METHODOLOGY FOR CARBON CAPTURE AND STORAGE

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CONTENTS

1 SOURCES

The following have informed the development of the methodology:

- "Carbon dioxide capture, transportation, and geological storage — Quantification and verification", Standard ISO/TR 27915:2017
- "Carbon Dioxide Transport, Injection and Geological Storage", Chapter 5 in Volume 2 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
- "The GHG Protocol for Project Accounting", World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI)
- "A Greenhouse Gas Accounting Framework for Carbon Capture and Storage Projects", Centre for Climate and Energy Solutions
- "Methodology for the quantification, monitoring, reporting and verification of greenhouse gas emissions reductions and removals from carbon capture and storage projects, Version 1.1., published by the American Carbon Registry
- "Guidelines for Carbon Capture, Transport and Storage", WRI
- "General Technical Support Document for Injection and Geologic Storage of CO_2 under Subpart RR and UU of the GHGRP", US EPA
- "High-Level Criteria for crediting Carbon Geostorage Activities" Provisional Version 1.0, IETA
- "Impact Assessment Report Part 1/2 and Part 2/2" Accompanying documents to Proposal for a Regulation of the European Parliament and of the Council establishing a Union certification framework for carbon removals, EU Commission Staff Working Document, Brussels

This methodology uses the latest version of the following modules and tools:

Capture Modules

- *VMD00XX: CO_2 Capture from Air (Direct Air Capture)*
- *VMD00XX: CO_2 Capture from Fossil Fuel or Geothermal Based Power and Heat Generation* (under development)
- *VMD00XX: CO_2 Capture from Industrial Processes* (under development)
- *VMD00XX: CO_2 Capture from Oil and Gas Production and Processing* (under development)
- *VMD00XX: CO_2 Capture from Biogenic Sources (BECCS)* (under development)

Transport Module(s)

- *VMD00XX: Module for CO_2 Transport*

Storage Modules

- *VMD00XX: CO_2 Storage in Saline Aquifers*
- *VMD00XX: CO_2 Storage in Depleted Oil and Gas Reservoirs* (under development)

Other Modules/Tools

- *VMT00XX: Tool for Differentiation between Emission Reductions and Removals in Carbon Capture and Storage Projects* (under development)
- *VMT00XX: Tool for Baseline Quantification and Allocation of Project Emissions in Projects with VCS and non-VCS-CO_2 flows in Carbon Capture and Storage Projects* (under development)

This methodology uses the latest versions of the following CDM Tools:

- CDM *TOOL 01: Tool for demonstration and assessment of additionality*
- CDM *TOOL 06: Methodological tool: Project emissions from flaring*
- CDM *TOOL 27: Investment Analysis*

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

Additionality and Crediting Method	
Additionality	Project method
Crediting Baseline	Project method

This methodology establishes criteria and procedures to quantify the greenhouse gas (GHG) emission reductions and removals from Carbon Capture and Storage (CCS) projects (herein referred to as project activities).

This methodology utilizes a modular framework (hereinafter referred to as the methodology framework) where this methodology document provides overarching requirements for projects and separate module documents establish criteria and procedures for quantifying emissions from corresponding capture, transport, and storage activities. The methodology framework allows for the quantification of any combination of eligible capture, transport, and storage activities using this modular approach.

3 DEFINITIONS

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

Atmospheric Carbon Dioxide (CO_2)
Well-mixed carbon dioxide in the free atmosphere at ambient air temperature, where the concentration of CO_2 is not impacted by local point sources but may vary because of regional anthropogenic and natural emission sources.

Bioenergy Carbon Capture and Storage (BECCS)
The capture of CO_2 resulting from either the combustion of renewable and sustainable biomass in a bioenergy plant to produce electricity and/or heat, or the processing of renewable and sustainable biomass in a plant to produce biofuels (e.g., by anaerobic digestion or fermentation)

Biogenic Sources
Sources of carbon/carbon dioxide that originate from organic materials (i.e., recently living organisms, such as plants). Carbon dioxide might be released from these sources by combustion, decomposition, or biomass processing. The biomass can be solid (e.g., wood), liquid (e.g., bioethanol), or gaseous (e.g., biogas)

Capture Facility
The capture facility includes the CO_2 separation and capture process (e.g., absorption, adsorption, membrane, electro-chemical or cryogenic process) and typically a CO_2 conditioning process. A capture facility may consist of several independent capture units applying the same or different processes. Such units may share some auxiliary equipment, but the main CO_2 separation and the capture process (e.g., the absorber column) would not be shared. For some industries, such as the ethanol or natural gas industry, the CO_2 stream produced may be concentrated and not require separation equipment.

CO_2 Conditioning
The process of treatment of an incoming CO_2 stream to achieve the required conditions for transport and/or injection and storage of the CO_2 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.

Direct Air Capture (DAC)

A process to capture and concentrate atmospheric CO_2 using various separation methods.

Flue Gas

Flue gas is the gas that contains the CO_2 from a source facility that is captured under the CCS project activity. It may contain water vapor, particulates, heavy metals, acidic gases, etc. It is generated as a result of a combustion process, a chemical process, or the release of non-condensable gases. Furthermore, flue gas may be generated by the CCS project activity (i.e., CO_2 released from the project activity (e.g., from a boiler) that may or may not be captured.

Geological Reservoir

Subsurface body of rock with sufficient porosity and permeability to receive, transmit and contain fluids, particularly super-critical or dense phase CO_2, including areas or zones for expansion and migration of the CO_2 plume defined by the reservoir modelling.

Geological Storage Complex

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

Intermediate Storage

Intermediate storage includes the processes and equipment on a site that enables temporary storage of CO_2 in transit, during the transfer of CO_2 from one mode of transport to another (e.g., transfer of CO_2 from a pipeline to transport by ship).

