Verified Carbon Standard

VCS Module

VMD0058

CO_2 STORAGE IN SALINE AQUIFERS AND DEPLETED HYDROCARBON RESERVOIRS

Version 1.0

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Sectoral Scope 16: Carbon Capture and Storage

This module was developed by the CCS+ Initiative and Verra. The CCS+ Initiative is a collaboration of 48 member companies. Perspectives Climate Group GmbH and South Pole Carbon Asset Management Ltd. served as the secretariat and consultants to the initiative throughout this methodology.

CONTENTS

1 SUMMARY DESCRIPTION

This module provides procedures and requirements for project activities that store CO_2 in saline aquifers or depleted hydrocarbon reservoirs for eligible carbon capture and storage (CCS) project activities under *VM0049 Carbon Capture and Storage*.

Project emissions from storage ($PE_{Sto,y}$) are calculated in Equation (1).

Leakage emissions from storage ($LE_{Sto,y}$) are calculated in Equation (10).

2 SOURCES

This module is used in combination with the most recent versions of *VM0049* and the following methodologies, modules, and tools:[1]

Capture Modules

- *VMD0056 CO_2 Capture from Air (Direct Air Capture)*
- *VMD00XX CO_2 Capture from Bioenergy Combustion*
- *VMD00XX CO_2 Capture from Bioproduction Processes*
- *VMD00XX CO_2 Capture from Post-combustion Flue Gases in Fossil Fuel Power and Heat Generation*
- *VMD00XX CO_2 Capture from Industrial Processes*
- *VMD00XX CO_2 Capture from Oil and Gas Production and Processing*
- *VMD00XX CO_2 Capture from Precombustion Processes in Fossil Fuel Power and Heat Generation*
- *VMD00XX CO_2 Capture from Oxyfuel Combustion in Fossil Fuel Power and Heat Generation*

Transport Module

- *VMD0057 Project Emissions from CO_2 Transport for CCS Projects*

Other Modules, Tools, and Requirements

- *VT0010 Emissions from Electricity Consumption* (t CO2e)
- *VT00XX Differentiating Reductions and Removals in CCS Projects*
- *VT00XX Accounting Non-VCS CO_2 in CCS Projects*

[1] Modules labeled "*VMD00XX*" and tools labeled "*VT00XX*" are under development.

- Geologic Carbon Storage (GCS) Non-Permanence Risk Tool
- *GCS Requirements*

3 DEFINITIONS

In addition to the definitions set out in the *VCS Program Definitions* and *VM0049*, the following definitions apply to this module.

Conformance
The degree of agreement among reservoir model predictions, current measurement data, and performance for the storage reservoir in a geologic carbon storage project

Depleted hydrocarbon reservoir
A subsurface reservoir that holds residual hydrocarbons (e.g., oil or gas) and has been produced by drilling of legacy wells

Legacy wells
Wells that have been drilled prior to the project activity in the storage site. They must be included in the site characterization and monitoring plan.

Saline aquifer
An underground water source with total dissolved solids greater than 3000 mg/L

Storage site
Refers to all of the components within the storage module boundary.

4 APPLICABILITY CONDITIONS

This module applies to project activities that store CO_2 safely and permanently in saline aquifers or depleted hydrocarbon reservoirs per the criteria and procedures established in the most recent version of VM0049.

This module is applicable when all of the following conditions are met:

1) The project activity injects a CO_2 stream for permanent storage into a saline aquifer or depleted hydrocarbon reservoir.
2) The project activity has mandatory monitoring point(s) for CO_2 injection downstream of all intermediate storage, compression, and other CO_2 stream conditioning (per Section 6.3).

3) The project activity has at least one isolation valve on each wellhead or within 10 m of the point where the CO_2 stream enters the subsurface by run-of-pipe to isolate the surface and subsurface.

This module is not applicable under the following conditions:

4) The project activity consists solely of upgrades to existing CCS storage facilities or changes in operational practices leading to improved storage efficiency.

Note – For storage projects already registered under VCS, such improvements may occur and are considered in calculating the baseline and project emissions over the crediting period.

5) The project activity includes injection of CO_2 for enhanced oil recovery (EOR) or enhanced gas recovery (EGR).

6) The project activity intentionally extracts CO_2 from the reservoir for purposes unrelated to operation and maintenance of the storage site.

5 PROCEDURES

5.1 Module Boundary

The module boundary includes the surface facilities and subsurface equipment at the injection site, including the injection and monitoring wells and all monitoring equipment. The boundary also includes the area of review and the extent of the CO_2 plume within the geological storage complex. Projects with a point of custody transfer may use that as the upstream extent of the module boundary.

Commonly used processes to be considered in determining project emissions under this module are:

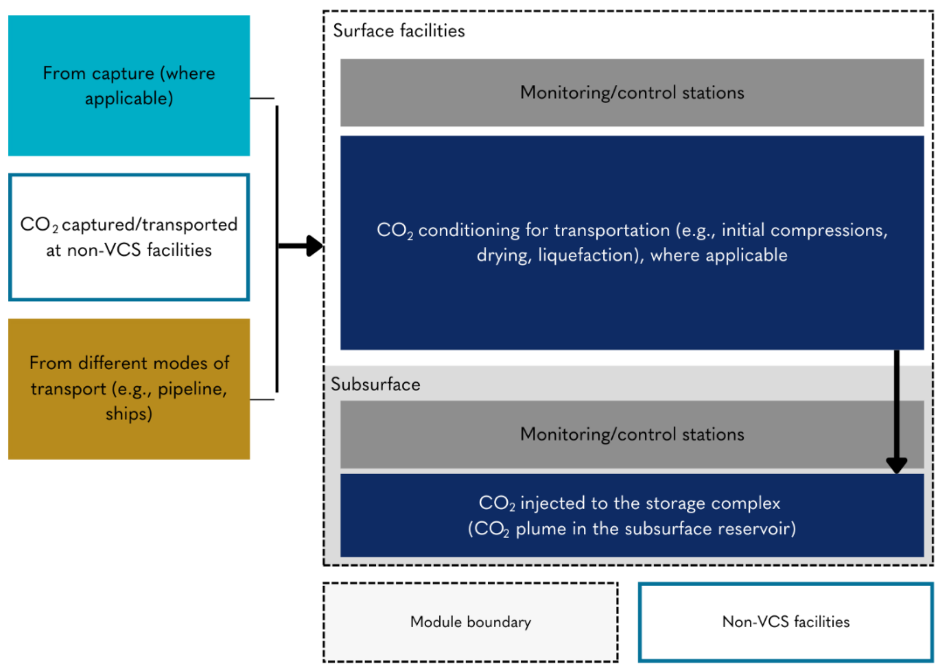
- Intermediate storage of CO_2
- Final compression and/or conditioning of CO_2 before injection
- Injection pipelines and wells, legacy wells, wellhead piping, valves, and monitoring instrumentation
- Supervisory control and data acquisition (SCADA)/communication equipment
- Injection well workovers or other maintenance operations
- CO_2 booster pumps, seal losses, and electricity consumption
- CO_2 compression with interstage cooling, valve/seal losses, and electricity consumption or fuel use
- Dehydration units (e.g., tri-ethylene glycol (TEG), desiccants, refrigeration) and associated reboilers or regeneration units

Section 5 of the most recent version of *VM0049* provides further details on determining the module boundary. The project proponent must ensure that equipment is not omitted or double counted.

