Gold Standard for the Global Goals

Climate Security & Sustainable Development

METHODOLOGY TOOL

GS4GG PAA 400 MT 003

SDG 13

EMISSIONS AND MONITORING REQUIREMENTS FOR GEOLOGICAL STORAGE

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SUMMARY

This Methodology Tool 3 (herein referred to as Tool 3), covers the emissions calculations and monitoring requirements for activities which inject carbon dioxide (CO_2) as a gas, supercritical fluid, dissolved in water, or in a liquid state into saline aquifers or depleted hydrocarbon reservoirs. Tool 3 shall be applied in conjunction with the Gold Standard for the Global Goals (GS4GG)-approved methodology for Biomass Fermentation with Carbon Capture and Geologic Storage. It is not applicable to active hydrocarbon reservoirs, or reservoirs located under marine environments, or reservoirs where the Area of Review crosses international boundaries.

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SUMMIT CARBON SOLUTIONS

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TABLE OF CONTENTS

1| KEY INFORMATION

1.1.1 | The following table describes the key information for the application of the methodology.

Table 1. Key Information

Item	Description
Tool summary	Tool 3 covers the emissions calculations and monitoring requirements for activities which involve the injection of captured CO_2 into saline aquifers or depleted hydrocarbon reservoirs.
Applicable mitigation type	☐ Emission reductions ☒ Removals
Applicable activity scale	☒ Micro scale (e.g., ≤10,000 tCO_2e per year) ☒ Small scale (e.g., ≤60,000 tCO_2e per year) ☒ Large scale (e.g., >60,000 tCO_2e per year)
Applicable methodologies	Biomass Fermentation with Carbon Capture and Geologic Storage
Limitations	Tool 3 is applicable only to activities which inject CO_2 as a gas, supercritical fluid, dissolved in water, or in a liquid state into saline aquifers or depleted hydrocarbon reservoirs. Active hydrocarbon reservoirs, or reservoirs located under marine environments, or reservoirs where the Area of Review crosses international boundaries are not eligible.

2| APPLICABILITY CRITERIA

2.1 | General Applicability

2.1.1 | Tool 3 shall be used in conjunction with the GS4GG methodology for Biomass Fermentation with Carbon Capture and Geologic Storage.

2.1.2 | Tool 3 is applicable only to activities which inject CO_2 as a gas, supercritical fluid, dissolved in water, or in a liquid state into saline aquifers or depleted hydrocarbon reservoirs.

2.1.3 | The eligible activity shall demonstrate compliance with the requirements outlined in Annex 1.

2.2 | Storage Site Applicability

2.2.1 | The eligible activity shall demonstrate—either through regulatory approval requirements and regulatory oversight provisions or through independent certification—that the activity has followed necessary procedures and provisions to ensure that the storage site:

a. has sufficient capacity to accept the required CO_2 injection volumes, and

b. has sufficient injectivity to allow CO_2 injection at the required rates, and

c. will provide long-term containment of CO_2 in a geologic reservoir (i.e., geologic storage), and

d. operates in a way that shall not induce seismicity or earth deformation which may cause an adverse impact, and

e. has design and/or operating procedures which ensure safety and environmental protection. The safeguards, which are considered within the scope of Tool 3, are in addition to the scope of GS4GG Safeguarding Principles & Requirement.

2.2.2 | An eligible activity involving more than one storage site shall demonstrate compliance with the requirements for each storage site.

2.2.3 | Tool 3 is not applicable to activities which involve the injection of captured CO_2 into the following:

a. Active hydrocarbon reservoirs. For avoidance of doubt, this includes reservoirs used for injection for secondary recovery and/or enhanced hydrocarbon recovery.

b. Reservoirs located below marine environments.

c. Reservoirs for which the Area of Review spans an international boundary.

2.3 | Activity Ownership Eligibility

2.3.1 | The activity developer—by means of direct ownership or contractual arrangement or other such arrangement between the activity developer and the storage site operator(s) for the activity—shall have:

a. valid licenses and/or permits issued by the regulator(s) described throughout or other such authorisations to drill injection and monitoring wells, and

b. valid licenses and/or permits issued by the regulator(s) described throughout or other such authorisations to operate the storage site, and

c. surface access rights to the storage site's injection and monitoring wells to allow monitoring during the injection period, closure period, and post-closure period, as documented in the storage site monitoring program document and closure plan, and

d. access to the required monitoring data and supporting documentation set forth in Tool 3.

2.3.2 | The activity developer shall, at validation and each verification, fulfil the following conditions:

a. Activity developer shall be the pore space tenure holder or have an enforceable and irrevocable agreement with the pore space tenure holder(s) which grants the activity developer the right to seek activity certification and ownership of Gold Standard Verified Emissions Reductions (GS-VERs) generated.

i. The pore space tenure holder shall possess title(s) or lease(s) for the relevant pore space within the geologic formations comprising the storage complex, spanning the anticipated extent of the CO_2 storage area.

b. Activity developer shall be the storage site operator or joint operator or have an enforceable and irrevocable agreement with the storage site operator(s) that grants the activity developer the right to seek activity certification and ownership of GS-VERs generated.

c. When an agreement grants the activity developer the right to seek activity certification and ownership of GS-VERs generated, the agreement shall include clauses that clearly assign responsibility for each of the following at the storage site:
   i. Remedial liability[1]
   ii. Climate liability[2]
   iii. Tort liability[3]
   iv. The qualifying criteria and/or conditions for storage site closure acceptance
   v. Storage site closure activities as provided in the closure plan
   vi. Funding for storage site closure activities as provided in the closure plan

d. When ownership of the activity or storage site or parties to the agreements change, the activity developer shall have an executed assignment and novation agreement which serves to transfer all rights and obligations in the original agreements and title(s) and lease(s) to the relevant pore space to the new owners and new parties to the agreement.

3| NORMATIVE REFERENCES

3.1.1 | Tool 3 refers to following methodologies, tools, and documents:

a. GS4GG:
   i. Principles & Requirements
   ii. Safeguarding Principles & Requirements
   iii. Biomass Fermentation with Carbon Capture and Geologic Storage
   iv. Engineered Removals Activity Requirement

[1] e.g., liability for ongoing monitoring for re-abandonments or for site reclamation

[2] i.e., liability for greenhouse gases released from the storage complex

[3] i.e., liability for damages to third parties

v. Methodology Tool 4: Reversal Risk Calculations for Geological Storage

b. Other Sources:

i. International Organization for Standardization (ISO) 27914: Carbon dioxide capture, transportation and geological storage — Geological storage

ii. Underground Injection Control (UIC) Program Class VI Well Area of Review Evaluation and Corrective Action Guidance (United States Environmental Protection Agency [U.S. EPA], 2013)

iii. UIC Program Class VI Well Site Characterization Guidance (U.S. EPA, 2013)

iv. UIC Program Class VI Well Plugging, Post-Injection Site Care, and Site Closure Guidance (U.S. EPA, 2016)

v. UIC Program Class VI Well Testing and Monitoring Guidance (U.S. EPA, 2013)

vi. Estimating geological CO_2 storage security to deliver on climate mitigation, Alcalde et al. (2018)

vii. Criteria and Standards Applicable to Class VI Wells, Subpart H

viii. UIC Program Class VI Well Construction Guidance (U.S. EPA, 2012)

ix. Directive 2009/31/EC of the European Parliament

x. Carbon Capture and Sequestration Protocol Under the Low Carbon Fuel Standard (California Air Resources Board, 2018)

xi. Carbon Capture and Storage Projects Methodology, V 2.0 Draft (American Carbon Registry, 2022)

4| DEFINITIONS

4.1.1 | The definitions outlined in the GS4GG Glossary and Engineered Removals Activity Requirement shall apply, in addition to those outlined below.

Table 2. Terms and Definitions

TERM	DEFINITION
Abandonment (plugging and abandonment)	The processes or procedures used to permanently end the operation of a well by plugging and sealing it (adapted from ISO 27914, 2017).[4]

[4] ISO 27914: Carbon dioxide capture, transportation and geological storage — Geological storage (Geneva, Switzerland, 2017). https://www.iso.org/standard/64148.html.

