



**Verified Carbon
Standard**

MODULE FOR CO₂ STORAGE IN SALINE AQUIFERS AND DEPLETED HYDROCARBON RESERVOIRS



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1 SOURCES

This module is used in combination with the latest version of the following methodologies, modules, and tools:

- *VM00XX Methodology for Carbon Capture and Storage*

Capture Modules

- *VMD00XX Module for CO₂ Capture from Air (Direct Air Capture)*
- *VMD00XX Module for CO₂ Capture from Bioenergy Combustion*
- *VMD00XX Module for CO₂ Capture from Bioproduction Processes*
- *VMD00XX Module for CO₂ Capture from Post combustion Flue Gases in Fossil Fuel Power and Heat Generation*
- *VMD00XX Module for CO₂ Capture from Industrial Processes*
- *VMD00XX Module for CO₂ Capture from Oil and Gas Production and Processing*
- *VMD00XX Module for CO₂ Capture from Precombustion Processes in Fossil Fuel Power and Heat Generation*
- *VMD00XX Module for CO₂ Capture from Oxyfuel Combustion in Fossil Fuel Power and Heat Generation*

Transport Module

- *VMD00XX Module for CO₂ Transport*

Other Modules/Tools

- *VT00XX Tool for Differentiating Reductions and Removals in CCS Projects*
- *VMT00XX: Tool for non-VCS CO₂ in Carbon Capture and Storage Projects*
- *GCS Non-Permanence Risk Tool*

VCS Program Requirements/Tool(s):

- *Geologic Carbon Storage (GCS) Requirements*

2 SUMMARY DESCRIPTION OF THE MODULE

This module provides procedures and requirements for project activities that store CO₂ in saline aquifers or depleted hydrocarbon reservoirs for eligible Carbon Capture and Storage (CCS) project activities under *VM00XX Methodology for Carbon Capture and Storage*.

3 DEFINITIONS

In addition to the definitions set out in the *Program Definitions* of the VCS Program, the following definitions apply to this module:

Depleted Hydrocarbon Reservoir

A subsurface reservoir that previously had hydrocarbons (e.g., oil or gas). These have been produced through legacy wells.

CO₂ Conditioning

The treatment of an incoming CO₂ stream to achieve the required conditions for transport and/or injection and storage of the CO₂ in a CCS project activity. It may include various processes, including but not limited to refrigeration, dehydration, desulphurization, deoxygenation, and compression.

Conformance

The degree of agreement between reservoir model predictions and current measured data and performance from the storage reservoir for a geologic carbon storage (GCS) project.

Geological Reservoir

Subsurface body of rock with sufficient porosity and permeability to receive, transmit, and contain fluids, particularly super-critical or dense phase CO₂, including areas or zones for expansion and migration of the CO₂ plume defined by the reservoir modelling.

Geological Storage Complex

The geological storage complex consists of the geological reservoir and an overlying impermeable seal (or caprock) that prevents the escape of the fluids and includes other reliable trapping mechanisms.

Intermediate Storage

Intermediate storage includes the processes and equipment on a site that enables temporary storage of CO₂ in transit during the transfer of CO₂ from one mode of transport to another (e.g., transfer of CO₂ from a pipeline to transport by ship).

Legacy Wells

Wells that have been drilled prior to the project activity and penetrate the primary and/or secondary seal(s) of the storage complex. They must be included in the site characterization and monitoring plan.

Mandatory Monitoring Point

The locations where equipment is required to be in place to measure the volume of CO₂.

Non-condensable Gas

Non-condensable gases do not condense into the liquid phase within a system's operating pressure and temperature. They are relevant for geothermal power/heat plants.

Non-VCS CO₂

CO₂ that flows through a CCS project boundary that is not eligible for crediting in the VCS

Saline Aquifer

An underground water source with total dissolved solids greater than 3,000 mg/L.

Storage Facility

Any facility used for geological storage of CO₂ within the storage module project boundary.

VCS-CO₂

The CO₂ captured, transported (as applicable), and stored inside the project boundary of a proposed/registered CCS project under the VCS Program.

4 APPLICABILITY CONDITIONS

In addition to the criteria set forth in the latest version of the Geological Carbon Storage Requirements, this module applies to project activities that store CO₂ safely and permanently in saline aquifers or depleted hydrocarbon reservoirs per the criteria and procedures established under the latest version of the *VM00XX Methodology for Carbon Capture and Storage*.

This module is applicable under the following conditions:

- 1) The project activity injects a CO₂ stream for permanent storage into a saline aquifer or depleted hydrocarbon reservoir.
- 2) The project activity has mandatory monitoring point(s) for CO₂ injection downstream of all intermediate storage, compression, or other CO₂ stream conditioning (per Section 7.3), and
- 3) The project activity has an isolation valve on the wellhead or within 10m of the point where the CO₂ stream enters the subsurface by run-of-pipe to isolate the surface and sub-surface,

This module is not applicable under the following conditions:

- 1) Project activities that store CO₂ with intentions to produce it in the future for any reason.
- 2) Efficiency improvement projects: Upgrades to existing CCS storage facilities or changes in operational practices leading to improved storage efficiency cannot be registered as a new project activity by itself. For storage projects already registered under VCS, such

improvements may occur and would be considered in calculating the baseline and the project emissions over the crediting period for that respective project.

- 3) Injection of CO₂ for enhanced oil recovery (EOR) or enhanced gas recovery (EGR)
- 4) Injection of CO₂ in a storage complex with a saline aquifer connected to a producing hydrocarbon reservoir.

5 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 CO₂ 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 CO₂
- Final compression and/or conditioning of CO₂ before injection
- Injection pipelines and wells, legacy wells, wellhead piping, valves, and monitoring instrumentation
- SCADA/communication equipment
- Injection well pad workovers or other maintenance operations
- CO₂ booster pumps, seal losses, and electricity consumption
- CO₂ compression with interstage cooling, valve/seal losses, and electricity consumption or fuel use
- Dehydration units (triethylene glycol or TEG, Desiccants, Refrigeration, etc.) and associated reboilers or regeneration units

The physical boundary of the module is shown in Figure 1.

