MODULE FOR CO_2 CAPTURE FROM AIR (DIRECT AIR CAPTURE)

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CONTENTS

1 SOURCES

The following have also informed the development of the module:

- "Best Practices for Life Cycle Assessment (LCA) of Direct Air Capture with Storage", U.S. Department of Energy, Office of Fossil Energy and Carbon Management
- "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
- "Carbon Capture and Sequestration Protocol under the Low Carbon Fuel Standard", California Air Resources Board
- "Modalities and procedures for carbon dioxide capture and storage in geological formations as clean development mechanism project activities", UNFCCC
- "Commission Implementing Regulation (EU) 2018/2066" of the European Commission, Directorate-General for Climate Action
- "EU Directive on the geological storage of carbon dioxide" of the European Parliament and of the Council

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: 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)

2 SUMMARY DESCRIPTION OF THE MODULE

This module provides procedures and requirements for Direct Air Capture (DAC) project activities eligible under the latest version of *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:

Atmospheric Carbon Dioxide (CO_2)

Well-mixed carbon dioxide in the free atmosphere at ambient air temperature, where the concentration of CO2 is not impacted by local point sources but may vary because of regional anthropogenic and natural emission sources.

Capture Facility
The capture facility includes mainly the CO2 separation and capture process (e.g., by absorption, adsorption, membrane, electro-chemical or cryogenic process) and typically a CO2 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 CO2 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 CO2 stream produced may already have a high degree of CO2 concentration that does not require an additional separation process within the capture facility

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

Direct Air Capture (DAC)
A process to capture and concentrate atmospheric CO_2 using various separation methods

Membrane Process
Membrane-based CO_2 capture uses semi-permeable materials that allow for the selective transport and separation of CO_2

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
The combustion of fossil fuel in an oxygen-rich environment increases the CO_2 concentration of the resulting flue gases.

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.

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).

4 APPLICABILITY CONDITIONS

This module applies to project activities that capture CO_2 from ambient air using the latest version of *VM00XX Methodology for Carbon Capture and Storage*.

This module is applicable under the following conditions:

1) Project activities must capture atmospheric CO_2 from ambient air. They may co-capture CO_2 from on-site point sources including oxy-fuel combustion. Capture may occur using one, or a combination of, the following processes:
    a) Chemical or physical absorption or adsorption, with liquid solvents or solid sorbents (e.g., amines);
    b) Membrane processes;
    c) Electrochemical processes; or
    d) Cryogenic processes.
2) Project activities must regenerate the primary capture fluid or media, such that it is not a one-time use or disposable material, and that a concentrated CO_2 stream is recovered from regeneration and available for subsequent transport (where applicable) and storage.
3) Capture facilities in the project activity must be new, an expansion of existing facilities, or a refurbishment of existing facilities that would have been decommissioned at the project start date in the absence of the project activity.
4) Existing and new capture facilities may share auxiliary facilities and equipment (e.g., utilities).

This module is not applicable under the following conditions:

1) Project activities that only capture CO_2 from point sources at source facilities.
2) Efficiency improvement projects where:
    a. Upgrades are to existing DAC facilities that not at risk of decommissioning or,
    b. changes in operational practices lead to improved capture efficiency.

(For DAC projects already registered under VCS, such improvements may occur)

5 MODULE BOUNDARY

The spatial extent of the module boundary includes the capture site. Commonly used equipment or processes include:

- Equipment used to generate airflow to the capture process (e.g., fans);
- Capture of CO_2 in contactors, beds, or vessels by absorption, adsorption, or other processes;
- Regeneration processes to generate a CO_2 stream and recover captured fluid or media;
- Conditioning of CO_2 to allow further processing of CO_2 along the CCS segments (namely transport and storage); and
- Co-located utilities for the CO_2 capture process (e.g., air separation units, water treatment systems, steam systems, etc.)

The module boundary of the capture site does not overlap with the module boundary of the transport segment. Please refer to the latest version of *VMD00XX: Module for CO_2 Transport* for further details of the module boundary of the transport segment.

For project activities that transport non-VCS CO_2, the equipment that captures non-VCS CO_2 is not in the module or project boundary. The CO_2 conditioning, monitoring, and control units in the module boundary may process non-VCS CO_2 flows. The upstream extent of the module boundary is the location(s) of the first isolation valve supplying the non-VCS CO_2 to the project capture site, or the custody transfer point in the case of projects with diverse ownership. This would be upstream of the point where non-VCS CO_2 streams mix with CO_2 credited in the project.