This module calculates the total emissions from the sources listed in Table 1. In cases where non-VCS[2] CO_2 flows through the project boundary, the most recent version of *VT00XX Accounting non-VCS CO_2 in CCS Projects* must be used to calculate the proportion of emissions from project sources associated with that non-VCS CO_2.

The boundary for this module is shown in Figure 1.

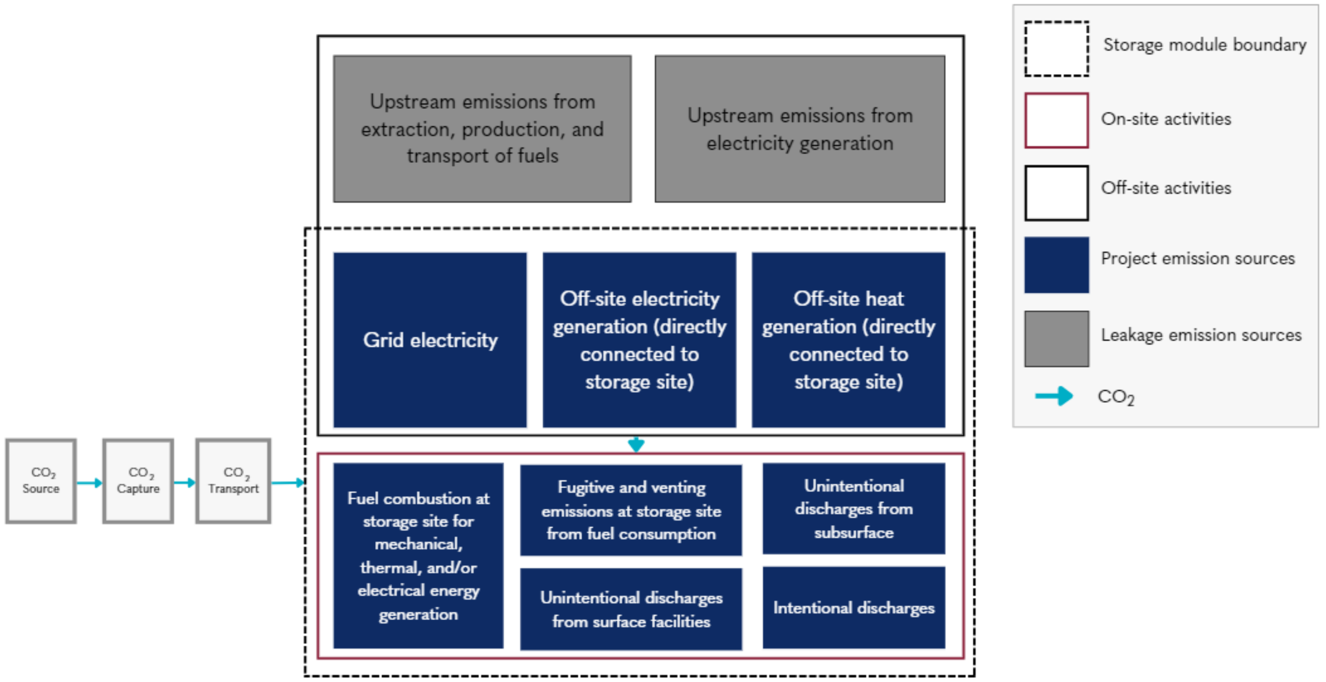
Figure 1 - Module boundary for CO_2 storage in saline aquifers or depleted hydrocarbon reservoirs



Emission sources, including both primary and secondary effects included in this module, are shown in Figure 2.

[2] Non-VCS CO_2 is defined as "CO_2 that flows through a CCS project boundary that is not eligible for crediting in the VCS" in *VT00XX Accounting non-VCS CO_2 in CCS Projects.*

Figure 2 - Included greenhouse gas sources



The greenhouse gases (GHGs) included in or excluded from the module boundary are detailed in Table 1. This module assumes that no storage of CO_2 relevant to the project activities took place in the baseline scenario. As such, no emissions sources associated with the baseline scenario are included in Table 1.

Table 1: GHG sources included in or excluded from the module boundary

Source		Gas	Included?	Justification/Explanation
Project	Electricity consumption	CO_2	Yes	Major emission source
		CH_4	Yes	Included for completeness
		N_2O	Yes	Included for completeness
		Other	No	Excluded for simplicity; emissions are considered negligible.
	Fuel consumption	CO_2	Yes	Major emission source
		CH_4	Yes	Included for completeness
		N_2O	Yes	Included for completeness
		Other	No	Excluded for simplicity; emissions are considered negligible.
		CO_2	Yes	Included. Any loss of CO_2 due to fugitive emissions or venting during storage is inherently deducted from

				the overall calculation of GHG emission reductions since only injected CO_2 volumes are quantified as the baseline emissions.
	Fugitive and venting emissions from CO_2 stream processing	CH_4	No	Excluded as not considered under the baseline scenario.
		N_2O	No	Excluded as not considered under the baseline scenario.
		Other	No	Excluded for simplicity; emissions are considered negligible.
	Leaks of CO_2 from the storage site (intentional and unintentional discharge from surface and subsurface)	CO_2	Yes	Major emission source
		CH_4	No	Excluded as not considered under the baseline scenario.
		N_2O	No	Excluded as not considered under the baseline scenario.
		Other	No	Excluded for simplicity; emissions are considered negligible.
	Fugitive and venting emissions from on-site fuel use	CO_2	No	Excluded for simplicity; emissions are considered negligible.
		CH_4	Yes	Significant emission source
		N_2O	No	Excluded for simplicity; emissions are considered negligible.
		N_2O	No	Excluded for simplicity; emissions are considered negligible.