Active hydrocarbon reservoir	A geologic reservoir bearing hydrocarbons (e.g., oil and gas) which are economically recoverable with current technology.
Area of Review	The geographical area(s) of a geologic storage complex, or part of it, designated for assessment of the extent to which a storage activity, or part of it, could affect life and human health, the environment, competitive development of other resources, or infrastructure. The delineation of an Area of Review defines the outer perimeters on the land surface within which assessments will be conducted as may be required by regulatory authorities (adapted from ISO 27914, 2017) or, alternatively, as defined by the storage site regulator(s).
Blowout	An unintended flow of wellbore or formation fluids (oil, gas, water, or other substance) to the surface that cannot be controlled by existing wellhead or blowout prevention equipment or, in the case of an underground blowout, a flow from one pool to another pool that cannot be controlled by increasing the fluid density.
Carbon capture and geologic storage	The separation and capture of CO_2 from the atmosphere or from atmospheric emissions of industrial processes and the transport and safe, permanent geologic storage of the CO_2.
Carbon dioxide plume	The three-dimensional extent within the subsurface where CO_2 is present.
Casing	Pipe material placed inside a drilled hole to prevent the surrounding strata from collapsing into the hole (ISO 27914, 2017).
Closure period	The period between the cessation of injection and the demonstration of compliance with the criteria for site closure (ISO 27914, 2017).
Confining layer/strata/zone	A geologic formation, group of formations, or part of a formation stratigraphically overlying the injection zone(s) that acts as barrier to fluid movement (40 CFR 146.81(d)).
Containment	Retention of CO_2 and formation fluids within a storage complex (ISO 27914, 2017).
Corrective action	Action taken to correct material irregularities or to contain breaches in order to prevent or minimise damage to, or release of CO_2 from, a storage complex (ISO 27914, 2017).
Depleted hydrocarbon reservoir	A geologic reservoir from which hydrocarbons (e.g., oil and gas) have been extracted, and which is now characterised by the absence of both ongoing or planned extraction activities and economically recoverable hydrocarbons using current technology.

Element of concern	A valued element or objective for which risk is evaluated and managed (ISO 27914, 2017).
Enhanced hydrocarbon recovery	The practice of extracting hydrocarbons from a geologic reservoir through the alteration of the physical and/or chemical properties of the fluids contained therein.
Geologic reservoir	A three-dimensional confined region in the subsurface that has the ability to store fluids inside its pore space.
Geologic storage	Long-term containment of CO_2 injected into a geologic reservoir.
Injection period	The period between commencement and cessation of injection at the storage site wherein CO_2 is actively being injected into the subsurface.
Injection site	The area on the ground surface, defined by the operator and/or regulator, where CO_2 injection facilities are developed and operational activities take place. It begins at the point of CO_2 delivery and ends directly before the storage complex (e.g., at the perforations in the injection well).
Injectivity	The rate and pressure at which fluids can be pumped into the storage complex without exceeding specific and/or defined limits that serve to prevent fracturing the storage complex (adapted from ISO 27914, 2017).
Liner	A casing string that does not extend to the surface.
Loss event	The atmospheric emission of CO_2 from a storage reservoir exceeding the greater of either one tonne or 0.001% of the total quantity of CO_2 injected at that storage site.
Mechanical integrity	The mechanical condition of a well such that engineered components maintain their original dimensions and functions, solid geological materials are kept out of the wellbore, and fluids including CO_2 are prevented from uncontrolled flow into, out of, along, or across the wellbore, cement sheath, annulus, casing, tubing, and/or packers (ISO 27914, 2017).
Packer	A mechanical device that seals the outside of tubing to the inside of casing, isolating an annular space (ISO 27914, 2017).
Pore space	A cavity or void, whether natural or artificially created, in a subsurface sedimentary stratum.
Pore space tenure holder	The person or entity which possesses title or lease to a pore space.
Post-closure period	The period that begins after the demonstration of compliance with the criteria for site closure (ISO 27914, 2017).

Post-injection period	The period beginning with the cessation of injection and including the closure and post-closure periods.
Primary seal	A continuous geological unit above a geologic reservoir that is part of a storage complex and effectively restricts migration of fluids out of the geologic reservoir and migration out of the storage complex (ISO 27914, 2017).
Protected groundwater	Water found beneath the water table in fully saturated soils and geologic formations that is used for human consumption (see "underground source of drinking water" in this table), agricultural, or industrial uses or is protected from contamination by legislation or regulation.
Regulator	The authority(ies), or any combination thereof, that provide regulatory oversight of storage site(s).
Reversal	A situation in which the net emissions reductions or removals—including the quantity emitted during a loss event—in a monitoring period are negative, or a loss event which occurs in the post-injection period.
Saline aquifer	Geological formations consisting of water-permeable rocks which contain saltwater brines.
Secondary recovery	The extraction of oil and/or gas from a geologic reservoir through injection of external fluids, which pressurises and displaces fluids from the reservoir into the wellbore.
Secondary seal	A geological unit that effectively restricts migration of fluids in the sedimentary succession between the primary seal(s) and protected groundwater or protected resources.
Site characterisation	The detailed evaluation of one or more candidate sites for CO_2 storage identified in the screening and selection stage of a CO_2 storage activity to confirm and refine storage complex integrity, storage capacity, and injectivity estimates and to provide basic data for initial predictive modelling of fluid flow, geochemical reactions, geomechanical effects, risk assessment, and monitoring and validation program design (ISO 27914, 2017).
Site closure	The end of the closure period, which occurs when the storage site operator has demonstrated compliance with criteria for site closure.
Storage complex	The subsurface geological system extending vertically to comprise geologic reservoirs and identified seal(s) and extending laterally to the defined limits of the CO_2 storage activity (adapted from ISO 27914, 2017).
Storage activity	The physical and temporal extent of activities associated with an activity for the geological storage of CO_2 that includes site selection and characterisation, data collection, permitting,

	design and construction of site facilities (site pipelines, compressors, etc.), well drilling, receipt of CO_2 at the storage site, CO_2 injection during the active injection phase, and site closure (including well and facilities abandonment) (adapted from ISO 27914, 2017).
Storage site	The physical and spatial extent, at the surface and in the underlying strata, encompassing the injection and storage of CO_2 and locations where the storage complex is monitored. Includes the injection site, storage complex, and associated infrastructure required to operate and monitor the injection and storage activity (such as, for example, monitoring wells).
Storage site operator	The person(s) or entity(ies) possessing valid licenses and/or permits issued by the regulator(s) described throughout or other such authorisations to drill injection and monitoring wells and to operate the storage site, as well as possessing surface access rights to the storage site's injection and monitoring wells to allow monitoring during the injection period, closure period, and post-closure period.
Storage unit	The geological reservoir(s) into which CO_2 is injected for the purpose of geologic storage (adapted from ISO 27914, 2017).
Transfer of liability	The transfer of certain rights, responsibilities, and liabilities associated with storage site(s) from the storage site operator to a regulator after injection has ceased, the storage site(s) has been closed per the closure plan, and the regulator is satisfied that the criteria and/or conditions for site closure have been attained. Certain liabilities may include tort liability (i.e., liability for harm to third parties), remedial liability (e.g., liability for ongoing monitoring, for re-abandonments, or for site reclamation) and climate liability (i.e., liability for greenhouse gases released from the storage complex).[5]
Tubing	A tubular string normally run inside the injection or production casing that acts as the primary conduit for fluids (ISO 27914, 2017).
Underground source of drinking water	Water source found beneath the water table in fully saturated soils and/or geologic formations that is used for human consumption or agricultural or industrial uses or that is protected from contamination by legislation or regulation (adapted from ISO 27914, 2017).