The boundary for this module is presented in Figure 1.

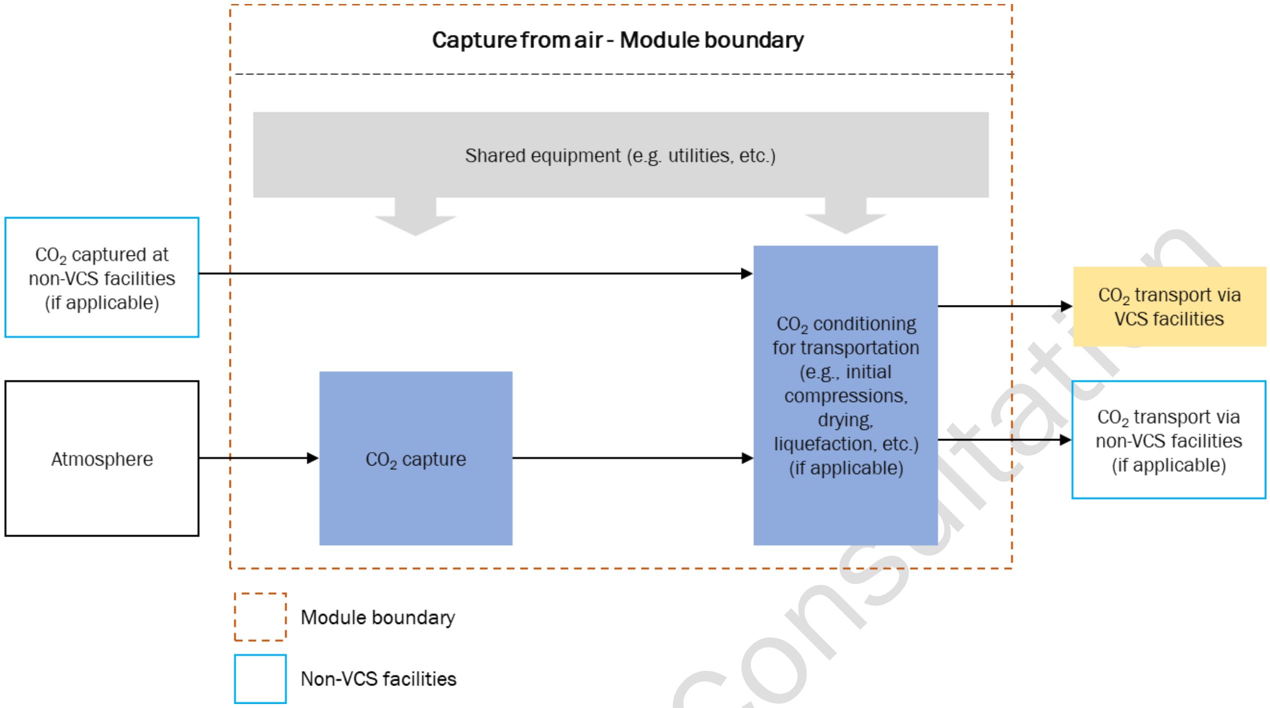

Figure 1: Module boundary for a DAC project

Emission sources, including both primary effects in the project boundary and secondary effects as leakage, that are considered in this module are illustrated relative to the module boundary in Figure 2.