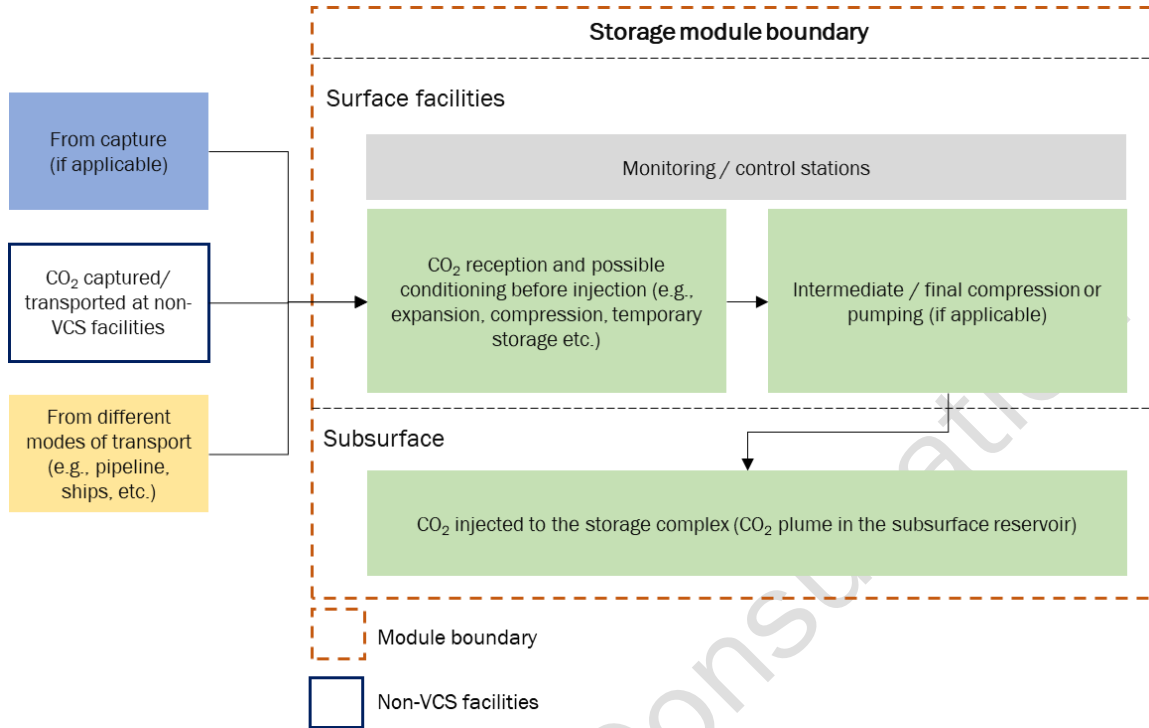


Figure 1- Module Boundary for CO₂ Storage

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

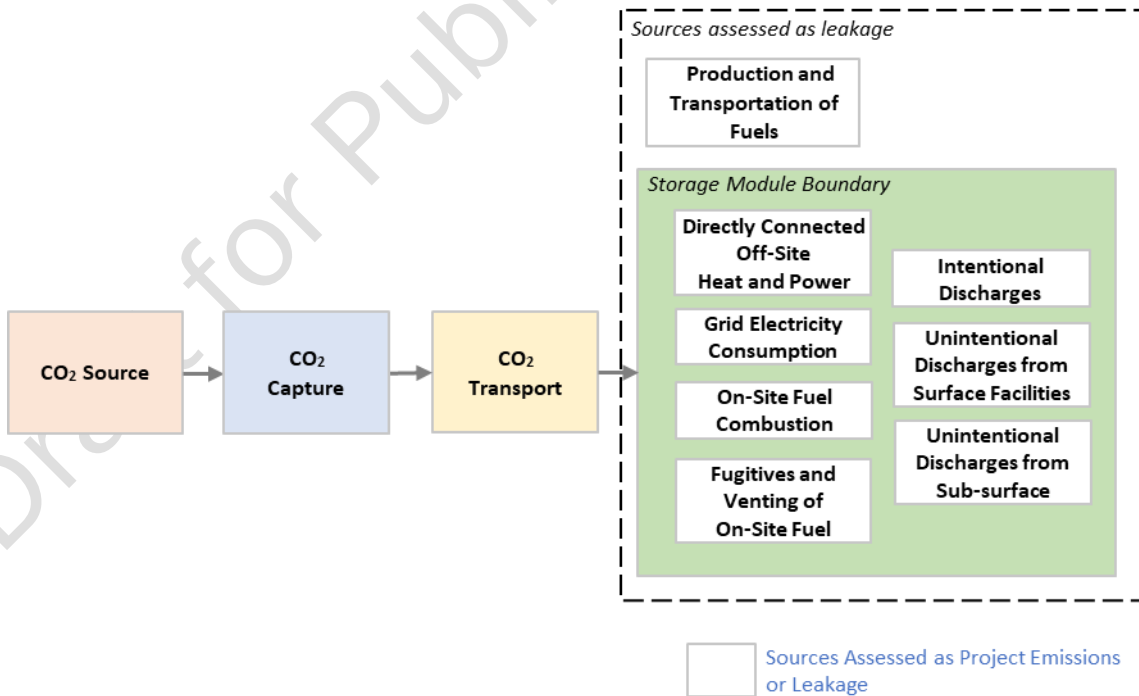


Figure 2- Boundary for Primary and Secondary Project Activity Effects

The GHGs included or excluded from the module boundary are detailed in Table 1.