[5] Bankes, N. (2019) "Alberta's approach to the transfer of liability for carbon capture and storage activities," Int. J. Risk Assessment and Management, Vol. 22, Nos. 3/4, pp. 311–323

5| SCOPE AND BOUNDARY

5.1 | Scope

5.1.1 | Tool 3 is applicable to activities that apply the GS4GG methodology for Biomass Fermentation with Carbon Capture and Geologic Storage to inject CO_2 as a gas, supercritical fluid, dissolved in water, or in a liquid state into saline aquifers or depleted hydrocarbon reservoirs.

5.2 | Boundary

5.2.1 | The activity boundary shall include the following:

a. Surface locations specified by global positioning system (GPS) coordinates (five decimals) for all injection and monitoring wells and, if applicable, any identified wellbores in the Area of Review
b. Bottomhole locations specified by GPS coordinates (five decimals) for all injection and monitoring wells and, if applicable, any identified wellbores in the Area of Review
c. An azimuthal projection of the storage site's Area of Review delineated with geodetic polygons in a KML file
d. The total area of the storage site's Area of Review

6| SAFEGUARDS

6.1.1 | The activity shall adhere to the Gold Standard Principles & Requirements and the Safeguarding Principles & Requirements as well as those outlined in the applied methodology.

7| BASELINE EMISSIONS AND REMOVALS

7.1.1 | Baseline emissions and removals do not apply and are not covered in Tool 3.

8| ACTIVITY REMOVALS

8.1.1 | Activity removals do not apply and are not covered in Tool 3.

9| ACTIVITY EMISSIONS

9.1 | Calculation of activity emissions

9.1.1 | The activity emissions from storage sites in the monitoring period *y* ($AE_{storage_y}$)[6], including emissions from the migration of CO_2 beyond the storage complex to the atmosphere, shall be calculated as follows:

[6] For avoidance of doubt, $AE_{storage_y}$ corresponds with Parameter ID 40, $M_{CO_2 leaked_y}$ in the methodology for Biomass Fermentation with Carbon Capture and Geologic Storage.

$$AE_{storage_y} = M_{CO_2\,unmitigated_y} + \sum_s \sum_j \left(M_{CO_2\,detected_{s,j,y}} \right) \qquad (eq.1)$$

Where:			ID/ section
$AE_{storage_y}$	=	Activity emissions from the migration of CO_2 beyond the storage complex to the atmosphere in monitoring period y (tCO_2)	N/A
$M_{CO_2\,unmitigated_y}$	=	Mass of CO_2 which could have migrated through physical leakage pathways without detection or mitigation in monitoring period y (tCO_2)	Parameter 7
s	=	Storage site	N/A
j	=	Detection event	N/A
$M_{CO_2\,detected_{s,j,y}}$	=	Mass of CO_2 which has migrated beyond the storage complex of storage site *s* to the atmosphere detected in event *j* and monitoring period *y* (tCO_2)	Parameter 6

9.1.2 | The mass of CO_2 which has migrated beyond the storage complex of storage site *s* to the atmosphere detected in event *j* and monitoring period *y* ($M_{CO_2\,detected_{s,j,y}}$) is the total mass assessed by the storage site operator for all leakage pathways associated with each storage site *s.*

9.1.3 | The mass of CO_2 which could have migrated through physical leakage pathways without detection or mitigation in monitoring period *y* ($M_{CO_2\,unmitigated_y}$) shall be calculated as follows[7]:

[7] Where the undetected leakage ($M_{CO_2\,undetected_y}$) is greater than or equal to the project's buffer contributions in the period, there is a potential "surplus" of storage site activity emissions that have not been mitigated by buffer contributions and thus must be accounted for as project emissions by the activity developer (i.e., $M_{CO_2\,undetected_y}$ y = "surplus"). Where the undetected leakage is less than the project's buffer contributions in the period, all undetected storage site activity emissions are mitigated by the project's buffer contributions (i.e., $M_{CO_2\,undetected_y}$ = 0).

When multiple techniques are applied to monitor a single leakage pathway, the quantity that could have leaked without detection is bounded by the most sensitive technique. Thus, the lowest estimate shall be applied (min) for any technique monitoring as the undetected leakage for a given pathway. These values are summed to determine the total undetected leakage for the storage site.

$$M_{CO_2\,unmitigated_y} = \begin{cases} 0, & M_{CO_2\,undetected_y} \leq BufferTransfer_y \\ M_{CO_2\,undetected_y} - Buffer\ Transfer_y, & M_{CO_2\,undetected_y} > BufferTransfer_y \end{cases} \quad \textit{(eq.2)}$$

and

$$M_{CO_2\,undetected_y} = \sum_s \sum_i \left(\min_z \left(M_{CO_2\,undetected_{s,i,z,y}} \right) \right) \quad \textit{(eq.3)}$$

Where:			ID/ section
$M_{CO_2\,undetected_y}$	=	Mass of CO_2 which could have migrated through leakage pathways at activity storage sites without detection in monitoring period y (tCO_2)	N/A
$M_{CO_2\,undetected_{s,i,z,y}}$	=	Mass of CO_2 which could have migrated through leakage pathway i at storage site s without detection by monitoring technique z in monitoring period y (tCO_2)	Section 9.1.4, Section 9.1.5, Parameter 10
$Buffer\ Transfer_y$	=	Quantity of GS-VERs contributed to the buffer account in monitoring period y (tCO_2)	Parameter 9

9.1.4 | Where the threshold for the detection of CO_2 migration through leakage pathway *i* at storage site *s* using monitoring technique *z* ($DT_{CO_2\,s,i,z}$), specified in the storage site monitoring program document as **unidimensional** (i.e., has units of tCO_2), the mass of CO_2 which could have migrated through leakage pathway *i* at storage site *s* without detection by monitoring technique *z* in period *y* ($M_{CO_2\,undetected_{s,i,z,y}}$) shall be calculated as follows[8]:

[8] The first term ($Q_{s,i} \times D_{s,i,z,y} \times F_{unmonitored_{s,i,z,y}}$) assumes maximum leakage throughput through a leakage pathway during the period where the pathway is not monitored. The second term accounts for the leakage through a pathway during the period where the pathway *is* monitored. This quantity cannot be greater than either a) a "full throttle" leak (i.e., $\left(Q_{s,i} \times D_{s,i,z,y} \times (1 - F_{unmonitored_{s,i,z,y}})\right)$, nor b) the detection threshold when accumulated over all the instances the parameter was sampled by the monitoring technique $\left(N_{sampled_{s,i,z,y}} \times DT_{CO_2\,s,i,z}\right)$. Hence, the lowest (min) of either value is taken.

$$M_{CO_2\,undetected_{s,i,z,y}} = \left(Q_{s,i} \times D_{s,i,z,y} \times F_{unmonitored_{s,i,z,y}}\right) + \min_{i,z}\left(\left(N_{sampled_{s,i,z,y}} \times DT_{CO_2{}_{s,i,z}}\right), \left(Q_{s,i} \times D_{s,i,z,y} \times \left(1 - F_{unmonitored_{s,i,z,y}}\right)\right)\right) \quad \textit{(eq.4)}$$

Where:			ID/ section
$Q_{s,i}$	=	Mass flow rate of CO_2 through leakage pathway i at storage site s in the event of a loss of storage site integrity (tCO_2 per day)	Parameter 3
$D_{s,i,z,y}$	=	Duration of period of monitoring leakage pathway i at storage site s in monitoring period y (days)	Parameter 13
$F_{unmonitored_{s,i,z,y}}$	=	Fraction of period y during which leakage pathway i at storage site s is not monitored by monitoring technique z in monitoring period y (dimensionless)	Equation 5, Parameter 11
$N_{sampled_{s,i,z,y}}$	=	Number of samples collected by monitoring technique z for leakage pathway i at storage site s during monitoring period y (count)	Parameter 12
$DT_{CO_2{}_{s,i,z}}$	=	Threshold for detection of CO_2 migration through leakage pathway i at storage site s using monitoring technique z	Parameter 5

