes. Where possible, flow meters should be placed immediately ahead of the downstream application, such that they account for all capture, compression, and fugitive losses or venting.
- Flow rate data should be used to determine the cumulative volume of CO₂ captured.
- The DAC project operator should sample and analyze the CO₂ stream at a frequency sufficient to yield data representative of the chemical and physical characteristics of the captured gas. Fluid samples should be collected from a point such that the sample is representative of the composition of the gas. Project operators should provide a demonstration of the suitability of the sample point, along with any calculations required for complex systems.
- The fluid composition should be metered downstream of the capture and processing equipment, and volume measured upstream, prior to any mixing of new or recycled CO₂.

Transfer of liabilities

If there is a transfer of liabilities associated with geologically stored CO₂ to the state or other jurisdiction, and the geologic storage operator demonstrates that storage is permanent and without risks of losses, the date and condition of the transfer of liabilities should be clarified, and post-closure monitoring may follow regulatory guidance.

When CO₂ injection into the storage site ceases, the storage site should be closed in accordance with the approved plan. The closure can happen if:

- The total quantity of CO₂ authorized to be geologically stored is reached, or it is deemed unsafe to continue injection
- The geologic storage operator requested site closure (for example, if injection becomes uneconomical)
- A competent authority withdraws the storage permit (for example, if the geologic storage operator fails to meet adequate requirements)

The activities at closure of a geologic storage site include updating the provisional post-closure plan, cessation of injection, plugging and abandonment of selected wells, equipment removal, and on-site inspection. The post-closure monitoring phase starts after well closure. The primary goal of post-closure monitoring is to ensure that the stored CO₂ is behaving as expected without any detectable leakages and, where relevant, the site reaches specified conditions for the transfer of liabilities to the state. The length of this post-closure monitoring phase is determined by how long it will take to meet the criteria of evolution towards long-term stability of the CO₂ stored in the reservoir. The duration of this phase may be stipulated by a relevant regulator. During the post-closure monitoring period, the geologic storage operator is liable to remedy any leakage or significant irregularities, prior to any transfer of liabilities to the state.

Approaches for estimating storage permanence in geologic reservoirs

Storage duration in geological formations aims to be permanent. Secure geologic storage is possible with the correct characterization and modeling of the natural system that will retain the CO₂, and the design of engineered systems compatible with retaining carbon in that reservoir. Where such characterization and operations are done properly, this process can result in zero CO₂ losses from geologic storage (e.g., defined as less than 1 percent of the total injected mass lost over 100 to 1000 years).⁸ The most likely pathway for CO₂ loss is via an injection or recovery well that was not properly completed to isolate subsurface zones from each other and from the surface. Such failed wells provide a pathway for direct transmission of CO₂ from the reservoir to the surface, and any resulting leakage should be apparent, and the failed well repaired. Losses of CO₂ from failed wells that are not detected and repaired are still likely to constitute a small share of CO₂ emissions relative to the rate at which CO₂ is injected into the reservoir, because of limits to the rate at which CO₂ can escape along such pathways (e.g., due to wellbore and porous media flow limits and pressure declines). However, leakage through faults can occur as well.

Monitoring is necessary to ensure the correct characterization, modeling, and operation of the storage system and that the predicted levels of storage permanence are attained. The primary means of confirming storage performance is by comparing observations to models of high CO₂ retention. If an error is found in these assumptions, a prudent operator or regulator can modify operations and mitigate that problem to avoid any losses before they occur (e.g., by accepting less CO₂ in a problematic well and directing more CO₂ into an alternate zone). Direct measurement for the detection of leakage and associated fugitive CO₂ emissions can also be deployed. For example, a zone above the injection horizon can be monitored for pressure or other changes that would be indicative of losses from the storage zone.

Models are also used to design monitoring, such that no detection of CO₂ along potential escape pathways near wells is strong evidence of no leakage above the monitoring design threshold. Methods for direct detection of CO₂ in shallow environments, such as groundwater, soil atmosphere, or ocean water, have been developed and are available. However, these environments are also active both in terms of CO₂ respiration and removals and in terms of dynamic physical processes (weather, climate, land use, fluid movements, etc.). Detection of CO₂ leakage into such dynamic environments is attenuated, delayed, and difficult to separate from background processes.