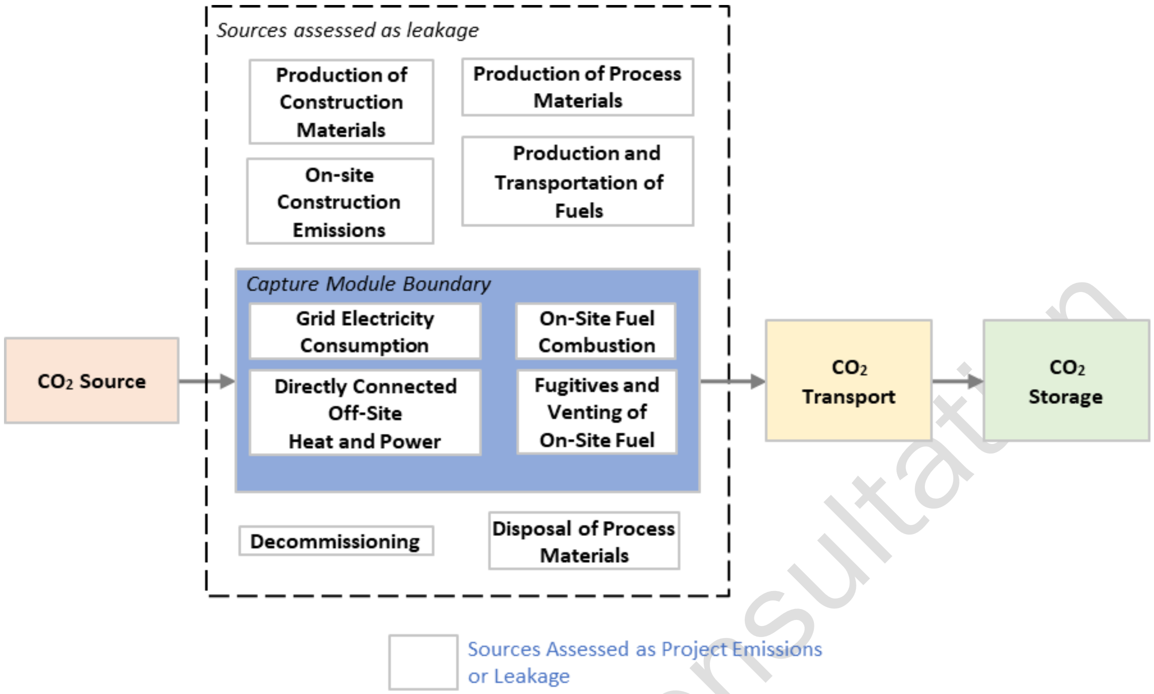

Figure 2: Boundary for Primary and Secondary Project Activity Effects

The GHGs included in or excluded from, the module boundary are detailed in Table 2.

Table 1: GHG Sources Included or Excluded from the DAC Module Boundary

Source		Gas	Included?	Justification/Explanation
Baseline	Atmosphere with no CO_2 removed	CO_2	Yes	CO_2 captured and injected under the project activity would not have been captured in the absence of the project
		CH_4	No	Only CO_2 injection is considered under the baseline. This is conservative.
		N_2O	No	Only CO_2 injection is considered under the baseline. This is conservative.
		Other	No	Only CO_2 injection is considered under the baseline. This is conservative.
Project	Electricity consumption	CO_2	Yes	Major emission source
		CH_4	Yes	Significant upstream emission source
		N_2O	Yes	Included for completeness
		Other	No	Excluded for simplicity, emissions are considered negligible.
		CO_2	Yes	Major emission source

Source		Gas	Included?	Justification/Explanation
	Fuel consumption	CH_4	Yes	Significant upstream emission source
		N_2O	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_2O	No	Excluded as also not considered under the baseline scenario.
		Other	No	Excluded for simplicity, emissions are considered negligible.

6 BASELINE SCENARIO

Project proponents must demonstrate that in the absence of the project activity, no capture of CO_2 from the atmosphere would occur. This must be demonstrated by providing credible evidence that a viable alternative to the project activity was either:

1) No capture facility existed at the capture facility location prior to the start of the project activity (greenfield capture facilities); or
2) New capture facilities or expanded capture facilities are installed at an existing capture facility location (expansion of existing capture facilities);
3) An existing capture facility would be decommissioned prior to the start of the project activity (refurbishment of an existing capture facility).

CO_2 stored in the project boundary may be accounted as non-VCS-CO_2 if none of the three points above apply

Heat consumed by a DAC facility may be considered waste heat if the proponent demonstrates that the heat source:

1) is from a source outside the project boundary;
2) Was not otherwise used at the heat source, or was not delivered, sold, or utilized by a consumer prior to the project start date; and
3) Was dissipated to ambient heat sinks prior to the project start date.

7 QUANTIFICATION PROCEDURES

The following sections provide guidance for determining project emissions from DAC capture activities, i.e., $PE_{Cap,y}$.

7.1 Quantification of Project Emissions

The project emissions are calculated as per Equation (1)

$$PE_{Cap,y} = PE_{Comb\_Fuel,y} + PE_{Fuel\_FV,y} + PE_{Elec,y} - PE_{nonVCS\ CO2,y} \quad (1)$$

Where:

$PE_{Cap,y}$	=	Project emissions from capture in year y (tCO_2e)
$PE_{Comb\_Fuel,y}$	=	Project emissions from fuel combustion to operate equipment for capture and conditioning processes in the year y (tCO_2e).
$PE_{Fuel\_FV,y}$	=	Fugitive and venting and other operational emissions from on-site fuel use (e.g., natural gas use) in the physical boundary of the DAC facility in year y (tCO_2e).
$PE_{Elec,y}$	=	GHG emissions from electricity consumption to operate capture and conditioning processes in the year y (tCO_2e).
$PE_{nonVCS\ CO2,y}$	=	Project emissions from processes and equipment related to non-VCS sources. in year y (tCO_2e) to be determined as per the latest version of the *VMT00XX: Tool for Baseline Quantification and Allocation of Project Emissions in Projects with VCS and non-VCS-CO2 flows in Carbon Capture and Storage Projects*. For projects without non-VCS CO_2, $PE_{nonVCS\ CO2,y}$= 0 (tCO_2e)

7.1.1 Project emissions from fuel combustion

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

$$PE_{Comb\_Fuel,y} = \sum_i (Q_{Fuel,i,y} \times EF_{Fuel,CO2,i}) + \sum_i (Q_{Fuel,i,y} \times EF_{Fuel,CH4,i}) \times GWP_{CH_4} + \sum_i (Q_{Fuel,i,y} \times EF_{Fuel,N2O,i}) \times GWP_{N_2O} \quad (2)$$

Where:

$PE_{Comb\_Fuel,y}$	=	Project emissions from fuel combustion for mobile equipment, on and off-site power and heat generation in year y (tCO_2e)
$Q_{Fuel,i,y}$	=	Quantity of each type of fuel i for on-site and off-site mobile equipment, power and heat generation in year y (m^3 or kg or GJ)
$EF_{Fuel,CO2,i}$	=	CO_2 emission factor of fuel i in year y (tCO_2/m^3, tCO_2/kg or tCO_2/GJ)
$EF_{Fuel,CH4,i}$	=	CH_4 emission factor of fuel i in year y (tCH_4/m^3, tCH_4/kg or t CH_4/GJ)
$EF_{Fuel,N2O,i}$	=	N_2O emission factor of fuel i in year y (tN_2O/m^3, tN_2O/kg or tN_2O/GJ)
GWP	=	Global warming potential (for CH_4 and N_2O respectively)

<u>Co-capture of fossil fuel combustion CO_2 in the DAC facility:</u>

When a DAC process co-captures CO_2 from onsite fossil fuel combustion, the total CO_2 captured from the DAC facility contains both atmospheric and fossil CO_2. The co-captured fossil CO_2 is included as a part of the project emissions in Equation (2) because the quantity of fossil fuel used in the process must be measured as a part of all on-site fuel use. All project emissions are subtracted from the baseline emissions resulting in the net carbon dioxide removal. The quantification thus tolerates the co-capture of fossil fuel combustion emissions at DAC sites when the baseline of total CO_2 injected is applied.

<u>Off-site fuel consumption:</u>

If power or heat are 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:

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

Where:

$Q_{fuel\_cogen,i,y}$	=	Total mass of a fuel type i used by the cogeneration unit to generate electricity and/or heat in year y (metric tons/year)
$Heat_{DAC,y}$	=	Quantity of useful thermal energy supplied to the DAC facility by the cogeneration unit in year y (MWh/year)
$Electricity_{DAC,y}$	=	Quantity of electricity supplied to the DAC facility by the cogeneration unit in year y (MWh/year). Equals zero if only heat supplied to the DAC facility

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

Waste heat:

Project emissions from the consumption of waste heat can be assumed to be zero for heat sources that meet the criteria of waste heat in the baseline section.

Biogenic fuel sources:

Where biofuel or biomass is used, it must comply with the definition and conditions of renewable and sustainable biomass as provided by the latest version of *VMD00XX: CO_2 Capture from Biogenic Sources.* Otherwise, emissions from the combustion of biofuel or biomass must be accounted for using Equation (2).

7.1.2 Fugitive and venting emissions from on-site fuel use

DAC projects that have on-site fuel use (e.g., natural gas) must quantify fugitive and venting emissions during facility operations. These emissions are quantified following the approach in the *Mandatory Reporting of Greenhouse Gas Emissions* by the U.S. EPA based on component counts and respective emission factors.