Mandatory Monitoring Point

The locations where equipment is required to be in place to measure the volume of CO_2

Mode of Transport

Refers to how CO_2 can be moved from an entry point (e.g., a capture site) to a point of delivery (e.g., other modes of transport or storage). This typically includes CO_2 transport by pipelines, ships, rail, and/or trucks

Non-condensable Gas

Non-condensable gases are gases that do not condensate into the liquid phase within the operating temperature of a system. They are relevant for geothermal power/heat plants

Non-VCS-CO_2

The CO_2 captured outside the project boundary of a CCS project activity registered under VCS that is conditioned, transported, or stored using (some of) the facilities of the registered CCS project activity.

Oxy-fuel Combustion
Fossil fuel combustion in an oxygen-rich environment increases the CO_2 concentration of the resulting flue gases. After this combustion, CO_2 can be captured from the flue gas (see post-combustion capture).

Point Source
The anthropogenic emission source at an identifiable geographical point (e.g., a stack, venting valve, etc.). The term is limited to stationary sources.

Post-combustion Capture
Post-combustion carbon capture refers to capturing CO_2 from exhaust gas streams after the combustion of fuels containing carbon.

Pre-combustion Capture
Pre-combustion capture refers to removing carbon dioxide from fuels before combustion. It separates carbon dioxide typically from a gasification and reforming process.

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

Solvent
Solvent-based CO_2 capture involves the chemical or physical absorption of CO_2 from flue gas into a liquid carrier.

Sorbent
Sorbent-based CO_2 capture involves the chemical or physical adsorption of CO_2 using a solid sorbent.

Source Facility
The facility (e.g., power plant) where CO_2 is generated and from where CO_2 is captured. A source facility might be further distinguished by different processes generating CO_2 (e.g., a captive power plant and a chemical plant at one facility each generating CO_2) or into several units of the same process (e.g., several anaerobic digesters at one facility from which CO_2 can be captured).

Storage Facility
Any facility used for geological storage of CO_2

Supercritical CO_2
A state of CO_2 when the pressure and temperature are above their critical values. The critical temperature of a gas is the temperature above which the gas cannot be liquefied at any pressure. This temperature for pure CO_2 is 31.11°C (88°F). Critical pressure is required to liquefy the gas at its critical temperature. The critical pressure for pure CO_2 is 7.39 MPa (1072 psi).

Transport Facility
Any facilities used to transport CO_2

Transport of CO_2
A network, single pipeline, or any other mode of transport that has been purpose-built to transport CO_2, or which is existing but dedicated to and authorized for the transport of CO_2

Transport Segment
A portion of a CO_2 transportation system that connects a capture facility to intermediate storage, other transport segments, intermediate storage facilities and storage facilities. Transport segments have one mode of transport.

VCS-CO_2
The CO_2 captured, transported (as applicable), and stored inside the project boundary of a proposed/registered CCS project under the VCS Program

4 APPLICABILITY CONDITIONS

This methodology is globally applicable to project activities that capture atmospheric CO_2 or CO_2 from point sources at a source facility and store it safely and permanently in geological storage complexes.

This methodology is applicable under the following conditions:

1. Project activities must include at least one eligible capture activity and at least one eligible storage activity. Project activities must transport the project CO_2 stream to storage sites that are not co-located or are not adjoining the capture sites using an eligible transport activity.
2. The eligible CO_2 capture activities include:
   - Direct Air Capture (DAC) as defined in *VMD00XX: CO_2 Capture from Air (Direct Air Capture)*;
   - Post-combustion capture from power plants, heat generation operations, or Combined Heat and Power (CHP) units based on fossil fuel combustion or based on geothermal energy as defined in *VMD00XX: CO_2 Capture from Fossil Fuel or Geothermal Based Power and Heat Generation*;
   - Flue gas capture from industrial processes including the chemical industry, mineral production, steel production, cement plants, and hydrogen (H2) production, as defined in *VMD00XX: CO_2 Capture from Industrial Processes*;
   - Flue gas capture from oil and gas production and processing including the capture of native CO_2, acid gas removal, and Liquified Natural Gas (LNG)

production as defined in *VMD00XX: CO_2 Capture from Oil and Gas Production and Processing*; or

- Capture from biogenic sources, including the capture of CO_2 from biomass combustion (direct or indirect) or biofuel production processes (e.g., biogas or ethanol production) as defined in *VMD00XX: CO_2 Capture from Biogenic Sources (BECCS).*

3. The eligible transport activities include intermediate storage facilities and transport by pipeline, ship/barge, rail, and trucks as defined in *VMD00XX: Module for CO_2 Transport.*
4. The eligible storage activities include storage in saline aquifers as defined in *VMD00XX: CO_2 Storage in Saline Aquifers* or depleted oil and gas reservoirs as defined in *VMD00XX: CO_2 Storage in Depleted Oil and Gas Reservoirs*.
5. Capture activities must have a concentrated CO_2 stream of at least 95% purity delivered to the storage site for geologic sequestration.
6. Projects must adhere to all applicable regulations of the national/regional/local project jurisdiction related to the capture, transport, and storage of CO_2.
7. Where the project facilities include refrigeration systems that utilize industrial refrigerants, they must:
    - Only use refrigerants that are not controlled substances under the Montreal Protocol (e.g., HCFCs) or under the Kigali Amendment (e.g., HFCs); and
    - Have a global warming potential (GWP) below 5.

This methodology is not applicable for project activities that:

- Utilize captured CO_2 as a feedstock for products or services (i.e., carbon capture and utilization);
- Capture and store CO_2 through enhanced weathering, carbon mineralization, biochar production, or ocean alkalinity enhancement;
- Divert CO_2 streams from other storage or utilization activities;
- Produce CO_2 for the purpose of capturing it;
- Extract CO_2 from a geologic formation for the purpose of capturing it; or
- Reduce energy-related emissions from an existing CCS activity, through technology improvement, operational improvement, a shift in the mode of transportation, or a switch to less carbon-intensive energy sources.

