VCS Methodology

VM0043

CO_2 UTILIZATION IN CONCRETE PRODUCTION

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Sectoral Scopes 4 & 6

Version 1.0 of this methodology was developed by Carbon Cure and Carbonomics.

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1 SUMMARY DESCRIPTION

Additionality, Crediting Method, and Mitigation Outcome	
Additionality	Activity method
Crediting Baseline	Project method
Mitigation Outcome	Reductions and Removals

This methodology is globally applicable to project activities that capture CO_2, which would have otherwise been emitted into or remained in the atmosphere and utilize that gas as a feedstock in the production of ready-mix or pre-cast concrete. These project activities reduce greenhouse gas (GHG) emissions by sequestering CO_2 via the production of concrete. This manufacturing process has the additional benefit of requiring less Portland cement, which further reduces upstream emissions from cement production. The project activity takes place at the location where the concrete is manufactured (mixed with cement, water, aggregates, etc.).

2 SOURCES

This methodology is informed by the following methodologies:

- CDM methodology, AMS-III.BA, *Recovery and recycling of materials from E-Waste, v2.0*
- VCS methodology, VM0031, *Methodology for Precast Concrete Production using Sulphur Substitute, v1.0*
- VCS methodology, VM0040, *Methodology for Greenhouse Gas Capture and Utilization in Plastic Materials*
- VCS Tool, VT0011 - *Electricity System Emission Factors*

3 DEFINITIONS

Captured CO_2
Carbon dioxide captured from the atmosphere or a point source that would have otherwise remained in or been emitted to the atmosphere. Captured CO_2 from the atmosphere or from sustainable biomass point source emissions are eligible to be labelled as carbon dioxide removals. All other captured CO_2 is an emission reduction.

Cement

Portland cement, Portland limestone cement, or blended cement. Blended cement also includes supplementary cementitious materials. Portland cement, the most common, is a hydraulic cement powder made by grinding a clinker comprised of calcinated limestone and other secondary ingredients, including up to 5% limestone. This methodology will simply use the term cement to refer to all types.

Cement replacement

A material that can fully replace Portland cement as the binder in concrete, often referred to as Alternative Cementitious Material (ACM).

Clinker

A dark grey nodular material made by heating ground limestone and clay at a temperature of about 1400°C - 1500°C. The nodules are ground up to a fine powder to produce cement, with a small amount of gypsum added to control the setting properties.

Concrete

Concrete is a material traditionally composed of coarse aggregates (e.g., sand, gravel), cement or cement replacement, and possibly supplementary cementitious materials that hardens upon addition of water and following a curing process to form a stone-like substance. Concrete is used in several forms, including ready mix and pre-cast (drycast and wetcast).

Feedstock

The CO_2 captured as part of project activities used along with other materials to produce concrete.

Mix Design

The masses of ingredients, including cement (or cement replacement), sand, gravel, aggregate, water, and any other additives used by a project proponent to produce a unit of concrete of a given type and compressive strength. This mix design could be used in the project activity and would then be referred to as the project mix design. In addition, the mix design could be what would have occurred in the absence of the project activity, which is then referred to as the baseline mix design. The baseline mix design is determined in order to assess how much cement would have been used in the baseline scenario. The same mix design can be used at multiple facilities.

Precast Concrete

Concrete that is cast in a mold and then cured in a controlled environment in a manufacturing plant, instead of mixing and pouring it at the construction site. Examples include concrete masonry, hardscapes, and reinforced concrete elements.

Supplementary Cementitious Material (SCM)

Material that is a waste by-product of another industrial process and that contributes to the properties of a cementitious mixture through hydraulic or pozzolanic activity, or both, without the need for additional thermal processing or calcining. Examples include pozzolans like fly ash, slag cement, silica fume, biogenic limestone, biochar etc.

Waste CO_2
Carbon dioxide from an anthropogenic source that would have otherwise been emitted to the atmosphere.

4 APPLICABILITY CONDITIONS

This methodology is globally applicable to project activities that capture CO_2, which would have otherwise been emitted to or remained in the atmosphere, and utilize it as a feedstock in the production of concrete.

This methodology is applicable under the following conditions:

1) Project activities manufacture ready-mix or pre-cast concrete products using CO_2 as a feedstock, a process that requires lower amounts of cement than concrete production processes that do not use CO_2 as a feedstock.

2) The concrete products produced by the project activity have equivalent or better performance (e.g., compressive strength and code compliance) as the baseline concrete products that would have otherwise been produced and used in the absence of the project.

3) Project activities produce a concrete material that will be used and sold in the commercial market.

4) The use of supplementary cementitious materials (SCM) in cement and concrete is eligible either in the baseline or project scenario.

5) Where project activities produce pre-cast products, the products replace pre-cast products made in the traditional form (without CO_2 as feedstock and higher cement content) and do not replace other products made of different materials.
   CO_2 from direct air capture (DAC) is an acceptable source of CO_2 for this project activity.

6) If CO_2 is captured from an emissions source that is regulated by a cap-and-trade or emission trading system (ETS) program, the project proponent must review the facility's emissions reporting to regulators to ensure it is not reducing its emissions output based on the amount of CO_2 captured and supplied to the project activity. Alternatively, the project proponent can receive an attestation from the facility that it is not reporting lower emissions due to the capture of CO_2 for the project activity. If such reporting is not available or an attestation cannot be provided, the project activity must not count emissions reductions for the sequestering of CO_2 into concrete (although emission reductions can still be counted for the reduction in cement usage).

This methodology is not applicable under the following conditions:

1) Recycled concrete use in both the baseline or project scenario.

5 PROJECT BOUNDARY

As illustrated in Figure 1 below, the spatial extent of the project boundary encompasses:

- The project facility where concrete materials are produced;
- The facilities from which the CO_2 feedstock is sourced (if not direct air capture);
- The facilities where displaced Portland cement is manufactured.

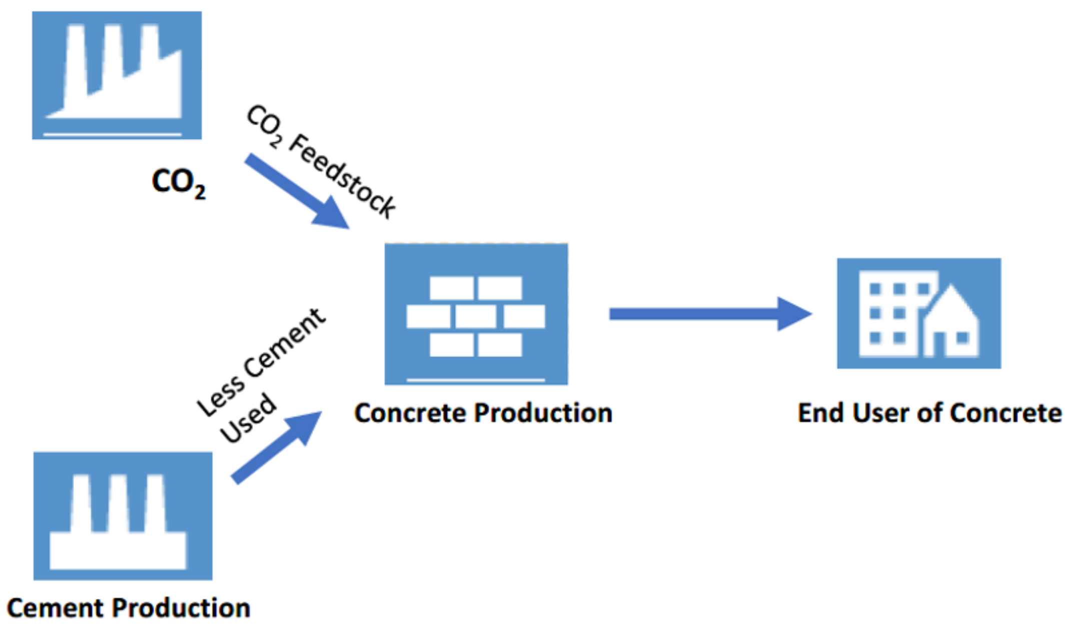

Figure 1: Spatial Boundary of the Project Activity

The greenhouse gases included in or excluded from the project boundary are shown in Table 1 below.

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

Source		Gas	Included?	Justification/Explanation
Baseline	Captured CO_2	CO_2	Yes	CO_2 is the main gas that can be captured by carbon capture and utilization technology
		CH_4	No	Only CO_2 captured and sequestered into concrete is considered for this methodology
		N_2O	No	Only CO_2 captured and sequestered into concrete is considered for this methodology

		Other	No	Other GHGs (HFCs, PFCs, SF_6) are not used in this process.
	GHGs from cement production, including calcination	CO_2	Yes	CO_2 process emissions occur as a by-product of the calcination process, where a calcium or magnesium carbonate such as limestone is heated with clay to form clinker (primarily calcium oxide) and CO_2. The heat required for the calcination process is typically supplied from the combustion of fossil fuels, resulting in the emission of further CO_2
		CH_4	No	Excluded for simplicity, emissions are considered negligible.
		N_2O	No	Excluded for simplicity, emissions are considered negligible.
		Other	No	Other GHGs (HFCs, PFCs, SF_6) are not used in this process.
Project	GHGs from the project facility	CO_2	Yes	Electricity, combusted natural gas or liquid/solid fuels are the primary energy sources that would be used to power a facility manufacturing concrete products and material. CO_2 is the primary emission from that combustion. This relates only to the incremental increase in the use of equipment needed to sequester the CO_2. This does not refer to the entire facility itself.
		CH_4	No	Excluded for simplicity, emissions are considered negligible.
		N_2O	No	Excluded for simplicity, emissions are considered negligible.
		Other	No	Other GHGs (HFCs, PFCs, SF_6) are not used in this process.
	GHGs from cement production	CO_2	Yes	CO_2 process emissions occur as a by-product of the calcination process, where a calcium or magnesium carbonate such as limestone is heated with clay to form clinker (primarily calcium oxide) and CO_2. The heat required for the calcination process is typically supplied from the combustion of fossil fuels, resulting in the emission of further CO_2
		CH_4	No	Excluded for simplicity, emissions are considered negligible.
		N_2O	No	Excluded for simplicity, emissions are considered negligible.
		Other	No	Other GHGs (HFCs, PFCs, SF_6) are not used in this process.
	GHGs from capturing, compressing and	CO_2	Yes	Main GHG associated with the electricity requirements and fossil fuel usage associated with processing captured CO_2. Note also that the default factors for transportation emissions

	transporting CO_2			(tCO_2e/tonne-mile) includes all GHGs from transportation.
		CH_4	No	Excluded for simplicity, emissions are considered negligible.
		N_2O	No	Excluded for simplicity, emissions are considered negligible.
		Other	No	Other GHGs (HFCs, PFCs, SF_6) are not used in this process.

6 BASELINE SCENARIO

The baseline scenario is the continuation of manufacturing ready-mix or pre-cast concrete products through traditional processes (i.e., not using CO_2 capture and utilization technology for reduced cement use). The project proponent must demonstrate that the CO_2 used as feedstock is released to or remains in the atmosphere in the baseline scenario and that the project does not divert it from other uses.

Project proponents must source CO_2 from sources that would have otherwise been emitted or remained in the atmosphere. Examples of ineligible sources include but are not limited to the following:

1) CO_2 taken from a well, which is connected to a geologic reservoir, where the CO_2 would have otherwise stayed underground;

2) CO_2 captured from an industrial source where that CO_2 would have otherwise been captured and then injected into a geologic reservoir; and

3) CO_2 that is diverted from other utilization applications.

4) CO_2 generated for the purpose of capture

If a project proponent were to take CO_2 from such sources, then it cannot claim emission reductions from the injection and mineralization of CO_2 into concrete. In addition, the amount of CO_2 from an unknown or ineligible source that is supplied to the project but lost and not mineralized must be considered a project emission, as determined in Section 8.2.5.

7 ADDITIONALITY

This methodology uses an activity method for the demonstration of additionality.

Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the mo version of the VCS Program Rules and Requirements.[1]

Step 2: Positive List

The applicability conditions of this methodology represent the positive list. The project must demonstrate that it meets all applicability conditions, and in so doing, it is deemed as complying with the positive list and as being additional.

The positive list was established using the activity penetration option (Option A in the *VCS Methodology Requirements*[2]). Justification for the activity method is provided in Appendix I.

8 QUANTIFICATION OF REDUCTIONS AND REMOVALS

8.1 Baseline Emissions

Emissions in the baseline scenario are associated with two components. The first component is the emissions associated with the production of Portland cement. The second component is the CO_2 that is captured and sequestered in the ready-mix or pre-cast concrete products produced by the project activity.