Therefore, near-surface detection or quantification methods may be best used in a targeted manner, for example, if a release has occurred or is suspected.

- **Flux-based approaches:** The most accurate approach to determine carbon stock changes is to measure the flow and the concentration of the CO₂ transferred from one carbon pool to another. These measurements provide direct and accurate estimates of the transferred CO₂. The sensors should be calibrated at regular intervals following well-established procedures to ensure that measurement accuracy is high, and uncertainty is low (usually < 5% measurement error).
- **Indirect approaches:** Physical or chemical approaches can be used to track the fate of the injected CO₂. These may ensure that the trapping mechanisms in place are efficient and that the CO₂ remains within the geological formation. Indirect physical or chemical approaches provide an indirect indication of unexpected leakage or successful CO₂ storage.
- **Remote sensing-based approaches:** Several types of remote sensing data are available to detect land and sea floor management practices and carbon stocks. Remote sensing technology can effectively cover much larger areas in comparison to direct measurement-based methods. Background measurements of the CO₂ flux due to background processes prior to the carbon storage operation must be undertaken. Local calibration and/or model development are required to derive predictions from the remotely sensed data.
- **Model-based approaches:** A common approach for estimating CO₂ storage capacity is reservoir modelling. Model-based approaches use mathematical modelling based on various input variables (e.g., temperature, pressure, rock properties, management practices, etc.) to estimate the subsurface behavior of CO₂ in the geologic reservoir. Companies should provide evidence that, during operations, the model estimates do not deviate from the confidence intervals for the predicted subsurface CO₂ behavior defined prior to injection. The accuracy of models is variable and depends on the robustness of the model, the calibration of the fixed parameters to the application, and the accuracy of the input variables. For example, if a model is used in new geological settings for which it was not previously calibrated, it may not be reliable. As the CO₂ storage capacity depends on both reservoir properties and migration of the injected CO₂ (e.g., based on the number of wells and the start of their operation), an uncertainty study is usually performed. The result of such a study gives a confidence interval of possible outcomes and their probability.

Accounting for and reporting losses of stored geologic carbon

As set forth in Requirement 23.GS, detected net geologic carbon stock losses must be accounted for and reported either as fossil fuel and industrial emissions or as reversals, in the year the losses occur. Companies report net geologic carbon stock losses as fossil fuel and industrial emissions if the carbon pools are within the GHG inventory boundary in the reporting years. Companies report net geologic carbon stock losses as reversals, either as reversals of CO₂ removals with geologic or reversals of CO₂ capture with geologic storage, if the carbon pools are no longer within the GHG inventory boundary in the reporting year.

If ongoing monitoring ends, or companies lose the ability to monitor carbon stocks associated with previously reported CO₂ removals with geologic storage, companies must account for and report reversals (or, if the carbon pool is still in the inventory boundary, report as fossil fuel and industrial emissions) equal to the previously reported net removals with geologic storage (see Chapter 12 for details). Where companies have closed the injection site in accordance with regulations and demonstrated that storage is permanent and without risk of CO₂ losses from the reservoir, post-closure monitoring may follow regulatory guidance, and companies do not need to assume all carbon stocks associated with previously reported removals are emitted.

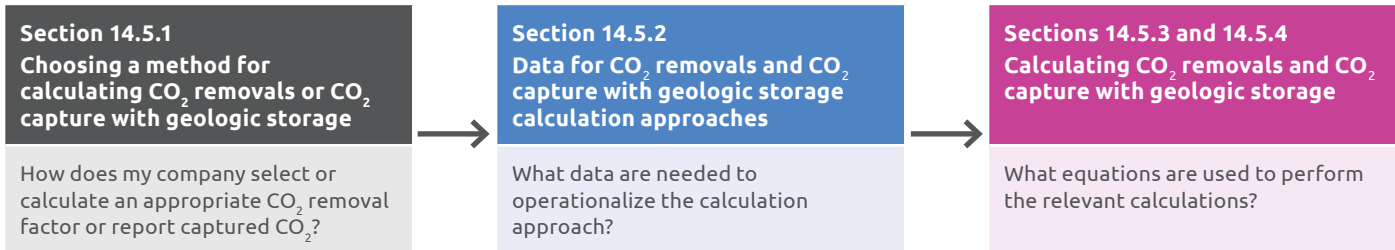


14.5 Calculating CO₂ removals and CO₂ capture with geologic storage

Figure 14.3 provides an overview of the calculation guidance in Section 14.5. Specifically, this section provides calculation guidance and methods for estimating:

- CO₂ capture with geologic storage (Section 14.5.3)
- CO₂ removals with geologic storage (Section 14.5.4)
- Carbon losses from enhanced oil recovery (Section 14.5.6)
- Gross technological CO₂ removals (Section 14.5.5)
- Fugitive GHG emissions from geologic reservoirs (Section 14.5.7)

Figure 14.3 Overview of Section 14.5



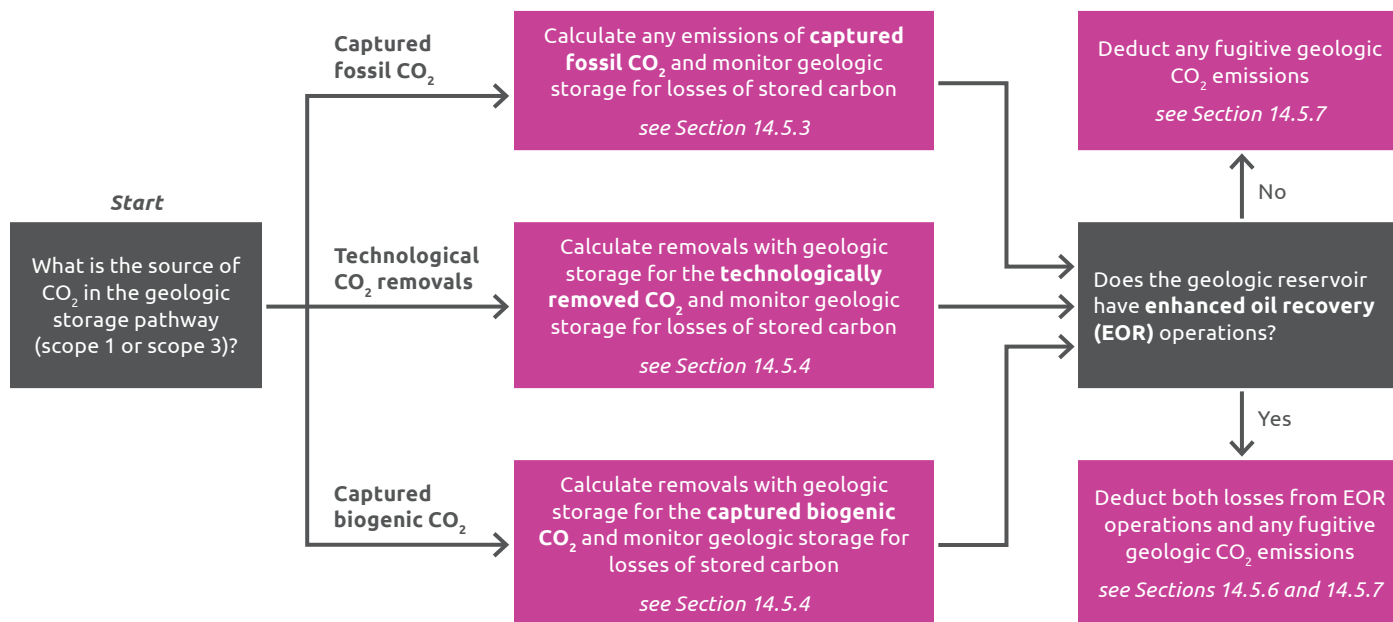
This chapter does not include calculation guidance and methods to estimate GHG emissions from the extraction, production, processing, refrigeration, transportation, distribution, storage, use, end-of-life, and other processes attributable to raw materials, captured CO₂, or oil and gas produced from geologic storage pathways. General accounting guidance on estimating such GHG emissions can be found in the GHG Protocol’s *Scope 3 Calculation Guidance*. Additional resources and databases with life cycle GHG emission factors are provided under the calculation tools and third-party life cycle databases on the GHG Protocol website. Companies should refer to more detailed sector-specific guidance as needed.