The modules used with this methodology provide more applicability conditions.

Under this methodology, only CO_2 streams captured using the following activities are applicable to generate removals:

- Activities that comply with *VMD00XX: CO_2 Capture from Air (Direct Air Capture); or*

- Activities that comply with the criteria provided by *VMD00XX: CO_2 Capture from Biogenic Sources (BECCS)*.

5 PROJECT BOUNDARY

The spatial extent of the project boundary consists of the sites, leases, rights-of-way, areas of review, and other land areas needed to operate and monitor the project. This may include multiple capture facilities, modes of transport, and storage sites.

The project boundary encompasses all module boundaries defined in the respective capture, transport, and storage modules of the methodology framework relevant to the project activity.

Module boundaries do not overlap, do not have gaps, and are defined in each respective module:

- For capture:
  - VMD00XX: CO_2 Capture from Air (Direct Air Capture)
  - VMD00XX: CO_2 Capture from Fossil Fuel or Geothermal Based 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 Biogenic Sources (BECCS)
- For transport:
  - VMD00XX: Module for CO_2 Transport
- For storage:
  - VMD00XX: CO_2 Storage in Saline Aquifers
  - VMD00XX: CO_2 Storage in Depleted Oil and Gas Reservoirs

For project activities that capture CO_2 from a source facility, the project boundary includes the elements of the source facility that are directly affected, modified, or added to capture CO_2 (e.g., equipment for flue gas capture). Otherwise, the source facility is not included in the project boundary.

The project boundary is illustrated in Figure 1.

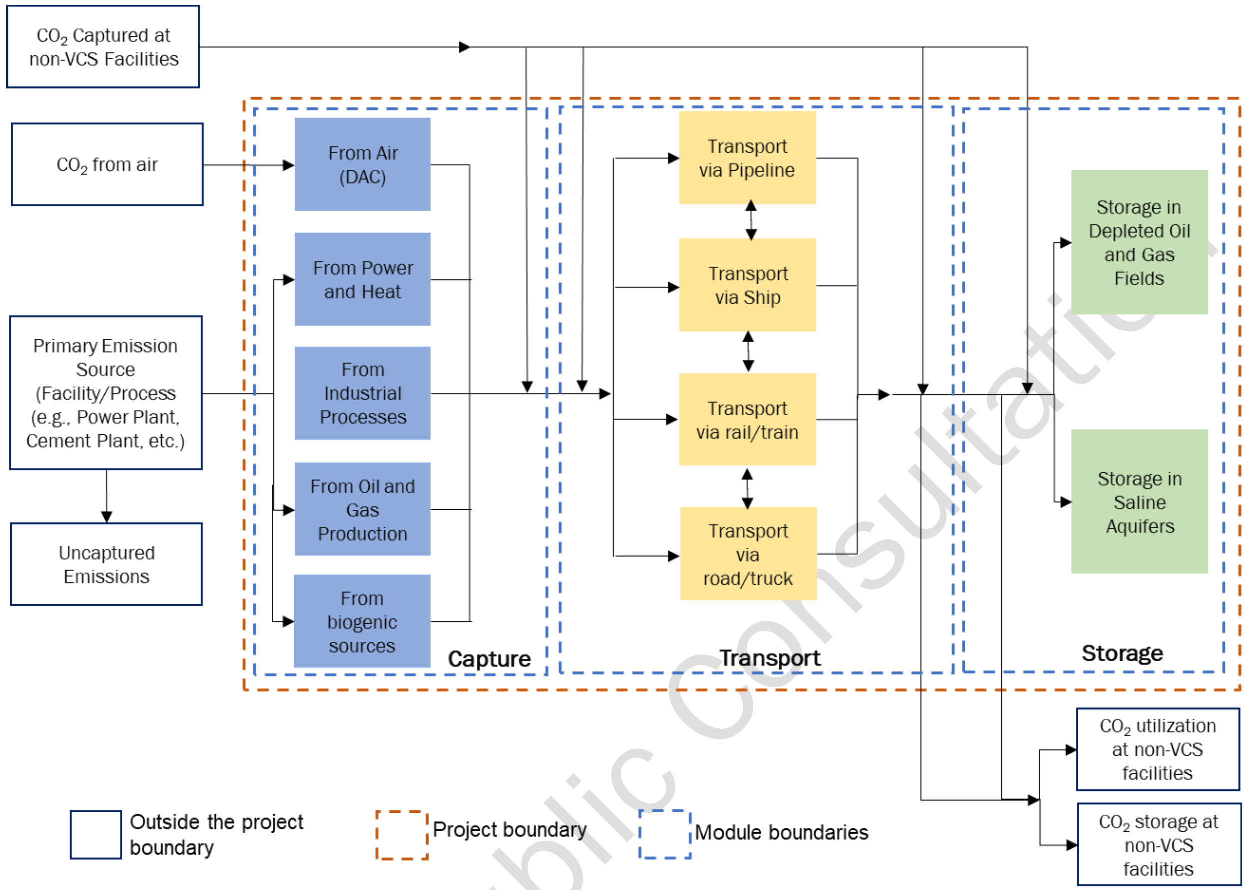

Figure 1: Project Activity Boundary

This methodology and its associated modules differentiate primary effects[1] on GHG sources and sinks that the proponent has control over, and secondary effects on GHG sources and sinks, which are related to, or affected by the project. A secondary effect is an unintended GHG emission source or sink, related to, or affected by the project. It is typically off-site and small relative to a project activity's primary effect.