Table 1: GHG Sources Included or Excluded from the Project Boundary

Source	Gas	Included?	Justification/Explanation	
Project	CO₂ Storage			
	Electricity consumption	CO ₂	Yes	Major emission source
		CH ₄	Yes	Significant upstream emission source
		N ₂ O	Yes	Included for completeness
		Other	No	Excluded for simplicity, emissions are considered negligible.
	Fuel consumption	CO ₂	Yes	Major emission source
		CH ₄	Yes	Significant upstream emission source
		N ₂ O	Yes	Included for completeness
		Other	No	Excluded for simplicity, emissions are considered negligible.
	CO ₂ stream processing	CO ₂	Yes	Included. Any loss of CO ₂ due to fugitive emissions or venting during capture is inherently deducted from the overall calculation of GHG emission reductions since only injected CO ₂ volumes are quantified as the baseline emissions.
		CH ₄	No	Excluded as also not considered under the baseline scenario.
		N ₂ O	No	Excluded as also 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	Yes	Depleted hydrocarbon reservoirs: emission source. <i>Saline aquifers: Excluded as also not considered under the baseline scenario.</i>
		N ₂ O	No	Excluded as also not considered under the baseline scenario.
Other		No	Excluded for simplicity, emissions are considered negligible.	

6 QUANTIFICATION PROCEDURES

6.1 Quantification of Project Emissions

The project emissions are calculated as follows:

$$PE_{Sto,y} = PE_{Comb_Fuel,y} + PE_{Elec,y} + ID_{Injection,y} + UD_{Injection,y} + ID_{Storage,y} + UD_{Storage,y} - PE_{nonVCS\ CO_2,y} \quad (1)$$

Where:

$PE_{Sto,y}$	=	Project emissions from storage in the year y (tCO ₂ e)
$PE_{Comb_Fuel,y}$	=	Project emissions from fuel combustion to operate equipment for storage processes in the year y (tCO ₂ e).
$PE_{Elec,y}$	=	Project emissions from electricity consumption to operate storage processes in the year y (tCO ₂ e).
$ID_{Injection,y}$	=	Intentional discharges of CO ₂ from surface equipment downstream from the mandatory monitoring points (tCO ₂ e)
$UD_{Injection,y}$	=	Unintentional discharges of CO ₂ from surface equipment downstream from the mandatory monitoring points (tCO ₂ e)
$ID_{Storage,y}$	=	Intentional discharges of CO ₂ from subsurface storage (tCO ₂ e)
$UD_{Storage,y}$	=	Unintentional discharges of CO ₂ from subsurface storage (tCO ₂ e)
$PE_{nonVCS,s,y}$	=	Project emissions from processes and equipment related to non-VCS sources in year y (tCO ₂ e) to be determined as per the latest version of the VMT00XX: <i>Tool for non-VCS CO₂ in Carbon Capture and Storage Projects</i> . For projects without non-VCS CO ₂ , $PE_{nonVCS,s,y} = 0$ (tCO ₂ e)

6.1.1 Project emissions from fuel combustion

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

$$PE_{Comb_Fuel,y} = \sum_i (Q_{Fuel,i,y} \times EF_{Fuel,CO_2,i}) + \sum_i (Q_{Fuel,i,y} \times EF_{Fuel,CH_4,i}) \times GWP_{CH_4} + \sum_i (Q_{Fuel,i,y} \times EF_{Fuel,N_2O,i}) \times GWP_{N_2O} \quad (2)$$

Where:

$PE_{Comb_Fuel,y}$ = Project emissions from fuel combustion for mobile equipment, on and off-site power and heat generation in year y (tCO₂e)

$Q_{Fuel,i,y}$ = Quantity of each type of fuel i for on-site and off-site mobile equipment, power and heat generation in year y (m³ or kg or GJ)

$EF_{Fuel,CO_2,i}$ = CO₂ emission factor of fuel i in year y (tCO₂/m³, tCO₂/kg or tCO₂/GJ)

$EF_{Fuel,CH_4,i}$ = CH₄ emission factor of fuel i in year y (tCH₄/m³, tCH₄/kg or t CH₄/GJ)

$EF_{Fuel,N_2O,i}$ = N₂O emission factor of fuel i in year y (tN₂O/m³, tN₂O/kg or tN₂O/GJ)

GWP = Global warming potential (for CH₄ and N₂O, respectively)

Off-site fuel consumption:

If power or heat is supplied from a directly connected off-site facility, $Q_{Fuel,i,y}$ must be determined as a proportion of the total fuel used to generate the total electricity and heat generated by the directly connected facility with the following Equation:

$$Q_{Fuel,i,y} = Q_{fuel_cogen,i,y} \times \frac{(Heat_{sto,y} + Electricity_{sto,y})}{(Heat_{cogen,y} + Electricity_{cogen,y})} \quad (3)$$

Where:

$Q_{Fuel,i,y}$ = Mass of a fuel type used by a third-party energy source to provide electricity and/or thermal energy to the storage module in year y (metric tons/year)

$Q_{fuel_cogen,i,y}$ = The total mass of a fuel type used by the energy facility unit to generate electricity and/or heat in year y (metric tons/year)

$Heat_{sto,y}$ = Quantity of useful thermal energy supplied to the storage module by the energy facility unit in year y (MWh/year)

$Electricity_{sto,y}$ = Quantity of electricity supplied to the storage module by the facility unit in year y (MWh/year)

$Heat_{cogen,y}$ = The total quantity of useful thermal energy produced by the energy facility unit in year y (MWh/year)

$Electricity_{cogen,y}$ = Total quantity of electricity produced by the energy facility unit in year y (MWh/year)

Waste heat:

Project emissions from waste heat are zero. Waste heat must meet the conditions in the baseline section.

Biogenic fuel sources:

Where biofuel or biomass that complies with the definition and conditions of sustainable biomass as provided by the latest version of *VMD00XX Module for CO₂ Capture from Bioenergy Combustion* is used, the emissions are considered zero. Otherwise, emissions from the combustion of biofuel or biomass must be accounted for using Equation (2).

6.1.2 Project emissions from electricity consumption

Project emissions from electricity consumption are calculated as follows:

$$PE_{Elec,y} = Q_{Elec,y} \times EF_{Elec} \tag{4}$$

Where:

- $PE_{Elec,y}$ = Project emissions from electricity consumption to operate equipment in the storage module the year y (tCO₂e).
- $Q_{Elec,y}$ = Total metered electricity usage to operate equipment in the storage module in year y (MWh/year)
- EF_{Elec} = Emissions factor for electricity generation (tCO₂e/MWh).