And

$$F_{unmonitored_{s,i,z,y}} = \begin{cases} 0\,, & \left(\frac{N_{sampled_{s,i,z,y}}}{f_{s,i,z,y}}\right) \geq D_{s,i,z,y} \\ \frac{D_{s,i,z,y} - \left(\frac{N_{sampled_{s,i,z,y}}}{f_{s,i,z,y}}\right)}{D_{s,i,z,y}}\,, & \left(\frac{N_{sampled_{s,i,z,y}}}{f_{s,i,z,y}}\right) < D_{s,i,z,y} \end{cases} \quad \textit{(eq.5)}$$

Where:			ID/ section
$f_{i,z,y}$	=	Sampling frequency of monitoring technique z for leakage pathway i at storage site s during period y (samples per day)	Parameter 4

9.1.5 | Where the threshold for detection of CO_2 migration through leakage pathway *i* at storage site *s* using monitoring technique *z*, $DT_{CO_2{}_{s,i,z}}$, specified in the storage site monitoring program document as a rate (i.e., has units of tCO_2 per day), $M_{CO_2\,undetected_{s,i,z,y}}$ shall be calculated as follows:

$$M_{CO_2\,undetected_{s,i,z,y}} = \left(Q_{s,i} \times D_{s,i,z,y} \times F_{unmonitored_{s,i,z,y}}\right) + \min_{i,z}\left(\left(\min\left(\left(\frac{N_{sampled_{s,i,z,y}}}{f_{s,i,z,y}}\right), \left(D_{s,i,z,y} \times (1 - F_{unmonitored_{s,i,z,y}})\right)\right) \times DT_{CO_2{}_{s,i,z}}\right), \left(Q_{s,i} \times D_{s,i,z,y} \times (1 - F_{unmonitored_{s,i,z,y}})\right)\right) \quad \textit{(eq.6)}$$

9.1.6 | Where the threshold for detection of CO_2 migration through leakage pathway *i* at storage site *s* using monitoring technique *z*, $DT_{CO_2{}_{s,i,z}}$, is specified in the storage site monitoring program document as a proportion (e.g., a concentration in ppm_{CO2}), $M_{CO_2\,undetected_{s,i,z,y}}$ shall be calculated as follows:

$$M_{CO_2\,undetected_{i,z,y}} = \left(Q_{s,i} \times D_{s,i,z,y} \times F_{unmonitored_{s,i,z,y}}\right) + \min_{i,z}\left(\left(\min\left(\left(\frac{N_{sampled_{s,i,z,y}}}{f_{s,i,z,y}}\right), \left(D_{s,i,z,y} \times (1 - F_{unmonitored_{s,i,z,y}})\right)\right) \times Q_{s,i} \times DT_{CO_2{}_{s,i,z}}\right), \left(Q_{s,i} \times D_{s,i,z,y} \times (1 - F_{unmonitored_{s,i,z,y}})\right)\right) \quad \textit{(eq.7)}$$

9.2 | Loss Reporting

9.2.1 | The activity developer shall notify Gold Standard no more than 30 calendar days after the date on which the developer was provided notice by the storage site operator of an evidenced loss event.

a. A loss event means the migration of CO_2 beyond the storage complex exceeding the materiality threshold of the greater of either one tonne or 0.001% of the total quantity of CO_2 injected at that storage site.

10| LEAKAGE EMISSIONS

10.1.1 | Leakage emissions do not apply and are not covered in Tool 3.

11| QUANTIFICATION OF UNCERTAINTY

11.1.1 | Potential sources of uncertainty, along with the associated Quality Assurance/Quality Control (QA/QC) requirements to minimise them, are summarised in the Monitoring Methodology section.

11.1.2 | The uncertainties associated with the parameters should be aggregated into an overall uncertainty estimate for emission reductions and removals. A 95% confidence interval shall be employed for quantifying uncertainty due to random errors. Commonly, this would imply following the statistical approaches provided in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (propagation of errors method). For some technologies and sectors, alternative approaches would be needed.

11.1.3 | When the uncertainty in the estimated value of emission reductions or removal is expected to be at a 95% confidence interval (within +/-10% range when

applicable), the activity may exclude such random errors. In the case of being outside +/-10% range at a 95% confidence interval, the activity should address such random errors by deducting the emission reductions/removals accordingly.

11.1.4 | Sources of non-random, systematic errors shall be likewise identified and reduced, with the remaining systematic uncertainty similarly addressed.

11.1.5 | The uncertainty estimation and means of addressal should be determined, to the extent possible, in the methodology, thereby simplifying or eliminating the associated procedure required from the activity. The requirements from the activity developer shall be presented in this section.

12| MONITORING METHODOLOGY

12.1 | General Monitoring Requirements

12.1.1 | The activity developer and/or storage site operator shall determine or calculate the fracture pressure of the storage site primary seal(s) and the geologic reservoir(s) into which CO_2 is injected.

a. The storage site shall not be operated such that faults are reactivated and, except during well stimulations, the reservoir pressure of the storage complex shall not exceed the fracture pressures of either the primary seal(s) or geologic reservoir(s) into which CO_2 is injected.

12.1.2 | The activity developer shall, by means of direct ownership, contractual agreement, or other such arrangement between the activity developer and the storage site operator, establish access to the required monitoring data and supporting documentation.

12.1.3 | The following conditions shall be met prior to storage site closure:

a. All injectors are plugged and abandoned.
b. All monitoring wells are plugged and abandoned, except any monitoring well that is required for post-closure monitoring. In such cases, the closure plan shall provide for, and consider as a closure activity, the plugging and abandonment of that monitoring well following the cessation of its use for post-closure monitoring.
c. There are no further corrective actions required to restore mechanical integrity to wells in the Area of Review.
d. There are no further remedial actions required to restore integrity to the storage complex.
e. There is no detectable migration of CO_2 outside of the storage complex.
f. The risk of significant adverse impacts on human health and the environment posed by the storage activity is *de minimis*. This risk shall not be assessed as *de minimis* if all of the following are not met:
    i. The storage complex is sufficiently understood. Sufficient understanding means that the incorporation of additional post-injection monitoring data into the reservoir model does not result in a statistically significant increase in both the uncertainty of

both the modelled reservoir pressures and the extent of the CO_2 plume and their error relative to observed data.

ii. In the period beginning with the cessation of injection and spanning 100 years thereafter:

a. The predicted reservoir pressure does not increase, and

b. The CO_2 plume is predicted to be stabilised, or

c. There are no unremediated leakage pathways that are contacted by the evolving CO_2 plume or pressure front.

12.1.4 | The activity developer and/or storage site operators shall be responsible for implementing the storage site monitoring program, including but not limited to any activities described in the storage site monitoring program document and/or required by regulators.

12.1.5 | The storage site monitoring program shall be documented in a storage site monitoring program document that is included as an annex to the Project Design Document.

a. The activity developer and/or storage site operators shall update the storage site monitoring program as required by the regulator or the activity developer. For avoidance of doubt, storage site operators and/or activity developers may update the storage site monitoring program at their discretion. Modifications to the storage site monitoring program shall be approved either by the regulator and reported at the time of verification or independently following the design change process and requirements of GS4GG.

12.1.6 | The storage site closure plan shall be documented in a storage site closure plan document that is included as an annex to the Project Design Document.

a. The activity developer and/or storage site operators shall update the closure plan upon the identification of any CO_2 migration beyond the storage complex by the monitoring program and upon renewal of the activity Design Certification Cycle.

b. The activity developer and/or storage site operators shall document the attainment of the criteria and conditions for storage site closure in the monitoring program results reported for the post-injection period directly preceding the post-closure period.