GHG sources, sinks and reservoirs within the project boundary and controlled by the project include the primary effects:

- CO2 capture, transport, and storage;
- Fuel combustion;
- Electricity and heat inputs (including grid electricity, onsite generation and directly connected offsite generation); and
- Process emissions (e.g., venting and fugitives).

[1] As defined in "The GHG Protocol for Project Accounting", published by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI)

GHG sources and sinks related to, or affected by the project are secondary effects and are considered leakage and include:

- Upstream fuel production and transport emissions including such effects in fuel consumption for electricity generation;
- Material inputs and consumables (e.g., chemicals) for operation; and
- Decommission and disposal activities for equipment and materials.

Materiality threshold

The materiality threshold determines which emissions are material and are either included in the GHG quantification or excluded. A leakage source should be included in the quantification if it is estimated to be over 2% of the net project emission reductions and removals over the anticipated typical project lifetime. The following leakage sources are excluded:

- Production and transport of equipment and materials used for construction of project facilities;
- Research and development activities;
- Staff commuting;
- Direct and indirect land use change as a result of construction and operation of project facilities and equipment.

The GHG sources included or excluded from the project boundary are shown in Table 1. More details of GHG sources and sinks are provided in the capture, transport, and storage modules.

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

Source		Gas	Included?	Justification/Explanation
Baseline	CO_2 source facilities or the atmosphere	CO_2	Yes	CO_2 captured and injected
		CH_4	No	Only CO_2 is included. This is conservative.
		N_2O	No	Only CO_2 is included. This is conservative.
		Other	No	Only CO_2 is included. This is conservative.
Project	CO_2 capture site	CO_2	Yes	Major source. Details are provided in each capture module.
		CH_4	Yes	Major source. Details are provided in each capture module.
		N_2O	Yes	Major source. Details are provided in each capture module.
		Other	No	Negligible

Source		Gas	Included?	Justification/Explanation
	CO_2 transport facility	CO_2	Yes	Major source. Details are provided in each transport module.
		CH_4	Yes	Major source. Details are provided in each transport module.
		N_2O	Yes	Major source. Details are provided in each transport module.
		Other	No	Negligible
	CO_2 storage site	CO_2	Yes	Major source. Details are provided in each storage module.
		CH_4	Yes	Major source. Details are provided in each storage module.
		N_2O	Yes	Major source. Details are provided in each storage module.
		Other	No	Negligible

6 BASELINE SCENARIO

This methodology uses a project method to determine the crediting baseline scenario.

The eligible baseline scenarios under this methodology are:

- For CO_2 captured from point sources: the CO_2 captured under the project activity would be emitted to the atmosphere in the absence of the project activity.
- For CO_2 captured from the atmosphere: the CO_2 captured under the project activity would not be captured in the absence of the project activity.

The capture modules provide further procedures and requirements for identifying the baseline scenario.

The baseline scenario applies to:

- Greenfield capture facilities;
- The addition or expansion of capture facilities at locations where capture facilities existed; and
- The refurbishment of capture facilities that would have been decommissioned in the absence of the project.

CO_2 streams with a different baseline scenario qualify as non-VCS-CO_2.

7 ADDITIONALITY

This methodology uses the project method to assess additionality. To demonstrate additionality, Steps 1 to 3 outlined below must be applied.

Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements of regulatory surplus set out in the latest version of the *VCS Methodology Requirements*.

The regulatory surplus check must consider the laws, statutes, regulatory frameworks, and policies applicable in the jurisdiction of the capture site.

Step 2: Implementation Barrier

Project proponents must demonstrate that they face an investment barrier (i.e., capital or investment return constraints) that would prevent the project from being implemented in the absence of carbon credit revenues.

To analyze the investment barrier, projects must conduct an investment analysis as per step 2 in the latest version of CDM *Tool 01 "Tool for the demonstration and assessment of additionality"* and CDM *Tool 27 "Investment Analysis"* following Option III. Apply the benchmark analysis.

The following must be followed for the investment analysis:

1) The assessment must be done from the perspective of the capture activity. Transport and storage activities must be treated as costs to the capture activity. This applies to both:
   a) Projects with diverse operatorship where costs may be incurred as real fees from transport and storage site operators, and
   b) vertically integrated projects, where capital and operating costs of the transport and storage site(s) must be internally accounted by the proponent.
2) Revenues (e.g., as a result of subsidies paid by governments) from capture, transport (if applicable) and storage activities must be incorporated into the investment analysis (e.g., a fee per ton of CO_2 transported and/or stored), regardless of the owner/operator of transport and storage facilities.
3) Where shared infrastructure is relevant to the economics of a project, costs or revenues must reflect the estimated (or contracted, if available) usage rate of transport and storage by each capture activity (e.g., if a capture activity uses 10% of the transport and storage capacity, the costs must be prorated and not reflect the entire cost of transport and storage).
4) When multiple capture activities exist, the investment analysis must consider all capture activities in the project in demonstrating the existence of an investment barrier.

5) When a project has undersubscribed transportation and/or storage usage at the time of the investment analysis, the expected usage rate, fee structure and return on investment must be used as inputs.

6) Revenue and indirect financial benefits (e.g., savings) at the CO_2 source facilities must be accounted. This is regardless of whether the operators of source facilities and operators of capture facilities are the same entity. Examples include:

   a) Savings from avoiding/reducing the payment of carbon tax or other fines/levies;

   b) Revenue generation based on the forecasted value of emissions allowances granted to the project activity for periods when VCUs are not issued (VCUs may not be issued for the same emission reduction or removal benefit if emissions allowances are also granted);

   c) Savings from avoiding or reducing costs for (flue) gas cleaning;

7) Payments from the capture facilities to the source facilities for the CO_2 captured are not considered costs in the investment analysis.