For on-site or directly connected off-site electricity generation, the emissions related to electricity consumption must be determined based on the related fuel consumption as per the provisions under the parameters $PE_{Comb_Fuel,y}$ and $PE_{Emb_Fuel,y}$.

Regional emission factors from compliance tools and data published by State or National government must be used for grid electricity consumption. Project proponents must reference the sources and provide evidence of the electricity procurement.

Project emissions from renewable energy power plants (i.e., wind, solar, hydro) that are directly connected and off-grid captive are zero. Project proponents must provide evidence of a direct connection.

For electricity consumption from a dedicated geothermal power plant, the emission factor must consider CO₂ emissions from releasing non-condensable gases.

6.1.3 Project emissions of intentional discharges

Project emissions from intentional discharges are a result of venting that is downstream of the mandatory monitoring points. Venting events can be differentiated by whether they originate from surface facilities or the subsurface. Surface venting includes activities resulting from operator intervention (e.g., blowdown of piping, pigging operations) or an automated system response to process conditions (e.g., pressure safety valve releasing in response to high pressure as per its design). For surface venting, the proponent may measure the quantity of CO₂ according to the conditions given in Approach 1, 2, or 3. Subsurface venting includes activities related to injection well maintenance. For subsurface venting, the proponent must determine the quantity of CO₂ according to Approach 1.

Approach 1: Measurement of venting

Under this approach $ID_{Injection/Storage,y}$ must be calculated with one of the following options:

Option 1: Mass flow

$$ID_{Injection/Storage,y} = FR_{mass,x} \times \%CO2_{mass,x} \times T_{x,y} \quad (5)$$

Where:

- $ID_{Injection/Storage,y}$ = Intentional discharges of CO₂ from the surface (i.e., injection) or subsurface (i.e., storage) in year y (tCO₂e)
- $FR_{mass,x}$ = Mass flow measured by mass flow meter x (tonnes)
- $\%CO2_{mass,x}$ = CO₂ concentration in the mass flow at mass flow meter x (% mass)
- $T_{x,y}$ = Venting time in year y (hour)

Option 2: Volumetric flow

$$ID_{Injection/Storage,y} = FR_{vol,x(STP)} \times \%CO2_{vol,x(STP)} \times \rho CO2_{x(STP)} \times T_{x,y} \quad (6)$$

Where:

- $FR_{vol,x(STP)}$ = Volumetric flow rate measured by flow meter x at actual conditions and converted to STP conditions (m³)
- $\%CO2_{vol,x(STP)}$ = Volumetric fraction of CO₂ in flow at flow meter x at STP conditions (% volume)
- $\rho CO2_{x(STP)}$ = Density of CO₂ at STP conditions (tCO₂/m³)

Please refer to Section 8.1 of *VM00XX Methodology for Carbon Capture and Storage* to determine CO₂ flow, density, and concentration.

Approach 2: Estimation of surface venting for isolated volumes

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

$$ID_{Injection,y} = \sum_i V_{i(STP)} \times \%CO2_{vol,x(STP)} \times \rho_{CO2,x(STP)} \tag{7}$$

Where:

- $ID_{Injection,y}$ = Intentional discharges of CO₂ downstream the mandatory monitoring point(s) of CO₂ injection in year y (tCO₂e)
- $V_{i(STP)}$ = Internal volume of each pipe, pipe fitting, and component i (m³) in the isolated vent section using engineering calculations based on the manufacturer's specifications and geometric data for the pipeline length converted to volume at STP conditions.
- i = Vent event index number

Please refer to Section 8.1 of *VM00XX Methodology for Carbon Capture and Storage* to determine CO₂ flow, density, and concentration.

Approach 3: Estimation of surface venting for non-isolated volumes

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

The proponent must determine the quantity of vented CO₂ ($ID_{Injection,y}$) by transient flow rate calculations for compressible fluids appropriate for the expected evolving conditions in the pipeline or component (gaseous, dense, super-critical, etc.) based on the approximate geometry of the escaping flow and pipelines/components connected to the venting.

6.1.4 Project emissions from unintentional discharges at the surface

The potential emission sources for unintentional discharges of CO₂ include but are not limited to:

- Components such as valves, pipe fittings/connectors, open-ended pipes, pressure relief valves, flanges, meters, and instruments; and
- Pipelines.

Two emission sources are considered for unintentional discharge of CO₂ at the surface:

Emission source 1: Fugitive emissions downstream of the mandatory monitoring point

In this scenario, $UD_{injection,y}$ can be determined per the following equations:

For pipeline:

$$UD_{Injection,y} = \sum EF_{pipeline} \times T_{i,y} \times d \times 0.001 \quad (8)$$

For other components:

$$UD_{Injection,y} = \sum EF_{component} \times T_{i,y} \times 0.001 \quad (9)$$

Where:

$UD_{Injection,y}$ = Unintentional discharges of CO₂ downstream from the mandatory monitoring point(s) of CO₂ injection in year y (tCO₂e)

$EF_{pipeline}$ = Emission factor derived from IPCC guidelines for GHG inventories, Chapters 4 and 5. A default value of 0.26 kg/(hr*km) for pipelines can be used¹. Alternatively, the emission factors may be derived from nationally appropriate regulations.

$EF_{component}$ = Emission factor derived from subpart W of US EPA, mandatory GHG reporting. A default value of 0.005 kg/hr/component can be used. Alternatively, the emission factors may be derived from nationally appropriate regulations, equivalent to the mentioned US EPA reporting guideline.

$T_{i,y}$ = Pressurized time of the pipeline or component in year y (hours)

d = Length of the pipeline from mandatory monitoring point to injection well (km)

Emission source 2: Rupture or line-break downstream of the mandatory monitoring point

A rupture or line-break failure is considered to have occurred if the flow rate through the failure is substantial enough to be a safety hazard or off-site nuisance due to odor or noise. Otherwise, the failure may be considered a fugitive emission.