12.2 | Storage Site Monitoring and Closure Requirements

12.2.1 | The activity developer and/or storage site operator shall prepare and maintain both a geological model and a dynamic reservoir model and shall apply these models to inform the operating limits of the storage site, the risk mitigation measures, and the storage site monitoring program and to predict the behaviour of the storage complex and the injected CO_2 therein.

a. The geological model shall comprise, at a minimum, a static geological model representing the flow, mineralogical, geochemical, and mechanical characteristics of the storage complex.

b. The reservoir model shall comprise at least the following:
    i. The geological static model per 12.2.1 |a.
    ii. A flow model representing the movement of CO_2 and other injected fluids through the storage complex using computational numerical modelling techniques.
c. The geological and reservoir models shall incorporate information acquired during the storage activity siting and reservoir characterisation activities as well as information specified in the storage activity monitoring program document and obtained from observed monitoring data, including as required *a priori* (e.g., for 12.2.1 |a, or per regulator's requirement) or as necessary *a posteriori* (e.g., for 12.2.2 | et seq. or 12.2.3 | et seq.):
    i. The geometric and/or spatial data, such as the areal extent of the storage complex
    ii. The geological data, such as porosity
    iii. The physical properties, such as temperature
    iv. Properties derived from constitutive relationships (e.g., relative permeability determined using saturation data and relative permeability-saturation relationships) or, alternatively, the constitutive relationships

12.2.2 |Prior to initiation of injection operations, and once injection operations have commenced and until storage site closure, the activity developer and/or storage site operator shall apply the geological and reservoir models to predict the flow, mineralogical, chemical, and mechanical characteristics of the storage reservoir and confining strata in response to the injected fluids and to do the following:

a. Predict induced seismicity and changes in the *in situ* stress regimes, rock mechanical properties, and chemical properties of the storage reservoir and the primary seal.
b. Inform and evaluate compliance with the operating limits of the storage site as specified in the storage site monitoring program, as applicable.
c. Evaluate the risk of migration of injected fluids beyond the storage complex and inform risk mitigation measures and the monitoring program.
d. Replicate, as applicable per above, observed storage site performance and the behaviour of injected CO_2 in the storage complex, including, at a minimum, the extent of the CO_2 plume and associated pressure front.
    i. Successful replication may not be possible without first calibrating the reservoir model. When this is the case, or when required by regulators, storage site operators shall apply best practices and appropriate model calibration methods (e.g., history matching) which seek to minimise uncertainties in the model outputs and/or statistical errors and residuals (e.g., the mean, mean absolute, or root mean square error and residual,

each respectively) between observed and modelled data for the storage site performance metrics or indicators.

e. Assess the predictive value of the reservoir model.

f. Predict storage site performance and the behaviour of injected CO_2, including, at a minimum, the extent of the CO_2 plume and associated pressure front throughout the injection and closure and through the end of the period ending 100 years after the cessation of injection.

g. Assess the observed behaviour of CO_2 relative to expectations.

12.2.3 | The activity developer and/or storage site operator shall prepare, maintain, and comply with a closure plan which describes how storage site closure is achieved as the result of a process consisting of closure activities undertaken to enable and demonstrate compliance with site-specific criteria or conditions. The storage site closure plan shall comprise *all* of the following:

a. All criteria and conditions for storage site closure, including those required by regulators and specified by the activity developer, as applicable, and, as specified by the storage site operator, the pore space tenure holder, and/or the surface tenure holder(s)

b. The metrics and/or indicators by which the criteria and/or conditions for storage site closure are measured or assessed

c. Descriptions and estimated costs[9] of, and the entity responsible for, each closure activity[10]

d. The duration of monitoring in the closure period and, if applicable, post-closure period

e. A schedule of the storage site closure activities, closure qualification process, and other processes and milestones relevant to storage site closure

12.2.4 | The activity developer and/or storage site operator shall execute a storage site monitoring program which is based on a systematic and specific risk assessment and designed to mitigate storage site risks, monitor storage site performance, attain storage site closure, and provide for corrective actions or remedial response activities and emergency response. The program shall comprise *at least* the following for all periods in the storage activity life cycle

[9] Estimated costs shall be discounted to present value, applying the most recent average annual inflation rate published by the World Bank. Ha, Jongrim, M. Ayhan Kose, and Franziska Ohnsorge (2021). "One-Stop Source: A Global Database of Inflation." Policy Research Working Paper 9737, World Bank, Washington, D.C. https://www.worldbank.org/en/research/brief/inflation-database

[10] A closure activity means any action in the post-injection or post-closure period that is required, *a priori*, for the performance metrics and/or indicators or criteria or conditions specified in the closure plan. For avoidance of doubt, monitoring in the post-closure period as applicable is a closure activity.

(pre-injection, injection, closure, post-closure periods, and, as applicable, post-closure monitoring period):

a. The objectives of the storage site monitoring program and storage site operating limits
b. A systematic assessment of the storage activity risks identifying elements of concern, including the identification and evaluation of artificial and natural leakage pathways in the Area of Review and reservoir model uncertainties
c. A discussion of the elements of concern related to results from past storage site monitoring program activities and reservoir modelling, including any loss events
d. The metrics, criteria, or indicators used to address elements of concern, monitor storage site performance, and/or demonstrate attainment of storage site closure conditions/criteria, including any parameters associated with their monitoring
e. The means of assessing and any monitoring parameters associated with the following:
    i. The predictive value of the reservoir model and, as applicable, methods used to calibrate the reservoir model
    ii. The integrity of the storage site
    iii. The metrics, criteria, or indicators used to address elements of concern, monitor storage site performance, and/or demonstrate attainment of storage site closure conditions/criteria
    iv. CO_2 migration within the storage complex or changes in the saturation of the CO_2 plume
    v. CO_2 migration beyond the storage complex, including the mass thereof and the associated leakage pathway(s)
    vi. CO_2 migration beyond the storage complex to the atmosphere, including the mass thereof and the associated leakage pathway(s)
f. The methods and techniques used for, and any parameters associated with, monitoring the atmosphere, subsurface, and near surface, including, as applicable, in and/or around wells identified in the Area of Review
g. The location, detection thresholds, spatial resolution, sampling frequency, and duration of monitoring for each parameter monitored as well as estimations for each leakage pathway of the mass flow rate of CO_2 through that leakage pathway in the event of a loss of storage site integrity for each parameter monitored
h. Emergency response plans, corrective action or remedial response plans for the storage site, and any plans or contingencies for corrective actions on wells in the Area of Review

i. The frequency for updating the storage site monitoring program as well as the reservoir model and conditions which would necessitate updates to either, including:
    i. Upon the identification of CO_2 migration beyond the storage complex
    ii. Upon the prediction of a loss event

12.3 | Activity Monitoring Requirements

12.3.1 | Upon obtaining evidence of CO_2 migration beyond the storage complex, the activity developer and/or storage site operator shall:
- a. immediately halt injection, and
- b. implement emergency response plans, corrective action or remedial response plans for the storage site, and/or contingencies for corrective actions on wells in the Area of Review as specified in and required by the storage site monitoring program document per 12.2.4 |h;, and
- c. update the closure plan, and
- d. Assess any releases per 12.2.4 |, including:
    i. CO_2 migration beyond the storage complex, including the mass thereof and the associated leakage pathway(s); and,
    ii. CO_2 migration beyond the storage complex to the atmosphere, including the mass thereof and the associated leakage pathway(s).

12.3.2 | When injection at a storage site is halted per 12.3.1 | a, the activity developer and/or storage site operator shall not resume injection at the storage site until each of the requirements at 12.3.1 | et seq. are met.

12.3.3 | Activity developers shall document the results of the storage site monitoring program, including:
- a. The quantity, if any, of CO_2 that has migrated beyond the storage complex
- b. Results from completed storage site monitoring program activities, including results from the assessment of the integrity of the storage complex and the performance metrics, indicators, and/or criteria specified in the storage site monitoring program document
- c. Uncertainties in the data obtained from the storage monitoring program and in the assessed performance metrics or indicators
- d. Permanent and/or indefinite changes, and justifications therefore, to the storage site monitoring program
- e. Updates to the reservoir model and discussion of the results from the application of reservoir modelling for each of monitoring requirements
- f. Descriptions of the methods and techniques used for, and parameters associated with, monitoring the atmosphere, subsurface, and near surface, which include areas in and/or around wells identified in the Area of Review, as applicable

g. Descriptions of, and causes for, any temporary deviations from the methods and techniques used for monitoring as specified in the storage site monitoring program document
h. The names, roles, and responsibilities of persons implementing the storage site monitoring program activities
i. The storage site closure criteria attained or conditions met, as applicable

12.3.4 | All data collected for monitoring shall be archived electronically and kept for at least two years after the end of the last crediting period.