8.1.1 Component 1: Avoided Cement Emissions (BE_{ACU}):

The first component of the baseline emissions calculation is the displacement of conventional cement production by the project activity. These baseline emissions are calculated in the equation below. The amount of displacement is calculated by determining the quantity of cement that would have been used in the absence of the project and multiplying that by the emissions factor of the cement. There are three options for determining the emissions factor.

$$BE_{ACU,y} = \sum_i \left(Q_{cement,i,b,y} \times EF_{cement}\right) \times (1 - DF) \quad (1)$$

[1] Section 3.5.3 of the *VCS Methodology Requirements*

[2] Section 3.5.10 of the *VCS Methodology Requirements, v4.4*

Where:

$BE_{ACU,y}$	= Emissions from the production of Portland cement that would have been used in the absence of the project (tCO_2e) in year y
$Q_{cement,i,b,y}$	= Quantity of Portland cement that would have been used in the baseline for concrete produced using a project mix design *i* in year y (tonnes)
EF_{cement}	= Emissions factor of Portland cement production (tCO_2e/tonne of cement)
DF	= Discount factor for upstream displacement (30%)

Determining $Q_{cement,i,b,y}$: Project proponents must use a testing procedure that measures the cement required to produce concrete products with equivalent or better functional or compressive strength per industry standards, such as ASTM Volume 04.02. This procedure involves comparing the compressive strength of concrete with and without the project activity to establish a cement use ratio between the project scenario and the baseline scenario applicable to all project concrete produced with mix design *i*.

Where concrete products do not utilize compressive strength as a metric, project proponents must apply the appropriate ASTM tests to determine functional equivalence. The testing process is outlined in Appendix II. Note that the equations below refer to concrete mix designs, which include both ready-mix and pre-cast concrete products.

$$Q_{cement,i,b,y} = \sum_{i} \left[Q_{cement,i,p,y} \times \left(\frac{\sum_n Q_{cement,b,i,test\ n}}{\sum_n Q_{cement,p,i,test\ n}} \right) \right] \quad (2)$$

Where:

$Q_{cement,i,p,y}$	= Quantity of Portland cement used in the project scenario for concrete produced using a project mix design *i* in year y (tonnes).
$Q_{Cement,p,i,test\ n}$	= Quantity of Portland cement used (e.g., tonnes) to prepare project compressive strength or equivalent test specimen *n* for concrete produced using project mix design *i*. The testing process is outlined in Appendix II.
$Q_{Cement,b,i,test\ n}$	= Quantity of Portland cement used (e.g., tonnes) to prepare baseline compressive strength or equivalent test specimen *n* for concrete produced using a baseline mix design, that results in a concrete of equivalent compressive strength to project mix design *i*. The testing process is outlined in Appendix II.

Requirements for mix designs: The key differentiation between mix designs include compressive strength, cement input, and carbon content. Requirements for mix designs are listed below.

A. Mix Design Assessment:

- The baseline mix design is determined to assess the amount of cement that would have been used in the baseline scenario.

- The same mix design can be utilized at multiple facilities.

B. Description and Rationale:

- The project proponent must describe the different mix designs in the Project Description (PD).
- Minor variations in the ratio of ingredients within different batches of concrete of the same mix design can be considered the same mix design category.
- A rationale for categorizing different mix designs must be provided. The categorization should consider how much concrete is produced with each mix, giving more importance to mix designs that are used in larger quantities.

C. New vs. Existing Concrete Facilities:

If the project operates in a new concrete facility, as opposed to an existing one (i.e., where baseline concrete was not previously produced), the concrete manufacturer must:

- Produce samples in an independent laboratory that is not undertaking the project activity.
- Develop baseline samples with the equivalent or better function and/or compressive strength as the project concrete, enabling an accurate comparison between the baseline and project scenarios.

2) Use an independent laboratory that is accredited by a credible/relevant agency of the host country.

Determining EF_{cement}: The emissions factor for the cement must be determined using one of the following options:

Option 1. Plant-Specific Data: Where the source of the cement used both in the baseline and project scenario is known, and the concrete production is co-located at the cement production facility (e.g., when the cement and concrete production is by the same company), plant-specific factors must be used if they are available. The information from the cement plant(s) must include total energy and fuel use (including electricity usage, on-site mobile fuel usage and regional electricity emission factors) and the project proponent must calculate the total GHG emissions per unit of cement produced.

Option 2. Environmental Product Declarations (EPDs): Where Option 1 is not applicable, project proponents may use environmental product declarations (EPDs) that provide key information on GHG intensity of cement. An EPD is a comprehensive summary report of environmental impacts of a material's production based on life cycle assessment (LCA) and verified by a third party. It provides a clear, consistent, and transparent basis for reporting broad environmental performance for similar types of materials or products.[3] When different cement sources are mixed together in a single truckload of concrete, a weighted average must be calculated based on the proportion of each cement source used.

[3] For example, the EPD published by the Portland Cement Association in the US cites that the cradle to gate total emissions per tonne of cement production is 1.040 tonnes of CO_2e. See: https://www.cement.org/docs/default-source/sustainabilty2/pca-portland-cement-epd-062716.pdf?sfvrsn=2. Many countries publish EPDs – for example, the UK can be found at https://cement.mineralproducts.org/documents/UK_Average_Portland_Cement_EPD.pdf.

EPDs typically incorporate the entire cradle-to-gate life cycle of the cement process and as such, they are not directly comparable to plant-specific data (Option 1) or the use of regional factors (Option 3). The use of an emissions factor based on the entire lifecycle would thus raise the EF_{cement} value and lead to a higher level of baseline emissions as compared to the other options. To compensate for this difference would therefore be conservative. Two studies have been identified that provide similar estimates of the emissions not directly associated with the cement production process itself. Specifically, it is estimated that extraction of the raw materials accounts for 12% of the cradle-to-gate impact of a cement LCA.[4] Another study estimates that figure as 11.2%.[5] Thus, where Options 1 and 3 are used, project proponents must increase the EF figure (tCO_2e/tonne of cement) by 11.2% in order to make all methods to determine the EF comparable.

Option 3: Use of Regional Factors: Where EPDs are not available, or where the project activity is in a country where the data needed for Options 1 and 2 are not available, the project proponent must use regional factors. Refer to Appendix III for the parameters needed to calculate regional factors. For this option, the following formula must be used to determine EF_{cement}.

$$EF_{cement} = \frac{M_{clinker}}{M_{cement}} \times EF_{clinker} \quad (3)$$

Where:

EF_{cement}	= Emission factor for Portland cement production (tCO_2e/tonne of cement)
$M_{Clinker}/M_{Cement}$	= Clinker to cement ratio (unitless).
$EF_{Clinker}$	= Emission factor of clinker (tCO_2e/tonne of clinker).

8.1.2 Component 2: Captured CO_2 ($CR_{CO2,cap}$ or $BE_{CO2,cap}$):

If the CO_2 is captured from the atmosphere through direct air capture or bioenergy[6] carbon capture technologies, it results in carbon dioxide removals and $CR_{CO2,cap}$ must be determined.

If the CO_2 is captured from flue gases resulting from fossil fuel combustion or other industrial processes (e.g., cement, blue hydrogen production), it results in emission reductions and $BE_{CO2,cap}$ must be determined. The source of CO_2 must be recorded to make this distinction.

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[4] "Improving the CO2 Performance of Cement, Part I: Utilizing Life-Cycle Assessment and Key Performance Indicators to Assess Development Within the Cement Industry", Roozbeh Feiz, et. al., Linkoping University Post Print.

[5] "A Life-Cycle Assessment of Portland Cement Manufacturing: Comparing the Traditional Process with Alternative Technologies", Deborah Huntzinger, et. al. *Journal of Cleaner Production*, 2009.

[6] To be eligible for the removal label, the CO_2 sourced from bioenergy carbon capture must be from renewable biomass that is sustainably sourced, for example this includes CO_2 from ethanol production facilities using renewable biomass feedstocks that are sustainable sourced.

There are two options for determining the amount of CO_2 captured and mineralized in the concrete or concrete products.

Option 1: Testing to Determine Quantity of CO_2 Stored in the Concrete: Determining the amount of CO_2 sequestered into the concrete products involves the testing of concrete samples using a carbon analyzer. This device can ascertain the level of carbon embedded in a sample of concrete products. The difference between the carbon contents of the baseline sample and the project sample indicates the additional CO_2 that is embedded in the project concrete. The testing procedure is detailed in Appendix IV. The results of the tests are used in the equations below:

$$BE_{CO2,cap,y} = \sum_i [Q_{concrete,i,p,y} \times (C_{project\ sample,i,y} - C_{baseline\ sample,i,y}) \times \frac{44}{12}] \quad (4a)$$

or

$$CR_{CO2,cap,y} = \sum_i [Q_{concrete,i,p,y} \times (C_{project\ sample,i,y} - C_{baseline\ sample,i,y}) \times \frac{44}{12}] \quad (4b)$$

Where:

$BE_{CO2,cap,y}$ = Baseline emissions from the capture of CO_2 (tCO_2e) in year y

$CR_{CO2,cap,y}$ = Carbon dioxide removals from the capture of CO_2 (tCO_2e) from the atmosphere in year y

$Q_{Concrete,i,p,y}$ = Quantity of concrete products produced by the project for product mix design *i* in year y (tonnes).

$C_{project\ sample,i,y}$ = Carbon content of samples of concrete products for each design mix *i* in year y taken from the project activity (kgC/kg of concrete in the sample)

$C_{baseline\ sample,i,y}$ = Carbon content of samples of concrete products for each design mix *i* in year y that are not using the project activity technology (kgC/kg of concrete in the sample)

Option 2: Default Efficiency of Mineralization: In some cases, one concrete manufacturer may be producing too many mix designs for the testing to be feasible or practical. In this case, project proponents may use a default based on the percentage of CO_2 injected into the process (as determined by a meter) and actually mineralized. This indicates the *efficiency of mineralization*. There have been tests done on this efficiency as outlined in Appendix VI. These tests show quite a range of results in terms of the efficiency of the uptake of CO_2 into the concrete, and there appears to be little correlation between the efficiency of mineralization and the percent dosing of CO_2. However, the lowest test result is 76%, meaning that about three-quarters of the CO_2 that is injected into the process is actually mineralized into the concrete. As a conservative default, the assumed efficiency of mineralization is set at 60%, which is applicable for both ready-mix and precast concrete.

$$BE_{CO2,cap,y} = Q_{CO2,meter,s,y}\ X\ 0.60 \quad (5a)$$

$$CR_{CO2,cap,y} = Q_{CO2,meter,s,y} \times 0.60 \quad (5b)$$

Where:

$Q_{CO2,meter,s,y}$	= Amount of CO_2 injected from source s in year y into the concrete production process, as determined by a flow meter (tCO_2) at the project activity location
0.60	= Conservative default for the efficiency of CO_2 mineralization into the concrete

8.2 Project Emissions

Project emissions are determined as follows:

$$PE_y = PE_{cement,y} + PE_{elec,y} + PE_{ffc,y} + PE_{CO2,y} + PE_{CO2,ineligible,y} \quad (6)$$

Where:

PE_y	= Project emissions in year y (tCO_2e)
$PE_{cement,y}$	= Emissions from the production of cement used at the project facility in year y (tCO_2e)
$PE_{elec,y}$	= Emissions from the incremental use of electricity by the CO_2 injection equipment at the project facility in year y (tCO_2e)
$PE_{ffc,y}$	= Emissions from the incremental combustion of fossil fuels by the CO_2 injection and any other related equipment at the project facility in year y (tCO_2e)
$PE_{CO2,y}$	= Emissions associated with the capture, compression and transport of CO_2 to the location where it will be sequestered in concrete in year y (tCO_2e)
$PE_{CO2,ineligible,y}$	=Amount of CO_2 non-mineralized that comes from a non-eligible source of CO_2 or when CO_2 source is unknown in year y (tCO_2e)

8.2.1 Project emissions from cement production

The project emissions from the amount of cement used at the project facility are calculated as follows:

$$PE_{cement,y} = \sum_i Q_{cement,i,p,y} \times EF_{cement} \times (1 - DF) \quad (7)$$

Where:

$PE_{cement,y}$	= Emissions from the amount of cement used at the project facility in year y (tCO_2e)
$Q_{cement,i,p,y}$	= Quantity of Portland cement used in the project for concrete produced using a project mix design *i* in year y (tonnes)

EF_{cement}	= Emissions factor for the Portland cement used in the project (tCO_2e/ tonne of cement). One of the three options described above must be used.
DF	= Discount factor for upstream displacement (30%)

8.2.2 Project emissions from electricity use

The project emissions from the use of electricity at the project facility are calculated as follows:

$$PE_{elec,y} = Q_{elec,y} \times EF_{elec} \tag{8}$$

Where:

$PE_{elec,y}$ (tCO_2e)	= Emissions from the use of electricity at the project facility in year y
$Q_{elec,y}$	= Quantity of electricity used by the CO_2 injection equipment from the grid in year y used to power the equipment needed to operate the project activity in year y (MWh)
EF_{elec}	= Emissions intensity of the electricity (tCO_2/MWh)

Determining EF_{elec}: Project proponents may follow one of two alternatives to calculate this parameter:

3) Use a grid emission factor published by a government agency. For example, for projects located in the United States use the eGrid emissions factor for the sub-region where the facility is located (latest available information). Where grid emission factors are not available from a government agency, an emission factor published by another reputable and recognized source, and reviewed for publication by an appropriate qualified, independent organization or appropriate peer review group may be used (if available).