¹ Note that $EF_{pipeline}$ and $EF_{component}$ are derived based on US Environmental Protection Agency (EPA), Mandatory Greenhouse Gas Reporting, Subpart W and converted to CO₂ emission factors on a mass basis. The conversion is carried out by using a conversion factor of 0.6 (CH₄ to CO₂) according to Chapter 5 of IPCC Guidelines for National Greenhouse Gas Inventories and a CO₂ density of 0.0526 kg/ft³ (used in US EPA) at the standard condition (15 °C, 1 atm).

When 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:

- Isolate the failure and
- Quantify the loss of CO₂ ($UD_{injection,y}$):
 - Emissions before isolation: determine the quantity of lost CO₂ 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 (gaseous, dense, super-critical, etc.) based on the approximate geometry of the escaping flow and pipelines/components connected to the failure. The estimation must be made for the approximate time between when the failure occurred and when the release was stopped. If the approximate time when the failure occurred is unknown, the leakage event's 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 stopped.
 - Emissions after isolation: use equations from section 6.1.3 for approach 2 to calculate the leaked emissions.

6.1.5 Project emissions from unintentional discharges from subsurface storage

Project emissions from unintentional discharges from the subsurface are CO₂ leaks from the geological storage complex. They are calculated according to the following Equation:

$$UD_{Storage,y} = \sum Q_{LE} + Q_{Threshold,y} \quad (10)$$

Where:

$UD_{Storage,y}$ = Unintentional discharges of CO₂ and/or CH₄ from subsurface storage in year y (tCO₂e)

Q_{LE} = Quantity of CO₂ and/or CH₄ released from a leak event from the storage reservoir in year y (tCO₂e)

$Q_{Threshold,y}$ = Maximum undetected quantity of CO₂ and/or CH₄ that may have leaked as defined in the monitoring program document (tCO₂e)

Section 7.3 provides more guidance on determining Q_{LE} and $Q_{Threshold,y}$.

6.2 Quantification of Leakage

Equation (11) accounts for the leakage emissions in this module.

$$LE_{Sto,y} = LE_{Fuel,y} + LE_{Elec,y} \quad (11)$$

Where:

- $LE_{Sto,y}$ = Leakage emissions from storage in the year y (tCO₂e)
- $LE_{Fuel,y}$ = GHG emissions from upstream fuel consumption for storage processes in the year y (tCO₂e).
- $LE_{Elec,y}$ = GHG emissions from upstream electricity consumption to operate storage processes in the year y (tCO₂e).

6.2.1 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 (12).

$$LE_{Fuel,y} = \sum (Q_{Fuel,i,y} \times EF_{Upstream_Fuel,i,y}) \quad (12)$$

Where:

- $LE_{Fuel,y}$ = Leakage emissions from upstream sources related to the fuel consumed in on-site equipment in the year y (tCO₂e).
- $Q_{Fuel,i,y}$ = Quantity of fuel type i used in the storage module equipment and/or third party (for off-site energy supply) in year y (m³ or kg or GJ)
- $EF_{Upstream_Fuel,i,y}$ = Emission factor of upstream fuel type i used in the storage module equipment in year y (tCO₂e/m³, tCO₂e/kg or tCO₂e/GJ)
Alternatively, a default factor can be used that equals 20% of the CO₂ Emission factor from the combustion of fuel i

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

Projects where no separate information on $EF_{Fuel,i}$ and $EF_{Upstream_Fuel,i,y}$ is available, may use a combined emission factor and apply it in Equation (2) accordingly.

The emission factor for the production, processing, and transport of fuel used for storage or used by a third party to provide heat or steam to the storage facility must be accounted for using a life cycle analysis (LCA) that is consistent with the storage module boundaries (i.e., primary and secondary effects).

6.2.2 Leakage emissions from upstream electricity consumption

Project emissions from upstream electricity consumption are calculated according to the following Equation (13).

$$LE_{Elec,y} = Q_{Elec,y} \times EF_{Upstream_Elec} \quad (13)$$

Where:

$LE_{Elec,y}$ = Leakage emissions from electricity consumption to operate equipment in the storage module the year y (tCO₂e).

$Q_{Elec,y}$ = Total metered electricity usage to operate equipment in the storage module in year y (MWh/year)

$EF_{Upstream_Elec}$ = Emissions factor for upstream GHG sources related to electricity generation (tCO₂e/MWh).

For on-site or directly connected off-site electricity generation, the emissions related to electricity consumption must be determined based on the related fuel consumption considering project and leakage emissions as described in this module.

For grid electricity consumption, published emission factors from regional compliance market-approved tools and/or data published by State or National government agencies must be used. Project proponents must reference the sources and provide evidence of the electricity procurement.

For directly connected wind, solar, or hydropower plants that are off-grid captive plants, energy supplied is deemed to have no emissions. Project proponents must provide evidence of a direct connection.

For electricity consumption from a dedicated geothermal power plant, CO₂ emissions from the release of non-condensable gases must be considered in the emission factor.

Projects where no separate information on EF_{Elec} and $EF_{Upstream_Elec}$ is available may use a combined emission factor and apply it in Equation (2) accordingly.

7 MONITORING

7.1 Data and Parameters Available at Validation

Additional data and parameters are defined in the respective *VM00XX Methodology for Carbon Capture and Storage* and related tools (VCS and CDM) as applicable. Please refer to Section 8.1 of *VM00XX Methodology for Carbon Capture and Storage* to determine CO₂ quantities.