8) Funding from governments or other institutions in the form of grants, tax credits, concessional loans, guarantees, contracts for difference, negative emission payments, or other subsidies (all herein referred to as public support mechanisms) must be reflected as revenues, savings, or in the determination of the benchmark as applicable.

   However, such public support mechanisms from governments should not be considered in the financial additionality analysis if:

   a) The government requires the proponent to try to generate and sell carbon credits as a condition for the public support mechanism; and

   b) The carbon credit revenue (in whole or part) displaces funds that would have otherwise been provided to the project from the public support mechanism.

9) For projects with non-VCS CO_2, further guidance on the investment analysis is provided in the *VMT00XX: Tool for Baseline Quantification and Allocation of Project Emissions in Projects with VCS and non-VCS-CO_2 flows in Carbon Capture and Storage Projects*

Selection and validation of appropriate benchmark

Where internal company benchmarks/expected returns are used, these must reflect the risk associated with investing in:

- technologies that are not mature, and whose performance in the field, in specific applications, has yet to be proven and documented at the time the decision to invest in the project is taken.
- activities applying technologies that are not mature and are highly capital-intensive,

- activities where different technologies and processes are combined in ways that result in a system of considerable complexity that has not been implemented at a commercial scale in any market, and
- business models with limited experience.

The internal company benchmarks/expected returns applied in the past by the company to assess investments with similar risks to the project activity may be applied. For example, investments in prior activities where the maturity of the technology/experience at the time the investment analysis was carried out was low/very limited; investments in prior activities where new, untested business models are introduced, etc.

If the company has no prior experience in undertaking projects with technologies/business models with similar risks as those posed by the project activity, then, the level of returns expected from venture capital investments may be used as a proxy for the returns expected when applying the Investment Analysis for the project activity. An investment return value of 21% is accepted under this methodology[2].

Contingencies for operating and maintenance (O&M) costs

Contingency costs account for costs that cannot be anticipated/forecasted when applying the investment analysis tool. Estimated contingency costs are expressed as a percentage (%) of the O&M costs used for the investment analysis completed for the comparable prior activity. One of the following options must be used to determine such costs in the context of operating and maintenance (O&M) costs in the project activity:

Option 1: Reference previously estimated contingency costs from other activities the proponent has done with a comparable level of technological maturity and risk to the project activity, at the time the other comparable prior activity was at final investment decision.

Option 2: Reference actual historical contingency costs incurred when implementing other activities the proponent has done using technologies with similar levels of maturity and risk to the project activity. The contingency costs are calculated by subtracting the O&M costs incurred over a given period of time, from the O&M costs that were estimated for the same period of time. The estimated O&M costs must be from background work such as feasibility studies used to inform the investment decisions.

Option 3: Use other approaches that have been applied in a relevant industrial sector (i.e. related to the applicable source facilities) to determine contingency costs, with a maximum value for this option at 15%.

Step 3: Common Practice

[2] Based on: Zider, Bob (1998), How Venture Capital Works. Harvard Business Review. pp. 133, available at: http://www.mengwong.com/school/HarvardBusinessReview/how_venture_works.pdf

The project must not be common practice, determined for each capture activity included or added as expansion as follows:

1) The project type must not be common practice in the respective sector and country.

- Common practice is defined as the project activity implemented in more than 20% of comparable source facilities in the sector and country.
- Similar project activities under validation, submitted for registration or registered under any GHG crediting program can be excluded from the common practice analysis.
- The sector refers to the source facility sector (e.g., fossil fuel or geothermal-based power and heat generation, industrial processes, oil & gas production and processing, bioethanol production, or biomass power and heat).
- DACCS may be considered not common practice by default, as there is no source facility.
- When multiple source facilities are used by a project, each would represent a different sector and require a respective common practice assessment.
- If different types of capture facilities are included in the project, a common practice assessment is required for each.

2) Where similar activities exist, the project proponent must identify barriers faced compared with existing projects to underpin the risks, costs, and/or limitations to regular advancement of the project activity to demonstrate that this is not common practice for the project activity.

Guidance for the common practice assessment is provided by the respective capture modules and in *The GHG Protocol for Project Accounting*, Chapter 7 (WRI-WBCSD).

Projects that demonstrate regulatory surplus, an implementation barrier and are not common practice are additional.

8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

This section establishes overarching quantification approaches for GHG emission reductions and/or removals. In addition, the approaches and equations in the capture, transport, and storage modules listed in Section 1 that are relevant to the project activity apply.

8.1 Baseline Emissions

Baseline emissions are calculated as per Equation (1):

$$BE_y = \sum_i Q_{CO2,injected,i,y} - \sum_i Q_{CO2,nonVCS,injected,i,y} \quad (1)$$

Where:

BE_y	=	Baseline emissions in year y (tCO_2e)
$Q_{CO2,injected,i,y}$	=	Mass of CO_2 injected (tCO_2) and monitored at injection point i in year y at the storage site(s). For DAC and BECCS, this equals the mass of atmospheric or biogenic CO_2 that would have remained in the atmosphere plus the mass of any fossil fuel CO_2 co-captured as part of the process.
$Q_{CO2,nonVCS,injected,i,y}$	=	Mass of non-VCS-CO_2 (tCO_2) injected at injection point i in year y at the storage site(s). If applicable, determined as per the latest version of *VMT00XX: Tool for baseline quantification and allocation of project emissions in projects with VCS and non-VCS-CO_2 flows in Carbon Capture and Storage projects*. This includes any CO_2 streams originating at capture facilities for which a valid baseline scenario cannot be demonstrated. This parameter equals zero when there is no non-VCS-CO_2 entering the project boundary.

Flow measurements must be performed using either volumetric flow meters or mass flow meters.

8.1.1 Methods for CO_2 measurement

This subsection provides methods and guidance[3] for measuring the amount of CO_2 injected for safe and permanent storage. The same methods apply for measuring the amount of CO_2 either captured, transported, received, or leaving the project boundary as applicable.