12.4 | Data and Parameters Not Monitored

Parameter ID	**1**
Data/parameter:	T_{ref}
Description	Activity developer's chosen reference temperature.
Data unit:	Kelvin
Equations referred:	Temperature and Pressure should be specified by the activity developer to ensure mass quantities are estimated at consistent conditions.
Purpose of data	Select the or more of the following option(s) ☒ Safeguarding
Value(s) applied	Selected by developer.
Source of data	Select the or more of the following option(s). 'Other source' may include official statistics, expert judgment, proprietary data, IPCC, commercial and scientific literature, etc. ☐ Measured ☒ Other source
Choice of data or measurement methods and procedures	Relevant academic, governmental, or industry sources [e.g., Standard Temperature and Pressure (ISO) or Normal Temperature and Pressure (NIST)].
Comments:	

Parameter ID	**2**
Data/parameter:	P_{ref}
Description	Activity developer's chosen references pressure.
Data unit:	Pascal (Pa)

Equations referred:	Temperature and Pressure should be specified by the activity developer to ensure mass quantities are estimated at consistent conditions.
Purpose of data	Select the or more of the following option(s) ☒ Safeguarding
Value(s) applied	Selected by developer.
Source of data	Select the or more of the following option(s). 'Other source' may include official statistics, expert judgment, proprietary data, IPCC, commercial and scientific literature, etc. ☐ Measured ☒ Other source
Choice of data or measurement methods and procedures	Relevant academic, governmental, or industry sources [e.g., Standard Temperature and Pressure (ISO) or Normal Temperature and Pressure (NIST)]. Data from pressure and temperature compensated instruments shall be converted to the activity's reference conditions. Conversion shall be done using the same pressure and/or temperature used for the specific meter calibration.
Comments:	

Parameter ID	**3**
Data/Parameter	$Q_{s,i}$
Description	Mass flow rate of CO_2 through leakage pathway *i* at storage site *s* in the event of a loss of storage site integrity
Data unit	tCO_2 per day
Equations referred	Equations 4, 6, and 7
Purpose of data	☒ Activity emissions
Value(s) applied	Storage site monitoring program specifications
Source of data	☒ Measured ☐ Other source
Choice of data or measurement methods and procedures	Data shall be corrected to the activity's reference temperature and pressure. Per 12.1.5 | and 12.2.4 |g, the estimated mass flow rate of CO_2 through each leakage pathway in the event of a loss of storage site integrity shall be specified in the storage site monitoring program document.

Comments:	

Parameter ID	**4**
Data/Parameter	$f_{s,i,z,y}$
Description	Sampling frequency of monitoring technique *z* for leakage pathway *i* at storage site *s* during period *y*
Data unit	Samples per day
Equations referred	Equations 5, 6, and 7
Purpose of data	☒ Activity emissions
Value(s) applied	Storage site monitoring program specifications
Source of data	☒ Measured ☐ Other source
Choice of data or measurement methods and procedures	Data shall be corrected to the activity's reference temperature and pressure. Per 12.1.5 | and 12.2.4 |g the sampling frequency for each parameter used to monitor each leakage pathway shall be specified in the storage site monitoring program document.
Comments	Used to determine the fraction of period *y* during which leakage pathway *i* at storage site *s* is not monitored by monitoring technique *z*, $F_{unmonitored_{si,z,y}}$ Used to determine the mass of CO_2 which could have migrated through leakage pathway *i* at storage site *s* without detection by monitoring technique *z* in period *y*, $M_{CO_2 undetected_{s,i,z,y}}$

Parameter ID	**5**
Data/Parameter	$DT_{CO_{2_{s,i,z}}}$
Description	Threshold for detection of CO_2 migration through leakage pathway *i* storage site *s* using monitoring technique *z*
Data unit	tCO_2, tCO_2 per day, or ppm_{CO2}
Equations referred	Equations 4, 6, and 7
Purpose of data	☒ Activity emissions
Value(s) applied	Storage site monitoring program document

Source of data	☒ Measured ☐ Other source
Choice of data or measurement methods and procedures	Per 12.1.5 | and 12.2.4 |g, the detection thresholds for sampling each parameter used to monitor each leakage pathway shall be specified in the storage site monitoring program document. Data shall be corrected to the activity's reference temperature and pressure.
Comments	Used to determine the fraction of period *y* during which leakage pathway *i* at storage site *s* is not monitored by monitoring technique *z*, $F_{unmonitored_{si,z,y}}$ Used to determine the mass of CO_2 which could have migrated through leakage pathway *i* at storage site *s* without detection by monitoring technique *z* in period *y*, $M_{CO_2 undetected_{s,i,z,y}}$

12.5 | Data and Parameters Monitored

Parameter ID	6	
Data/parameter:	$M_{CO_2 detected_{s,j,y}}$	
Description	Mass of CO_2 which has migrated beyond the storage complex of storage site *s* to the atmosphere detected in event *j* and period *y*.	
Data unit:	tCO_2	
Equations referred:	Equation 1.	
Purpose of data	Select the or more of the following option(s) ☒ Activity emissions	
Measurement methods and procedures	Per 12.1.5 | and 12.2.4 |e.vi., the means of assessing CO_2 migration beyond the storage complex to the atmosphere, including the mass thereof and the associated leakage pathway(s) shall be specified in the storage site monitoring program document. Methods to be selected/designed based on the storage sites' characteristics and leakage pathways.	
Entity/person responsible for the measurement	To be determined based on the measurement method selected.	
Measuring instrument(s)	Type of instrument	To be determined based on the measurement method selected.
	Accuracy class	-

	Calibration requirements	Calibration procedures and frequency to be determined based on the measurement method selected. The project developer must ensure that the equipment is calibrated in accordance with the local/national standards or the manufacturer's specifications. If local/national standards or the manufacturer's specifications are not available, international standards may be used.
	Location	To be determined based on the measurement method selected.
Measurement intervals	Continuous.	
QA/QC procedures	Monitored quantities shall be corrected to the activity's reference temperature and pressure.	
Comments:	Used to determine activity emissions from storage sites include emissions from the migration of CO_2 beyond the storage complex to the atmosphere in period y $PE_{storage_y}$.	

Parameter ID	**7**	
Data/Parameter	$M_{CO_2 unmitigated_y}$	
Description	Mass of CO_2 which could have migrated through physical leakage pathways without detection or mitigation in period *y*	
Data unit	tCO_2	
Equations referred	Equation 2	
Purpose of data	☒ Activity emissions	
Measurement methods and procedures	Calculated using Equation 2	
Entity/person responsible for the measurement	Activity developer	
Measuring instrument(s)	Type of instrument	N/A
	Accuracy class	N/A

	Calibration requirements	N/A
	Location	N/A
Measurement intervals	Calculated once per monitoring period *y*	
QA/QC procedures	N/A	
Comments	Used to determine activity emissions from storage sites, including emissions from the migration of CO_2 beyond the storage complex to the atmosphere in period *y*, $PE_{storage_y}$	

Parameter ID	**8**	
Data/Parameter	$M_{CO_2 undetected_y}$	
Description	Mass of CO_2 which could have migrated through leakage pathways without detection in period y	
Data unit	tCO_2	
Equations referred	Equation 3	
Purpose of data	☒ Activity emissions	
Measurement methods and procedures	Calculated using Equation 3	
Entity/person responsible for the measurement	Activity developer	
Measuring instrument(s)	Type of instrument	N/A
	Accuracy class	N/A
	Calibration requirements	N/A
	Location	N/A
Measurement intervals	Calculated once per period *y*	
QA/QC procedures	None	