5.2 Quantification of Project Emissions

Project emissions are calculated as follows:

$$PE_{Sto,y} = PE_{Comb_{Fuel},y} + PE_{Elec,y} + PE_{Fuel_{FV},y} + ID_{Surface,y} + UD_{Surface,y} + ID_{Subsurface,y} + UD_{Subsurface,y} - PE_{nonVCS\ CO2,y} \quad (1)$$

Where:

$PE_{Sto,y}$	=	Project emissions from storage in year *y* (t CO_2e)
$PE_{Comb\_Fuel,y}$	=	Project emissions from fuel combustion to operate the on-site and/or third-party (for off-site heat/steam supply) equipment for storage processes in year *y* (t CO_2e)
$PE_{Elec,y}$	=	Project emissions from electricity consumption to operate equipment in the storage facility in year y calculated using *VT0010 Emissions from Electricity Consumption* (t CO2e)
$PE_{Fuel\_FV,y}$	=	Fugitive and venting from on-site fuel use (e.g., natural gas) at storage facilities in year *y* (t CO_2e)

$ID_{Surface,y}$	=	Intentional discharges of CO_2 from surface equipment downstream from mandatory monitoring points in year *y* (t CO_2e)
$UD_{Surface,y}$	=	Unintentional discharges of CO_2 from surface equipment downstream from mandatory monitoring points in year *y* (t CO_2e)
$ID_{Subsurface,y}$	=	Intentional discharges of CO_2 from subsurface storage in year *y* (t CO_2e)
$UD_{Subsurface,y}$	=	Unintentional discharges of CO_2 from subsurface storage in year *y* (t CO_2e)
$PE_{nonVCS\ CO2,y}$	=	Project emissions from processes and equipment related to non-VCS CO_2 in year *y* determined using the most recent version of *VT00XX Accounting non-VCS CO_2 in CCS Projects*; equal to zero for projects with no non-VCS CO_2 (t CO_2e)

5.2.1 Project Emissions from Fuel Combustion

Project emissions from fossil fuel combustion for mobile equipment, and power and heat generation are calculated as follows:

$$PE_{Comb_{Fuel},y} = \sum_d (Q_{Fuel,d,y} \times EF_{Fuel,CO2,d}) + \sum_d (Q_{Fuel,d,y} \times EF_{Fuel,CH4,d}) \times GWP_{CH4} + \sum_d (Q_{Fuel,d,y} \times EF_{Fuel,N2O,d}) \times GWP_{N2O} \quad (2)$$

Where:

$Q_{Fuel,d,y}$	=	Quantity of fuel type *d* used to operate on-site and/or third-party (for off-site heat/steam supply) equipment in year *y* (m^3 or kg or GJ)
$EF_{Fuel,CO2,d}$	=	CO_2 emission factor for combustion of fuel *d* (t CO_2/m^3 or t CO_2/kg or t CO_2/GJ); equal to zero for fuels derived from biomass[3]
$EF_{Fuel,CH4,d}$	=	CH_4 emission factor for combustion of fuel *d* (t CH_4/m^3 or t CH_4/kg or t CH_4/GJ)
$EF_{Fuel,N2O,d}$	=	N_2O emission factor for combustion of fuel *d* (t N_2O/m^3 or t N_2O/kg or t N_2O/GJ)
GWP_{CH4}	=	Global warming potential for CH_4 (t CO_2e/t CH_4)
GWP_{N2O}	=	Global warming potential for N_2O (t CO_2e/t N_2O)

[3] Sustainable biomass is defined in the most recent version of *VT00XX Differentiating Reductions and Removals in CCS Projects*.

Where no separate information on combustion emissions and upstream emissions is available for a given fuel, a combined emissions factor may be used as $EF_{Fuel,d}$ in Equation (2).

Off-site Fuel Consumption

The quantity of power or heat supplied from a directly connected off-site facility, $Q_{Fuel,d,y}$, is determined using Equation (3).

$$Q_{Fuel,d,y} = Q_{Cogen,d,y} \times \frac{(Heat_{Sto,y}/\eta_{Heat,y} + Electricity_{Sto,y}/\eta_{Elec,y})}{(Heat_{Cogen,y}/\eta_{Heat,y} + Electricity_{Cogen,y}/\eta_{Elec,y})} \quad (3)$$

Where:

$Q_{Cogen,d,y}$	=	Quantity of fuel type *d* used by the cogeneration unit to generate electricity and/or heat in year *y* (m^3 or kg or GJ)
$Heat_{Sto,y}$	=	Quantity of useful thermal energy supplied to the storage facility by the cogeneration unit in year *y* (MWh)
$Electricity_{Sto,y}$	=	Quantity of electricity supplied to the storage facility by the cogeneration unit in year *y*; equal to zero where only heat is supplied to the storage facility (MWh)
$Heat_{Cogen,y}$	=	Total quantity of useful thermal energy produced by the cogeneration unit in year *y* (MWh)
$Electricity_{Cogen,y}$	=	Total quantity of electricity produced by the cogeneration unit in year *y* (MWh)
$\eta_{Heat,y}$	=	Efficiency of thermal energy production from cogeneration unit determined in year *y* using the most recent version of CDM TOOL09
$\eta_{Elec,y}$	=	Efficiency of electricity production from cogeneration unit determined in year *y* using the most recent version of CDM TOOL09

Waste Heat

Project emissions from the consumption of waste heat may be assumed to be zero for heat sources that meet the definition of waste heat in *VM0049*. The emissions associated with the generation of heat that does not meet the definition of waste heat must be accounted for in Equation (2) or (3) as appropriate.

5.2.2 Fugitive and Venting Emissions from On-site Fuel Use

Project activities using natural gas must quantify fugitive and venting emissions during facility operations. Quantification is based on component counts and respective emission factors, fugitive emissions are quantified following the approach in the US Environmental Protection Agency's *Electronic Code of Federal Regulations*, Title 40, Part 98, Subpart W, § 98.233 (r).[4]

[4] Available at: https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98/subpart-W/section-98.233

Examples of emission sources for fugitive emissions include components such as valves, pipe fittings/connectors, open-ended pipes, pressure relief valves, flanges, meters, and instruments.

$$PE_{Fuel_{FV},y} = \left(\sum_n Count_{n,y} \times EF_n \times T_{n,y} \times 0.001 + \sum_m V_m\right) \times GWP_{CH_4} \tag{4}$$

Where:

$Count_{n,y}$	=	Total number of components *n* in natural gas service at the facility during year *y* (unitless)
EF_n	=	Emission factor for fugitive emissions for component *n* (kg CH_4/hr/unit)
$T_{n,y}$	=	Pressurized time of component *n* in year *y* (hours)
V_m	=	Vented CH_4 emissions for venting event *m* (t CH_4/event)
0.001	=	Conversion from kg to t

5.2.3 Project Emissions from Intentional Discharges

Project emissions from intentional discharges are a result of venting that is downstream of mandatory monitoring points. Venting events can be differentiated by whether they originate from surface facilities ($ID_{Surface}$) *or* the subsurface ($ID_{Subsurface}$).

Surface venting includes activities resulting from operator intervention (e.g., blowdown of piping and/or pigging operations) or an automated system response to process conditions (e.g., pressure safety valve releasing in response to high pressure as per design). These activities must be related to the operation and maintenance of the storage site. Extraction of CO_2 from the reservoir for utilization or other commercial interests is not allowed.

For surface venting, the project proponent must measure the quantity of CO_2 according to the conditions given in Approaches 1, 2, or 3 below.

Subsurface venting includes activities related to injection well maintenance. For subsurface venting, the project proponent must determine the quantity of CO_2 according to Approach 1.