Data / Parameter	GWP _{CH₄}
Data unit	t CO ₂ e/t CH ₄
Description	Global warming potential for CH ₄
Equations	(2)
Source of data	The latest version of the VCS Standard
Value applied	See the latest version of the VCS Standard.
Justification of choice of data or description of measurement methods and procedures applied	Unless otherwise directed by the VCS Program, the latest version of the VCS Standard requires that CH ₄ must be converted using the 100-year global warming potential derived from the IPCC Fourth Assessment Report.
Purpose of Data	Calculation of project emissions
Comments	

Data / Parameter	GWP _{N₂O}
Data unit	t CO ₂ e/t N ₂ O
Description	Global warming potential for N ₂ O
Equations	(2)
Source of data	The latest version of the VCS Standard
Value applied	See the latest version of the VCS Standard.
Justification of choice of data or description of	Unless otherwise directed by the VCS Program, the VCS Standard requires that N ₂ O must be converted using the 100-year global warming potential derived from the IPCC Fourth Assessment Report.

measurement methods and procedures applied	
Purpose of Data	Calculation of project emissions
Comments	

Data / Parameter	d
Data unit	km
Description	Length of the pipeline (km)
Equations	(8)
Source of data	Manufacture specifications, part lists, measurement
Value applied	-
Justification of choice of data or description of measurement methods and procedures applied	-
Purpose of Data	Calculation of project emissions

Data / Parameter	$EF_{pipeline}$
Data unit	kgCO ₂ /(hr*km)
Description	The emission factor of pipeline
Equations	(8)
Source of data	Nationally appropriate regulations, equivalent to the US EPA reporting guideline.
Value applied	-
Justification of choice of data or description of measurement methods and procedures applied	-

Purpose of Data	Calculation of project emissions
Data / Parameter	$EF_{component}$
Data unit	kgCO ₂ /(hr*km)
Description	The emission factor of components
Equations	(9)
Source of data	Nationally appropriate regulations, equivalent to the mentioned US EPA reporting guideline.
Value applied	-
Justification of choice of data or description of measurement methods and procedures applied	-
Purpose of Data	Calculation of project emissions

7.2 Data and Parameters Monitored

Refer to Section 8.1 of *VM00XX Methodology for Carbon Capture and Storage* to determine CO₂ quantities.

Data / Parameter:	$Q_{Fuel,i,y}$
Data unit:	m ³ , kg or GJ in a year y
Description:	Quantity of each fuel type i used in the storage module
Equations	(2) and (12)
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:	Flow meters must be operated within the manufacturer's specified operating conditions. Flow meters 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:	None

Data / Parameter:	$EF_{Fuel,CO_2,i}$
Data unit:	tCO ₂ /m ³ , tCO ₂ /kg or tCO ₂ /GJ
Description:	CO ₂ Emission factor from the combustion of fuel i in year y
Equations	(2)
Source of data:	The following data sources may be used: <ol style="list-style-type: none"> 1) Emission factor prescribed by 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. New York: Cambridge University Press: Intergovernmental Panel on Climate Change Retrieved May 18, 2022, from https://www.ipcc.ch/report/ar6/wg1/; 2) Emission factors published by US EPA or similar source; https://www.epa.gov/climateleadership/ghg-emission-factors-hub; or 3) Data provided by the fuel supplier.
Description of measurement methods and procedures to be applied:	Use the latest 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:	$EF_{Fuel,CH_4,i}$
Data unit:	tCH ₄ /m ³ , t CH ₄ /kg or t CH ₄ /GJ
Description:	CH ₄ Emission factor from the combustion of fuel i in year y
Equations	(2)
Source of data:	<p>The following data sources may be used:</p> <ol style="list-style-type: none"> 1) Emission factor prescribed by IPCC. (use the latest version). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press: Intergovernmental Panel on Climate Change Retrieved May 18, 2022, from https://www.ipcc.ch/report/ar6/wg1/; 2) Emission factors published by US EPA or a similar source, https://www.epa.gov/climateleadership/ghg-emission-factors-hub; or 3) Data provided by the fuel supplier.
Description of measurement methods and procedures to be applied:	Use the latest 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:	None

Data / Parameter:	$EF_{Fuel,N_2O,i}$
Data unit:	tN ₂ O/m ³ , tN ₂ O/kg or tN ₂ O/GJ

Description:	N ₂ O Emission factor from the combustion of fuel i in year y
Equations	(2)
Source of data:	The following data sources may be used: 1) Emission factor prescribed by 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. New York: Cambridge University Press: Intergovernmental Panel on Climate Change Retrieved May 18, 2022, from https://www.ipcc.ch/report/ar6/wg1/ ; 2) Emission factors published by US EPA or a similar source, https://www.epa.gov/climateleadership/ghg-emission-factors-hub ; or 3) Data provided by the fuel supplier.
Description of measurement methods and procedures to be applied:	Use the latest 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:	$EF_{Upstream_Fuel,i,y}$
Data unit:	tCO ₂ e/m ³ , tCO ₂ e/kg or tCO ₂ e/GJ
Description:	The upstream emission factor of fuel type i used in the storage module equipment in year y
Equations	(12)
Source of data:	The options for satisfying this requirement are as follows:

	<ul style="list-style-type: none"> Option 1) A qualified third-party may conduct an LCA in accordance with ISO 14040 and 14044, the latest edition, that uses either primary or published and peer-reviewed data²; or Option 2) The embodied emission factor for each fuel type can be calculated using regional compliance market-approved methods or equivalent (e.g., CA-GREET in the California Low Carbon Fuel Standard³ and GHGenius in the British Columbia Renewable and Low Carbon Fuel Requirements Regulation⁴or Option 3) Emission factors published in peer-reviewed literature⁴ that are representative both temporally and geographically of the transport plant operation.
Description of measurement methods and procedures to be applied:	Use the latest data published by the sources at the time of reporting project emissions.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Use the latest data published by the above sources at the time of reporting project emissions. In the case of peer-reviewed literature, the literature must have been published within a year of reporting project emissions. It must be temporally and geographically representative of the storage facility.
Purpose of data:	Calculation of leakage emissions
Calculation method:	N/A
Comments:	N/A
Data / Parameter:	$Q_{fuel_cogen,i,y}$

² Peer-reviewed literature means reviewed scientific literature published in reputable environmental and/or climate science journals. State or National government data on the carbon intensities of the fuels are also acceptable sources of data for determining emissions factors for fuels used by the transport facility.