Comments	Used to determine the mass of CO_2 which could have migrated through physical leakage pathways without detection or mitigation in period y, $M_{CO_2 \text{unmitigated}_y}$

Parameter ID	**9**	
Data/Parameter	Buffer Transfer_y	
Description	Quantity of GS-VERs contributed to the buffer account in period *y*	
Data unit	tCO_2	
Equations referred	Equation 2	
Purpose of data	☒ Activity emissions	
Measurement methods and procedures	Calculated using GS4GG Methodology Tool 4	
Entity/person responsible for the measurement	Activity developer	
Measuring instrument(s)	Type of instrument	N/A
	Accuracy class	N/A
	Calibration requirements	N/A
	Location	N/A
Measurement intervals	Calculated once per period *y*	
QA/QC procedures	None	
Comments		

Parameter ID	**10**
Data/Parameter	$M_{CO_2 \text{undetected}_{s,i,z,y}}$
Description	Mass of CO_2 which could have migrated through leakage pathway *i* at storage site *s* without detection by monitoring technique *z* in period *y*

Data unit	tCO_2	
Equations referred	Equations 4, 6, and 7	
Purpose of data	☒ Activity emissions	
Measurement methods and procedures	Where the threshold for detection of CO_2 migration through leakage pathway *i* at storage site *s* using monitoring technique *z*, $DT_{CO_{2_{s,i,z}}}$, specified in the storage site monitoring program document as unidimensional (i.e., has units of tCO_2), the mass of CO_2 which could have migrated through leakage pathway *i* at storage site *s* without detection by monitoring technique *z* in period *y*, $M_{CO_2\,undetected_{s,i,z,y}}$, shall be calculated using Equation 4. Where the threshold for detection of CO_2 migration through leakage pathway *i* at storage site *s* using monitoring technique *z*, $DT_{CO_{2_{s,i,z}}}$, specified in the storage site monitoring program document as a rate (i.e., has units of tCO_2 per day), $M_{CO_2\,undetected_{s,i,z,y}}$ shall be calculated using Equation 6. Where the threshold for detection of CO_2 migration through leakage pathway *i* at storage site *s* using monitoring technique *z*, $DT_{CO_{2_{s,i,z}}}$,, is specified in the storage site monitoring program document as a proportion (e.g., a concentration in ppm_{CO2}), $M_{CO_2\,undetected_{s,i,z,y}}$ shall be calculated using Equation 7.	
Entity/person responsible for the measurement	Activity developer	
Measuring instrument(s)	Type of instrument	N/A
	Accuracy class	N/A
	Calibration requirements	N/A
	Location	N/A
Measurement intervals	Calculated once per period *y*	
QA/QC procedures	None	

Comments	Used to determine the mass of CO_2 which could have migrated through leakage pathways at activity storage sites without detection in period *y*, $M_{CO_2 undetected_y}$

Parameter ID	**11**	
Data/Parameter	$F_{unmonitored_{s,i,z,y}}$	
Description	Fraction of period *y* during which leakage pathway *i* is not monitored by monitoring technique *z*	
Data unit	Fractional	
Equations referred	Equation 5	
Purpose of data	☒ Activity emissions	
Measurement methods and procedures	Where $\left(\frac{N_{sampled_{s,i,z,y}}}{f_{s,i,z,y}}\right) \geq D_{s,i,z,y}$, activity developers shall apply a value of zero. In all other cases, activity developers shall calculate the fraction of period *y* during which leakage pathway *i* at storage site *s* is not monitored by monitoring technique *z* using Equation 5.	
Entity/person responsible for the measurement	Activity developer	
Measuring instrument(s)	Type of instrument	N/A
	Accuracy class	N/A
	Calibration requirements	N/A
	Location	N/A
Measurement intervals	Calculated once per period *y*	
QA/QC procedures	None	
Comments:	Used to determine the mass of CO_2 which could have migrated through leakage pathway *i* at storage site *s* without detection by monitoring technique *z* in period *y*, $M_{CO_2 undetected_{s,i,z,y}}$	

Parameter ID	**12**

Data/Parameter	$N_{sampled_{s,i,z,y}}$	
Description	Number of samples collected by monitoring technique *z* for leakage pathway *i* at storage site *s* during period *y*	
Data unit	Count	
Equations referred	Equation 5	
Purpose of data	☒ Activity emissions	
Measurement methods and procedures	A count of the total number of distinct samples collected by monitoring technique *z* for leakage pathway *i* at storage site *s* during period *y*	
Entity/person responsible for the measurement	Activity developer	
Measuring instrument(s)	Type of instrument	N/A
	Accuracy class	N/A
	Calibration requirements	N/A
	Location	N/A
Measurement intervals	Calculated once per period *y*	
QA/QC procedures	None	
Comments	Used to determine the fraction of period *y* during which leakage pathway *i* at storage site *s* is not monitored by monitoring technique *z*, $F_{unmonitored_{si,z,y}}$ Used to determine the mass of CO_2 which could have migrated through leakage pathway *i* at storage site *s* without detection by monitoring technique *z* in period *y*, $M_{CO_2 undetected_{s,i,z,y}}$	

Parameter ID	**13**
Data/Parameter	$D_{s,i,z,y}$
Description	Duration of period of monitoring leakage pathway *i* at storage site *s* in period *y*
Data unit	Days

Equations referred	Equations 4, 5, 6, and 7	
Purpose of data	☒ Activity emissions	
Measurement methods and procedures	Estimated based on the dates delineating period *y*	
Entity/person responsible for the measurement	Activity developer	
Measuring instrument(s)	Type of instrument	N/A
	Accuracy class	N/A
	Calibration requirements	N/A
	Location	N/A
Measurement intervals	Calculated once per period *y*	
QA/QC procedures	None	
Comments	Used to determine the fraction of period *y* during which leakage pathway *i* at storage site *s* is not monitored by monitoring technique *z*, $F_{unmonitored_{si,z,y}}$ Used to determine the mass of CO_2 which could have migrated through leakage pathway *i* at storage site *s* without detection by monitoring technique *z* in period y, $M_{CO_2 undetected_{s,i,z,y}}$	

13| MONITORING REQUIREMENTS FOR ACTIVITIES WITH REVERSAL RISKS

13.1.1 |Requirements are as outlined in the applied methodology for Biomass Fermentation with Carbon Capture and Geologic Storage.

ANNEX 1

A1.1 | Storage Site Approvals

A1.1.1 | The activity developer shall obtain the necessary regulatory permits, licenses, certifications, or other authorisations for the storage site from the appropriate national or subnational entities and/or certification bodies.

A1.1.2 | The scope of the regulatory approval and/or independent certification process shall address the below requirements and include an evaluation of the specified information. Required information shall be included as part of activity documentation and shall be submitted before validation.

A1.1.3 | When the scope of the regulatory approval and/or independent certifications process does not align with the below requirements or does not include an evaluation of the specified information, or when the host country lacks an applicable regulatory framework, the activity shall follow the U.S. or EU regulations.

a. Storage Site and Reservoir Characterisation

A1.1.4 | The requirements and information specified for storage site characterisation are as follows.

a. The capacity and injectivity of the storage complex shall be sufficient to receive the total anticipated quantity and rate of injected CO_2, as noted below:
    i. The identified boundaries, areal extent, thickness, and geologic heterogeneity of the storage site’s geologic reservoir(s), and
    ii. Intrinsic petrophysical properties, such as porosity, permeability, pressure, and temperature within the storage site’s geologic reservoir(s), and
    iii. Petrophysical properties, including capillary pressure for CO_2, and reservoir fluids identified as present within the storage site’s geologic reservoir(s), and
    iv. The mineralogical composition of the storage site’s geologic reservoir(s) and the composition of fluids identified as present therein.
b. The integrity of the geologic reservoir and confining strata are sufficient to confine the total anticipated quantity and rate of injected CO_2 in the storage complex, as noted below:
    i. Identified potential natural or manmade pathways within the Area of Review that could allow for the migration or leakage of CO_2 outside the storage site's geologic reservoir(s), which include fractures, faults, legacy wells (whether abandoned or not), and boreholes
    ii. The stratigraphy, lithology, mineralogy, areal extent and continuity, thickness, and geologic heterogeneity of the storage site's primary seal

iii. The intrinsic petrophysical properties of the storage site's primary seal, including its porosity and permeability

iv. The composition of the injected CO_2 stream, the mineralogical composition of the storage site's geologic reservoir(s) and primary seal, and the composition of reservoir fluids identified within the storage complex

v. Information on any secondary seals and overlying permeable strata

vi. *In situ* stress regimes and rock mechanical properties of the storage reservoir and the primary seal

vii. Primary seal that is free of transmissive faults or fractures.