Calculation guidance for estimating land use change emissions, land use and land carbon leakage (where required), and land management emissions attributable to the production of biogenic materials associated with captured biogenic CO₂ with geologic storage pathways is provided in Chapters 7, 8, 9, and 10, respectively.

14.5.1 Choosing a method for calculating CO₂ removals or CO₂ capture with geologic storage

Figure 14.4 provides a decision tree to assist companies in calculating and reporting CO₂ removals and CO₂ capture with geologic storage, in accordance with this *Standard*.

Figure 14.4 Decision tree for calculating CO₂ removals or CO₂ capture with geologic storage



14.5.2 Data for CO₂ removals and CO₂ capture with geologic storage calculation approaches

Table 14.6 Checklist of data requirements, by geologic storage pathway

Geologic storage pathway	Data requirements
CO ₂ capture with geologic storage	<ul style="list-style-type: none"> Injected CO₂ into the geologic reservoir in the reporting year Fraction of injected CO₂ from captured fossil fuel and industrial CO₂ Losses of CO₂ from enhanced oil recovery in the reporting year, if applicable Fugitive CO₂ from the geologic reservoir in the reporting year
Technological CO ₂ removals and/or captured biogenic CO ₂ with geologic storage	<ul style="list-style-type: none"> Injected CO₂ into the geologic reservoir in the reporting year Fraction of injected CO₂ from captured biogenic CO₂ Fraction of injected CO₂ from other captured technologically removed CO₂ Losses of CO₂ from enhanced oil recovery in the reporting year, if applicable Fugitive CO₂ from the geologic reservoir in the reporting year

14.5.3 Calculating CO₂ capture with geologic storage

Companies that report no CO₂ emissions in scope 1, scope 2, or scope 3 for CO₂ that is captured and stored in geologic reservoirs must estimate any fugitive emissions of captured CO₂ following Equation 14.1 and track any losses of stored carbon using Equation 14.2.

Fugitive emissions of captured CO₂ occur when not all CO₂ emissions are captured from a facility (e.g., at a point source) or when not all the captured CO₂ reaches or remains stored in geologic reservoirs (e.g., fugitive emissions from losses of CO₂ or venting during transportation). Equation 14.1 can be applied to estimate fugitive losses when directly measuring CO₂ captured at a facility through site-level metering and CO₂ with geologic storage estimated in Equation 14.2.

Equation 14.1 Annual emissions of captured CO₂

$$E_CAPCO2 = CO2_CAP - CO2_STOR$$

Description	Unit	Source
E_CAPCO2 Carbon dioxide (CO ₂) emissions from captured CO ₂ in the reporting year	tonnes CO ₂ (year) ⁻¹	Calculated
CO2_CAP Captured CO ₂ in the reporting year	tonnes CO ₂ (year) ⁻¹	User input
CO2_STOR CO ₂ capture with geologic storage in the reporting year	tonnes CO ₂ (year) ⁻¹	Equation 14.2

CO₂ capture with geologic storage is estimated for a particular geologic storage reservoir using Equation 14.2. CO₂ capture with geologic storage should only be reported for the portion of captured CO₂ injected into a geologic reservoir that remains stored. If this value is negative for a given year, it should be reported as losses of stored carbon following the guidance in Section 14.4.4. Equation 14.2 estimates this value by factoring out loss of CO₂ from enhanced oil and gas recovery in the reporting year and fugitive CO₂ emissions from the geologic reservoir.

Equation 14.2 Annual CO₂ capture with geologic storage

$$CO2_STOR = [CO2_INJ - CO2_L - CO2_F] \times f_IC$$

Description	Unit	Source
CO2_STOR Carbon dioxide (CO ₂) capture with geologic storage in the reporting year	tonnes CO ₂ (year) ⁻¹	Calculated
CO2_INJ Injected CO ₂ into the geologic reservoir in the reporting year	tonnes CO ₂ (year) ⁻¹	User input
f_IC Fraction of injected CO ₂ from captured fossil fuel and industrial CO ₂	dimensionless	User input
CO2_L Losses of CO ₂ from enhanced oil recovery in the reporting year	tonnes CO ₂ (year) ⁻¹	Equation 14.5
CO2_F Fugitive CO ₂ from the geologic reservoir in the reporting year	tonnes CO ₂ (year) ⁻¹	Equation 14.6