The project proponent must actively monitor and report intentional discharge emissions using the approaches below. Please refer to Section 8.1 of VM0049 to determine CO_2 flow, density, and concentration.

Note - For projects registering in the VCS Program, emissions from intentional discharges may be assumed to be zero in the Project Description Template.

Approach 1: Measurement of Venting

Under this approach intentional discharges in year *y* must be calculated using either mass flow or volumetric flow.

Option 1: Mass flow

$$ID_{Surface,y}\ or\ ID_{Sub-surface,y} = \sum_{h} FR_{mass,h} \times \%CO2_{mass,h} \times T_{,h} \quad (5)$$

Where:

$ID_{Surface,y}$	=	Intentional discharges of CO_2 from the surface in year *y* (t CO_2e)
$ID_{Subsurface,y}$	=	Intentional discharges of CO_2 from the subsurface in year *y* (t CO_2e)
$FR_{mass,h}$	=	Mass flow rate for discharge event *h* (tonnes/hour)
$\%CO2_{mass,h}$	=	CO_2 concentration in the mass flow for discharge event *h* (% mass)
T_h	=	Venting time for discharge event *h* (hours)

Option 2: Volumetric flow

$$ID_{Surface,y}\ or\ ID_{Sub-surface,y} = \sum_{h} FR_{vol(STP),h} \times \%CO2_{vol(STP),h} \times \rho CO2_{(STP)} \times T_h \quad (6)$$

Where:

$FR_{vol(STP),h}$	=	Volumetric flow rate for discharge event *h* measured at actual conditions and converted to standard temperature and pressure (STP) conditions (m^3/hour)
$\%CO2_{vol(STP),h}$	=	Volumetric fraction of CO_2 in flow for discharge event *h* at STP conditions (% volume)
$\rho CO_{2(STP)}$	=	Density of CO_2 at STP conditions (t CO_2/m^3)

Approach 2: Estimation of Surface Venting for Isolated Volumes

Where any part of an isolated section of pipe is downstream of the mandatory monitoring point and is depressurized, project proponents must estimate the vented mass of CO2 using the volume of the isolated pipe and Equation (7).

$$ID_{Surface,y} = \sum_m \sum_n v_{n,m(STP)} \times \%CO2_{vol(STP)} \times \rho CO2_{(STP)} \quad (7)$$

Where:

$v_{n,m(STP)}$	=	The actual internal volume of each pipe, pipe fitting, and component *n* in the isolated vent section for venting event *m*, converted to a STP volume based on actual process conditions (m^3)

Approach 3: Estimation of Surface Venting for Non-Isolated Volumes

Where Approaches 1 and 2 are not applicable for surface venting (e.g., where the volume of the isolated pipe cannot be determined or the venting event was from a non-isolated and flowing pipe), use Approach 3.

The project proponent must determine the quantity of vented CO_2 ($ID_{Surface,y}$) by transient flow rate calculations for compressible fluids appropriate for the expected evolving conditions in the pipeline or component (e.g., gaseous, dense, super-critical fluids using a critical flow model) based on the approximate geometry of the escaping flow and pipelines/components connected to the venting. The project proponent must justify the appropriateness of all calculations, models, correlations, or empirical relationships used and demonstrate the result is conservative.

5.2.4 Project Emissions from Unintentional Discharges at the Surface

The project proponent must actively monitor and report unintentional discharge emissions using the approaches below. The potential emission sources for unintentional discharges of CO_2 include components (e.g., valves, pipe fittings/connectors, open-ended pipes, pressure relief valves, flanges, meters, instruments) and pipelines.

Note - For projects registering in the VCS Program, emissions from unintentional discharges may be assumed to be zero in the Project Description Template.

Two emission sources are considered for unintentional discharge of CO_2 at the surface.

Emission Source 1: Fugitive Emissions Downstream of the Mandatory Monitoring Point

In this scenario, $UD_{Surface,y}$ for pipelines and other components is determined as follows:

$$UD_{Surface,y} = \sum_{p} EF_p \times T_{p,y} \times b \times 0.001 + \sum_{n} EF_n \times T_{n,y} \times 0.001 \quad (8)$$

Where:

EF_p	=	Emission factor for pipeline p derived from nationally appropriate regulations or default value of 0.26(kg CO_2/hr/km)
EF_n	=	Emission factor of fugitive emissions for component n (kg CO_2/hr)
$T_{p,y}$	=	Pressurized time of pipeline p in year y (hours)
$T_{n,y}$	=	Pressurized time of component n in year y (hours)
b	=	Length of pipeline from mandatory monitoring point to injection well (km)

Emission Source 2: Rupture or Line-Break Downstream of Mandatory Monitoring Point

A rupture or line-break failure is considered to have occurred where the flow rate through the failure is substantial enough to be considered a safety hazard as defined in local requirements off-site nuisance due to odor or noise. Failures that qualify as a safety hazard must be corrected in accordance with local requirements upon detection and ahead of the calculations that follow. Otherwise, the failure may be considered a fugitive emission.

Where a component or pipeline that is downstream of the mandatory monitoring point and upstream of the wellhead and reservoir suffers a rupture or line-break failure, the proponent must:

1) Isolate the failure; and
2) Quantify the loss of CO_2 ($UD_{Surface,y}$) through:
   a) **Emissions before isolation**: Determine the quantity of lost CO_2 by estimating the flow rate through the failure using transient flow rate calculations for compressible fluids appropriate for the expected conditions in the pipeline or component (e.g., gaseous, dense, super-critical) based on the approximate geometry of the escaping flow and pipelines/components connected to the failure. The estimation must be for the approximate time between when the failure occurred and when the release was stopped. Where the approximate time at which the failure occurred is unknown, the leakage event duration must be estimated conservatively by assuming the leakage event existed from the last known and documented regular operation (e.g., last inspection) until the release was stopped.
   b) **Emissions after isolation**: Use Approach 3 in Section 5.2.3 to calculate leaked emissions.

5.2.5 Project Emissions from Unintentional Discharges from Subsurface Storage

Project emissions from unintentional discharges from the subsurface are CO_2 leaks (loss event) from the geological storage complex. They are calculated according to the following equation.

$$UD_{Subsurface,y} = \sum_a (Q_{LE,a}) + Q_{Threshold,y} \quad (9)$$

Where:

$Q_{LE,a}$	=	Quantity of CO_2 released from the storage reservoir during leak event *a* (tonnes)
$Q_{Threshold,y}$	=	Maximum undetected quantity of CO_2 that may have leaked, as defined in the monitoring plan (tonnes)

Section 6.3 provides guidance on determining $Q_{LE,a}$ and $Q_{Threshold,y}$.