The potential emission sources for fugitive emissions include but are not limited to, components such as valves, pipe fittings/connectors, open-ended pipes, pressure relief valves, flanges, meters, and instruments.

$$PE_{Fuel\_FV,y} = \left(\sum Count_{i,y} \times EF_{component\ i,y} \times T_{i,y} \times 0.001 + \sum V_i\right) \times GWP_{CH_4} \quad (4)$$

Where:

$PE_{Fuel\_FV,y}$	=	Fugitive and venting emissions from onsite fuel use in year y (tCO_2e)
$Count_i, y$	=	Total number of i[th] components at the facility in use during year y (quantity/unitless)
$EF_{component\ i,y}$	=	Emission factor derived from subpart W of US EPA, Mandatory GHG Reporting Program. 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 component i in year y (hours)
V_i	=	Vented CH_4 emissions for i[th] venting event (tCH_4/event)

7.1.3 Project emissions from electricity consumption

Project emissions from electricity consumption are calculated according to the following Equation (5).

$$PE_{Elec,y} = Q_{Elec,y} \times EF_{Elec} \tag{5}$$

Where:

$PE_{Elec,y}$	=	Project emissions from consumption of electricity to operate equipment in the DAC facility the year y (tCO_2e).
$Q_{Elec,y}$	=	Total metered electricity usage to operate equipment in the DAC facility in year y (MWh/year).
EF_{Elec}	=	Emissions factor for electricity generation (tCO_2e/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 used and provide evidence of the electricity procurement.

Renewable energy (i.e., wind, solar, hydro) from a directly connected, off-grid captive source is deemed to have no emissions. Project proponents must provide evidence of a direct connection.

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.

7.2 Quantification of Leakage

The leakage emissions are calculated as per Equation (8).

$$LE_{Cap,y} = LE_{Fuel,y} + LE_{Elec,y} + LE_{Mat,y} \tag{6}$$

Where:

$LE_{Cap,y}$	=	Leakage emissions from capture in year y (tCO_2e)
$LE_{Fuel,y}$	=	Leakage emissions from upstream sources related to fuel consumed in on-site equipment in the year y (tCO2e).

$LE_{Elec,y}$	=	Leakage emissions from consumption of electricity to operate equipment in the DAC facility the year y (tCO2e).
$LE_{Mat,y}$	=	Leakage emissions from capture materials used in the DAC process in year y (tCO_2e).

7.2.1 Leakage emissions from fuel consumption

Upstream emissions from the production and transportation of fuel to the DACs site and directly connected offsite facilities are calculated using Equation (7).

$$LE_{Fuel,y} = \sum_i (Q_{Fuel,i,y} \times EF_{Upstream\_Fuel,i,y}) \quad (7)$$

Where:

$LE_{Fuel,y}$	=	Leakage emissions from upstream sources related to fuel consumed in on-site equipment in the year y (tCO_2e).
$Q_{Fuel,i,y}$	=	Quantity of fuel type i used in the DAC facility equipment and/or third party (for offsite heat/steam supply) in year y (m^3 or kg or GJ)
$EF_{Upstream\_Fuel,i,y}$	=	Emission factor for upstream sources related to fuel type i used in the DAC facility and/or third party (for offsite heat/steam supply)in year y (tCO_2e/m^3, tCO_2e/kg or tCO_2e/GJ)

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 in the DAC facility or used by a third party to provide heat or steam to the DAC facility ($EF_{Upstream\_Fuel,i,y}$) must be determined for using a life cycle analysis (LCA) that is consistent with the DAC module boundaries (i.e., primary and secondary effects).

7.2.2 Leakage emissions from upstream fuels for electricity consumption

Leakage emissions from electricity consumption are calculated according to the following Equation (8).

$$LE_{Elec,y} = Q_{Elec,y} \times EF_{Upstream\_Elec} \quad (8)$$

Where:

$LE_{Elec,y}$	=	Leakage emissions from consumption of electricity to operate equipment in the DAC facility the year y (tCO_2e).

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

$EF_{Upstream\_Elec}$ = Emissions factor for upstream GHG sources related to electricity generation (tCO_2e/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 used 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, CO_2 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 (4) accordingly.

7.2.3 Leakage emissions from the consumption of capture materials

Capture materials are the chemicals and media used by a DAC process to capture atmospheric CO_2. Depending on technology, this may include capture solvents, solid sorbents, membranes, or catalysts, which may have to be replaced periodically due to loss or degradation over time. Examples include, but are not limited to aqueous potassium hydroxide (KOH), amine supported on activated carbon. These materials degrade over time and must be replaced during the life of the project. Leakage emissions from the replacement or makeup during subsequent years are calculated as per Equation (9) below.

$$LE_{Mat,y} = \sum_{i} (Q_{Mat,y} \times EF_{Mat}) \quad (9)$$

Where:

$LE_{Mat,y}$ = Leakage emissions from consumption of a capture material in the DAC facility in a year y (tCO_2e).