For supercritical phase CO_2, the volumetric flow rate measurement can be inaccurate due to impurities. To determine the amount of supercritical CO_2, a project activity must either use a mass flow meter while measuring the concentration of CO_2 in the stream or use a volumetric flow meter while measuring the concentration of all impurities in the stream that are greater than 0.25% (2500ppm) by mole fraction.

8.1.2 Measurement based on Mass Flow Rate

To determine the quantity of CO_2 using mass flow rate measurements, the proponent must multiply the mass flow rate by the concentration of CO_2 in that flow as per Equation (2) below.

[3] The guidance in this section is based on the US EPA's General Technical Support Document for Injection and Geologic Storage of CO_2 under Subpart RR and UU of the GHGRP, Section 3. Monitoring Methods for CO_2 Received and CO_2 Injected.

$$Q_{CO2,x} = FR_{mass,x} * \%CO2_{mass,x} \quad (2)$$

Where:

$Q_{CO2,x}$	=	Mass of CO_2 (tCO_2) injected, captured, transported, received, or leaving the project boundary as applicable
$FR_{mass,x}$	=	Mass flow measured by mass flow meter x (tonnes)
$\%CO2_{mass,x}$	=	Mass fraction of CO_2 in flow at flow meter x (% mass)

The mass fraction used in Equation (2) must be derived from the mole fraction (X_{CO2}) measured by sampling as per Equation (3).

$$\%CO2_{mass,x} = \frac{M_{CO2} * X_{CO2}}{\sum_{k=1}^{n} M_k * X_k} \quad (3)$$

Where:

$\%CO2_{mass,x}$	=	Mass fraction of CO_2 in flow at flow meter x (% mass)
M_{CO2}	=	Molar mass of CO_2
X_{CO2}	=	Mole fraction of CO_2 in flow at flow meter x (% mole)
M_k	=	Molar mass of component k
X_k	=	Mole fraction of component k in flow at flow meter x (% mole)
n	=	Number of components in the mixture with a mole fraction greater than 0.5% (5000ppm)

8.1.3 Measurement based on Volumetric Flow Rate

Alternatively, a measured volumetric flow rate and corresponding density can be used to determine the CO_2 mass for a project. This is achieved by multiplying the volumetric flow rate at Standard Temperature and Pressure[4] (STP) by the concentration of CO_2 in the flow and by the density of CO_2 at STP as per Equation (4).

$$Q_{CO2,x} = FR_{vol,x(STP)} * \%CO2_{vol,x(STP)} * \rho CO2_{x(STP)} \quad (4)$$

Where:

$FR_{vol,x(STP)}$	=	Volumetric flow rate measured by flow meter x at actual conditions and converted to STP conditions (m^3)

[4] STP must be selected and defined by the project proponents as per the industry practice in their geographical location.

$\%CO2_{vol,x(STP)}$	=	Volumetric fraction of CO_2 in flow at flow meter x at STP conditions (% volume)
$\rho CO_{2x(STP)}$	=	Density of CO_2 at STP conditions (tCO_2/m^3)

The volumetric CO_2 fraction must be derived from the mole fraction (X_{CO2}) measured by sampling and evaluated at STP as shown in Equation (5).

$$\%CO2_{vol,x(STP)} = \frac{X_{CO2}}{\sum_{k=1}^{n} X_k} \quad (5)$$

Where:

$\%CO2_{vol,x(STP)}$	=	Volumetric fraction of CO_2 in flow at flow meter x at STP conditions (% volume)
X_{CO2}	=	Mole fraction of CO_2 in flow at flow meter x (% mole)
X_k	=	Mole fraction of component k in flow at flow meter x (% mole)
n	=	Number of components in the mixture with a mole fraction greater than 0.5% (5000ppm), or for supercritical conditions greater than 0.25% (2500ppm)

Using the operating temperature and pressure, the actual volume of CO_2 can be converted into STP conditions as per Equation (6).

$$FR_{vol,x(STP)} = \frac{FR_{vol,x(P,T)} * \rho_{x(P,T)}}{\rho_{x(STP)}} \quad (6)$$

Where:

$FR_{vol,x(P,T)}$	=	Volumetric flow rate measured by flow meter x at actual conditions (m^3)
$\rho_{x(P,T)}$	=	Density of CO_2 at actual conditions (tCO_2/m^3)

8.2 Project Emissions

The overarching equation for project emissions is as per Equation (7):

$$PE_y = PE_{Cap,y} + PE_{Tra,y} + PE_{Sto,y} \quad (7)$$

Where:

PE_y = Project emissions in year y (tCO_2e)
$PE_{Cap,y}$ = Project emission from CO_2 capture in the year y (tCO_2e)
$PE_{Tra,y}$ = Project emissions from CO_2 transport in year y (tCO_2e)
$PE_{Sto,y}$ = Project emissions from CO_2 storage in year y (tCO_2e)

Quantification procedures for project emissions from capture, transport and storage are established under the respective modules listed in Section 1.

8.3 Leakage

The overarching equation for leakage emissions is as per Equation (8):

$$PE_y = PE_{Cap,y} + PE_{Tra,y} + PE_{Sto,y} \quad (8)$$

Where:

LE_y = Leakage emissions in year y (tCO_2e)
$LE_{Cap,y}$ = Leakage emission from CO_2 capture in the year y (tCO_2e)
$LE_{Tra,y}$ = Leakage emissions from CO_2 transport in year y (tCO_2e)
$LE_{Sto,y}$ = Leakage emissions from CO_2 storage in year y (tCO_2e)

Quantification procedures for leakage emissions from capture, transport and storage are established under the respective modules listed in Section 1.