³ CA-GREET (<https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation>) is adapted from the open-source Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model (<https://greet.es.anl.gov/>) from Argonne National Laboratory (<https://www.anl.gov/>) based out of Lemont, Illinois in the United States.

⁴ GHGenius (<https://www.ghgenius.ca/index.php/modelling-resources/about-ghgenius>) is an open-source LCA model developed and maintained by (S&T) Squared Consultants Inc. and can be used to analyze the emissions of many contaminants associated with the production and use of traditional and alternative transportations fuels.

Data unit:	<i>m³, kg or GJ</i>
Description:	Quantity of fuel consumed in the Cogeneration unit
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:	Aggregated annually
QA/QC procedures to be applied:	<p>Flow meters must be operated within the manufacturer's specified operating conditions at all times.</p> <p>Flow meters must be routinely calibrated, inspected, and maintained according to the manufacturer's specifications.</p>
Purpose of data:	Calculation of project emissions
Calculation method:	See above
Comments:	Invoices and/or contracts with the third party must be in place to allow proper data collection.

Data / Parameter:	<i>Heat_{Sto,y}</i>
Data unit:	<i>MWh</i>
Description:	Quantity of useful heat consumed by the storage module
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:	See above
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 consumed by the storage module
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:	See above
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:	Quantity of total useful heat produced by the Cogeneration unit
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:	See above
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:	Quantity of electricity produced by the Cogeneration unit
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:	See above

Comments:	Invoices and/or contracts with the third party must be in place to allow proper data collection.
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Data / Parameter:	$Q_{Elec,y}$
Data unit:	MWh
Description:	Quantity of electricity consumed by the storage module
Equations	(4) and (13)
Source of data:	Utility receipts/invoices or metered data for off-grid use.
Description of measurement methods and procedures to be applied:	Measured from electricity meters or calculated from receipts/invoices. Engineering estimates based on equipment size and manufacturer efficiency estimates can be used for equipment where it can be demonstrated that the specific electricity consumption of the equipment is less than 1% of the total electricity consumption.
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 and leakage emissions
Calculation method:	See above
Comments:	N/A

Data / Parameter:	EF_{Elec}
Data unit:	tCO ₂ e/MWh
Description:	Emissions factor for electricity generation, including upstream emissions from electricity generation and transport
Equations	(4)
Source of data:	The following data sources may be used: <ol style="list-style-type: none"> 1) For grid electricity consumption, regional emission factors from compliance tools and data published by the State or National government must be used. Examples of such tools/sources are listed in Appendix I of <i>VMD00XX: CO₂ Capture from Air (Direct Air Capture)</i>. 2) Renewable energy (i.e., wind, solar, hydro) from a dedicated/off-grid captive source is deemed to have no emissions.

	3) For electricity consumption from a dedicated geothermal power plant, CO ₂ emissions from the release of non-condensable gases must be considered in the emission factor as provided by the operator of the geothermal power plant.
Description of measurement methods and procedures to be applied:	In line with data sources used.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Use the latest published data or tools by the sources at the time of reporting project emissions.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$T_{x,y}$
Data unit:	hour
Description:	Venting hours in year y
Equations	(5) and (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:	
Purpose of data:	Calculation of project emissions

Calculation method:	N/A
Comments:	None

Data / Parameter:	$T_{i,y}$
Data unit:	hour
Description:	Operating hours of component i in year y
Equations	(8) and (9)
Source of data:	Measurement on-site
Description of measurement methods and procedures to be applied:	The operating time of the monitored component must be recorded
Frequency of monitoring/recording:	Monitored continuously
QA/QC procedures to be applied:	
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	Q_{LE}
Data unit:	tCO _{2e}
Description:	Quantity of CO ₂ and/or CH ₄ released as a result of a leak event from the storage reservoir
Equations	(10)
Source of data:	Calculated based on procedures as provided in Section 6.1.5
Description of measurement methods	Calculated based on procedures as provided in Section 6.1.5

and procedures to be applied:	
Frequency of monitoring/recording:	Continuously
QA/QC procedures to be applied:	Depending on the method(s) used
Purpose of data:	Calculation of project emissions
Calculation method:	Calculated based on procedures as provided in Section 6.1.5
Comments:	N/A

Data / Parameter:	$Q_{Threshold,y}$
Data unit:	tCO ₂ e
Description:	Maximum undetected quantity of CO ₂ and/or CH ₄ that may have leaked
Equations	(10)
Source of data:	Calculated based on procedures as provided in Section 6.1.5
Description of measurement methods and procedures to be applied:	Calculated based on procedures as provided in Section 6.1.5
Frequency of monitoring/recording:	Updated in line with the updated monitoring program
QA/QC procedures to be applied:	Depending on the method(s) used
Purpose of data:	Calculation of project emissions
Calculation method:	Calculated based on procedures as provided in Section 6.1.5
Comments:	N/A

7.3 Description of the Monitoring Program

In addition to the monitoring program requirements detailed in the latest version of the VCS Standard, the Geological Carbon Storage Requirements, and the related GCS Non-Permanent Risk Tool, the monitoring program must support the permanent storage of CO₂ injected by ensuring the containment of the plume over time. This must include surface and subsurface equipment for continuous monitoring (e.g., pressure and temperature gauges) and a defined monitoring program (e.g., set seismic data acquisition frequencies).

A loss of conformance occurs if the injected CO₂ 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 the primary and/or secondary seal(s). A loss of conformance may lead to a loss of containment.

A loss of containment occurs if the injected CO₂ migrates out of the geological storage complex and its respective seal(s). A loss of containment may occur in another zone or directly in the atmosphere. For example, this can 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.