$Q_{Mat,i,y}$ = Quantity of make-up capture material 'i' consumed by the DAC facility in a year y (kg or m^3 or units).

$EF_{Mat,i}$ = GHG emissions from the production of the capture material 'i' (tCO_2e/kg, tCO_2e/m^3, $tCO_2e/unit$, etc.).

Emissions from the production of capture materials, EF_{Mat} must be calculated using a compliance market-approved tool or a commercially available LCA tool which includes data based on peer-reviewed publications if the material is not directly represented in the tool. Examples of open-source compliance tools are listed in Appendix I. Alternatively, a qualified third party may conduct an LCA in accordance with ISO 14040 and 14044, latest editions, that uses either primary or published and peer-reviewed data.

8 DATA AND PARAMETERS

8.1 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.

Data / Parameter	GWP_{CH4}
Data unit	$t\ CO_2e/t\ CH_4$
Description	Global warming potential for CH_4
Equations	(2), (4)
Source of data	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	$t\ CO_2e/t\ N_2O$
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 VCS Standard requires that N_2O 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:	$EF_{Component}$
Data unit:	tCO_2e/hr
Description:	Emissions factor for fugitive emissions
Equations	(4)
Source of data:	The following data sources may be used: 1) Subpart W of US EPA, Mandatory GHG Reporting Program 2) Equivalent national regulation
Value applied	0.005 kg/hr or emission factors may be derived from nationally appropriate regulations, equivalent to the mentioned US EPA reporting guideline
Description of measurement methods and procedures to be applied:	In line with data sources used.
Purpose of data:	Calculation of project and leakage emissions
Comments:	

8.2 Data and Parameters Monitored

Additional data and parameters are defined in the respective *VM00XX Methodology for Carbon Capture and Storage* and related tools (VCS and CDM) as applicable.

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 DAC facility or directly connected energy facilities providing energy to the DAC facility
Equations	(2), and (7)
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:	Continuous, aggregated monthly
QA/QC procedures to be applied:	Flow meters must always 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:	

Data / Parameter:	$EF_{Fuel,CO2,i}$
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: 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:	

Data / Parameter:	$EF_{Fuel,CH4,i}$
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:	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:	

Data / Parameter:	$EF_{Fuel,N2O,i}$
Data unit:	$tN_2O/m3$, tN_2O/kg or tN_2O/GJ
Description:	N_2O 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:	

Data / Parameter:	$EF_{Upstream\_Fuel,i,y}$
Data unit:	tCO_2e/m^3, tCO_2e/kg or tCO_2e/GJ
Description:	The upstream emission factor of fuel type i used in the DAC facility or directly connected energy facilities providing energy to the DAC facility in year y
Equations	(2)(7)
Source of data:	The options for satisfying this requirement are as follows: • Option 1) A qualified third-party may conduct an LCA in accordance with ISO 14040 and 14044, latest edition, that uses either primary or published and peer-reviewed data[1]; or • Option 2) The 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 Standard[2] and GHGenius in the British Colombia Renewable and Low Carbon Fuel Requirements Regulation[3]; or • Option 3) Emission factors published in peer-reviewed literature that are representative both temporally and geographically of the DAC 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.[3]
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 DAC facility

[1] 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 DAC project onsite.

[2] 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.

[3] 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 analyze the emissions of many contaminants associated with the production and use of traditional and alternative transportations fuels.

Purpose of data:	Calculation of leakage emissions
Calculation method:	N/A
Comments:	See also Appendix I: Secondary Emissions Data Sources.

Data / Parameter:	$Q_{fuel\_cogen,i,y}$
Data unit:	*m³, kg or GJ*
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:	Continuous or for every invoice, aggregated monthly
QA/QC procedures to be applied:	Flow meters must be operated per the manufacturer's specified operating conditions at all times. Flow meters must be routinely calibrated, inspected, and maintained according to the manufacturer's 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:	$Heat_{DAC,y}$
Data unit:	*MWh*
Description:	Quantity of useful heat consumed by the DAC facility
Equations	(3)

Source of data:	Utility receipts/invoices or metered data for heat usage.
Description of measurement methods and procedures to be applied:	Direct measurement of steam flows and characteristics (or other heat transfer fluid) at cogeneration facility taking into consideration energy content in steam and condensate return as applicable based on steam properties.
Frequency of monitoring/recording:	Continuous, aggregated monthly
QA/QC procedures to be applied:	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:	$Electricity_{DAC,y}$
Data unit:	*MWh*
Description:	Quantity of electricity consumed by the DAC facility
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:	Continuous, aggregated monthly
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:	Continuous, aggregated monthly
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	Measured from electricity meters or calculated from receipts/invoices.

and procedures to be applied:	
Frequency of monitoring/recording:	Continuous, aggregated monthly
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.