viii. Information on natural seismicity and tectonic activity in the region where the storage site is located

c. Underground sources of drinking water shall be sufficiently protected from the migration of injected CO_2 or other reservoir fluids into the source or between sources, as noted below:

i. The stratigraphy, lithology, mineralogy, areal extent and continuity, thickness, and geologic heterogeneity of relevant permeable strata overlying the storage site's geologic reservoir(s)

d. The location and operation of the storage site shall not pose an unacceptable risk to other surface and subsurface activities or to valuable resources, as noted below:

i. Proximity to, and impacts to or from, other surface and subsurface activities, including waste fluid disposal operations, geothermal energy generation operations, hydrocarbon extraction, mining, dissolved mineral extraction, and natural gas or other geologic storage operations

ii. Proximity to, and impacts to or from, valuable resources including, geothermal energy resources, hydrocarbons, mines, and minerals

A1.1.5 | The activity developer and storage site operators are encouraged to refer to the relevant materials[11] for further guidance.

[11] Relevant materials:

- 40 CFR 146.83
- UIC Program Class VI Well Site Characterization Guidance, Section 3
- Directive 2009/31/EC, Article 4
- Directive 2009/31/EC, Annex I
- ISO 27914, Sections 5.3–5.4

b. Well Infrastructure Design, Construction, and Operating Limits

A1.1.6 | The requirements and information specified for well infrastructure design, construction, and operating limits are as follows.

a. The design and mechanical integrity of legacy wellbores and boreholes shall be sufficient to confine fluids in the subsurface and protect underground sources of drinking water from the migration of injected CO_2 or other reservoir fluids into the source or between sources, as noted below:

i. Identified legacy wellbores and boreholes (including unrecorded wellbores) within the Area of Review which could provide for the migration of CO_2 outside of the storage complex as well as their status and characteristics, and

ii. The construction type and material composition of legacy wellbores and boreholes and their potential interactions with injected CO_2 and other reservoir fluids, and

iii. The type and extent of mechanical defects in legacy wellbore and borehole casings, tubings, and packers as well as information regarding the quality of the cement sheath and/or plug, and

iv. The ability of legacy wellbore and borehole components, materials, cement sheaths, and/or plugs to endure exposure to the expected formation and wellbore/borehole loads and fluids as well as to prevent the movement of fluid into the wellbore or borehole or through cement, and

v. Remedial and/or corrective action plans for the timely abandonment or recompletion of legacy wellbores or boreholes to isolate the wellbore or borehole from the storage complex and/or underground sources of drinking water.

b. The mechanical integrity and quality of the storage site's injection well(s) and monitoring well(s) shall be sufficient to confine fluids in the storage complex and protect underground sources of drinking water from the migration of injected CO_2 or other reservoir fluids into the source or between sources, as noted below:

i. The injection well design shall provide injection at depths and rates appropriate for the storage site and provide sufficient strength and extent to prevent the movement of fluids into or between underground sources of drinking water as well as to endure exposure to the anticipated storage site conditions for the lifetime of the storage site until closure.

ii. The well casings, cements, tubing strings, liners, and associated surface equipment (from the toe of the injection well through to the point of delivery of CO_2 to the injection site) used to construct injection and monitoring wells shall be of sufficient grade, weight, size, and geometry to endure exposure to the anticipated storage site conditions for the lifetime of the storage

site until closure, including temperature, pressure, corrosivity, and mechanical stresses.

iii. The injection well and any monitoring wells shall be constructed with both a surface casing extending from the ground surface through the base of the lowermost underground source of drinking water and, unless otherwise approved by the regulator, at least one long-string casing extending from the ground surface through to the injection depth which is distinct from the surface casing.

iv. The cementing programs for the injection well and any monitoring wells shall provide a well-bonded cement sheath placed in the casing annuli sufficient to endure exposure to the anticipated injection and post-injection conditions and which, unless otherwise approved by the regulator, span the entire length of each casing string. A cement sheath is well-bonded only if its quality and continuity are verified to prevent the movement of fluids into or between underground sources of drinking water using technology capable of evaluating the quality and continuity of a cement sheath.

A1.1.7 | The activity developer and storage site operators are encouraged to refer to the relevant materials[12] for further guidance.

c. Storge Site Monitoring

A1.1.8 | The monitoring program for the storage site which facilitates the identification, evaluation, and implementation of measures to manage storage site risks and enables the prediction, detection, and quantification of CO_2 migration beyond the storage complex shall:

a. include storage site monitoring activities throughout the injection and post-injection periods and provide unambiguous assignment of responsibility for those monitoring activities, and

b. facilitate the identification of storage site risks and the evaluation of risk mitigation practices and support the demonstration of attainment of the acceptance criteria required for the storage site's closure, and

c. establish the detection thresholds, spatial resolution, location, sampling frequency, and duration of monitoring activities which facilitate the

[12] Relevant materials:
- 40 CFR 146.90
- UIC Program Class VI Well Testing and Monitoring Guidance
- Directive 2009/31/EC, Article 13
- Directive 2009/31/EC, Annex II
- ISO 27914, Section 9

identification and quantification of CO_2 migration beyond the storage complex.

A1.1.9 | The activity developer and storage site operators are encouraged to refer to the relevant materials[13] for further guidance.

d. Storage Site Closure

A1.1.10 | The requirements and information specified for storage site closure are as follows.

a. The integrity of the storage site at end of life and ability to confine fluids in the storage complex is established according to a closure qualification process that allows closure of storage sites only when:

i. the specified timeline, if any, defined by statute or regulation has elapsed, and

ii. the conditions required at 12.1.3 | et. seq. and any qualifying criteria and/or conditions for closure acceptance defined by statute or regulation or specified by the regulator are met, and

iii. the site closure activities, closure activity costs, and post-closure liabilities are unambiguously defined and responsibilities for each are unambiguously assigned. Post-closure liabilities include tort liability (i.e., liability for harm to third parties), remedial liability (e.g., liability for ongoing monitoring, re-abandonments, or site reclamation), and climate liability (i.e., liability for greenhouse gases released from the storage complex).

A1.1.11 | The activity developer and storage site operators are encouraged to refer to the relevant materials[14] for further guidance.

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[13] Relevant materials:

- 40 CFR 146.84
- UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance, Section 4
- UIC Program Class VI Well Plugging, Post-Injection Site Care, and Site Closure Guidance, Section 2
- Paragraph 4. Directive 2009/31/EC, Article 16
- Directive 2009/31/EC, Annex I
- ISO 27914, Section 7.6

[14] Relevant materials:

- 40 CFR 146.93
- UIC Program Class VI Well Plugging, Post-Injection Site Care, and Site Closure Guidance, Section 2
- UIC Program Class VI Well Plugging, Post-Injection Site Care, and Site Closure Guidance, Section 3.4

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- Directive 2009/31/EC, Article 17
- Directive 2009/31/EC, Article 18
- Directive 2009/31/EC, Annex I
- Directive 2009/31/EC, Annex II
- ISO 27914, Section 10
- ISO 27914, Sections 5.5 and 10
- Bankes, N. (2019). "Alberta's approach to the transfer of liability for carbon capture and storage activities," Int. J. Risk Assessment and Management, Vol. 22, Nos. 3/4, pp. 311–323