5.3 Quantification of Leakage

Equation (10) accounts for leakage emissions in this module.

$$LE_{Sto,y} = LE_{Fuel,y} + LE_{Elec,y} - LE_{nonVCS\ CO2,y} \quad (10)$$

Where:

$LE_{Sto,y}$ = Leakage emissions from storage in year *y* (t CO_2e)

$LE_{Fuel,y}$ = Leakage emissions from upstream fuel consumption for storage processes in year *y* (t CO_2e)

$LE_{Elec,y}$ = Leakage emissions from electricity consumption to operate equipment in the storage facility in year y calculated using *VT0010 Emissions from Electricity Consumption* (t CO2e)

$LE_{nonVCS\ CO2,y}$ = Leakage emissions from processes and equipment related to non-VCS sources in year *y* determined using the most recent version of *VT00XX Accounting Non-VCS CO_2 in CCS Projects*; equal to zero for projects with no non-VCS CO_2 (t CO_2e)

5.3.1 Leakage Emissions from Fuel Consumption

Upstream emissions from the production and transportation of fuel to the storage site and directly connected off-site facilities are calculated using Equation (11).

Equation (11) is not required if an emissions factor covering both fuel combustion ($EF_{Fuel,d}$) and upstream emissions ($EF_{Upstream\_Fuel,d,y}$) was used in Equation (2).

$$LE_{Fuel,y} = \sum_{d} (Q_{Fuel,d,y} \times EF_{Upstream\_Fuel,d,y}) \tag{11}$$

Where:

$Q_{Fuel,d,y}$ = Quantity of fuel type *d* used to operate on-site and/or third-party (for off-site heat/steam supply) equipment in year *y* (m^3 or kg or GJ)

$EF_{Upstream\_Fuel,d,y}$ = Emission factor for upstream sources related to fuel type *d* used in equipment in the storage module boundary in year *y* (t CO_2e/m^3 or t CO_2e/kg or t CO_2e/GJ)

Where power and heat are supplied from an off-site facility, $Q_{Fuel,d,y}$ must be determined as a proportion of the total fuel used to generate the total electricity and heat at the directly connected facility using Equation (3).

5.4 Uncertainty

The main source of uncertainty identified for the project activities covered in this module is measurement error. Significant uncertainty may exist in the project-specific monitoring program for unintentional discharges (i.e., leaks from the reservoir) but is discounted through the conservative deduction $Q_{Threshold}$ (see Section 6.3) and may be ignored. All other potential sources of uncertainty are either considered de minimis or accounted for in the conservativeness of the default factors.

Uncertainty of measurement error related to project emissions from fuel combustion for storage activities is considered de minimis where the metering equipment used for determining fuel volumes, $Q_{fuel,d,y}$, uses a custody transfer meter or fiscal metering for a transaction.

Uncertainty of measurement or estimation error from intentional discharges at the storage site is considered de minimis where the magnitude of the emissions from venting is less than 2% of the net emission reduction or removal benefit of the project.

Proponents whose projects do not meet the above conditions for a source of uncertainty must include that source of uncertainty in their uncertainty assessment.

6 DATA AND PARAMETERS

Additional data and parameters are defined in *VM0049* and related tools (VCS and CDM) as applicable.

6.1 Data and Parameters Available at Validation

Data/Parameter	GWP_{CH4}
Data unit	t CO_2e/t CH_4
Description	Global warming potential for CH_4
Equations	(2), (4)
Source of data	Most recent version of the *VCS Standard*
Value applied	See the most recent version of the *VCS Standard*.
Justification of choice of data or description of measurement methods and procedures applied	Required by the *VCS Standard*
Purpose of data	Calculation of project emissions
Comments	N/A

Data/Parameter	GWP_{N2O}
Data unit	t CO_2e/t N_2O

Description	Global warming potential for N_2O
Equations	(2)
Source of data	Most recent version of the *VCS Standard*
Value applied	See the most recent version of the *VCS Standard*.
Justification of choice of data or description of measurement methods and procedures applied	Required by the *VCS Standard*
Purpose of data	Calculation of project emissions
Comments	N/A

Data/Parameter	*b*
Data unit	Km
Description	Length of pipeline from mandatory monitoring point to injection well
Equations	(8)
Source of data	Manufacturer specifications, part lists, measurement
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of data	Calculation of project emissions
Comments	N/A

Data/Parameter	EF_p
Data unit	kg CO_2/hr/km
Description	Emission factor for pipeline *p*

Equations	(8)
Source of data	Derived from US Environmental Protection Agency (EPA). *Mandatory Greenhouse Gas Reporting, Subpart W* and converted to CO_2 emission factors on a mass basis using a conversion factor of 0.6 (CH_4 to CO_2) and a CO_2 density of 0.0526 kg/ft^3 (US EPA) at standard conditions (15 °C, 1 atm). The CH_4 to CO_2 conversion factor used is taken from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2 Energy, Chapter 5 Carbon Dioxide Transport, Injection and Geological Storage, Box 5.1. Deviation of Default emission factors for CO2 pipeline transport (https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_5_Ch5_CCS.pdf)
Value applied	Factor from nationally appropriate regulations or default value of 0.26. Projects using the default value must ensure that the assumptions and underlying conversion factors taken from the above data sources are current.
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of data	Calculation of project emissions
Comments	N/A

Data/Parameter	EF_n
Data unit	kg CO_2/hr
Description	Emission factor of fugitive emissions for component *n*
Equations	(4), (8)
Source of data	Derived from US Environmental Protection Agency (EPA). *Mandatory Greenhouse Gas Reporting, Subpart W* and converted to CO_2 emission factors on a mass basis using a conversion factor of 0.6 (CH_4 to CO_2) and a CO_2 density of 0.0526 kg/ft^3 (US EPA) at standard conditions (15 °C, 1 atm). The CH_4 to CO_2 conversion factor is taken from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2 Energy, Chapter 5 Carbon Dioxide Transport, Injection and Geological Storage, Box 5.1. Deviation of Default emission factors for CO2 pipeline transport (https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_5_Ch5_CCS.pdf)

Value applied	Use the most recent data published by the above sources at the time of reporting project emissions.
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of data	Calculation of project emissions
Comments	N/A

6.2 Data and Parameters Monitored

Data/Parameter	$Q_{Fuel,d,y}$
Data unit	m^3 or kg or GJ
Description	Quantity of fuel type *d* used to operate on-site and/or third-party (for off-site heat/steam supply) equipment in year *y*
Equations	(2), (11)
Source of data	Fuel receipts/invoices or flow meter readings
Description of measurement methods and procedures to be applied	Measured from flow meters or calculated from fuel receipts/invoices.
Frequency of monitoring/recording	Aggregated annually
QA/QC procedures to be applied	Measuring equipment (e.g., flow meters, weighing scale) must operate within the manufacturer's specified operating conditions and must be routinely calibrated, inspected, and maintained according to the manufacturer's specifications.
Purpose of data	Calculation of project and leakage emissions
Calculation method	Volumetric gas flow meter readings must be corrected for temperature and pressure.
Comments	N/A