8.4 Emission Reductions and Removals

Emission reductions or emission removals are generally calculated as per Equation (9):

$$ER_y = BE_y - PE_y - LE_Y \quad (9)$$

Where:

ER_y = Emissions reductions or removals in year y (tCO_2e)
BE_y = Baseline emissions in year y (tCO_2e)
PE_y = Project emissions in year y (tCO_2e)
LE_y = Leakage emissions in year y (tCO_2e)

Projects that generate both, emission reductions and removals must follow the latest version of *VMD00XX: Differentiation between emission reductions and removals in Carbon Capture and Storage Projects*.

9 MONITORING

9.1 Data and Parameters Available at Validation

Additional data and parameters are defined in the respective capture, transport, and storage modules and related tools (VCS and CDM) as applicable.

Data / Parameter	T_{STP}
Data unit	K
Description	Temperature at STP
Equations	(4), (5), (6)
Source of data	Industry practice
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Standard Temperature and Pressure must be defined to allow the conversion of volumetric flow from operating to standard conditions
Purpose of Data	Calculation of baseline and project emissions
Comments	Project description must clearly identify what standard temperature is used as reference.

Data / Parameter	P_{STP}
Data unit	Pa
Description	Pressure at STP
Equations	(4), (5), (6)
Source of data	Industry practice
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Standard Temperature and Pressure must be defined to allow the conversion of volumetric flow from operating to standard conditions

Purpose of Data	Calculation of baseline and project emissions
Comments	Project description must clearly identify what standard pressure is used as reference.

Data / Parameter	$\rho_{x(STP)}$
Data unit	tCO_2/m^3
Description	Density of CO_2 at STP
Equations	(4), (6)
Source of data	Industry practice adopting internationally accepted data sets following equation of states as applicable, e.g., Span and Wagner (for further information see National Institute of Standards and Technology (NIST) available at https://webbook.nist.gov/chemistry/fluid/ or similar.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Density depends on temperature and pressure as defined under STP conditions
Purpose of Data	Calculation of baseline and project emissions
Comments	Project description must clearly identify what standard temperature is used as reference.

Data / Parameter	M_{CO2}
Data unit	g/mol
Description	Molar mass of CO_2
Equations	(3)
Source of data	CDM TOOL 06: Methodological tool: Project emissions from flaring, Version 04.0
Value applied	44.0095
Justification of choice of data or description of measurement methods and procedures applied	A physical constant

Purpose of Data	Calculation of baseline and project emissions
Comments	N/A

9.2 Data and Parameters Monitored

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Data / Parameter:	T_x
Data unit:	K
Description:	The temperature at operating conditions in flow at flow meter x
Equations	(6)
Source of data:	Temperature meters
Description of measurement methods and procedures to be applied:	Instruments with recordable electronic signals (analogical or digital) are required. Examples include thermocouples, thermo-resistance, etc.
Frequency of monitoring/recording:	Monitored continuously, i.e., same time interval as flow rate measurement
QA/QC procedures to be applied:	The metering equipment must be installed and calibrated in accordance with either the specifications of local/national standards or the manufacturer's specifications. If local/national standards or the manufacturer specification is not available, international standards (e.g., IEC, ISO). must be followed.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Average value over the same time interval as the flow rate measurement
Comments:	N/A

Data / Parameter:	P_x
Data unit:	Pa

Description:	Pressure at operating conditions in flow at flow meter x
Equations	(6)
Source of data:	Pressure meters
Description of measurement methods and procedures to be applied:	Instruments with recordable electronic signal (analogical or digital) are required. Examples include pressure transducers, etc.
Frequency of monitoring/recording:	Monitored continuously, at least as frequent and at the same time interval as the flow rate measurement
QA/QC procedures to be applied:	The metering equipment must be installed and calibrated in accordance with either the specifications of local/national standards or the manufacturer's specifications. If local/national standards or the manufacturer specification is not available, international standards (e.g., IEC, ISO). must be followed.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Average value over the same time interval as the flow rate measurement
Comments:	N/A

Data / Parameter:	$FR_{mass,x}$
Data unit:	Tonnes
Description:	The mass measured by mass flow meter x
Equations	(2)
Source of data:	Mass flow meters
Description of measurement methods and procedures to be applied:	Mass flow rates must be determined by commercially available devices that measure the mass flow rate of a fluid flowing through a measurement channel. Common types of mass flow meters include but are not limited to, Coriolis meters, thermal meters, impeller meters, and twin turbine meters.
Frequency of monitoring/recording:	Monitored continuously, i.e., one measurement at least every 15 minutes.

QA/QC procedures to be applied:	The metering equipment must be installed and calibrated in accordance with either the specifications of local/national standards or the manufacturer's specifications. If local/national standards or the manufacturer specification is not available, international standards (e.g., IEC, ISO). must be followed.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Direct measurement (preferred) or as the accumulated mass for each sampling interval of mole fractions (composition analysis).
Comments:	Further guidance: US EPA's General technical support document for injection and geologic sequestration of carbon dioxide: subparts RR and UU GHG reporting program

Data / Parameter:	X_{CO2}
Data unit:	% mole
Description:	Mole fraction of CO_2 in flow at flow meter x
Equations	(3), (5)
Source of data:	Composition analysis
Description of measurement methods and procedures to be applied:	Mole fractions must be determined by commercially available devices. Common approaches include, but are not limited to IR spectroscopy and gas chromatography.
Frequency of monitoring/recording:	Option A: At least weekly. Option B: At least monthly if used in combination with continuous IR spectroscopy (i.e., measurement interval of at least every 15 minutes).
QA/QC procedures to be applied:	The metering equipment must be installed and calibrated in accordance with either the specifications of local/national standards or the manufacturer's specifications. If local/national standards or the manufacturer specification is not available, international standards (e.g., IEC, ISO). must be followed.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Direct measurement Option A: Use the lower value of two consecutive composition analyses to calculate continuous (i.e., at least every 15 minutes) values in between the two composition measurements. Option B: Use values from IR spectroscopy measurements