4) Use the latest version of the VCS Tool VT0011 – *Electricity System Emission Factors*.

8.2.3 Project emissions from fossil fuel use

The project emissions from the incremental combustion of fossil fuels used to power the equipment needed to run the project activity are calculated as follows[7]:

$$PE_{ffc,y} = \sum_a \left(Q_{ff,a,y} \times FC_a \times EF_a\right) \tag{9}$$

Where:

$PE_{ffc,y}$	= Emissions from the combustion of fossil fuels used at the project facility in year y (tCO_2e)
$Q_{ff,a,y}$	= Quantity of fossil fuel a used by the CO_2 injection equipment in year y (volume of liquid fuel, mass of solid fuel or cubic meters of natural gas)

[7] Note that incremental means just the energy requirements required to inject the CO2 into the concrete – in other words, just the additional energy to carry out the project activity, which would not have taken place in the baseline scenario.

FC_a = Energy content of fuel type a combusted (TJ/unit of fuel)

EF_a = Emission factor of fuel type a (tCO_2/TJ)

8.2.4 Project emissions from CO_2 processing and transport

The project emissions from the capture, compression and transport of CO_2 to the location where it will be sequestered in concrete can be calculated using two options.

Option 1:

$$PE_{CO2,y} = PE_{CO2,processing,y} + PE_{CO2,transport,y} \quad (10)$$

Where:

$PE_{CO2,y}$ = Emissions associated with the capture, compression and transport of CO_2 to the location where it will be sequestered in concrete in year y (tCO_2e)

$PE_{CO2,processing,y}$ = Emissions associated with the capture, compression and processing of CO_2 in year y (tCO_2e)

$PE_{CO2,transport,y}$ = Project emissions associated with the transport of CO_2 to the project site in year y (tCO_2e)

$$PE_{CO2,processing,y} = Q_{CO2,meter,y} \times \frac{\sum_a (Q_{ff,a,y,processing} \times FC_a \times EF_{ff,a,processing}) + Q_{elec\ processing,y} \times EF_{elec}}{Total_{CO2\ processed,y}} \quad (11)$$

Where:

$PE_{CO2,processing,y}$ = Emissions associated with the capture, compression and processing of CO_2 in year y (tCO_2e)

$Q_{CO2,meter,y}$ = Amount of CO2 injected in year *y* into the concrete production process, as determined by a flow meter (tCO_2) at the project activity location.

$Q_{ff,a,y,processing}$ = Total quantity of fossil fuel used to capture, compress, process CO_2 in year y (gallons (oil fuels), cubic meters (natural gas), tonnes (solid fuels))[8]

FC_a = Energy content of fuel type a for the entire CO_2 production facility (TJ/unit of fuel)

$EF_{ff,a,processing}$ = Emission factor of fuel *a* (tCO_2/TJ)

EF_{elec} = Emissions intensity of the electricity (tCO_2/MWh)

[8] This parameter refers to the fuel used at the entire facility where the CO_2 would be emitted but is instead being captured and processed for use "CO_2 production facility" (or facilities if multiple sources are used) in year y (volume of liquid fuel, mass of solid fuel or cubic meters of natural gas).

$Q_{elec,processing,y}$ = Total quantity of electricity from the grid in year y used to capture, compress and process CO_2 (MWh)

$Total_{CO_2\ processed,y}$ = Total amount of CO_2 processed from the facility (or facilities) supplying the captured CO_2 in year y (tCO_2)[9]

Note that where the CO_2 is sent via pipeline from the production facility to the project facility, the energy requirements of moving that gas through the pipeline must be included in the processing equation (Eq. 11) rather than Equation 12, which uses default factors for modes of transport such as ship, air, and rail.

The supplier(s) of the CO_2 will be required to provide information on the electricity and fuel requirements of all energy required to capture, compress and transport (via pipeline) the CO_2 to the point where it is used by the project activity in a 12-month period. If 12 months of data are not available, it can be estimated or extrapolated from monthly data. This includes each location where the processing emissions take place in order to determine the electricity intensity of the grid at that location. This information comprises:

1. At the point of capture, provide the following:
    a. Quantity of total CO_2 captured,
    b. Total amount of electricity used to carry out the capture process,
    c. Total amounts and types of all fossil fuels used in the process, and
    d. Source of CO_2.

2. For the points of compression and (if applicable) transport , provide the following:
    a. Quantity of total CO_2 compressed/transported,
    b. Total amount of electricity used to carry out compression/transport, and
    c. Total amounts and types of all fossil fuels used in the process.

3. If third-party suppliers of the CO_2 provide this information, that the third-party must agree to spot-checking by the verifier VVB for backup documentation to confirm the data. If this backup documentation cannot be provided, the project proponent will not be able to count emission reductions from the sequestration of CO_2 into concrete during that project crediting period. In this situation, carbon credits can still be awarded for avoided cement usage.

Option 2:

Project proponents may elect to use a default of 200 kWh/tonne of CO_2 processed. To convert kWh to GHG emissions, the project proponent would use the EF_{elec} at the facility where the CO_2 is being processed. Note that this figure does not include the transport of gaseous CO_2 via pipeline, which must be calculated in addition to the default. Appendix V explains the derivation of this default factor.

$$PE_{CO2,processing,y} = Q_{CO2,meter,y} \times 200\frac{kWh}{tonne} \times EF_{elec} \qquad (11a)$$

Where:

[9] This will be measured at the source of the CO_2 production, and any fugitive emissions of CO_2 from the pipeline will be considered *de minimis*.

$Q_{CO2,meter,y}$ = Amount of CO2 injected in year y into the concrete production process, as determined by a flow meter (tCO_2) at the project activity location.

EF_{elec} = Emissions intensity of the electricity (tCO_2/MWh)

The project emissions from the transport of CO_2 from the capture site to the project site are calculated as follows:

$$PE_{CO2,transport,y} = \sum_i \left(Q_{CO2,supplied,y,i} \times miles\ transported_i \times EF_{CO2,i} \right) \quad (12)$$

Where:

$PE_{CO2,transport,y}$ = Project emissions associated with the transport of CO_2 to the project site in year y (tCO_2e)

$Q_{CO2,supplied,y,i}$ = Amount of CO_2 procured in year y and brought to the project activity site by mode *i* (tCO_2)

miles transported $_i$ = Miles that CO_2 is transported to reach the point of use in year y by mode i (miles)

$EF_{CO2,i}$ = CO_2 emission factor for mode i (barge, rail, or truck), (tCO_2/tonne-mile). *See Table 3 below*

Note that the parameter $Q_{CO2,supplied,y,i}$ must be measured when Option 1 is used to determine $BE_{CO2,cap}$. Because this option employs carbon content testing (and not metering to determine the quantity of CO_2), data from the supplier is required. For projects that apply Option 2, which measures CO_2 through a meter, the parameter $Q_{CO2,supplied,s,y,i}$ may be substituted by $Q_{CO2,meter,s,y,}$

Modal Transport of CO_2 and other materials/inputs: CO_2 may be transported via railway, truck, etc. from the point of capture to the project activity site. However, other materials may also be transported, such as sustainable and renewables biomass waste that is transported to the project activity to burn and provide biogenic CO_2 for mineralization, or the finished product to the source of the CO_2. In either case, the formula would work the same – the quantity of material in tonnes would be shipped a certain number of miles and multiplied together to determine the number of tonne-miles.

A tonne-mile refer to shipping one tonne of product for one mile. If the CO_2 is not captured on the same site where the concrete is produced, the project proponent must gather specific data from the CO_2 deliverer. This data must include the total tonnes delivered and the total miles traveled. Note that not all tonne-miles are equivalent in terms of their impact. The US EPA's globally applicable Center for Corporate Climate Leadership program identifies different GHG emission factors for different modes of transport (Table 3).[10] Also, Equation 12 combines units that multiply the tonnes of CO_2 shipped by the tonnes of emissions from transporting that CO_2. The final unit, however, is tonnes of emissions.

[10] https://www.epa.gov/sites/production/files/2020-04/documents/ghg-emission-factors-hub.pdf

Table 3: Quantifying GHG Emissions Associated with Transport*

Transport Mode	Emissions in metric tCO_2/tonne-mile
Rail	0.0000231
Waterborne	0.000044
Truck	0.00023
Air	0.00139

**Note: these factors may be updated by US EPA, and project proponents have the option of using updated figures. The figures above have been converted from the original EPA table to metric tonnes from short tons.*

8.2.5 Project emissions from ineligible CO_2 sources

When the source of CO_2 is not known, the project proponent must assume it comes from an ineligible source, such as a geologic reservoir. The CO_2 that is mineralized, i.e., absorbed into the cement, would not be eligible for a VCU and count as a project emission. When the CO_2 sources are known and eligible, this value would be 0.

$$PE_{CO2,ineligible,y} = Q_{CO2,meter,ineligible,y} \tag{13}$$

Where:

$PE_{CO2,ineligible,y}$	= Amount of CO_2 non-mineralized that comes from a non-eligible source of CO_2 or when CO_2 source is unknown in year y (tCO_2e)
$Q_{CO2,meter,ineligible,y}$	= Amount of CO_2 injected from source ineligible on unknown in year y into the concrete production process, as determined by a flow meter (tCO_2) at the project activity location

8.3 Leakage Emissions

No sources of leakage have been identified for this project activity.

8.4 Net Reductions and Removals

Net GHG emission reductions are calculated as follows:

$$ER_y = BE_{ACU,y} - PE_{cement,y} + BE_{CO2,cap,y} - \left(\frac{BE_{ACU,y} - PE_{cement,y} + BE_{CO2,cap,y}}{BE_{ACU,y} - PE_{cement,y} + BE_{CO2,cap,y} + CR_{CO2,cap,y}}\right) \times \left(PE_{elec,y} + PE_{ffc,y} + PE_{CO2,y} + PE_{CO2,ineligible,y}\right) \tag{14}$$

Where:

ER_y = Net GHG emissions reductions in year y (tCO_2e)

$BE_{ACU,y}$	= Emissions from the production of Portland cement that would have been used in the absence of the project activity (avoided cement usage) (tCO_2e) in year y
$BE_{CO2,cap,y}$	= Baseline emissions from the capture of CO_2 (tCO_2e) in year y
$CR_{CO2,cap,y}$	= Carbon dioxide removals from the capture of CO_2 (tCO_2e) in year y
$PE_{cement,y}$	= Emissions from the production of cement used at the project facility in year y (tCO_2e)
$PE_{elec,y}$	= Emissions from the incremental use of electricity by the CO_2 injection equipment at the project facility in year y (tCO_2e)
$PE_{ffc,y}$	= Emissions from the incremental combustion of fossil fuels by the CO_2 injection and any other related equipment at the project facility in year y (tCO_2e)
$PE_{CO2,y}$	= Emissions associated with the capture, compression and transport of CO_2 to the location where it will be sequestered in concrete in year y (tCO_2e)
$PE_{CO2,ineligible,y}$	=Amount of CO_2 non-mineralized that comes from a non-eligible source of CO_2 or when CO_2 source is unknown in year y (tCO_2e)

Net carbon dioxide removals are calculated as follows:

$$CR_y = CR_{CO2,cap,y} - \left(\frac{CR_{CO2,cap,y}}{BE_{ACU,y} - PE_{cement,y} + BE_{CO2,cap,y} + CR_{CO2,cap,y}}\right) \times \left(PE_{elec,y} + PE_{ffc,y} + PE_{CO2,y} + PE_{CO2,ineligible,y}\right) \quad (15)$$

Where:

CR_y	= Net carbon dioxide removals in year y (tCO_2e)
$CR_{CO2,cap,y}$	= Carbon dioxide removals from the capture of CO_2 (tCO_2e) in year y
$BE_{ACU,y}$	= Emissions from the production of Portland cement that would have been used in the absence of the project activity (avoided cement usage) (tCO_2e) in year y
$BE_{CO2,cap,y}$	= Baseline emissions from the capture of CO_2 (tCO_2e) in year y
$PE_{cement,y}$	= Emissions from the production of cement used at the project facility in year y (tCO_2e)
$PE_{elec,y}$	= Emissions from the incremental use of electricity by the CO_2 injection equipment at the project facility in year y (tCO_2e)
$PE_{ffc,y}$	= Emissions from the incremental combustion of fossil fuels by the CO_2 injection and any other related equipment at the project facility in year y (tCO_2e)
$PE_{CO2,y}$	= Emissions associated with the capture, compression and transport of CO_2 to the location where it will be sequestered in concrete in year y (tCO_2e)

$PE_{CO2,ineligible,y}$	=Amount of CO_2 non-mineralized that comes from a non-eligible source of CO_2 or when CO_2 source is unknown in year y (tCO_2e)

9 MONITORING

9.1 Data and Parameters Available at Validation

Data / Parameter	DF
Data unit	Dimensionless
Description	Discount factor for upstream displacement
Equations	1
Source of data	*VCS Methodology Requirements, v4.4*
Value applied	0.30
Justification of choice of data or description of measurement methods and procedures applied	The default value of 30% for upstream displacement was applied. Project proponents may propose a methodology revision with a different discount factor for upstream displacement in accordance with the latest version of the *VCS Methodology Requirements*.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	EF_{cement}
Data unit	tCO_2e/t of cement
Description	Emission factor for the production of Portland cement
Equations	1, 3, 7
Source of data	Project proponent and/or cement production facilities
Value applied	Project-specific
Justification of choice of data or description of measurement methods and procedures applied	One of the following options must be used: **Option 1. Plant-Specific Data:** When the source of the cement used both in the pre-project and post-project scenario is known, project

	proponents must use site-specific factors if they are available. See Section 8.1. **Option 2. Environmental Product Declarations (EPDs):** Where Option 1 is not applicable, project proponents must use EPDs that provide key information on GHG intensity of Portland cement. See Section 8.1. **Option 3. Use of Regional Factors:** To be applied where EPDs are not available, or where the project activity is located in a country where the data needed for Options 1 and 2 are not available. See Section 8.1
Purpose of Data	Calculation of baseline and project emissions, because the use of cement occurs in both the baseline and project scenarios.
Comments	For Option 1, plant-specific data on fuel use, electricity use and cement production must be provided by the cement producer, and the producer must be available to provide actual data and evidence (utility bills, etc.) directly to the validation/verification body, if requested.

Data / Parameter	$EF_{Clinker}$
Data unit	tCO_2e/t
Description	Emission factor for the production of clinker
Equations	3
Source of data	World Business Council for Sustainable Development's the Cement Sustainability Initiative report, *Cement Industry Energy and CO_2 Performance "Getting the Numbers Right"*.
Value applied	See Table A.1 in Appendix III.
Justification of choice of data or description of measurement methods and procedures applied	For use with Option 3 above, determining the emission factor of Portland cement using regional factors.
Purpose of Data	Calculation of baseline and project emissions, because the use of cement occurs in both the baseline and project scenarios.
Comments	N/A

Data / Parameter	$M_{Clinker}/M_{Cement}$
Data unit	Ratio
Description	Clinker to cement ratio
Equations	3
Source of data	World Business Council for Sustainable Development's the Cement Sustainability Initiative report, *Cement Industry Energy and CO_2 Performance: "Getting the Numbers Right"*.
Value applied	See Table A2 in Appendix III.
Justification of choice of data or description of measurement methods and procedures applied	For use with Option 3 above, determining the emission factor of cement using regional factors.
Purpose of Data	Calculation of baseline and project emissions, because the use of cement occurs in both the baseline and project scenarios.
Comments	N/A

Data / Parameter	$FC_{,a}$
Data unit	TJ
Description	Energy content per unit of fuel type *a*.
Equations	9, 11
Source of data	IPCC
Value applied	Will vary depending on fuel
Justification of choice of data or description of measurement methods and procedures applied	The *IPCC Guidelines for National Greenhouse Gas Inventories* is internationally recognized and the data provided in the guidelines is peer reviewed.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	EF_a
Data unit	tCO_2e/TJ

Description	Emission factor of fuel type *a*.
Equations	9
Source of data	IPCC
Value applied	Will vary depending on fuel
Justification of choice of data or description of measurement methods and procedures applied	The *IPCC Guidelines for National Greenhouse Gas Inventories* is internationally recognized and the data provided in the guidelines is peer reviewed.
Purpose of Data	Calculation of project emissions.
Comments	N/A

Data / Parameter	$EF_{ff,a,processing}$
Data unit	tCO_2e/TJ
Description	Emission factor of fuel type a.
Equations	11
Source of data	IPCC
Value applied	Will vary depending on fuel
Justification of choice of data or description of measurement methods and procedures applied	The *IPCC Guidelines for National Greenhouse Gas Inventories* is internationally recognized and the data provided in the guidelines is peer reviewed.
Purpose of Data	Calculation of project emissions.
Comments	N/A

Data / Parameter	$EF_{CO2,i}$
Data unit	Tonne of CO_2 per tonne-mile
Description	Emission factor for mode of transport.
Equations	12

Source of data	Table in Section 8 from EPA Center for Corporate Climate Leadership (2020)
Value applied	Will vary depending on the fuel
Justification of choice of data or description of measurement methods and procedures applied	This is an accurate and simplified default for considering the emission factors of different modes of transport.
Purpose of Data	Calculation of project emissions.
Comments	N/A

Data / Parameter	Default factor for amount of energy required to capture, treat and compress a tonne of CO_2
Data unit	kWh/tonne
Description	Default factor for amount of energy required to capture, treat and compress a tonne of CO_2
Equations	11(a)
Source of data	See Appendix V
Value applied	200 kWh/tonne of CO_2 processed
Justification of choice of data or description of measurement methods and procedures applied	See Appendix V
Purpose of Data	To provide an option for determining project emissions from capturing CO_2 if that information is not available from the CO_2 supplier.
Comments	

Data / Parameter	Default efficiency of mineralization
Data unit	Ratio
Description	The efficiency of mineralization allows estimating the amount of CO_2 injected that is mineralized into the concrete.
Equations	5(a), 5(b)
Source of data	See Appendix VI

Value applied	0.60
Justification of choice of data or description of measurement methods and procedures applied	See Appendix VI
Purpose of Data	The production of numerous mix designs makes comprehensive testing impractical. In this case, project proponents must use a default based on the percentage of CO_2 injected into the process (as determined by a meter) and actually mineralized.
Comments	This parameter indicates the efficiency of mineralization. There have been tests done on this efficiency as outlined in Appendix V. These tests show quite a range of results in terms of the efficiency of the uptake of CO_2 into the concrete, and there appears to be little correlation between the efficiency of mineralization and the percent dosing of CO_2. However, the lowest test result is at 76%, meaning that three-quarters of the CO_2 that is injected into the process actually is mineralized into the concrete. At a conservative default, the assumed efficiency of mineralization will be set at 60%.

Note: All defaults/parameters have been reviewed and none are likely to change significantly in the future.

9.2 Data and Parameters Monitored

Data / Parameter:	$Q_{cement,i,p,y}$
Data unit:	Tonne
Description:	Quantity of cement used in the project for concrete or pre-cast products produced using a project mix design *i* in year y.
Equations	2, 7
Source of data:	Project proponent
Description of measurement methods and procedures to be applied:	Use standard weighing procedures to determine mass of cement used to produce ready-mix or pre-cast concrete products over the course of year y.
Frequency of monitoring/recording:	Measured continuously, recorded at least monthly
QA/QC procedures to be applied:	Any equipment, such as scales, should be calibrated according to the manufacturer's specifications, with calibration certificates available for verification.
Purpose of data:	Calculation of baseline and project emissions.

Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$Q_{Cement,b,i,test\ n}$
Data unit:	Tonne
Description:	Quantity of Portland cement used to prepare baseline compressive strength test specimen n for concrete produced using a mix design that results in a concrete of equivalent compressive strength to project mix design *i.*
Equations	2
Source of data:	Project proponent
Description of measurement methods and procedures to be applied:	See Appendix II
Frequency of monitoring/recording:	Once per project crediting period for each mix design. If project proponents have a large number of mix designs at a given project site or across a portfolio of locations, testing can be performed on the company's mix designs that comprise at least 50% of production volume. In cases where additional mix designs or changes in existing mix designs mean that the 50% production volume threshold changes, then further testing will occur for all project instances. Any new mix designs added during the project crediting period will also be tested.
QA/QC procedures to be applied:	See Appendix II
Purpose of data:	To calculate how much cement would have been used in the absence of the project by assessing the amount of cement in baseline concrete is required to obtain the equivalent or better compressive strength as the project concrete. This is used to calculate baseline emissions.
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$Q_{Cement,p,i,test\ n}$
Data unit:	Tonne

Description:	Quantity of Portland cement used to prepare project compressive strength test specimen n for concrete produced using project mix design *i*
Equations	2
Source of data:	Project proponent
Description of measurement methods and procedures to be applied:	See Appendix II
Frequency of monitoring/recording:	Once per project crediting period for a given corporation's mix designs that comprise 50% or more of production volume. In cases where additional mix designs or changes in existing mix designs mean that the 50% production volume threshold changes, then further testing will occur for all project instances. Any new mix designs added during the project crediting period will also be tested.
QA/QC procedures to be applied:	See Appendix II
Purpose of data:	Calculation of baseline emissions by comparing the amount of cement in the project activity concrete and the amount of cement that would be required in the baseline concrete.
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$Q_{CO2,meter,s,y}$
Data unit:	Tonne
Description:	Amount of CO_2 injected from source *s* in year *y* to produce concrete and pre-cast products, as determined by a flow meter.
Equations	5a, 5b, 11, 11a
Source of data:	Measurements at project facility and information from CO_2 providers.
Description of measurement methods and procedures to be applied:	Use calibrated flow meters. The amount of CO_2 must be metered before entering the production process and must be subject to standard calibration and QA/QC procedures. Note that the monitoring will take place at the point of CO_2 injection. Project proponents must specify in the project description where the CO_2 injection and monitoring will take place.

	Project proponents must track the source of CO_2 when it goes into the concrete production process. A clear record must be provided to the VVB, such as sales records or receipts from the CO_2 supplier. For removals, the project proponent must provide clear and transparent evidence that the source is a DAC or biogenic CO_2 facility. If the process involves only, sourcing information would not be required; however a description of the process and sample testing (as per Option 1 in Component 2 as described in Section 8.1) must be provided to the VVB.
Frequency of monitoring/recording:	Data must be monitored continuously and recorded at least on a daily basis.
QA/QC procedures to be applied:	Calibration of meters must be conducted according to the equipment manufacturer's specifications. Records, sales receipts should be provided from CO_2 supplier, for example, the market CO_2 company or the DAC supplier. If a source cannot be determined precisely, it will be assumed to be ineligible.
Purpose of data:	Calculation of baseline emissions when measuring how much CO_2 was injected into the concrete and for project emissions when determining emissions from processing. The source is used determine whether CO_2 source qualifies as a carbon removal or an emission reduction under VCS guidelines
Calculation method:	N/A
Comments:	Project proponents may use a mass-flow meter to measure mass of CO_2. Proponents may also use a volumetric meter to determine cubic feet or meters of gas collected, but this number must be converted to mass by multiplying the measured volume by the density of CO_2 at normal temperature and pressure (20 degrees C at 1 atmosphere). The density of CO_2 at NTP is 1.842 kg/m^3.[11] In the project proponent's monitoring plan, each unit of quantification (e.g.: per batch or mass of concrete produced and reported) may indicate the source of CO_2 so when all units are summed together, it is clear how much CO_2 mineralized comes from a source that would qualify as a removal and how much CO_2 would be considered an emission reduction.