Data/Parameter	$EF_{Fuel,CO2,d}$

Data unit	t CO_2/m^3 or t CO_2/kg or t CO_2/GJ
Description	CO_2 emission factor for combustion of fuel *d*
Equations	(2)
Source of data	The following data sources may be used: 1) Emission factor from IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* 2) Emission factors published by US EPA https://www.epa.gov/climateleadership/ghg-emission-factors-hub or similar source 3) Data provided by the fuel supplier or manufacturer where the data used is consistent with that reported to a regulatory body.
Description of measurement methods and procedures to be applied	Use the most recent data published by the above sources at the time of reporting project emissions.
Frequency of monitoring/recording	Annual
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data/Parameter	$EF_{Fuel,CH4,d}$
Data unit	t CH_4/m^3 or t CH_4/kg or t CH_4/GJ
Description	CH_4 emission factor for combustion of fuel *d*
Equations	(2)
Source of data	The following data sources may be used:

	1) Emission factor from IPCC (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* 2) Emission factor from US EPA https://www.epa.gov/climateleadership/ghg-emission-factors-hub or a similar source 3) Data provided by the fuel supplier or manufacturer where the data used is consistent with that reported to a regulatory body.
Description of measurement methods and procedures to be applied	Use the most recent data published by the above sources at the time of reporting project emissions.
Frequency of monitoring/recording	Annual
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data/Parameter	$EF_{Fuel,N2O,d}$
Data unit	t N_2O/m^3 or t N_2O/kg or t N_2O/GJ
Description	N_2O emission factor for combustion of fuel *d*
Equations	(2)
Source of data	The following data sources may be used: 1) Emission factor from IPCC (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* 2) Emission factor from US EPA https://www.epa.gov/climateleadership/ghg-emission-factors-hub or a similar source

	3) Data provided by the fuel supplier or manufacturer where the data used is consistent with that reported to a regulatory body.
Description of measurement methods and procedures to be applied	Use the most recent data published by the above sources at the time of reporting project emissions.
Frequency of monitoring/recording	Annual
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data/Parameter	$Q_{Cogen,d,y}$
Data unit	m^3 or kg or GJ
Description	Quantity of fuel type *d* used by the cogeneration unit to generate electricity and/or heat in year *y*
Equations	(3)
Source of data	Fuel receipts/invoices or flow meter readings, as applicable
Description of measurement methods and procedures to be applied	Measured from flow meters or calculated from fuel receipts/invoices.
Frequency of monitoring/recording	Continuous or for every invoice, aggregated annually
QA/QC procedures to be applied	Measuring equipment (e.g., flow meters, weighing scale) must operate within the manufacturer's specified operating conditions and must be routinely calibrated, inspected, and maintained according to manufacturer specifications.
Purpose of data	Calculation of project emissions

Calculation method	Monthly fuel consumption is determined by summing the quantities from calibrated device readings or fuel receipts/invoices.
Comments	Invoices and/or contracts with the third party must be in place to allow proper data collection.

Data/Parameter	$Heat_{Sto,y}$
Data unit	MWh
Description	Quantity of useful thermal energy supplied to the storage facility by the cogeneration unit in year *y*
Equations	(3)
Source of data	Utility receipts/invoices or metered data for heat usage
Description of measurement methods and procedures to be applied	Measured from calorimeters or calculated from receipts/invoices.
Frequency of monitoring/recording	Aggregated annually
QA/QC procedures to be applied	The calorimeter must be routinely calibrated, inspected, and maintained according to manufacturer specifications.
Purpose of data	Calculation of project emissions
Calculation method	Monthly supplied heat is determined by summing the quantities from calibrated device readings or fuel receipts/invoices.
Comments	Invoices and/or contracts with the third party must be in place to allow proper data collection.

Data/Parameter	$Electricity_{Sto,y}$
Data unit	MWh
Description	Quantity of electricity supplied to the storage facility by the cogeneration unit in year *y*
Equations	(3)
Source of data	Utility receipts/invoices or metered data for electricity use

Description of measurement methods and procedures to be applied	Measured from electricity meters or calculated from receipts/invoices.
Frequency of monitoring/recording	Aggregated annually
QA/QC procedures to be applied	Electricity meters must be routinely calibrated, inspected, and maintained according to manufacturer specifications.
Purpose of data	Calculation of project emissions
Calculation method	Monthly supplied electricity is determined by summing the quantities from calibrated device readings or fuel receipts/invoices.
Comments	Invoices and/or contracts with the third party must be in place to allow proper data collection.

Data/Parameter	$Heat_{Cogen,y}$
Data unit	MWh
Description	Total quantity of useful thermal energy produced by the cogeneration unit in year *y*
Equations	(3)
Source of data	Utility receipts/invoices or metered data for heat produced
Description of measurement methods and procedures to be applied	Direct measurement of steam flows (or other heat transfer fluid) and characteristics at the cogeneration facility, taking into consideration energy content in steam and condensate return
Frequency of monitoring/recording	Aggregated annually
QA/QC procedures to be applied	Calorimeters must be routinely calibrated, inspected, and maintained according to manufacturer specifications.
Purpose of data	Calculation of project emissions
Calculation method	Monthly useful thermal energy produced by the energy facility is determined by summing the quantities from calibrated device readings or fuel receipts/invoices.

Comments	Invoices and/or contracts with the third party must be in place to allow proper data collection.

Data/Parameter	$Electricity_{Cogen,y}$
Data unit	MWh
Description	Total quantity of electricity produced by the cogeneration unit in year *y*
Equations	(3)
Source of data	Utility receipts/invoices or metered data
Description of measurement methods and procedures to be applied	Measured from electricity meters or calculated from receipts/invoices.
Frequency of monitoring/recording	Aggregated annually
QA/QC procedures to be applied	Invoices and/or contracts with the third party
Purpose of data	Calculation of project emissions
Calculation method	Monthly electricity produced by the energy facility is determined by summing the quantities from calibrated device readings or fuel receipts/invoices.
Comments	Invoices and/or contracts with the third party must be in place to allow proper data collection.