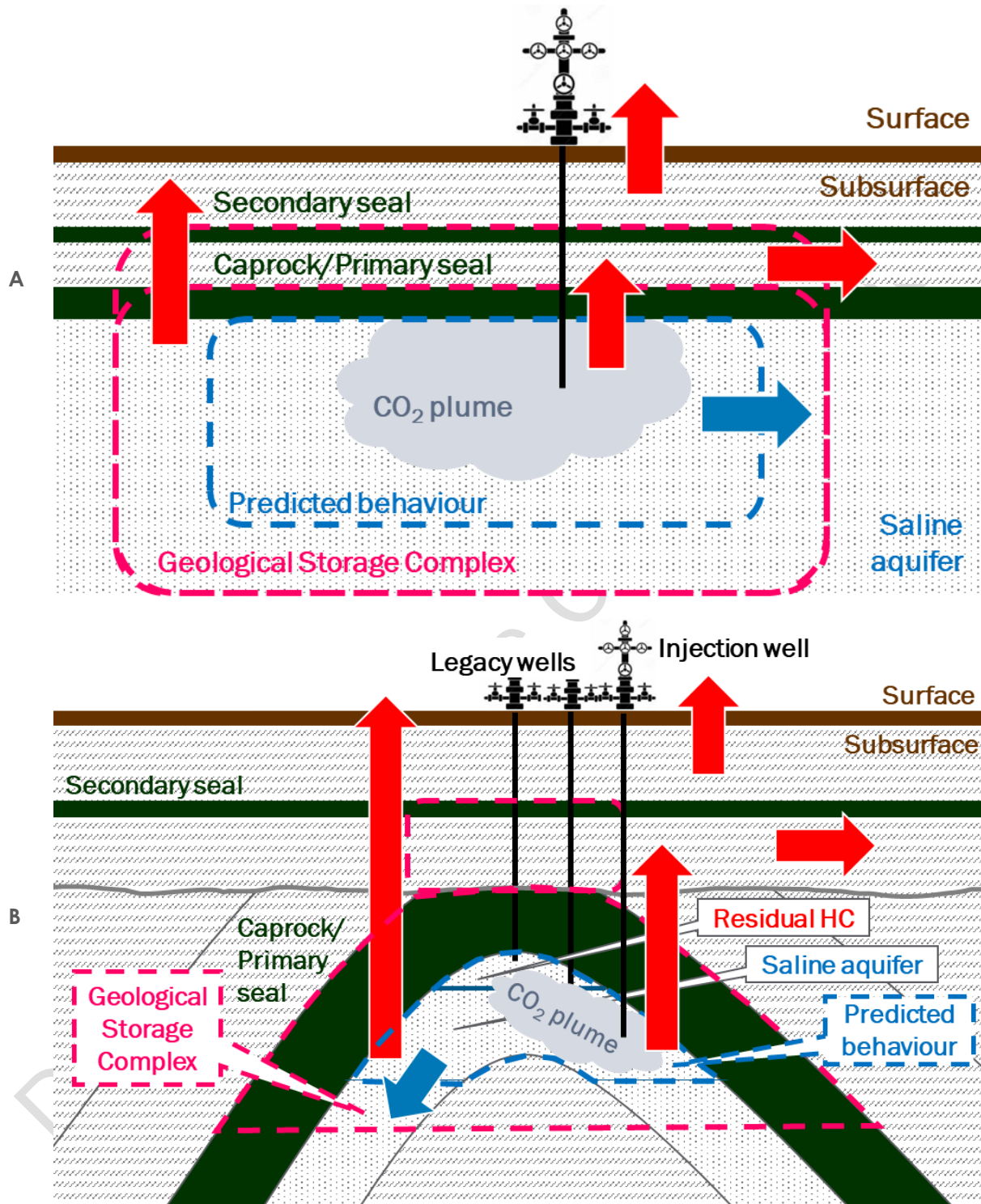


Figure 3: Simplified representation of loss of containment (red arrows) and conformance (blue arrow) examples for A. Saline aquifers and B. Depleted Hydrocarbon Reservoirs.

The monitoring program document must:

- Outline the mandatory monitoring point(s) for CO₂ injection downstream of all intermediate storage, compression, or other CO₂ conditioning. The location of the mandatory monitoring points must be as follows:
 - For onshore injection wells:
 - No farther than 500m by run-of-pipe from all injection wellhead(s) when multiple injection wellheads are served by one mandatory monitoring point or
 - No farther than 300m by run-of-pipe for the injection wellhead when one injection wellhead is served by one mandatory monitoring point.
 - For offshore injection wells:
 - No farther than 500m by run-of-pipe from the pipeline landfall point, when off-shore wells are connected by sub-sea pipeline to on-shore facilities or
 - No farther than 500m by run-of-pipe from the submersion point when off-shore wells are connected to fixed or floating platforms.
- Describe techniques used to detect, localize, and quantify subsurface CO₂ 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,
- Define a specific detection threshold to detect a loss of containment (e.g., tCO₂/year or tCO₂) for each monitoring technique.
- 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 document.
- Outline how the reservoir model and monitoring approaches are used to localize and quantify the loss of containment and
- Define the maximum undetected leak ($Q_{Threshold,y}$) by considering all the following:
 - 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);
 - For continuous monitoring approaches, the threshold for detection as defined in the monitoring program document, and
 - For discontinuous monitoring approaches, the threshold for detection and the expected mean time to detect a loss of containment as defined in the monitoring program document.

Upon identification of a loss of CO₂ conformance, and prior to the subsequent verification, the proponent must:

- Evaluate the potential for future release to the atmosphere,
- Identify the root cause(s) for the loss of conformance, and
- Revise the monitoring program to reflect the changed CO₂ migration.

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

Upon localization and quantification of a loss of containment, the proponent must assess to determine if the loss of containment can be repaired. The project may not resume injection at the concerned storage site until fully re-established containment.

At the concerned storage site, the project will not generate emissions reduction or removal credits until the following conditions are resolved:

- The loss of containment is stopped, permanent storage is restored, and
- The loss of containment is quantified.

Projects are no longer eligible if the quantity of greenhouse gases (CO₂ and CH₄) lost in CO₂e is more than 10% of the total CO₂ injected in the project.

Project proponents must follow jurisdictional regulations where the project activity occurs. The procedures of the VCS Program Documents Registration and Issuance Process and the GCS *Non-Permanence Risk Tool* apply if a loss of containment occurs.

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