Note that the CO₂ that is captured and injected into the geologic reservoir (*CO₂-INJ*) can derive from a variety of sources, including fossil CO₂ from other geologic formations and CO₂ captured from industrial facilities combusting fossil fuels or other materials as part of the long-term carbon cycle. When calculating annual CO₂ capture with geologic storage, companies account for the fraction of injected CO₂ that represents captured fossil fuel and industrial CO₂ (*f_{IC}*). Captured CO₂ can also derive from carbon that originates from biogenic or technological CO₂ sinks, such as biogenic CO₂ captured at facilities combusting biogenic feedstocks or CO₂ captured at a DAC facility. Pathways that store CO₂ removed directly from the atmosphere via biogenic or technological sinks are reported as removals with geologic storage (see Section 14.5.4).

When a geologic storage pathway includes enhanced oil recovery, losses of geologic carbon must be included in the estimate, following the calculation guidance in Section 14.5.5. Fugitive geologic CO₂ emissions should be detected through ongoing monitoring of wells into the geologic reservoir, areas where leakage has been detected, or other fugitive GHG emissions, as determined through the geologic storage permitting process and following the calculation guidance in Section 14.5.6.

Where data are available, companies should directly track the flow of captured CO₂ from facilities with emission capture to the injection well at a geologic reservoir. The following data should be used to monitor captured CO₂ flows and estimate any fugitive emissions of captured CO₂:

- Volume, mass, or flow measurements at the emission capture sites of CO₂ transferred to the transportation and distribution system (e.g., ships, trains, pipelines, barges)
- Volume, mass, or flow measurements at each CO₂ exchange within the transportation and distribution system
- Volume, mass, or flow measurement of the CO₂ transfer from the transportation and distribution system to the geologic reservoir (e.g., for transfer from ships to the injection facilities)
- Where relevant to the transportation and distribution system, analysis of the CO₂ concentration in the gas stream

Based on this data, fugitive emissions of captured CO₂ during transportation and distribution can be calculated using level or flow measurements at each loading and offloading point. Any vented volumes and fugitive CO₂ emissions should be accounted for based on the difference between inputs and outputs between each step of the CO₂ transportation and distribution system.



14.5.4 Calculating CO₂ removals with geologic storage

Removals with geologic storage are only reported for the portion of CO₂ injected into the reservoir of recent atmospheric origin (i.e., originating from biogenic carbon or other technological CO₂ removal processes) that remains stored in geologic carbon pools. Annual removals with geologic storage for a particular geologic storage reservoir can be estimated using Equation 14.3.

Equation 14.3 Annual CO₂ removals with geologic storage

$$CO2_RGS = [CO2_INJ - CO2_L - CO2_F] \times [f_IB + f_IT]$$

Description		Unit	Source
<i>CO2_RGS</i>	Carbon dioxide (CO ₂) removals with geologic storage in the reporting year	tonnes CO ₂ (year) ⁻¹	Calculated
<i>CO2_INJ</i>	Injected CO ₂ into the geologic reservoir in the reporting year	tonnes CO ₂ (year) ⁻¹	User input
<i>f_IB</i>	Fraction of injected CO ₂ that is captured biogenic CO ₂	dimensionless	User input
<i>f_IT</i>	Fraction of injected CO ₂ that is from other technologically removed CO ₂ processes	dimensionless	User input
<i>CO2_L</i>	Losses of CO ₂ from enhanced oil recovery in the reporting year	tonnes CO ₂ (year) ⁻¹	Equation 14.5
<i>CO2_F</i>	Fugitive CO ₂ from the geologic reservoir in the reporting year	tonnes CO ₂ (year) ⁻¹	Equation 14.6

The fraction of CO₂ injected that is derived from biological sinks is estimated based on the share of biogenic CO₂ sourced from biogenic CO₂ capture facilities (e.g., bioenergy carbon capture facilities). Companies must also satisfy Requirement 25 by demonstrating that no significant land use change emissions are attributable to the biogenic materials (i.e., that contain the biogenic CO₂ or carbon). The fraction of CO₂ injected that is derived from other technologically removed CO₂ is estimated based on the amount of CO₂ sourced from technological CO₂ removal facilities (e.g., direct air capture facilities). If the source and/or fractional composition of injected CO₂ is unknown (i.e., a company does not know if the injected CO₂ is derived from biological or technological sinks), Requirement 21.GS is not met and removals cannot be reported.