Data / Parameter:	$Q_{Elec,y}$
Data unit:	*MWh*
Description:	Quantity of electricity consumed by the DAC facility
Equations	(5) and (8)
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:	Continuous, aggregated monthly
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:	

Data / Parameter:	EF_{Elec} and $EF_{Upstream\_Elec}$

Data unit:	tCO_2e/MWh
Description:	Emissions factor for electricity generation, optionally including upstream emissions from electricity generation and transport
Equations	(5)(8)
Source of data:	The following data sources may be used: 3) For grid electricity consumption, regional emission factors from Compliance tools, and data published by State or National government must be used. Examples of such tools/sources are listed in Appendix I. 4) Renewable energy (i.e., wind, solar, hydro) from a dedicated/off-grid captive source is deemed to have no emissions. 5) 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 and leakage emissions
Calculation method:	N/A
Comments:	

Data / Parameter:	$Q_{Mat,y}$
Data unit:	*kg or m³ or units*
Description:	Quantity of Capture material consumed by the DAC facility
Equations	(9)
Source of data:	Receipts/invoices or flow meter or weighing scale/equipment readings, whichever is applicable.
Description of measurement methods	Measured from material flow meters or weighing equipment or calculated from receipts/invoices.

and procedures to be applied:	
Frequency of monitoring/recording:	Aggregated annually. As per the flow meter or weighing equipment specification by the manufacturer. Manufacturers must be compliant with ISO standards. Alternatively, the sum of all receipts/invoices for capture materials over the given year y must be used.
QA/QC procedures to be applied:	Flow meters must be routinely calibrated, inspected, and maintained according to manufacturer specifications.
Purpose of data:	Calculation of leakage emissions
Calculation method:	See above
Comments:	

Data / Parameter:	EF_{Mat}
Data unit:	*tCO_2/kg, tCO_2/m^3 or $tCO_2/units$*
Description:	GHG emissions from the production of the capture materials
Equations	(9)
Source of data:	Emissions from the production of capture material must be calculated using: 1) Compliance market-approved tool. Examples of open-source Compliance tools: CA-GREET, GHGenius; 2) A third-party audited assessment that is in line with ISO 14044 guidelines can be used to calculate the emissions; or 3) Data published in peer-reviewed literature, such as scientific journals.
Description of measurement methods and procedures to be applied:	In line with sources of data.
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.
Purpose of data:	Calculation of leakage emissions

Calculation method:	N/A
Comments:	See Appendix I for examples of sources of data.

Data / Parameter:	$Count_{i,y}$
Data unit:	Number
Description:	Total number of i^{th} components at the facility in use during year y
Equations	(4)
Source of data:	Records of DAC facility (e.g., pipe and instrument drawing, parts lists)
Description of measurement methods and procedures to be applied:	Counting based on DAC facility records.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Use the latest data available from DAC facility.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	

Data / Parameter:	$T_{i,y}$
Data unit:	*hours*
Description:	Pressurized time of component i in year y
Equations	(3)
Source of data:	Records of DAC facility (e.g., control systems, recorded operational data)
Description of measurement methods	Data from DAC facility records.

and procedures to be applied:	
Frequency of monitoring/recording:	Continuous, aggregated monthly
QA/QC procedures to be applied:	Use the latest data available from DAC facility.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	

Data / Parameter:	V_i
Data unit:	$tCH_4/event$
Description:	Vented CH_4 emissions for i^{th} venting event
Equations	(3)
Source of data:	Data from DAC facility
Description of measurement methods and procedures to be applied:	**Option 1:** Direct measurement of venting **Option 2:** Estimated based on isolated volumes of pipes and equipment **Option 3:** Estimation based on non-isolated volumes of pipes and equipment: The proponent must determine the quantity of vented CH_4 by transient flow rate calculations for compressible fluids, appropriate for the expected evolving conditions in the pipeline or component based on the approximate geometry of the escaping flow and pipelines/components connected to the venting.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Cross-checked based on energy balance related to metered fuel use.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	See Appendix I for examples of sources of data and Section **Error! Reference source not found.** for further details on the replacement of capture materials.