Data/Parameter	$Count_{n,y}$
Data unit	Unitless
Description	Total number of components *n* in natural gas service at the facility during year *y*
Equations	(4)
Source of data	Records of storage facility (e.g., pipe and instrument drawing, parts lists)

Description of measurement methods and procedures to be applied	Counting based on facility records as per US EPA *Electronic Code of Federal Regulations Title 40,* Chapter I, Subchapter C, Part 98, Subpart W § 98.233. Available at: https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98/subpart-W/section-98.233#p-98.233(a)(1)
Frequency of monitoring/recording	Annual
QA/QC procedures to be applied	Use the most recent data available from the storage facility.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data/Parameter	T_y
Data unit	hours
Description	Venting time in year *y*
Equations	(5), (6)
Source of data	Measurement on-site
Description of measurement methods and procedures to be applied	Venting time must be recorded.
Frequency of monitoring/recording	Monitored continuously
QA/QC procedures to be applied	Use the most recent data available from the storage facility.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data/Parameter	V_m

Data unit	t CH_4/event
Description	Vented CH_4 emissions for venting event *m*
Equations	(4)
Source of data	Data from the storage facility
Description of measurement methods and procedures to be applied	**Option 1:** Direct measurement of venting **Option 2:** Estimated based on isolated volumes of pipes and equipment **Option 3:** Estimated based on non-isolated volumes of pipes and equipment. The project proponent must determine the quantity of vented CH_4 by transient flow rate calculations for compressible fluids appropriate for the expected evolving conditions in the pipeline or component based on the approximate geometry of the escaping flow and pipelines/components connected to the venting.
Frequency of monitoring/recording	Annual
QA/QC procedures to be applied	Cross-checked based on energy balance related to metered fuel use.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data/Parameter	$V_{n,m(STP)}$
Data unit	m^3
Description	Internal volume of each pipe, pipe fitting, and component *n* in the isolated vent section for venting event *m*, at STP conditions
Equations	(7)
Source of data	Manufacturer specifications, engineering calculations, and geometric data for the pipeline and components
Description of measurement methods and procedures to be applied	The internal volume is determined through engineering calculations that use geometric data (e.g., length, diameter) and manufacturer specifications for each pipe, pipe fitting, and component within the isolated vent section. The volume is calculated for each vent event *m*.
Frequency of monitoring/recording	Recorded for each vent event *m* and aggregated annually

QA/QC procedures to be applied	Manufacturer specifications should be cross-checked with as-built documentation and verified for accuracy. Any deviations or assumptions used in the calculation must be documented and justified.
Purpose of data	Calculation of project and leakage emissions
Calculation method	The volume is calculated by applying geometric formulae to the dimensions of the pipeline and components, using the specified internal diameters and lengths as provided by the manufacturer or engineering drawings.
Comments	N/A

Data/Parameter	$T_{p,y}$
Data unit	hours
Description	Pressurized time of pipeline *p* in year *y*
Equations	(8),
Source of data	Measurement on-site
Description of measurement methods and procedures to be applied	The operating time of the monitored pipeline or component must be recorded.
Frequency of monitoring/recording	Monitored continuously
QA/QC procedures to be applied	Use the most recent data available from the storage facility.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data/Parameter	$T_{n,y}$
Data unit	hours

Description	Pressurized time of component *n* in year *y*
Equations	(4), (8)
Source of data	Measurement on-site
Description of measurement methods and procedures to be applied	The operating time of the monitored pipeline or component must be recorded.
Frequency of monitoring/recording	Monitored continuously
QA/QC procedures to be applied	Use the most recent data available from the storage facility.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data/Parameter	$Q_{LE,a}$
Data unit	tonnes
Description	Quantity of CO_2 released from the storage reservoir during leak event *a*
Equations	(9)
Source of data	Estimated
Description of measurement methods and procedures to be applied	Use the reservoir model, and monitoring data available to estimate a quantity of CO_2 released from the reservoir
Frequency of monitoring/recording	At each loss event
QA/QC procedures to be applied	Dependent on the method(s) used

Purpose of data	Calculation of project emissions
Calculation method	Calculated based on procedures provided in Section 6.3.
Comments	N/A

Data/Parameter	$Q_{Threshold,y}$
Data unit	tonnes
Description	Maximum undetected quantity of CO_2 that may have leaked, as defined in the monitoring plan
Equations	(9)
Source of data	Calculated based on procedures provided in Section 6.3
Description of measurement methods and procedures to be applied	Calculated based on procedures provided in Section 6.3
Frequency of monitoring/recording	Updated in line with the updated monitoring plan
QA/QC procedures to be applied	Dependent on the method(s) used
Purpose of data	Calculation of project emissions
Calculation method	Calculated based on procedures provided in Section 6.3
Comments	N/A

Data/Parameter	$EF_{Upstream\_Fuel,d,y}$
Data unit	t CO_2e/m^3 or t CO_2e/kg or t CO_2e/GJ
Description	Emission factor for upstream sources related to fuel type *d* used in equipment in the storage module boundary in year *y*,
Equations	(11)

Source of data	The value of this parameter may be obtained from the following sources: 1) An LCA conducted by a qualified third party in accordance with the most recent versions of ISO 14040 and 14044, that uses either primary or published and peer-reviewed data[5] 2) A compliance market-approved tool (e.g., such as CA-GREET[6], GHGenius[7]); 3) Emission factors published in peer-reviewed literature[8] that are representative of the fuels used at the storage site both temporally and geographically 4) Data provided by the fuel supplier or manufacturer where the data used is consistent with that reported to a regulatory body.
Description of measurement methods and procedures to be applied	Use the most recent data published by the above sources at the time of reporting project emissions.
Frequency of monitoring/recording	Annual
QA/QC procedures to be applied	Use the most recent data published by the above sources at the time of reporting project emissions. Where peer-reviewed literature is used, it must have been published within a year of reporting project emissions. It must be temporally and geographically representative of the storage site.
Purpose of data	Calculation of leakage emissions
Calculation method	N/A
Comments	N/A

[5] State or national government data on a fuel's carbon intensity are also acceptable sources of data for determining emission factors for fuels used by the transport facility.

[6] The Greenhouse Gases, Regulated Emissions and Energy use in Technologies (GREET) model. Available at: https://greet.es.anl.gov/

[7] Model for Life Cycle Assessment of Transportation Fuels. Available at: https://www.ghgenius.ca/

[8] Peer-reviewed literature must be indexed in the Web of Science: Science Citation Index (SCI; available at https://mjl.clarivate.com), as specified in Section 2.5.2 of the *VCS Methodology Requirements, v4.4*.

6.3 Description of the Monitoring Plan

Each project must have a monitoring plan that supports the permanent storage of CO_2 injected by ensuring the containment of the plume over time. In addition to the requirements given in the *VCS Standard* and the *GCS Requirements*, the monitoring plan must:

1) Outline the mandatory monitoring point(s) for CO_2 injection downstream of all intermediate storage, compression, or other CO_2 conditioning.
    a) For onshore injection wells:
        i) Where multiple injection wellheads are served by one mandatory monitoring point, it must be located 500 m or less by run-of-pipe from all injection wellhead(s).
        ii) Where one injection wellhead is served by one mandatory monitoring point, it must be located 300 m or less by run-of-pipe from the injection wellhead.
    b) For offshore injection wells:
        i) Where offshore wells are connected by sub-sea pipeline to onshore facilities, the mandatory monitoring point must be located 500 m or less by run-of-pipe from the pipeline landfall point.
        ii) Where offshore wells are connected to fixed or floating platforms, the mandatory monitoring point must be located 500 m or less by run-of-pipe from the submersion point.
2) Describe techniques used to detect, localize, and quantify subsurface CO_2 movement outside the geological storage complex of the project, including relevant parameters of each technique such as the detection threshold, probability of detection, resolution, and frequency.
3) Define a specific detection threshold to detect a loss of containment (e.g., t CO_2/year or t CO_2) for each monitoring technique.
4) Define the expected mean time to detect a loss of containment at the project-specific threshold for each intermittent monitoring technique (considering the planned frequency of use). The specific detection threshold to detect a loss of containment and the expected mean time to detection must also be specified in the project description.
5) Outline how the reservoir model and monitoring approaches are used to localize and quantify the loss of containment.
6) Define the maximum undetected leak ($Q_{Threshold,y}$) by considering all of the following:
    a) Leak estimations for each likely pathway (based on each unique loss of containment incident) and the summation of the emissions released from each pathway respectively (total sum);

b) For continuous monitoring approaches, the threshold for detection as defined in the monitoring plan, and

c) For discontinuous monitoring approaches, the threshold for detection and the expected mean time to detect a loss of containment as defined in the monitoring plan.