[11] www.engineeringtoolbox.com/gas-density-d_158.html

Data / Parameter:	$C_{baseline\ sample,i,y}$
Data unit:	kgC/kg of concrete
Description:	Carbon content of baseline concrete or pre-cast product as measured in test samples.
Equations	4a, 4b
Source of data:	Project proponent tests (see Appendix IV)
Description of measurement methods and procedures to be applied:	See Appendix IV
Frequency of monitoring/recording:	Once per design mix. If project proponents have a large number of design mixes at a given project site or across a portfolio of locations, testing can be performed once per crediting period on a company's mix designs that comprise at least 50% of production volume.
QA/QC procedures to be applied:	For all concrete products the project proponent must conduct a minimum of three decomposition tests for the baseline products. For relevant project mix design – for both pre- and post-project concrete – the project proponent will conduct a minimum of three decomposition tests. The three tests must reveal a carbon content that is within 10% of each other, or the project proponent should continue testing the individual batch until three results within 10% of each other are obtained. The actual test result used in the calculations of baseline emissions must be the lowest of the three samples for the post-project concrete and the highest of the three results for the pre-project concrete – thus ensuring the most conservative result. All test procedures and results will be made available to the validation/verification body.
Purpose of data:	Calculation of baseline emissions.
Calculation method:	N/A
Comments:	See Appendix IV

Data / Parameter:	$C_{project\ sample,i,y}$
Data unit:	kgC/kg of concrete
Description:	Carbon content of project concrete or pre-cast product as measured in test samples
Equations	4a, 4b

Source of data:	Project proponent tests (see Appendix IV)
Description of measurement methods and procedures to be applied:	See Appendix IV
Frequency of monitoring/recording:	Once per design mix. If project proponents have a large number of design mixes at a given project site or across a portfolio of locations, testing can be performed once per crediting period on a company's mix designs that comprise 50% or more of production volume.
QA/QC procedures to be applied:	For all concrete products the project proponent must conduct a minimum of three decomposition tests for the project products/materials. In the case of ready-mix and pre-cast concrete products, this testing will be done for each design mix. For relevant project mix design – for both pre- and post-project concrete – the project proponent must conduct a minimum of three decomposition tests. The three tests must reveal a carbon content that is within 10% of each other, or the project proponent should continue testing until three results within 10% of each other are obtained. The actual test result used in the calculations of baseline emissions must be the lowest of the three samples for the post-project concrete and highest of the three results for the pre-project concrete – thus ensuring the most conservative result. All test procedures and results will be made available to the validation/verification body.
Purpose of data:	Calculation of baseline emissions
Calculation method:	N/A
Comments:	See Appendix IV

Data / Parameter:	$Q_{Concrete,i,p,y}$
Data unit:	Tonne
Description:	Quantity of concrete products produced by the project for project mix design *i* in year y.
Equations	4a, 4b
Source of data:	Project proponent (see Section 8.1)

Description of measurement methods and procedures to be applied:	Standard procedures to weigh concrete product, which is standard industry practice for all concrete suppliers.
Frequency of monitoring/recording:	Measured continuously, recorded at least daily
QA/QC procedures to be applied:	Standard procedures to ensure accuracy of weighing methods, including manufacturer-recommended calibrations for measuring devices, which would be standard industry practice for all concrete suppliers. Project proponents will keep clear records of all concrete produced and used at construction sites, which can be presented to the validation/verification body.
Purpose of data:	Calculation of baseline emissions.
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$Q_{elec,y}$
Data unit:	MWh
Description:	Quantity of electricity used by the CO_2 injection equipment from the grid in year y used to power the equipment needed to operate the project activity in year y (MWh)
Equations	8
Source of data:	Measurements at project facility or electric utility bills; and from CO_2 supplier.
Description of measurement methods and procedures to be applied:	Use calibrated electricity meters. Calibration must be conducted according to the equipment manufacturer's specifications. Alternatively, utility billing data can be used.
Frequency of monitoring/recording:	Data must be monitored continuously and recorded on at least a daily basis. If utility data is used, monthly bills are acceptable.
QA/QC procedures to be applied:	The consistency of metered electricity generation should be cross-checked with receipts from electricity purchases where applicable.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A

Comments:	In cases where the individual piece of equipment used does not have a separate meter to calculate electricity use from just that device – and where utility bills cannot distinguish between the use of that equipment and the rest of the facility – project proponents may use sample data. This option may be used if the electricity or fossil fuel consumption is minor. For sampling, the energy consumption and quantity of CO_2 injected must be measured during a representative time period to estimate the specific energy use per amount of CO_2 injected: • Energy consumption: measured with a data logger or other similar method • Amount of CO_2 injected: measured with a flow meter This specific energy consumption must be multiplied by the total amount of CO_2 injected during the monitoring period to obtain the total energy consumption. If the sampling approach is applied, project proponents must take multiple readings throughout the year at multiple facilities to obtain a representative sample. The most conservative sample (e.g., highest specific energy consumption) must be used to determine project emissions.

Data / Parameter:	$Q_{elec,processing,y}$
Data unit:	MWh
Description:	Quantity of electricity from the grid in year y used to capture, compress and process CO_2.
Equations	11
Source of data:	Measurements at CO_2 supplier facility or their electric utility bills.
Description of measurement methods and procedures to be applied:	Use calibrated electricity meters. Calibration must be conducted according to the equipment manufacturer's specifications. Alternatively, utility billing data can be used.
Frequency of monitoring/recording:	Data must be monitored continuously and recorded on at least a daily basis. If utility data is used, monthly bills are acceptable.
QA/QC procedures to be applied:	The consistency of metered electricity generation should be cross-checked with receipts from electricity purchases where applicable.
Purpose of data:	Calculation of project emissions.
Calculation method:	N/A
Comments:	

Data / Parameter:	EF_{elec}
Data unit:	tCO_2e/MWh
Description:	Emission intensity of electricity used
Equations	8, 11, 11a
Source of data:	US EPA eGrid, utility data or similar source if the project is in another country.
Description of measurement methods and procedures to be applied:	In developing countries, project proponents may use the *VCS Tool VT0011 - Electricity System Emission Factors* to calculate this parameter. In the United States, the eGrid emissions factor published by the US Environmental Protection Agency for the US sub-region where the facility is located (latest available information) may be used.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	As per the latest version of the *VCS Tool VT0011 - Electricity System Emission Factors*, if used
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$Q_{ff,a,y}$
Data unit:	Gallons (oil fuels), meters^3 (natural gas), tonnes (solid fuels)
Description:	Quantity of fossil fuel *a* used by the CO_2 injection equipment in year y (volume of liquid fuel, mass of solid fuel or cubic meters of natural gas)
Equations	9
Source of data:	Measurements at project facility.
Description of measurement methods and procedures to be applied:	Use calibrated flow or gas meters. Calibration must be conducted according to the equipment manufacturer's specifications. Use calibrated scales for solid fuels.

Frequency of monitoring/recording:	Data must be monitored continuously and recorded on at least monthly basis.
QA/QC procedures to be applied:	The consistency of metered fuel use should be cross-checked with receipts from fuel suppliers where applicable.
Purpose of data:	Calculation of project emissions.
Calculation method:	N/A
Comments:	In cases where the individual piece of equipment used to inject CO_2 does not have a separate meter to calculate fossil fuel use from just that device – and where utility bills cannot distinguish between the use of that equipment and the rest of the facility – project proponents may use sample data. This option may be used if the electricity or fossil fuel consumption is minor. For sampling, the fuel consumption and quantity of CO_2 injected must be measured during a representative time period to estimate the specific energy use per amount of CO_2 injected: • Fuel consumption: measured with a data logger or other similar method • Amount of CO_2 injected: measured with a flow meter This specific fuel consumption must be multiplied by the total amount of CO_2 injected during the monitoring period to obtain the total energy consumption. If the sampling approach is applied, project proponents must take multiple readings throughout the year at multiple facilities to obtain a representative sample. The most conservative sample (e.g., highest specific energy consumption) must be used to determine project emissions.

Data / Parameter:	$Q_{ff,a,y,processing}$
Data unit:	Gallons (oil fuels), cubic meters (natural gas), tonnes (solid fuels)
Description:	Quantity of fossil fuel *a* used the CO_2 supplier to capture and process the CO_2 for delivery to the project site.
Equations	11
Source of data:	Measurements at CO_2 supplier facility.
Description of measurement methods and procedures to be applied:	Use calibrated flow or gas meters, or scales or delivery volumes. Calibration must be conducted according to the equipment manufacturer's specifications.

Frequency of monitoring/recording:	Data must be monitored and recorded monthly.
QA/QC procedures to be applied:	The consistency of metered fuel use should be cross-checked with receipts from fuel suppliers where applicable.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	The project proponent must know the source of the CO_2 in order to quantify the GHG reductions associated with the mineralization of CO_2.

Data / Parameter:	$Q_{CO2,supplied,y,i}$
Data unit:	Tonne
Description:	Amount of CO_2 procured in year y and brought to the project activity site by mode *i*.
Equations	12
Source of data:	Purchase and sales records from the project proponent or from CO_2 supplier.
Description of measurement methods and procedures to be applied:	Use of sales records/receipts from CO_2 supplier
Frequency of monitoring/recording:	Monthly
QA/QC procedures to be applied:	N/A
Purpose of data:	Determination of project emissions associated with transporting CO_2 to project site.
Calculation method:	N/A
Comments:	Note that the variable $Q_{CO2,supplied,y,i}$ is distinct from $Q_{CO2,meter,s,y}$. The CO_2 <u>supplied</u> to the site is necessary to determine the emissions associated with transporting the gas, and it is possible that CO_2 is brought by multiple transportation modes. This parameter measures that by determining the amount of CO_2 supplied by each mode *i*. Project proponents should keep accurate records of all CO_2 supplied by different transportation modes. It is logical to assume that all CO_2 from the supplier(s) will equal

	$Q_{CO2,meter,s,y}$. However, that cannot necessarily be guaranteed. If some CO_2 supplied is not actually injected, then this parameter is conservative because summing $Q_{CO2,supplied,y,i}$ for each mode will always be equal to or greater than $Q_{CO2,meter,y}$. So, if anything, this parameter will overcount project emissions. Project proponents must demonstrate that the captured CO_2 is coming from a source where the gas would – in the absence of the project activity – be emitted. The project proponent should obtain an attestation from the supplier of the CO_2 or provide other evidence that the captured CO_2 would not have otherwise been sequestered (e.g., CO_2 coming from a location supplying an Enhanced Oil Recovery project).

Data / Parameter:	Miles transported in year y by mode *i*
Data unit:	Miles
Description:	Miles of shipped CO_2 to the project site by mode *i*.
Equations	12
Source of data:	CO_2 supplier, transporter and project proponent.
Description of measurement methods and procedures to be applied:	The company supplying or transporting the CO_2 should provide data to project proponent about total number of tonnes delivered and total miles driven/shipped by barge/ moved by train from the CO_2 supply point to the final destination (and which mode(s) were used – rail, truck, barge, etc.).
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Records from CO_2 supplier or transporter should be available at project verification.
Purpose of data:	Calculation of project emissions.
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$Total_{CO2processed,y}$

Data unit:	Tonne
Description:	Total amount of CO_2 processed from the facility supplying the captured CO_2 in year y.
Equations	11
Source of data:	CO_2 supplier and project proponent
Description of measurement methods and procedures to be applied:	CO_2 supplier to provide records for project proponent.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Validation/verification body can ask to check production records of CO_2 supplier.
Purpose of data:	Calculation of project emissions.
Calculation method:	N/A
Comments:	The project proponent must know the source of the CO_2 to quantify the GHG reductions associated with processing of CO_2.

9.3 Description of the Monitoring Plan

The project will monitor the data parameters identified in Section 9.2, including the following:

- Quantities of cement produced for the concrete supplied both in the baseline and project scenarios (scales or screws conveyor scale can be used to measure weight of material, as well as invoices and other records to indicate product sales – all of which can generate records for validation/ verification body to review to check the integrity of the data).
- Quantity and source of CO_2 supplied, transported and injected into the concrete (determined by meter, and meter data, along with calibration measurements can be provided to the validation/verification body).
- Quantity of CO_2 embedded into the concrete (described earlier).
- Quantity of electricity and fuel used as part of the concrete production process at the project facility (utility bills, invoices from fuel suppliers, flow meters and electricity meters can all provide records for verification).
- Production and sale of concrete produced by the project activity. This will be

monitored through industry-standard weighing techniques. Sales records can also be provided to ensure the concrete is entering the market and thus displacing concrete.

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 for 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;
- Monitoring roles and responsibilities, including experience and training requirements;
- GHG information management systems, including the location, back up, 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).

All data collected as part of monitoring must be archived electronically and kept at least for two years after the end of the last project crediting period. 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 large 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.

10 REFERENCES

Portland cement Association (2023). *Environmental Product Declaration for Portland Cement. https://www.cement.org/wp-content/uploads/2024/07/pca_epd_portland_athena_final_revised_nov2023-1.pdf* and UK Average Portland Cement; Mineral Products Association (MPA) UK (2022). https://cement.mineralproducts.org/MPACement/media/Cement/Publications/2017/EPD_UK_Average_Portland_Cement_04-2022.pdf

S J Kemp, D Wagner and I Mounteney (2010). *"Low Level Detection of Carbonate Species Using Thermogravimetric and Differential Thermal Analysis."* British Geological Survey.