When the geologic storage pathway includes enhanced oil and gas recovery, loss of geologic carbon must be included in the estimate, following the guidance in Section 14.5.6. Fugitive geologic CO₂ emissions should be detected through ongoing monitoring of wells into the geologic reservoir and areas where leakage of fugitive GHG emissions has been detected, as determined through the geologic storage permitting process and following the guidance in Section 14.5.5.

14.5.5 Calculating gross technological CO₂ removals

If companies choose to account for gross technological CO₂ removals (e.g., CO₂ removed from the atmosphere by a DAC facility) and report them under the “gross CO₂ fluxes” accounting category for transparency, they can apply Equation 14.4. While this equation can be applied to estimate the total CO₂ removed from a DAC facility, companies should use volume, mass, or flow measurements to track the CO₂ as it is delivered to a geologic storage injection site to detect any fugitive losses of CO₂ during transportation, processing, and distribution.

Equation 14.4 Gross technological CO₂ removals

$$CO2_T = V_CO2 \times \frac{C_CO2}{100} \times \rho_CO2$$

Description	Unit	Source
<i>CO2_T</i> Captured and transferred carbon dioxide (CO ₂) to the downstream applications, metered at the point of transfer, in the reporting year	tonnes CO ₂ (year) ⁻¹	Calculated
<i>V_CO2</i> Volume of CO ₂ that has been captured and input into the downstream applications, metered at the point of transfer with the downstream application, in the reporting year	m ³ CO ₂ (year) ⁻¹	User input
<i>C_CO2</i> Concentration of CO ₂ in the gas stream measured at the input to the downstream application at standard conditions	%	User input
<i>ρ_CO2</i> Density of CO ₂ under standard conditions: 0.001977	tonnes (m ³) ⁻¹	User input

14.5.6 Calculating losses from enhanced oil and gas recovery

Companies are required to account for any losses of carbon from the geologic reservoir when estimating removals with geologic storage or CO₂ capture with geologic storage for geologic storage pathways with enhanced oil and gas recovery. Annual losses of carbon from a geologic reservoir can be determined using Equation 14.5.

Equation 14.5 Losses of carbon from a geologic reservoir in the reporting year

$$CO2_L = C_PROD \times \frac{44}{12} + CO2_VENT - CO2_R$$

Description	Unit	Source
<i>CO2_L</i> Losses of carbon dioxide (CO ₂) from enhanced oil recovery in the reporting year	tonnes CO ₂ (year) ⁻¹	Calculated
<i>C_PROD</i> Carbon (C) produced from the geologic reservoir in the reporting year	tonnes C (year) ⁻¹	User input
<i>CO2_VENT</i> CO ₂ recovered and vented on site in the reporting year	tonnes CO ₂ (year) ⁻¹	User input
<i>CO2_R</i> CO ₂ recovered and reinjected into the geologic reservoir in the reporting year	tonnes CO ₂ (year) ⁻¹	User input
<i>44/12</i> Conversion factor: C to CO ₂	dimensionless	Constant

The annual carbon produced from the geologic reservoir is determined based on the total annual mass of carbon from any natural gas, oil, or other hydrocarbons produced from the well. Geologic storage operators must also report any CO₂ recovered and vented from wells or processing facilities on site (i.e., as gross CO₂ emissions from geologic storage). Any CO₂ that is recovered and reinjected into the geologic reservoir can be subtracted from the carbon produced from the well, as this does not constitute a loss of carbon leaving the geologic storage system.

14.5.7 Calculating fugitive geologic CO₂ emissions

Fugitive GHG emissions from geologic reservoirs are not expected to occur from appropriately selected and managed geological reservoirs. However, a monitoring system must be in place to detect, account for, and report fugitive GHG emissions or reversals. Companies should put in place a comprehensive monitoring program that can detect fugitive emissions and that can provide calibration parameters for numerical models developed as part of the storage operations.