9 REFERENCES

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10 APPENDIX I: SECONDARY EMISSIONS DATA SOURCES

10.1 Established Tools and Datasets for CCS Projects in the United States:

A large variety of Life Cycle Inventory (LCI) data sources exist in both the public and commercial domain (e.g., ecoinvent, GaBi, etc.). Public data sources from the United States Department of Energy (DOE) and the Federal Government are provided below for reference:

- National Energy Technology Laboratory (NETL)
    - Natural gas model: https://netl.doe.gov/energy-analysis/details?id=35d27478-88a0-4ef4-ab51-2e1bbcf5332e
    - Gate-to-grave saline aquifer storage model: https://netl.doe.gov/energy-analysis/details?id=94309bc8-0539-42d3-9c13-01f2f34f27e3
- U.S. Electricity baseline
    - Grid Mix Explorer Excel tool: https://netl.doe.gov/energy-analysis/details?id=f0f94954-3627-4e9b-a5c0-c29cfe419d1c
    - openLCA unit processes: https://www.lcacommons.gov/lca-collaboration/Federal_LCA_Commons/US_electricity_baseline/datasets
- Unit Process Library: https://netl.doe.gov/node/2573
- Argonne National Laboratory (ANL) The Greenhouse gases, Regulated Emissions and Energy use in Technologies (GREET): https://greet.es.anl.gov/
- United States Federal Life Cycle Analysis Commons: https://www.lcacommons.gov/lca-collaboration
- National Renewable Energy Lab United States Life Cycle Inventory Database (USLCI): https://www.nrel.gov/lci/
- United States Environmental Protection Agency Environmentally-Extended Input-Output (USEEIO) Models: https://www.epa.gov/land-research/us-environmentally-extended-input-output-useeio-models

Table 2: Key Data Collection Processes, Parameters and Sources

Data Category	Parameters	DOE and Other Federal Resources
Project Operation	Inputs and outputs associated with the facility operations, including any on-site emissions	Unique to each project – user input based on the engineering model
Consumables – Electricity	• Consumption mix technology contributions by generation type • Inclusive not only of generation facility emissions but also fuel and material supply chains, where applicable • Future grid mixes based on the proposed year of deployment using data provided in EIA's Annual Energy Outlook 'Reference Case'	• U.S. Electricity Baseline (NETL) – regionalized consumption mixes with options to customize technological representation • ANL GREET
Consumables – Heat	• For onsite combustion: direct emissions should be included in DAC operation, but the fuel supply chain (e.g., natural gas) is accounted for separately. • For offsite combustion: both fuel combustion and fuel supply chain should be accounted	• NETL • ANL GREET • Federal LCA Commons
Non-Consumables – Construction/Capital Activities	Amounts (mass or dollars) of key materials (e.g., steel, concrete, aluminum, copper, plastics) for process equipment and site infrastructure	• Process-based LCA could be conducted with material LCI data from NETL, GREET, Federal LCA Commons • Alternatively, estimating data based on purchasing could leverage the U.S. EEIO approach
Consumables – Process Chemicals and Water	Inclusive of initial system charges as well as any required routine makeup over the life of the facility (solvents, sorbents, etc.)	• Highly dependent on the chemical – some data are available from NETL, GREET, and U.S. LCI • Alternatively, estimating data based on purchasing could leverage the U.S. EEIO approach

CO_2 compression, transport, injection, MRV	Initial on-site compression of the captured CO_2 should be included in the DAC site electricity consumption but required boost compression and transport are included here. Storage site activities include site prep, well construction, injection, and brine management – these are all variable by site and could be parameterized if desired to evaluate geographic/geologic variability	• NETL gate-to-grave assessment of saline aquifer storage of CO_2
Waste management	Handling, transporting, and managing process wastes from DAC operations	• U.S. LCI for landfilling or incineration; GREET or NETL for transport
Land use change	Site disturbance/clearing to facilitate DACS operations and infrastructure	• GREET and NETL have land use change/conversion factors
Decommissioning	Deconstruction, waste disposal, material recycling	• Proxy industrial facility for these impacts (e.g., power plant decommissioning is included in some of the NETL LCAs)

10.2 Established Tools and Datasets for CCS Projects in the EU

- European Commission Joint Research Centre, Definition of Input Data to Assess GHG Default Emissions from Biofuels in EU legislation, Latest Edition

10.3 Established Tools and Datasets for CCS Projects in Canada

- Environment and Climate Change Canada, Fuel Life Cycle Assessment (LCA) Model Database and Methodology, Latest Edition