Neupane, Debendra, et al. (2015). *"Distribution of mineralized carbonate and its quantification method in enzyme mediated calcite precipitation technique"*. ScienceDirect.

US Geological Survey. *Data on cement production in the United States*. https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-cement.pdf

European Ready Mix Concrete Association. (2019). *Ready Mix Concrete Industry Statistics*. https://ermco.eu/wp-content/uploads/2022/10/ERMCO-Statistics-Report-2019-July-2020-FINAL.pdf

Lafarge-Holcim annual report. (2023). https://www.holcim.com/investors/publications/annual-report-2023

ASTM C39 - Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens; Global - ACI 214R-11 Guide to Evaluation of Strength Test Results of Concrete; Global - ACI 214.4R-10 Guide for Obtaining Cores and Interpreting Compressive Strength Results Europe EN 12390-3:2019 Testing hardened concrete.

H.-W. Häring, ed. (2008), *Industrial gases processing*, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim.

Monkman, S. (2018). *Sustainable Ready Mixed Concrete Production Using Waste CO2: A Case Study*. https://www.researchgate.net/publication/339106379_Sustainable_Ready_Mixed_Concrete_Production_Using_Waste_CO2_A_Case_Study

In: SP-330 Proceedings Fourteenth International Conference: Recent Advances in Concrete Technology and Sustainability Issues, American Concrete Institute, Beijing, China, pp. 163–174. https://www.concrete.org/store/productdetail.aspx?ItemID=SP330.

2024 US Merchant CO2 Report, the largest source of CO_2 is from ethanol plants (36%). Hydrogen refining and ammonia production are also significant sources of CO_2 supply.

Huntzinger, D., et al. (2009). *A Life-Cycle Assessment of Portland Cement Manufacturing: Comparing the Traditional Process with Alternative Technologies*, Journal of Cleaner Production.

US EPA Center for Corporate Climate Leadership. Emission Factors for Greenhouse Gas Inventories. https://www.epa.gov/sites/production/files/2020-04/documents/ghg-emission-factors-hub.pdf

Roozbeh Feiz, et. al. *Improving the CO2 Performance of Cement, Part I: Utilizing Life-Cycle Assessment and Key Performance Indicators to Assess Development Within the Cement Industry*, Linkoping University Post Print.

APPENDIX I: ACTIVITY METHOD

The concept of using greenhouse gases as a raw material for the production of useful products is only a few years old. A number of start-up companies are developing technologies that use captured GHGs to produce tangible products, with what has been termed "Carbon Capture and Utilization" (CCU). Products created through CCU processes can act as long-term storage of the captured GHGs used in their production and displace products created through conventional processes. The level of commercial activity for CCU products is very low, as it is a new technology.

Per the VCS rules, Verra will reassess whether the activity penetration levels remain within the permitted threshold within three years of the initial approval of the methodology. At that time, Verra will base its assessment on national boundaries, focusing on countries where concrete production utilizes CO2 sequestration. Also, and in the spirit of conservativeness, where sub-national regulations or policies may impact the likelihood of the project activity being implemented, Verra may use such boundaries as the basis of the reassessment of the activity penetration rate.

In the case of CO_2 sequestration in the production of concrete, the only baseline scenarios that are reasonable to consider are (1) the continued manufacturing of concrete with no production involving CO_2 sequestration, or perhaps (2) the large-scale adoption of this technology many years into the future, at which point if the 5% activity penetration threshold (see below) is exceeded, this activity method would no longer be eligible to continue.

CCU technology – whether it is locking captured CO_2 into solid materials or liquid fuels – is still in its infancy, as illustrated by the Carbon XPrize[12], a competition similar to the Ansari XPrize (incentivizing reusable spacecraft technology) and designed to incentivize the CCU industry. The mere existence of the Carbon XPrize illustrates the lack of any mature CCU sector. A number of start-up companies are working on sequestering CO_2 into plastics, concrete, carbon nanotubes and other solids, though most of these companies are pre-commercial or just reaching commercial scale. Those that have begun commercial production have very low penetration rates in their respective target markets. Because these CCU technologies are so new, the level of adoption is close to zero.

As of the writing of this methodology, there is no large-scale commercial application of the technology to capture and sequester CO_2 in concrete. There is limited activity in sequestering GHGs in concrete and other similar building materials. Some of the companies include CarbonCure, Partanna and CarbiCrete.

Best estimates at the time of writing indicate that CarbonCure sequesters the most CO_2 by volume in concrete. In 2024, CarbonCure's technology was used in 16.1 million cubic yards of ready-mix and pre-cast concrete – compared to an average of 18.3 billion cubic yards of concrete poured globally per year (approximately 0.088% of the market by volume).[13] Other companies, such as Partanna and CarbiCrete, are in the early stages of commercialization. While this is likely to change over time, the

[12] See https://carbon.xprize.org/prizes/carbon

[13] https://gccassociation.org/concretefuture/cement-concrete-around-the-world

fact that the Carbon XPrize is so focused on helping these companies is an indication of how early-stage these markets are.

In addition, it should be noted that as of the writing of this methodology, CarbonCure's technology has been available for more than six years, demonstrating that while the project is commercially available at a modest scale, its growth has been limited – indicating barriers to penetration in the wider market. Some of these barriers include:

- Regulatory: Engineering approval of concrete mixes is required for commercial buildings on a case-by-case basis. This limits the volume that producers can create using innovative types of concrete and requires interaction with major engineers/architects within each geographic region to remove barriers to implementation. There are limited region-specific policies that promote the use of CO_2-mineralization on a large scale, and no state level or federal level regulation or legislation that requires its use. In short, producers can view CO_2-containing concrete as a 'nice to have' rather than a 'need to have'.

- Time Burden: Quality control processes require up to six months to 'normalize' addition of CO_2-mineralization equipment to the manufacturing process (for new plants). This represents additional costs that many producers – particularly smaller ones – will most likely not want to incur.

- Market Fragmentation/Current Practice: The concrete manufacturing industry is extremely fragmented. This represents additional barriers to implementation as each company must be engaged with on an individual basis. An IBISWorld Report outlines that even the largest producers rarely control more than 10% of the overall market. Many producers own one or two plants.

Positive List

This methodology uses Option A: Activity Penetration (AP) to determine additionality. Under this option, a methodology must demonstrate that the project activity has achieved a low level of penetration relative to its maximum adoption potential (MAP). AP is determined by dividing the observed adoption (OA) of the project activity by the project activity's MAP.

MAP is defined as "the total adoption of a project activity that could currently be achieved given current resource availability, technological capability, level of service, implementation potential, total demand, market access and other relevant factors within the methodology's applicable geographically defined market." In this case, the MAP is defined as all sales and use of concrete globally. In order to qualify as additional, the project AP can be no higher than 5%. In this case, the project activity has not reached true commercial scale. To determine the total market size, the best metric would be the volume of global ready-mix and pre-cast concrete production. As referenced above, CarbonCure's technology penetration, which accounts for a majority of market penetration for CO_2 sequestration in concrete, accounts for approximately 0.088% of market penetration by volume.

Therefore, the activity penetration level of the project activity covered by this methodology is clearly below the five percent threshold, and the project activity may be deemed additional.

APPENDIX II: TESTING PROCEDURES TO DETERMINE BASELINE CEMENT QUANTITY

Testing procedures will be established by project proponents at either a lab or the company's plants) that measure quantities of cement needed to produce concrete with equivalent compressive strength both with and without the project processes to establish a ratio of Project Scenario: Baseline Scenario cement use. The test batches will yield the equivalent or better levels of compressive strength (or have the project-level mix have a greater strength than the baseline). In the case of testing dry-cast concrete, test batches can include samples of the finished precast product. These tests will determine how much cement would have been used in the baseline design mix to achieve the equivalent or better level of compressive strength as the project design mix. The result will be a calculation of how much cement is used per unit of concrete in the baseline scenario and the project scenario. This can then be applied to all project concrete or concrete products produced with that mix design. Baseline quantities of cement and project-level quantities must go through a testing procedure for each project or product mix design. The test batches must yield the equivalent or better levels of compressive strength (or have the project level mix have a greater strength than the baseline). The procedures are outlined in detail below.

For concrete products, there may be a range of functional equivalence tests as outlined in ASTM Volume 04.02: Concrete and Aggregates.

Determining $Q_{Cement,p,i,test\ n}$

$Q_{Cement,p,i,test\ n}$ must be determined by measuring the quantity of cement used to prepare project compressive strength (or other measures of functional equivalence relevant to specific pre-cast products) for test specimen *n* based on project mix design *i*, where the measurement of the quantity of cement and preparation, curing, and testing of the test specimen meets the requirements of the ASTM or CSA concrete standard test method or match the equivalent or better level for compressive strength relevant in the baseline for the type of concrete in question[14]. For each project mix design, a minimum of three batches must be tested and the three tests should fall within the relevant ASTM standards measure for functional equivalence. For product mix designs, a minimum of 3 units should be tested from 3 different batches. In all cases, the number of batches and specimens tested must meet or exceed the requirements of the relevant ASTM or CSA standard test method. This determination (for both $Q_{Cement,b,i,test\ n}$ and $Q_{Cement,p,i,test\ n}$) needs only be done once during the project crediting period for a given project mix design, but should be repeated for relevant project mix designs.

[14] See: *ASTM C39 - Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*
Global - ACI 214R-11 Guide to Evaluation of Strength Test Results of Concrete
Global - ACI 214.4R-10 Guide for Obtaining Cores and Interpreting Compressive Strength Results
Europe EN 12390-3:2019 Testing hardened concrete. Compressive strength of test specimens

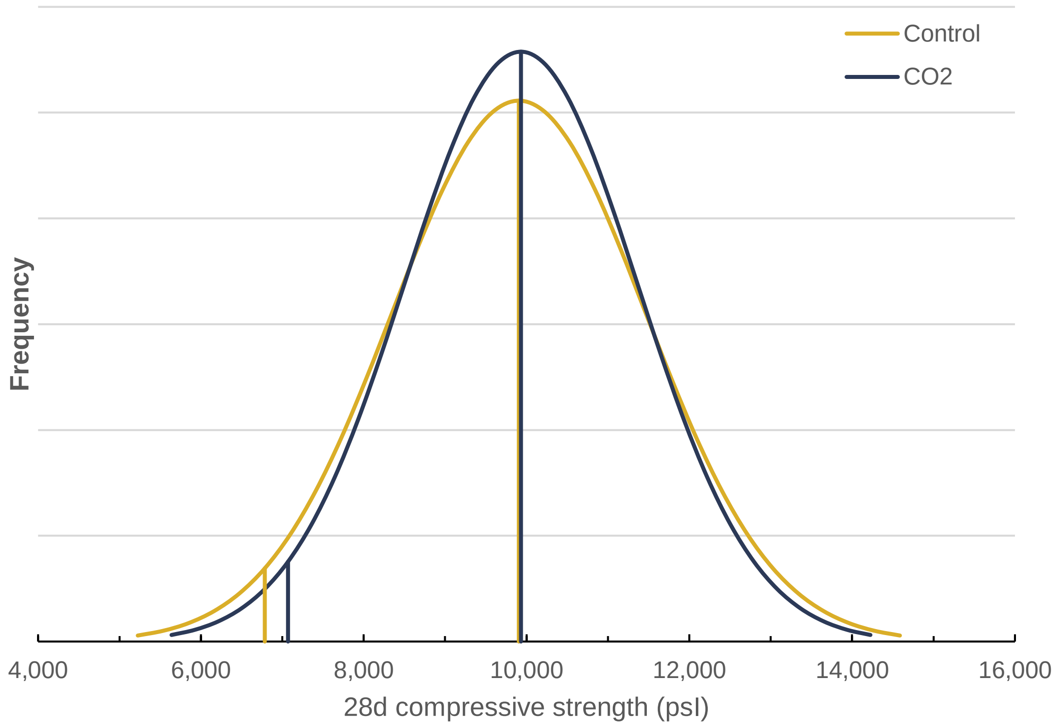
If project proponents have a large number of design mixes at a given project site or across a portfolio of locations, testing can be performed on a company's mix designs that comprise at least 50% of production volume.

Determining $Q_{Cement,b,i,test\ n}$

$Q_{Cement,b,i,test\ n}$ must be determined by measuring the quantity of cement used to prepare baseline compressive strength test (or other measure of functional equivalence relevant to specific pre-cast products) for specimen *n* based on a mix design that is intended to result in a concrete of equivalent compressive strength to project mix design *i*, where the measurement of the quantity and preparation, curing, and testing of the test specimens are identical to what is used for the determination of $Q_{Cement,p,i,test\ n}$. The mix design used must include the same amount of SCMs, if any, added at the concrete facility (excluding any SCMs in blended cement provided by a cement supplier) per m^3 of concrete as in the project mix design.