6.3.1 Loss of Conformance and Containment Events

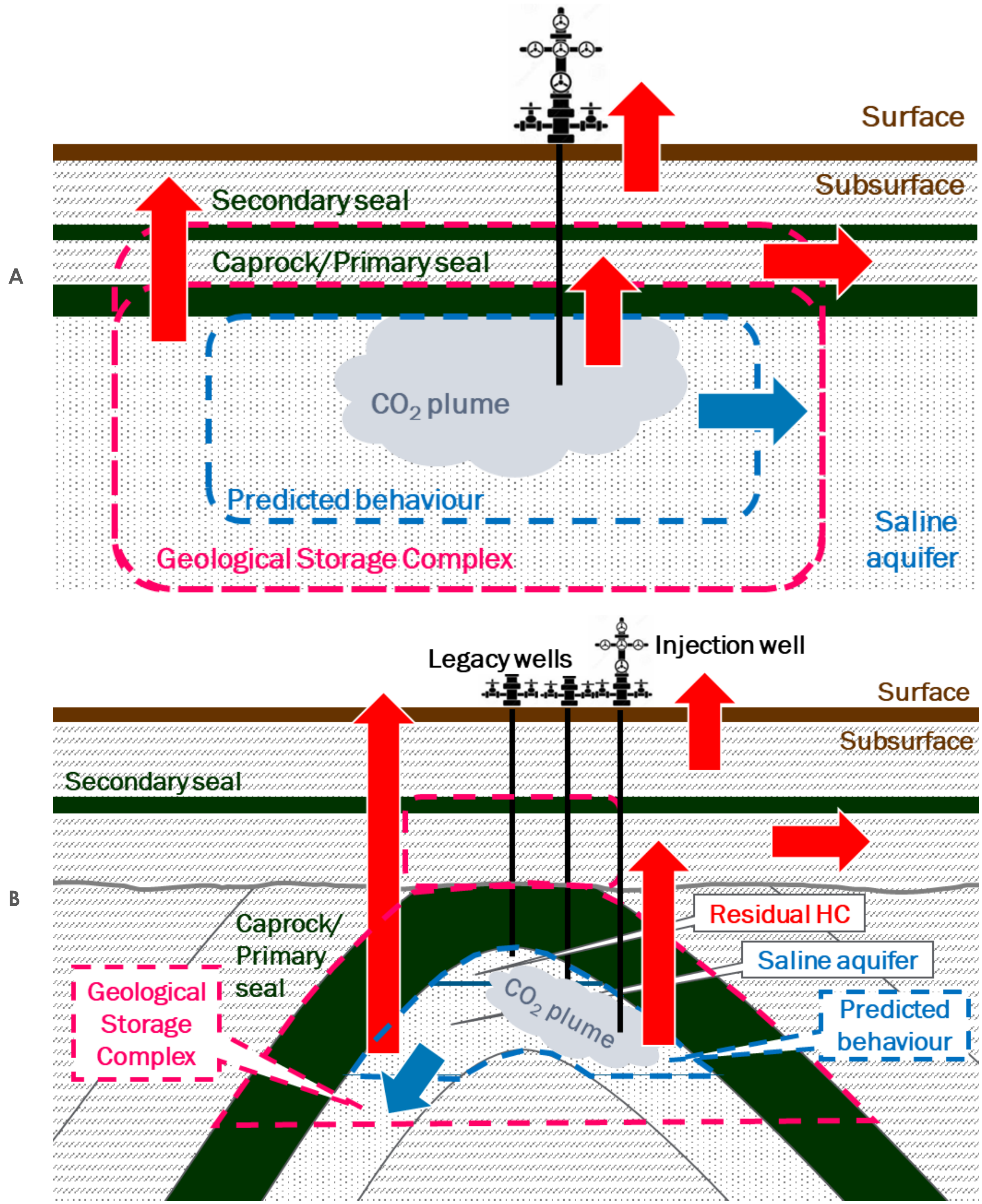
The monitoring plan must be able to detect losses of conformance and containment.

A loss of conformance occurs where the injected CO_2 does not adhere to the predicted behavior based on the reservoir model but remains within the target geological storage complex and does not migrate outside of a seal(s). A loss of conformance may lead to a loss of containment.

A loss of containment occurs where the injected CO_2 migrates out of the geological storage complex and its respective seal(s). A loss of containment may occur in another subsurface layer or directly in the atmosphere. For example, this may occur along a wellbore or natural or induced fractures.

A simplified representation of the subsurface is provided in Figure 3. Acknowledging the complexity and heterogeneity of the subsurface, only one type of reservoir and several potential flow pathways are provided as examples.

Figure 3: Simplified representation of losses of containment (red arrows) and conformance (blue arrow) examples for A) saline aquifers and B) depleted hydrocarbon reservoirs



Upon identification of a loss of CO_2 conformance, and prior to the subsequent verification, the project proponent must:

1) Evaluate the potential for current or future release to the atmosphere,
2) Identify the root cause(s) for the loss of conformance, and
3) Revise the monitoring plan to reflect the changed CO_2 migration.

Upon detecting a loss of containment, the project proponent must halt injection at the affected storage site.

Upon localizing and quantifying a loss of containment, the project proponent must determine whether the loss of containment can be repaired. Injection at the concerned storage site must not resume until containment has been fully re-established.

At the concerned storage site, the project cannot generate emission reduction or removal credits until the following conditions are resolved:

a) The loss of containment is stopped,
b) Permanent storage is restored, and
c) The loss of containment is quantified.

Projects are no longer eligible where the quantity of CO_2 lost is more than 10% of the total CO_2 injected in the project.

The procedures of the *VCS Registration and Issuance Process* and the *GCS Non-Permanence Risk Tool* apply where a loss of containment occurs. If in a monitoring period, the net emission reduction or removal benefits are negative as a result of a loss event, the proponent must submit a loss event report using the *Loss Event Report Template*.

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DOCUMENT HISTORY

Version	Date	Comment
v1.0	October 24, 2024	Initial version