Comments:	Further guidance: US EPA's General technical support document for injection and geologic sequestration of carbon dioxide: subparts RR and UU GHG reporting program

Data / Parameter:	X_k
Data unit:	% mole
Description:	Mole fraction of component k in flow at flow meter x
Equations	(3), (5)
Source of data:	Composition analysis
Description of measurement methods and procedures to be applied:	Mole fractions must be determined by commercially available devices Common types of devices include, but are not limited to, gas chromatography.
Frequency of monitoring/recording:	Option A: At least weekly. Option B: At least monthly if used in combination with continuous IR spectroscopy (i.e., measurement interval of at least every 15 minutes).
QA/QC procedures to be applied:	The metering equipment must be installed and calibrated in accordance with either the specifications of local/national standards or the manufacturer's specifications. If local/national standards or the manufacturer specification is not available, international standards (e.g., IEC, ISO). must be followed.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Direct measurement Option A: Use the lower value of two consecutive composition analyses to calculate continuous (i.e., at least every 15 minutes) values in between the two composition measurements. Option B: Use values from IR spectroscopy measurements
Comments:	Further guidance: US EPA's General technical support document for injection and geologic sequestration of carbon dioxide: subparts RR and UU GHG reporting program

Data / Parameter:	M_k
Data unit:	g/mol

Description:	Molar mass of component k
Equations	(3)
Source of data:	Physical property tables
Description of measurement methods and procedures to be applied:	N/A
Frequency of monitoring/recording:	To be updated based on components k found in the CO_2 stream
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$FR_{vol,x(P,T)}$
Data unit:	m^3
Description:	The volumetric flow measured by flow meter x
Equations	(6)
Source of data:	Volumetric flow meters
Description of measurement methods and procedures to be applied:	Volumetric flow rates must be determined by commercially available devices that measure the flow rate of a fluid flowing through a measurement channel. Common types of flow meters include but are not limited to, rotameters, turbine meters, orifice meters, wedge meters, ultra-sonic flow meters, and vortex flow meters.
Frequency of monitoring/recording:	Monitored continuously, i.e., one measurement at least every 15 minutes.
QA/QC procedures to be applied:	The metering equipment must be installed and calibrated in accordance with either the specifications of local/national standards or the manufacturer's specifications. If local/national standards or the

	manufacturer specification is not available, international standards (e.g., IEC, ISO). must be followed.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Direct measurement (preferred) or calculated as the accumulated volume for each sampling interval of mole fractions (composition analysis).
Comments:	Further guidance: US EPA's General technical support document for injection and geologic sequestration of carbon dioxide: subparts RR and UU GHG reporting program

Data / Parameter:	$\rho_{x(P,T)}$
Data unit:	tCO_2/m^3
Description:	Density of CO_2 at actual conditions
Equations	(6)
Source of data:	Industry practice adopting internationally accepted data sets following equation of states as applicable, e.g., Span and Wagner (for further information see National Institute of Standards and Technology (NIST) available at https://webbook.nist.gov/chemistry/fluid/ or similar.
Description of measurement methods and procedures to be applied:	Density is derived from measurement of temperature and pressure at actual conditions.
Frequency of monitoring/recording:	Aligned to the measurement of $FR_{vol,x(P,T)}$
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Density of CO_2 at actual conditions
Comments:	The actual density of liquid or supercritical phase CO_2 depends strongly on operating conditions as well as the stream mixture composition. The available theoretical models to calculate the density of CO_2 may not span all potential process conditions. The EPA provides a generic protocol to calculate the density of CO_2 in liquid or supercritical state at process conditions or conditions at the point of transfer/measurement in the full technical guidance under Section 3.2

	Further guidance: US EPA's General technical support document for injection and geologic sequestration of carbon dioxide: subparts RR and UU GHG reporting program

9.3 Description of the Monitoring Plan

The project proponent must establish, maintain, and apply a monitoring plan and GHG information system that includes criteria and procedures for obtaining, recording, compiling, and analyzing data, parameters, and other information important for quantifying and reporting GHG emissions relevant to the project and baseline scenarios. Monitoring procedures must address the following:

- Types of data and information to be reported;
- Units of measurement;
- Origin of the data;
- Monitoring methodologies (e.g., estimation, modeling, measurement, and calculation);
- Type of equipment used;
- Monitoring times and frequencies;
- QA/QC procedures;
- Monitoring roles and responsibilities, including experience and training requirements;
- GHG information management systems, including the location, backup, and retention of stored data.
- Where measurement and monitoring equipment is used, the project proponent must ensure the equipment is calibrated according to current good practice (e.g., relevant industry standards).

QA/QC procedures must include, but are not limited to:

- Data gathering, input, and handling measures;
- Input data checked for typical errors, including inconsistent physical units, unit conversion errors;
- Typographical errors caused by data transcription from one document to another, and missing data for specific time periods or physical units;
- Input time series data checked for unexpected variations (e.g., orders of magnitude) that could indicate input errors;
- All electronic files to use version control to ensure consistency;

- Physical protection of monitoring equipment;
- Physical protection of records of monitored data (e.g., hard copy and electronic records);
- Input data units checked and documented;
- All sources of data, assumptions, and emission factors are documented.

Furthermore, all monitoring provisions related to Geologic Carbon Storage (GCS) as per the latest version of the VCS Program Document VCS Standard and Non-Permanence Risk Tool for Geologic Carbon Storage must comply.

Additional criteria and procedures for monitoring the project are established in respective capture, transport, and/or storage modules and related Tools (VCS and CDM).

10 REFERENCES

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