Test specimens must all be of the same volume, and equal to the volume of the specimens used to determine $Q_{Cement,p,i,test\ n}$. The same number of specimens across the same number of batches as tested for $Q_{Cement,p,i,test\ n}$ must be tested. In instances where specific pre-cast products do not utilize compressive strength as a metric, project proponents will ascertain and apply the appropriate ASTM code equivalent tests for these products. For concrete products using compressive strength testing, baseline test specimens must have an average 28-day compressive strength that is equal to or less than the average 28-day compressive strength determined for the project test specimens used in determining $Q_{Cement,p,i,test\ n}$. Where the average baseline test specimen compressive strength is greater than the average project test specimen compressive strength after completing at least three tests for a given mix design, the project proponent or concrete producer will conduct additional testing of either the project or baseline mix design (discarding an equivalent number of initial test specimen results for either the project or baseline as applicable) until the average project compressive strengths is equal to or greater than the baseline level strength. Provided below is an example of 28-day compressive strength data for reference or baseline concrete mix (control) and a reduced cement concrete mix produced with CO_2.

If project proponents have a large number of design mixes at a given project site or across a portfolio of locations, testing can be performed on a company's mix designs that comprise 50% or more of production volume.

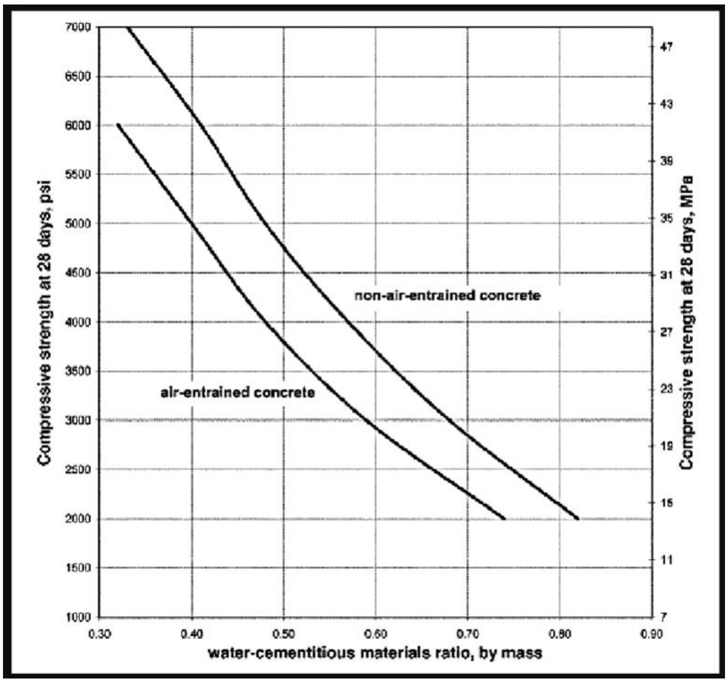


Two mixes are compared in the graph above. The reference mix contains 470 lbs of cement, 120 lbs of fly ash and 350 lbs of slag per cubic yard. The cement content was reduced 20% for CO_2 mix to 378 lbs per cubic yard. The reference concrete data comprised of numerous tests, with an average 28-day compressive strength of 9,906 psi and a standard deviation of 1,560 psi. The CO_2 set was also comprised of multiple tests, with an a with an average 28-day compressive strength of 9,932 psi and a standard deviation of 1,431 psi. Because the post-project concrete has a compressive strength equal to or greater than the baseline concrete, this requirement in the methodology is met.

Cases when testing is not done on all mix designs: In instances where there is a large number of mix designs and testing is completed for at least 50% of production volume for a producer, the following is applied. A) For the mix designs that testing was conducted for, the results of the testing data is used to quantify the cement cut; or B) For the mix designs that testing was not conducted for, project proponents will use the average cement cut from all the mix designs that testing was completed for but apply a 1 standard deviation deduction. For example, if mix design A (5% cement cut), mix design B (4.5% cement cut) and mix design C (4.0% cement cut) have the relevant tests completed and make up 50% of the production volume for a producer, the average of the mixes (4.5% cement cut) minus one standard deviation (0.005) comes out to (4.0% cement cut). The 4.0% cement cut value can be applied for all mix designs in that monitoring period that have not been tested, the tested values for the other mix designs are used for them. Removing a standard deviation ensures that the approach is conservative, and that the flexibility in testing ensures that the process is feasible and scalable in instances where there are a large number of mix designs. Note in instances where there is only one mix design for a producer the coefficient of variance is used, this is simply the standard deviation of the project samples divided by the average value and applies the same approach noted above.

Three Point Curves: Three Point Curves are common with concrete producers. A three-point curve is a simple way, to obtain a relationship between one factor that is varied to 3 different levels and a measured result using the least number of experiments. All other factors are kept constant. For concrete mixtures the three-point curve is used to establish mixture proportions for selected project requirements.[15] A concrete mix is generally not static over the course of a year in most climates, so the cement content will be adjusted up and down depending on the season and the weather on certain days. The mixes may vary slightly on a humid day compared to a dry day, for example. Concrete producers thus complete a three-point curve in their lab with the same mix design at three different water/cement (w/c) ratios, creating a linear line that decreases as the w/c increases (strength goes down as w/c goes up). Such testing can be allowed under this methodology for project mixes, which can then be compared to the appropriate baseline design mix. Without the ability to use three-point curves, depending on when the baseline is established, the CO_2 mix may have more cement than the baseline but less than the equivalent mix at that time of year. The figure below provides an illustration of this concept; in this instance, the three points on the non-air entrained concrete line are those at 7120 psi, 4200 psi, and 2250 psi along the line.

The figure below provides an illustration of this concept, in this instance the three points on the non-air entrained concrete line are those at 7120 psi, 4200 psi and 2250 psi along the line.



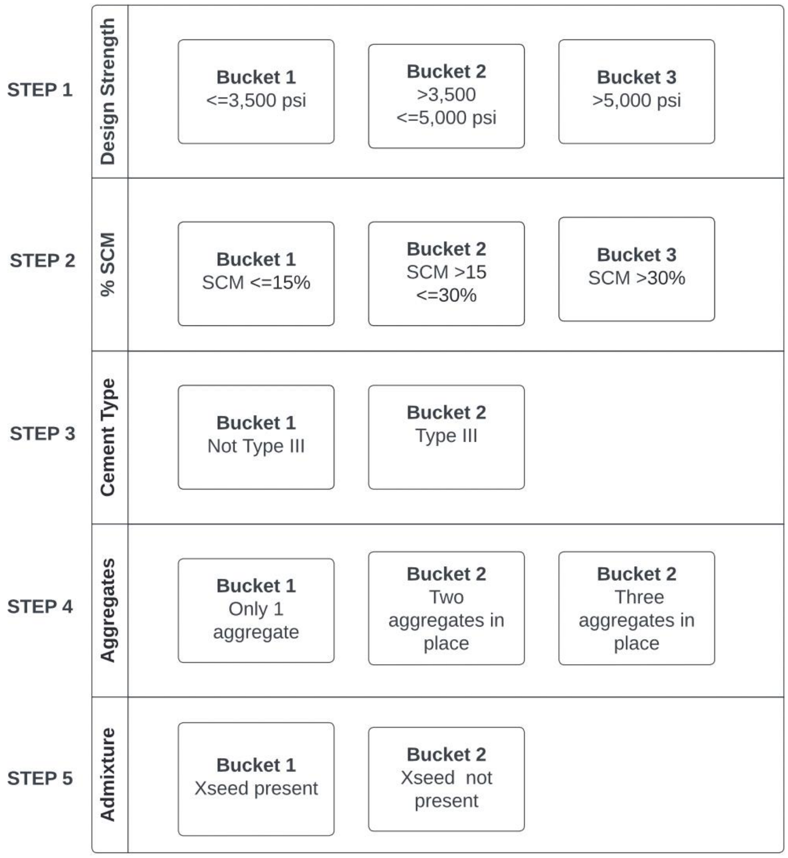
Approach to Defining and Categorizing Individual Mix Designs

In many cases, there can be small and immaterial changes in the "recipes" of specific mix designs at an individual concrete plant, and thus it's not practical to test them all. In the PD, project proponents should provide transparent criteria and reasoning for how to categorize different design mixes. If there is a mix in which these criteria change beyond a certain level as specified in the PD, this would constitute a new mix design and thus require separate compressive strength and carbon-content testing. Examples would include but not

[1515] See https://www.nrmca.org/wp-content/uploads/2020/04/Tip7w.pdf be limited to: (1) changes in SCM type of percent content; (2) different type of cement used; (3) different requirements for compressive strength or different application (pavement, blocks, columns); or (4) material changes in other ingredients such as admixtures and aggregates.

The figure below lists a theoretical categorization of different design mixes. For example, if the SCM content in one concrete mix was 15%, but a slightly altered mix brings this level to 20%, it would be within the same mix. But if that SCM level goes above 30%, that would represent a new mix. In the PD, project developers should present transparent reasoning for why the “borders” from one design mix to the next are set where they are.

The example below separates mix designs based on their criteria (design strength (psi), cement type (e.g., type I/II), % SCMs, blend of aggregates (e.g., coarse+fine), strength enhancing admixtures (e.g., Xseed). For example, a concrete mix that had 20% SCM, had a strength of 3,000 PSI, used a Type III Cement, used only one aggregate and a certain admixture would be one mix design. But if the SCM level went to 30% and everything else stayed the same, it would be considered a separate mix design. Using these five different categories and the number of “buckets” in each, a total of 108 possible unique combinations can be part of this project. Thus, there would be 108 potential design mixes.



APPENDIX III: EMISSIONS FACTOR OF CEMENT USING REGIONAL FACTORS

The factors in Table A1 include emissions from the chemical process of calcination and emissions from fuel combustion, and consider those facilities that combust a wide range of carbon intensive and biogenic fuel sources. Table A2 shows the typical ratio of clinker-to-cement on a regional basis throughout the world. These tables were sourced from VM0031 and derived from the Cement Sustainability Initiative report, *Cement Industry Energy and CO_2 Performance "Getting the Numbers Right"* (World Business Council for Sustainable Development).

Table A1: CO_2 emissions per tonne of clinker per kiln type (global average)

Kiln Type	$EF_{Clinker}$ (kg CO_2/t clinker)
Dry with preheater and precalciner	842
Dry with preheater and without precalciner	861
Dry without preheater	955
Semi wet/Semi dry	896
Wet	1043

Table A2: Ratio of Clinker to Cement on a Regional Basis

Region	Clinker to Cement Ratio (%)
Africa and Middle East	79
Asia excluding China, India, CIS and Japan	84
China and India	74
CIS	80
Europe	76
Japan, Australia and New Zealand	83
Latin America	74
North America	84
World (any areas of the world not including the locations listed above).	78

APPENDIX IV: ADDITIONAL INFORMATION ON TESTING AMOUNT OF CO_2 STORED IN CONCRETE

Concrete is generically comprised of coarse aggregate (stone), fine aggregate (sand), cement, and water. The injected CO_2 will be mineralized through a chemical reaction with the cement or cement replacement. To quantify the mineralized CO_2, project proponents must use carbon analyzers that are currently available and common in the industry.

The operating principle behind a carbon analyzer (often the device is used also to detect sulfur in solid materials) involves heating of a sample in oxygen rich environment to oxidize carbon and sulfur content of sample material to generate carbon monoxide, carbon dioxide and sulfur dioxide respectively. These gases are then passed through detection cells to measure content of carbon and sulfur. The measured data are compared with the mass of sample to identify content of respective elements in sample. The residual gas is finally discharged out. The results can be compared to the mass of the sample in order to determine a mass percentage of carbon and sulphur. Different companies supply these advanced analyzers with an infrared detection system for analyzing the percentage of carbon and sulphur in combustion gases.

According to the companies that manufacture these detectors, carbon content can be measured from 0.0001% to 6%. The device's software[16] displays analytical results in terms of the percentage of carbon and sulphur detected. Carbon content can be determined with a high level of precision in a wide range of materials, such as steel, cast iron, alloy, metal ore, ceramics, cement, lime, rubber, coal, coke, refractory, carbide, graphite, oil, catalyst, soil and other solid materials. The analyzers typically have two options – a resistance furnace and a high frequency induction furnace. Both share the same infrared detection system for analyzing the percentage of carbon in combustion gases.