Detection and quantification of fugitive geologic CO₂ emissions can occur by comparing baseline and monitoring data, as shown in Equations 14.6 and 14.7.

Equation 14.6 Fugitive geologic CO₂ emissions

$$CO2_F = M_CO2 - \Delta NAT_CO2 - IN_CO2$$

Description	Unit	Source
<i>CO2_F</i> Fugitive carbon dioxide (CO ₂) from the geologic reservoir in the reporting year	tonnes CO ₂ (year) ⁻¹	Calculated
<i>M_CO2</i> Measured CO ₂ at leakage site of fugitive emissions in the reporting year	tonnes CO ₂ (year) ⁻¹	Equation 14.7
<i>ΔNAT_CO2</i> Natural fluctuation of CO ₂ at the site in the reporting year	tonnes CO ₂ (year) ⁻¹	User input
<i>IN_CO2</i> Invariant theoretical CO ₂ baseline in the reporting year	tonnes CO ₂ (year) ⁻¹	User input

If fugitive geologic emissions are identified, an enhanced monitoring program should be implemented to quantify fugitive emissions to the atmosphere or ocean. The tools deployed will be site-specific.

The model used by the reporting company should follow best practices and include all relevant thermal–hydraulic–mechanical–chemical reservoir processes. The aim of the model is to simulate the expected fate of the injected CO₂. History matching should show agreement between the modeling and the monitored behavior (e.g., using flux-based, indirect, or remote sensing methods) of the carbon dioxide plume, and that no fugitive emissions are expected. All available evidence should indicate that stored CO₂ will be completely isolated from the atmosphere, in the short and long term.

Fugitive CO₂ emissions can also occur at injection or production, or leak from other wells that penetrate the storage formation. All wells, whether they are active or closed, should be identified and included in the monitoring plan. Wells should be sampled at regular intervals or measured continuously. A flux-based method can be used to quantify the amount of CO₂ transferred back to the surface. The amount of CO₂ measured must be compared to the background value using Equation 14.5 to estimate fugitive CO₂ emissions from wells within the geologic reservoir.

Equation 14.7 Annual measured fugitive geologic CO₂ emissions

$$M_{CO2} = FF_{CO2} \times A_{LEAK}$$

Description	Unit	Source
<i>M_CO2</i> Measured carbon dioxide (CO ₂) at leakage site in the reporting year	tonnes CO ₂ (year) ⁻¹	Calculated
<i>FF_CO2</i> CO ₂ flux at leakage site of fugitive emissions per unit of area, in the reporting year	tonnes CO ₂ (ha) ⁻¹ (year) ⁻¹	User input
<i>A_LEAK</i> Estimated area of leakage	ha	User input

Fugitive CO₂ emissions should be accounted for when determining annual CO₂ capture with geologic storage (see Section 14.5.3) and removals with geologic storage (see Section 14.5.4). Fugitive CO₂ emissions should also be reported in the appropriate scope, and any reversals should be accounted for following the guidance in Section 12.4.5.

Endnotes

- 1 This text includes elements that may change to align with the resolution on forest carbon accounting in future versions of this *Standard*. See Box 9.1.
- 2 See Chapter 5 for definitions of physical traceability and impact traceability.
- 3 This requirement is currently only applicable to geologic storage of biogenic carbon from agricultural products. Requirements for geologic storage of biogenic carbon from forest products are still pending to ensure alignment with the resolution on forest carbon accounting in future versions of this *Standard*.
- 4 IPCC 2023.
- 5 Detailed guidance on accounting for removals due to enhanced rock weathering is not provided in this version of the *Guidance*, due to the need for additional research and methodology development at the time of publication.
- 6 Available at <https://ghgprotocol.org/global-ghg-accounting-and-reporting-standard-financial-industry>.
- 7 See Chapter 5 for guidance on physical traceability versus impact traceability.
- 8 National Academies of Sciences, Engineering, and Medicine 2019.

Photo Credits

Pg. 348, Rowan Heuvel; Pg. 349, Jim Witkowski; Pg. 356, Grant Ritchie; Pg. 358, Wolfgang Weiser; Pg. 360, ThisisEngineering; Pg. 369, Paul-Alain Hunt; Pg. 372, Getty Images