For each mix design– for both the baseline and the project concrete – the project proponent must conduct a minimum of three analyzer tests. Each test must reveal a carbon content that is within 10% of the other two tests, or the project proponent should continue testing until three results within 10% of each other are obtained. If the project is installed in a new concrete facility, as opposed to an existing facility, where baseline concrete was not previously produced, then the concrete manufacturer would produce samples NOT using the project equipment and develop samples with the equivalent or better compressive strength or functional equivalence as the post-project concrete. Thus, there can be an "apples to apples" comparison.

The actual test result used in the calculations of quantity of CO_2 stored must be the lowest of the three samples for the project concrete and highest of the three results for the baseline concrete – thus ensuring the most conservative result. All test procedures and results will be made available

[16] See-ELTRA CHS Analyzers

to the validation/verification body. The test result is then extrapolated to all of the concrete produced for that project design mix in year y as shown in Equations 4a and 4b. The baseline concrete test results are reflected in the variable $C_{baseline\ sample,i,y}$. The project concrete test results are reflected in the variable $C_{project\ sample,i,y}$.

It is recommended that concrete samples should be acquired at the earliest time upon which the carbonate reaction is expected to be complete, before the sample sets. If the input sample is fully representative of the complete concrete composition, the result can be expressed in a straightforward manner as an amount of carbon or CO_2 per unit of concrete. The results are compared to a baseline carbon content of an equivalent concrete that has not been produced using carbon dioxide.

For example, a concrete sample that is analyzed to have a net increase in carbon of 0.05% by mass concrete translates to one cubic meter (m^3) of concrete (typically about 2400 kg) contains 1.2 kg of carbon. A conversion from carbon to CO_2 by multiplying by the ratio of their molar masses (44 for CO_2, 12 for C) would result in a conclusion of 4.4 kg of CO_2 per m^3 of concrete.

If the mineralized CO_2 is in low abundance (1% or less by weight of cement) with respect to the concrete then project proponents have the option of minimizing the analysis of the components that are not reacting with CO_2. The sample can be processed to increase the fraction of the cement paste fraction by, for example, removing coarse aggregates. Then the same test can be performed on the baseline and post-project materials (in this case without the aggregates that would not react with CO_2 in the project scenario).

One percent by weight of cement is around 0.1% by weight of concrete (assuming the concrete is 10% by mass cement). Thus, if one starts with concrete then it would be hard to measure the CO_2. But if one can process the concrete to have a sample that is mostly cement (removing aggregate) then the denominator changes and the abundance of what is measured goes up – thus making it easier to quantify.

Sampling in this manner can be done in two states: 1) on fresh concrete, where the mortar (cement and sand) is separated from the aggregates; and 2) when the concrete has hardened where a sample can be crushed -- as long as the coarse aggregates are not crushed. The testing procedure should be clearly spelled out for the verifier with results made available. Project proponents may want to consider videoing a sample test to make it easier for a verifier to understand the procedure. The project proponent should also clearly describe and show calculations for how the test results in terms of carbon content of the sample are scaled up to account for this processing step.

APPENDIX V: DEFAULT FACTOR FOR EMISSIONS INTENSITY OF LIQUID CO2 PROCESSING

As the analysis below shows, the energy required to capture and compress CO_2 into a liquid form can be generalized. This default is much more energy-intensive than capturing the gas and putting it in a pipeline, so this option would be more conservative if also applied to transporting the CO_2 through a pipeline.

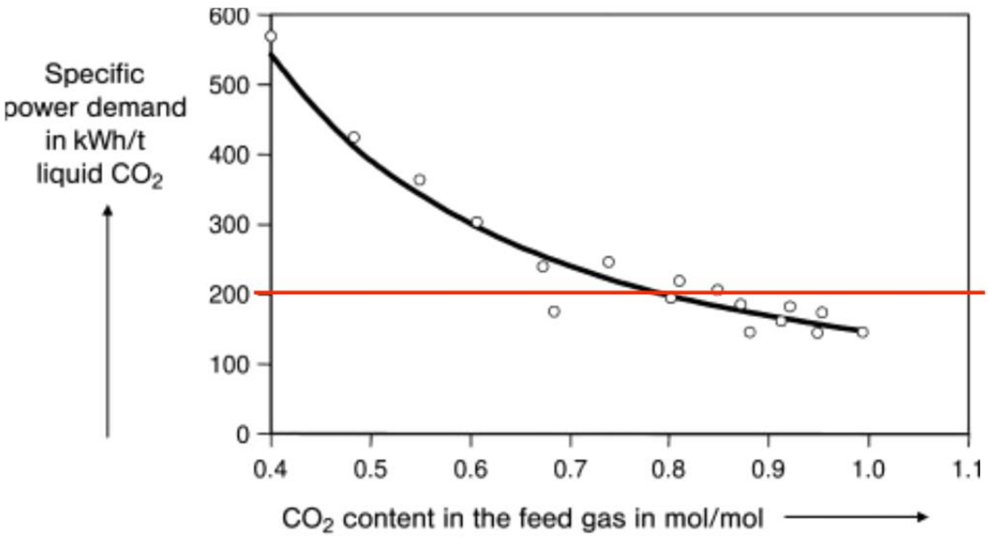
According to the *2017 US Merchant CO2 Report*, the largest source of CO_2 is from ethanol plants (34%). Hydrogen refining and ammonia production are also significant sources of CO_2 supply. The reference book *Industrial Gases Processing* provides background on processing industrial gases.[17] The table below indicates the CO_2 partial pressures, with ethanol plants being the lowest. This represents the most conservative measure, as explained below.

Table 6.1 CO_2 Sources.

Source	CO_2 partial pressure
CO_2-fraction from acid-gas scrubbings in ammonia or other synthesis gas plants or H_2-generation plants (cf. Section 5.2)	1.0 to 1.2 bar
CO_2-containing off-gas from fermentation plants, e.g. in breweries	0.9 to 0.95 bar
CO_2 from underground deposits (also in mixtures with hydrocarbons)	1 to 30 bar
Natural gas purification plants, so-called sweetening plants	1.0 to 1.2 bar
Ethylene oxide plants	0.8 to 0.95 bar

The figure below indicates the specific power demand (kWh/t liquid CO_2) displayed against CO_2 content in the feed gas (mol/mol). The partial pressure of an individual gas is equal to the total pressure multiplied by the mole fraction of that gas, so partial pressure and mole fraction are proportional. In the figure it is shown that above molar fractions of 0.8 there would be an energy requirement of 200 kWh/tonne of liquid CO_2. If a higher pressure is used, then the kWh/tonne number would be lower and thus less conservative. For this reason, the 200 kWh/tonne figure is the most conservative.

[17] H.-W. Häring, ed., *Industrial gases processing*, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2008.



Source: H.-W. Häring, ed., *Industrial gases processing*, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2008.

APPENDIX VI: DEFAULT EFFICIENCY OF MINERALIZATION

To determine how much carbon dioxide that is introduced is actually mineralized into concrete, a detailed technical study was conducted.[18] For this study, an industrial carbon dioxide utilization technology (CarbonCure) was installed at a ready-mix concrete producer. The work considered the impact on 12 months of operation both in terms of the carbon dioxide converted during the concrete production and to determine environmental impact of the technology and the avoided cement.

The carbon quantification involves three steps: sample collection and drying, separation, and carbon analysis. A sample of freshly produced masonry concrete was collected from the production line and dried with a hot plate. The sample was then sieved through an 80 μm sieve to both provide a homogeneous sample for analysis as well as to increase the proportion of cement in the sample being analyzed. The cement is the only reactive component in the concrete mixture; minimizing or excluding the aggregates increases the signal in the subsequent measurement. The total carbon and sulphur contents of the sieved fines were then measured using an Eltra CS-800 carbon and sulphur analyzer. Any changes in total carbon relative to control samples were assumed to be a product of the introduction of CO_2 as all other variables were fixed.

Eight batches were produced with a CO_2 addition and compared to a historical data set comprising nine batches (produced across seven different days). The average conversion was 93%. This is attributable to random variations in sample proportions following drying and sieving of the concrete and potentially an inherent heterogeneity of the fly ash. On average, the replicate CO_2 measurements had an average precision ±20% bwc. The conversion rate in the environmental calculations was assumed to be 93%. With 9.4 tons (8.5 tonnes) of CO_2 utilized during the year production there were 8.7 tons (7.9 tonnes) mineralized through conversion to calcium carbonate.

For the purposes of this methodology, while the actual average conversion rate was quite high (93% of the introduced CO_2 was actually absorbed, there are scientific uncertainties and thus the default efficiency for CO_2 mineralization into the concrete will be set to a much lower level of 60%.

Although the technical study entails ready-mix concrete only, as a conservative measure, the resulting default mineralization efficiency value is applicable to both ready-mix and pre-cast concrete products.

[18] S. Monkman, *Sustainable Ready Mixed Concrete Production Using Waste CO2: A Case Study*, in: SP-330 Proceedings Fourteenth International Conference: Recent Advances in Concrete Technology and Sustainability Issues, American Concrete Institute, Beijing, China, 2018: pp. 163–174. See https://www.concrete.org/store/productdetail.aspx?ItemID=SP330.

APPENDIX VII: RELATIONSHIP TO APPROVED OR PENDING METHODOLOGIES

Approved and pending methodologies under the VCS Program and approved GHG programs which fall under the same sectoral scope were reviewed to determine whether an existing methodology could be reasonably revised to meet the objective of the proposed methodology. Five methodologies were identified under the same sectoral scope. Two were outside the scope, including VM0040 (sectoral scope 3) and AM0027 (sectoral scope 5). These are all set out in Table 2. No other similar methodologies under Verra or any other approved GHG program are applicable to project activities which capture and use greenhouse gases to produce concrete, and thus no existing methodology can be reasonably revised to meet the objective of this methodology.

Table 2: Similar Methodologies

Methodology	Title	GHG Program	Comments
VM0030	Methodology for Pavement Application using Sulphur Substitute, v1.0	VCS	Not applicable to project activities that utilize captured CO_2 to manufacture concrete. This methodology uses sulphur substitute.
VM0031	Methodology for Precast Concrete Production using Sulphur Substitute, v1.0	VCS	Not applicable to project activities that utilize captured CO_2 to manufacture concrete. This methodology uses sulphur substitute. However, this methodology accepts the general premise that less cement production means lower emissions, an important concept for this proposed methodology.
VM0040	Methodology for Greenhouse Gas Capture and Utilization in Plastic Materials	VCS	Not applicable to project activities that utilize captured CO_2 to manufacture concrete. This methodology focuses only on plastic polymers.
AM0027	Substitution of CO_2 from fossil or mineral origin by CO_2 from renewable sources in the production of inorganic compounds	CDM	Applicable only to projects that produce inorganic compounds where fossil or mineral sources of CO_2 are presently used as an input and where renewable sources of CO_2 are available as a substitute input in the project activity case. The initial project for this methodology produced sodium and ammonium bicarbonates in a process that was integrated into a renewable biomass plant. The processing of biomass and the renewable energy component are specifically listed in the applicability criteria, which is not the case with the proposed methodology. In addition, the sodium bicarbonate may not be permanently sequestered, which is a requirement for this proposed methodology.
AMS-III.BA	Recovery and recycling of materials from E-Waste	CDM	Provides precedent for determining emission reductions from the displacement of production of conventional materials.

ACM0015	Emission reductions from raw material switch in clinker production	CDM	Not applicable to project activities that utilize captured CO_2 to manufacture concrete. However, this methodology deals with reducing cement content and adding other materials, such as fly-ash. It should also be noted that the use of supplemental cementitious materials (SCM) that can generate credits in other offset protocols *cannot* count towards carbon credits in this proposed protocol.
ACM0005	Increasing the Blend in Cement Production	CDM	Applicable to projects that use increased amounts of blended materials such as slag and coal ash. Not applicable to project activities that utilize captured CO_2 to manufacture concrete.

DOCUMENT HISTORY

Version	Date	Comment
v1.0	05 Apr 2021	Initial version
v1.1	23 Dec 2024	Minor revision to VM0043, which encompasses: • Inclusion of a discount factor for upstream displacement • Separation of removals and reductions • Expansion of the applicability to include pre-cast concrete products • Correction to Equation 5 • Inclusion of procedure in case the electricity consumption for CO_2 injection is not available or cannot be measured separately • Inclusion of requirements related to the source of CO_2 • Revisions to the definitions of “Precast concrete” and “Supplementary Cementitious Material (SCM)” and the addition of a definition of “Cement replacement” • Update to the cement production and market penetration values in Appendix-I • Update the approach to define, categorize and test individual mix designs • Update the testing procedure to determine baseline cement quantity • Methodology renamed to *VM0043 CO_2 Utilization in Concrete Production*